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**Quelles stratégies pour améliorer le régime alimentaire
de jeunes femmes égyptiennes en milieu urbain ?
Analyse des déséquilibres et identification de stratégies
nutritionnelles par méthodes mixtes**

Chloé Brouzes

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Quelles stratégies pour améliorer le régime alimentaire de jeunes femmes égyptiennes en milieu urbain ?

Analyse des déséquilibres et identification de stratégies nutritionnelles par méthodes mixtes

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Abréviations

AGS : Acides Gras Saturés

ET : Énergie Totale

FAO : Food and Agriculture Organization

IMC : Indice de Masse Corporelle

OMS : Organisation Mondiale de la Santé

TIP : Trial of Improved Practices

Valorisation scientifique

Publications

Faisant l'objet du travail de thèse

Article 1: BROUZES, C. M. C., DARCEL, N., TOMÉ, D., DAO, M. C., BOURDET-SICARD, R., HOLMES, B. A. & LLUCH, A. 2020. Urban Egyptian Women Aged 19–30 Years Display Nutrition Transition-Like Dietary Patterns, with High Energy and Sodium Intakes, and Insufficient Iron, Vitamin D, and Folate Intakes. *Current Developments in Nutrition*, 4, 10

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Article 3: BROUZES C.M.C., TAWFIK AHMED FARID M., EMAD EL SAYED F., TOMÉ D., DARCEL N., LLUCH A., LEBRUN M. Women's motivations to follow dietary advice include taste, affordability and convenience but also aesthetic and self-confidence concerns. Results from a qualitative study in Egypt (*article en cours de finalisation*).

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GAZAN, R*, BROUZES, C.M.C.*, VIEUX, F., MAILLOT, M., LLUCH, A., & DARMON, N. (2018). Mathematical Optimization to Explore Tomorrow's Sustainable Diets: A Narrative Review. *Advances in Nutrition*, 9(5), 602-616. * Contribution égale.

BROUZES C.M.C., VIEUX F., MAILLOT M., BRIEND A., HANKARD R., LLUCH A., DARMON N. (2017). Contribution des laits de croissance et des compléments à l'adéquation nutritionnelle de régimes alimentaires d'enfants en bas âge. *Nutrition & Santé* 6(1), 1-13.

Communications

Communications orales

Brouzes C.M.C., Tomé D., Darcel N., Ferguson E., Lluch A. "How to Improve Dietary Practices of 19–30yo Egyptian Women Living in Urban Areas? An Optifood Analysis (OR25-04-19)." (2019): nzz051-OR25. **Nutrition 2019. Baltimore, US. Juin 2019.**

BROUZES C.M.C, DARCEL N., TOMÉ D., YOUSSEF SHAABAN S., GAMAL EL GENDY Y., KHALIL H., FERGUSON E., LLUCH A. Development of food-based recommendations for 19-30yo women living in urban Egypt using Optifood. **4th Federation of African Nutrition Societies, Kigali, Rwanda. August 2019.**

BROUZES C.M.C, DARCEL N., TOMÉ D., BOURDET-SICARD R., YOUSSEF SHAABAN S., GAMAL EL GENDY Y., KHALIL H., FERGUSON E., LLUCH A. En Égypte urbaine, les aliments consommés par les jeunes femmes peuvent en théorie garantir des apports nutritionnels suffisants, excepté pour le fer. JFN2019/295. **Journées Francophones de Nutrition, Meilleurs posters en 90 secondes, 27 Novembre 2019.**

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HOLMES B.A., DAO M.C., ZEKOVIC M., NIKOLIC M., MILESEVIC J., KADVAN A., OMAR S., HASHEM D., BROUZES C.M.C., GLIBETIC M. (2017) Egyptian dietary habits and food group distribution – findings from a cross-sectional study” **12th International food data conference, October 11th – 13th 2017, Buenos Aires, Argentine.**

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M.C. BROUZES C.M.C., EMAD EL SAYED F., LEBRUN M., ROGEAUX M., DARCEL N., TOMÉ D., LLUCH A. Les préoccupations esthétiques, psychologiques et les modes de vie des femmes Égyptiennes doivent être intégrés pour développer des recommandations alimentaires et des produits fortifiés acceptables. JFN2019/303. **Journées Francophones de Nutrition, 27-29 Novembre 2019, Rennes.**

1. INTRODUCTION GENERALE

Après le Nigeria et l’Ethiopie, l’Égypte est le troisième pays le plus peuplé d’Afrique. La population égyptienne s’urbanise progressivement (32% d’urbains en 1950, 43% en 2019, et 56% prévus en 2050) et s’installe notamment au Caire (United Nations, 2018). Sur les presque 100 millions d’Égyptiens, 20,5 ont rejoint la capitale, qui connaît de ce fait une croissance très rapide (Population Stat, 2019). Comme dans d’autres pays du Moyen-Orient, la dernière décennie a été particulièrement mouvementée sur le plan économique. La dévaluation de la livre égyptienne a été accompagnée par une forte inflation. L’Égypte n’étant pas auto-suffisante sur le plan alimentaire (l’Égypte importe 4,43 milliards de dollars de céréales par an (United Nations, 2017)), le prix des aliments, et en particulier des céréales, a augmenté (l’inflation était de 4,8 à 6% pendant la période 2000-2005 contre 70 et 60% en 2007 et 2008 respectivement (Kenawy and Fathy Abd-El Ghany, 2011, Shiller, 2012)). Les ménages égyptiens, qui allouent une proportion importante de leur budget à l’alimentation (40,8% (Kenawy and Fathy Abd-El Ghany, 2011)) subissent donc de fortes contraintes économiques et alimentaires.

Les changements économiques et démographiques peuvent s’accompagner d’un phénomène de « transition nutritionnelle », dont les marqueurs sont les niveaux d’activité physique, les pratiques alimentaires, le statut nutritionnel et *in fine* le type de maladies auxquelles est confrontée une population (Popkin, 2001, Popkin, 2004). L’Égypte, qui ne dispose pas de recommandations alimentaires nationales (Montagnese et al., 2019), constitue un exemple emblématique et pourtant peu étudié des pays en développement confrontés à une transition nutritionnelle. En effet, la sédentarisation et la transformation des habitudes alimentaires en Égypte coïncident avec une succession de crises économiques, des changements démographiques, une augmentation de la prévalence du surpoids et de l’obésité et une hausse des maladies dites « non transmissibles » (première cause (84%) de mortalité) (Galal, 2002, Ecker et al., 2016, NCD Risk Factor Collaboration, 2017, United Nations, 2018). Les femmes égyptiennes sont encore plus affectées par le surpoids et l’obésité que les hommes (NCD Risk Factor Collaboration, 2017). Par ailleurs, les carences nutritionnelles (responsables de retard de croissance chez les enfants) et l’anémie sont toujours des préoccupations pour le pays, en particulier chez les femmes (Galal, 2002, Egypt Ministry of Health and Population et al., 2015a, Tawfik et al., 2015).

Traditionnellement, les repas se déroulent autour d’une table, en trempant le pain par petits morceaux dans des préparations variées à base de légumineuses, légumes, fromage et/ou épices (sel, cumin, graines de sésame...) (Hassan-Wassef, 2004). Dans le cadre de l’alimentation traditionnelle, les céréales et les légumineuses constituent les sources principales d’énergie et de protéines et sont principalement accompagnées de légumes à feuilles vertes, d’herbes aromatiques, de graines (ex : sésame), de volaille, d’œufs et de foie. Le thé noir sucré a longtemps constitué une source d’énergie non négligeable pour les ouvriers, et est toujours bu tout au long de la journée en plus des sodas (Hassan-Wassef, 2004). A l’instar des pays voisins (Musaiger, 2004), les habitudes alimentaires traditionnelles égyptiennes se sont peu à peu érodées avec l’introduction de nouveaux aliments et modes de consommation (Hassan-Wassef, 2004). Dans les villes, de nombreux commerces de restauration rapide ont émergé (augmentation des ventes de 64% entre 2011 et 2016

(Springmann et al., 2018)), et des kiosques et vendeurs ambulants proposent une variété de snacks salés (chips) et sucrés (chocolats, biscuits, croissants industriels), ainsi que des sodas à des prix très abordables (Hassan-Wassef, 2004) (Figure 1). Le pain, qui a toujours occupé une place centrale dans l'alimentation égyptienne (« *Egyptians eat food with bread, and not bread with food* » (Hassan-Wassef, 2004)), est aujourd'hui plutôt consommé sous forme de sandwichs. En effet, l'alimentation sur le pouce, rapide, et à n'importe quelle heure de la journée et de la nuit (suivant les rythmes professionnels et personnels de chacun) a tendance à se substituer aux repas traditionnels égyptiens structurés et au domicile. Aujourd'hui, la majorité des produits manufacturés du marché semble avoir été conçue sans une profonde connaissance des problématiques nutritionnelles. La qualité des régimes alimentaires locaux pourrait être améliorée par de meilleurs choix alimentaires, et/ou une meilleure qualité nutritionnelle des produits disponibles.



Figure 1. Exemple d'un kiosque de rue vendant des chips, des biscuits et du soda au Caire.
(photo : Chloé Brouzes, 2017)

La modélisation de l'alimentation est une approche visant à identifier les changements de régimes alimentaires susceptibles d'améliorer les apports nutritionnels des populations, en prenant en compte différents paramètres du contexte alimentaire tels que la composition des aliments, les pratiques alimentaires, l'offre alimentaire et le prix des aliments. La modélisation permet en particulier d'identifier les nutriments les plus problématiques dans un environnement alimentaire donné, et de simuler des changements de composition du régime à partir d'aliments localement disponibles et éventuellement d'aliments d'intervention (produits prototypes et/ou existants permettant de mieux couvrir les besoins nutritionnels de la population). Des données sur le prix des aliments permettent de modéliser des régimes nutritionnellement adéquats qui soient également abordables économiquement

(Gazan et al., 2018). Cependant, l'acceptabilité des changements alimentaires modélisés est difficilement prédictible. Tester les changements de régimes proposés par le modèle auprès des populations ciblées renseigne sur les barrières et leviers pour que les changements modélisés soient adoptés et permet d'ajuster en conséquence les solutions envisagées.

Ces travaux de thèse ont confronté les solutions « théoriquement optimales » (développées à partir de données de consommation quantifiées et d'analyses par modélisation) aux attentes des femmes égyptiennes résidant en milieu urbain, afin d'identifier des changements de régimes et des produits pertinents pour améliorer la qualité des régimes alimentaires.

2. PARTIE

BIBLIOGRAPHIQUE

2.1. Surpoids et surnutrition chez les femmes au Moyen-Orient

2.1.1. Forte prévalence de surpoids et d'obésité

Au Moyen-Orient, la prévalence de l'obésité est particulièrement élevée, en particulier chez les femmes (Figure 2). Ainsi, 43% des femmes sont obèses en Égypte, contre 24% des hommes, et ces contrastes se retrouvent dans de nombreux pays (Émirats Arabes Unis : F : 43% *vs* H 28% ; Arabie Saoudite : F : 44% *vs* H : 32%, Jordanie : F : 45% *vs* H : 29% ; Libye : F : 41% *vs* H : 26%) (NCD Risk Factor Collaboration, 2017). Le surpoids des femmes égyptiennes s'accroît depuis 1980 (Figure 3), et l'indice de masse corporelle (IMC) moyen des femmes égyptiennes est aujourd'hui plus haut que celui des hommes (31,7 kg/m² pour les femmes *versus* 27,9 kg/m² pour les hommes, Figure 2 (NCD Risk Factor Collaboration, 2017)).

La forte prévalence du surpoids chez les femmes du Moyen-Orient serait liée à de faibles niveaux d'activité physique (du fait notamment de barrières socio-culturelles et d'un climat chaud) et à des grossesses multiples (Figure 4) (Badran and Laher, 2011). En effet, un an après la naissance de leur enfant, près d'un quart des femmes prennent au moins 4,55 kg par rapport à leur poids avant la grossesse (Olson et al., 2003). Une alimentation trop riche et des facteurs socio-économiques, démographiques et culturels peuvent favoriser l'obésité (Badran and Laher, 2011, El Ati et al., 2012) (Figure 4). En règle générale, les inégalités de genre face au surpoids s'estompent dans les catégories socio-économiques élevées et chez les personnes les plus éduquées, alors que les différences sont plus marquées en environnement urbain (*vs* rural) (El Ati et al., 2012).

L'Égypte apparaît cependant comme un cas particulier. L'IMC moyen des femmes égyptiennes est un des plus haut au monde (31,7 kg/m², soit un IMC moyen plus élevé que les femmes aux Mexique (28,6 kg/m²) et aux États-Unis (29,1 kg/m² (NCD Risk Factor Collaboration, 2017)), mais ne suit pas de gradient en fonction du niveau d'éducation (IMC de 30,0 à 31,1 kg/m², que les femmes aient reçu une éducation primaire, secondaire, ou aucune) (Egypt Ministry of Health and Population et al., 2015a). La prévalence de surpoids et d'obésité n'augmente que modérément selon les quintiles socio-économiques (80% dans la classe la plus basse contre 88% dans la classe la plus élevée), si bien que l'âge apparaît comme un des facteurs déterminants, en plus de la sédentarité et de l'alimentation. L'IMC moyen des Égyptiennes passe de 26,2 kg/m² pour les jeunes filles de 15-19 ans à 32,4 kg/m² pour les femmes de 40-49 ans (Egypt Ministry of Health and Population et al., 2015a). En résumé, pour les femmes égyptiennes, l'âge et le fait de résider en milieu urbain semblent être les facteurs les plus déterminants de surpoids et d'obésité parmi les facteurs démographiques et socio-économiques.

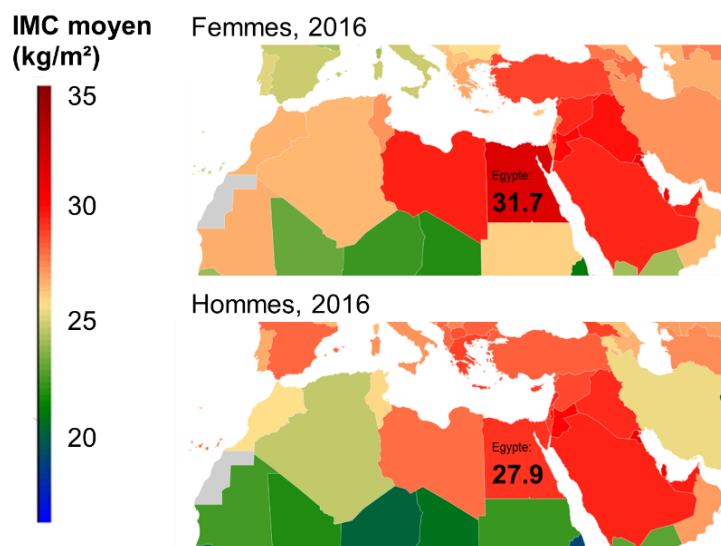


Figure 2. Indice de masse corporelle moyen des femmes et hommes dans les pays du Moyen-Orient.

(figure adaptée de (NCD Risk Factor Collaboration, 2017))

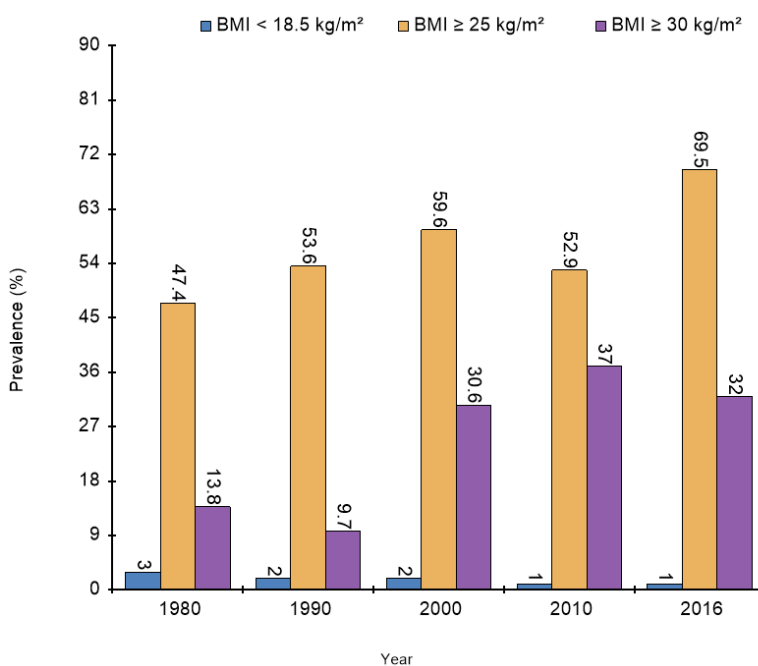


Figure 3. Évolution du statut pondéral chez les femmes égyptiennes entre 1980 et 2016.

La prévalence de sous-pondération (IMC < 18.5 kg/m²) est présentée en bleu, de surpoids (IMC ≥ 25 kg/m²) en orange et d'obésité (IMC ≥ 30 kg/m²) en violet. (graphique réalisé par l'Organisation Mondiale de la Santé (World Health Organization, 2016c)).

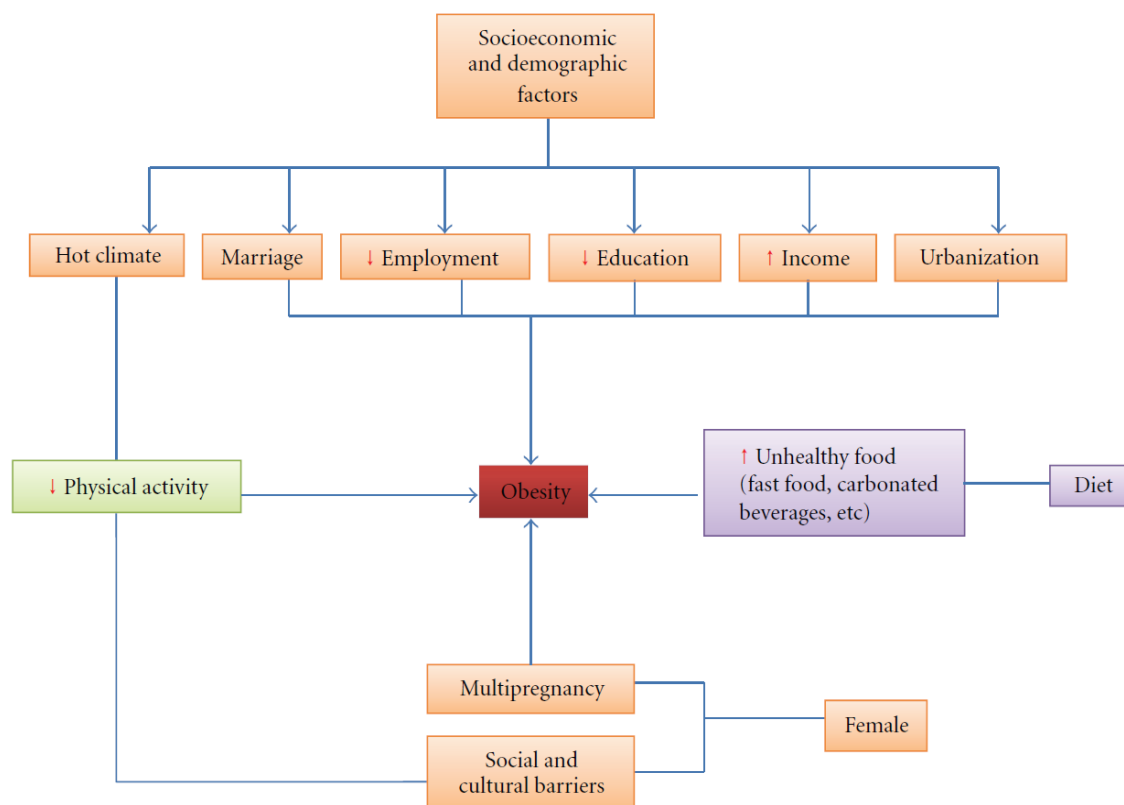


Figure 4. Facteurs pouvant conduire à l'obésité dans les pays du Moyen-Orient.

Les flèches pointant vers le haut indiquent les facteurs qui ont tendance à favoriser l'obésité, et les flèches pointant vers le bas indiquent les facteurs qui ont tendance à diminuer les risques d'obésité (figure extraite de (Badran and Laher, 2011)).

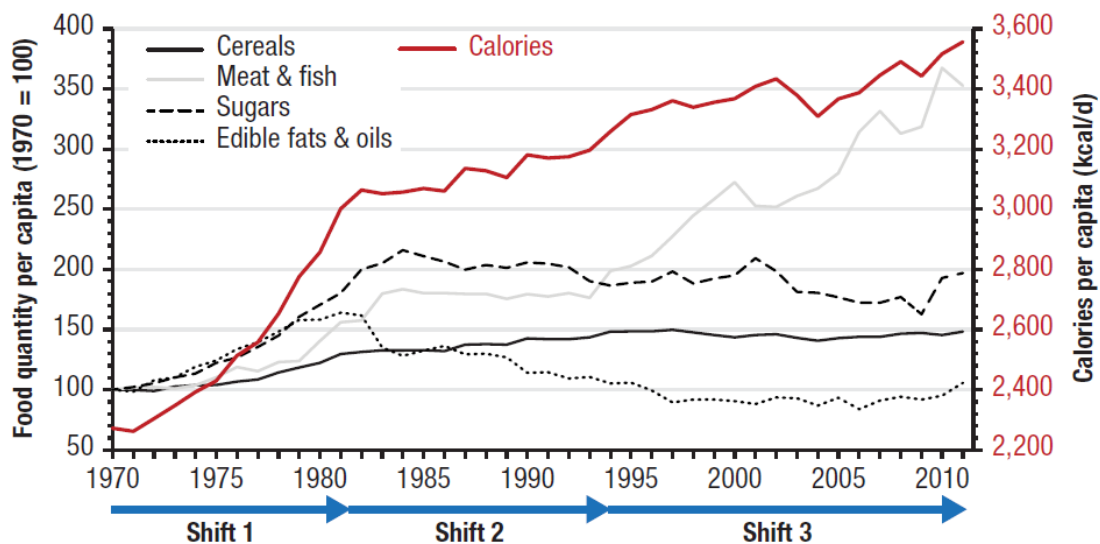
2.1.2. Disponibilité élevée des calories alimentaires

Les données de la FAO (Food and Agriculture Organization) démontrent que la disponibilité des calories alimentaires¹ était d'environ 3000 kilocalories par jour par personne (voire plus) pour 10 des 15 pays de la Méditerranée orientale entre 2003 et 2005 (Musaiger, 2011, FAO, 2014). Au cours des dernières décennies (1970-2005), ces pays ont augmenté leur consommation de produits animaux et de produits sucrés, et diminué leur consommation de fruits et légumes et de céréales complètes (Musaiger, 2011). Par conséquent, les apports en lipides, en acides gras saturés (AGS) et en sucres ont augmenté et les apports en fibres ont été réduits (Musaiger, 2011, FAO, 2014).

Dans la région méditerranéenne, les changements alimentaires coïncident avec des transitions démographiques, économiques et sociétales, bien que les liens de causalité soient

¹ La disponibilité des calories alimentaires peut être estimée en soustrayant les quantités totales de denrées alimentaires produites et importées aux quantités exportées, utilisées pour l'alimentation du bétail et les semences, pour la fabrication d'aliments à destination humaine, et perdues pendant le stockage et le transport.

loin d'être évidents. En effet, les transitions alimentaires sont concomitantes à des changements dans les politiques de subventions alimentaires, une augmentation des revenus et des prix des aliments, des évolutions concernant les modes d'approvisionnement (supermarchés plutôt que marchés en plein air), l'urbanisation de la région, ou encore la mondialisation des systèmes alimentaires. L'augmentation de la restauration rapide hors-foyer et l'exposition croissante à des publicités incitant à la consommation de produits alimentaires, souvent transformés, sont aussi citées comme de potentiels facteurs explicatifs de ces changements alimentaires (Musaiger, 2011). En Égypte, la disponibilité des calories alimentaires a augmenté depuis 1970 (Figure 5) (Ecker et al., 2016). On observe entre 1970 et 1980 une première phase au cours de laquelle le sucre et les matières grasses sont devenues de plus en plus disponibles, puis une deuxième phase de ralentissement de la disponibilité des calories. A partir des années 1990, la viande et le poisson sont devenus disponibles en quantités croissantes (Ecker et al., 2016, FAO, 2016). La plus grande disponibilité calorique implique certainement une plus grande consommation énergétique, bien que les études alimentaires quantifiées soient rares, en particulier chez les femmes. Seules quelques études ont permis de quantifier les apports énergétiques chez des populations spécifiques, parfois affectées par des maladies en lien avec une alimentation déséquilibrée. Les apports alimentaires et nutritionnels mesurés pour des enfants et adolescents indiquent des apports assez élevés compte tenu du peu d'activité physique présumée. Des apports caloriques élevés ont été estimés en utilisant un rappel de 24 heures sur trois jours chez des jeunes enfants obèses de 7 à 18 ans (enfants de 7 à 12 ans : 3747 ± 1086 kcal/jour, filles de 13-18 ans : 3268 ± 1464 kcal/jour (Hassan et al., 2010)). Dans la ville de Sohag (située en Haute-Égypte), un questionnaire de fréquence de consommation quantifié a permis d'estimer des apports caloriques moyens de 3167 ± 81 kcal par jour pour des adolescents (12-18 ans) avec une tension artérielle normale, 3349 ± 100 kcal/jour pour des adolescents au stade pré-hypertensif et 3207 ± 260 kcal/jour pour les hypertendus (Tayel et al., 2013). Chez des adolescentes de 17-18 ans issues de classes socio-économiques inférieures, les apports journaliers énergétiques (déterminés à l'aide de deux rappels de 24 heures et un carnet alimentaire sur une journée) étaient de 2184 ± 530 kcal/jour pour les normo-pondérales, 2713 ± 322 kcal/jour pour celles en surpoids, et 3338 ± 1176 kcal/jour pour les adolescentes obèses (Youssef et al., 2010). Les adolescentes en surpoids ou obèses consommaient plus fréquemment des sodas, de la restauration rapide et moins fréquemment des légumes que les jeunes filles normo-pondérales. Les adolescentes avec un IMC normal passaient significativement moins de temps devant la télévision par jour ($1,2 \pm 1,2$ heures) que les adolescentes en surpoids ($3,0 \pm 2,2$ heures) ou obèses ($3,2 \pm 2,5$ heures) (Youssef et al., 2010).



Source: Authors' representation based on data from FAOSTAT (2014).

Note: kcal/d = kilocalories per day.

Food availabilities are expressed in primary equivalences (including processed commodities). The food group "cereals" corresponds to the food group "cereals—excluding beer" in the Food Balance Sheets (FAOSTAT 2014); "meat & fish" corresponds to "meat" plus "offals," "fats, animals, raw," and "fish, seafood"; "milk & dairy products" corresponds to "milk—excluding butter"; "vegetables" corresponds to "vegetables"; "sugars" corresponds to "sugar & sweeteners"; and "edible fats and oils" corresponds to "butter, ghee" plus "vegetable oils."

Figure 5. Disponibilité des calories alimentaires par capita en Égypte entre 1970 et 2011.

(figure reprise de (Ecker et al., 2016))

2.1.3. Niveaux d'activité physique bas

L'Égypte est le pays du Moyen-Orient avec la plus grande proportion de population (78%) pratiquant moins de 10 minutes d'activité physique par jour. L'inactivité physique se retrouve dans d'autres pays de la région (Arabie Saoudite (68%), Iran (67%) et le Koweït (65%)) et en particulier chez les femmes (Musaiger and Al-Hazzaa, 2012). Les barrières à la pratique d'une activité physique des femmes dans les pays du Moyen-Orient sont nombreuses, expliquant probablement pourquoi les femmes pratiquent encore moins d'activité physique que les hommes en Arabie Saoudite, en Iran, au Koweït et en Syrie (données non disponibles en Égypte) (Musaiger and Al-Hazzaa, 2012). En effet, bien que l'Islam encourage les femmes à faire du sport, le port de certains types de voiles (comme le *krimar* et *nikab*, qui couvrent les cheveux, les oreilles, le cou, les épaules, voire le visage) entrave la réalisation de mouvements, et pousse les femmes à ne réaliser du sport qu'à la maison ou dans des salles de sports qui leurs sont réservées (Walseth and Fasting, 2003). Les femmes sont invitées à ne pratiquer que des sports non provocateurs (mouvements dits « non sexuels »), or l'interprétation de ce qui pourrait être perçu comme provocateur reste relative et personnelle : certaines participantes considéraient que la course à pied ou l'aérobique ne devraient pas être pratiqués devant des hommes, alors que d'autres considéraient ces sports comme adéquats (Walseth and Fasting, 2003). Enfin, la mobilité des femmes en Égypte est particulièrement freinée par un harcèlement sexuel très fréquent dans les rues (la place Tahir, au Caire, est par exemple

devenue un symbole de la violence de genre suite aux événements dramatiques de viols collectifs) (Fortier and Monqid, 2017). Bien que certaines femmes fassent preuve d'initiative et de combativité, la présence des femmes dans les rues égyptiennes est découragée par des contraintes au nom de la morale collective (Fortier and Monqid, 2017).

2.1.4. Facteurs sociologiques : représentations du corps des femmes au Moyen-Orient

L'image du corps de la femme au Moyen-Orient semble tiraillée entre tradition et modernité (Al-Jenaibi, 2011). Dans les générations plus anciennes, l'embonpoint féminin était perçu comme un signe de statut social plus élevé, mais aussi comme un symbole de fertilité, de prospérité et de beauté (Mokhtar et al., 2001). La femme, une fois mariée, se voit traditionnellement attribuer des responsabilités liées à la bonne tenue du foyer et à l'hospitalité, avec des activités essentiellement centrées autour de la préparation des repas, et ses rôles dans la sphère publique sont très limités (Batnitzky, 2008). Une considération inférieure des femmes par rapport aux hommes a déjà été corrélée à une santé mentale et physique dégradée (Whitehead et al., 2016) (Figure 6) avec des répercussions notables sur le surpoids (Batnitzky, 2008). Dans les pays arabophones, malgré des variations selon les pays, l'âge, le niveau d'éducation ou des facteurs religieux, on observe globalement un IMC plus élevé chez les femmes que chez les hommes (El Ati et al., 2012, Batnitzky, 2008). Alors que les tenues religieuses amples (*hijab*, *abaya*) semblent avoir un impact positif sur la satisfaction que les femmes ont de leur corps (Swami et al., 2014, Mussap, 2009a, Mussap, 2009b), le port de vêtements amples et camouflants a déjà été corrélé à des IMC plus élevés (Tiggemann and Andrew, 2012).

Aujourd'hui, des tensions émergent entre tradition, nouveaux idéaux de beauté, aspirations à la modernité et corpulences. A Dubaï par exemple, les idéaux de minceur, de plus en plus omniprésents, sont en contradiction avec les aspirations à la modernité (Trainer, 2010), et la prévalence de surpoids est alarmante (66% des hommes et 71% des femmes sont en surpoids) (NCD Risk Factor Collaboration, 2017). Pour « être moderne », il faut consommer de la restauration rapide (« fast foods »), se déplacer en voiture plutôt qu'à pied ou être assisté dans les tâches du quotidien par des domestiques (Trainer, 2010). Historiquement, les femmes étaient plutôt représentées dans les publicités et médias dans leurs rôles traditionnels de femmes tributaires de leur mari, mais aujourd'hui, les couvertures de magazines choisissent aussi comme égéries des femmes minces, et « seules, détachées, jolies, parées d'habits sophistiqués et chers » (Al-Jenaibi, 2011) (Figure 7).

Ces représentations, tantôt contradictoires, tantôt hybrides, semblent impacter les générations les plus jeunes. Aux Émirats Arabes Unis, toutes les étudiantes interrogées (âgées de 18 à 25 ans, n=50) reconnaissent qu'un embonpoint était perçu positivement par leurs grands-parents, alors que leurs amis, familles et futurs maris attendaient plutôt des jeunes filles qu'elles maintiennent une silhouette mince (Trainer, 2010). Cet attrait pour les

silhouettes plus fines a également été observé en Tunisie (Tlili et al., 2008). En Égypte, une étude a montré que plus les femmes lisaient des magazines sur les thématiques de la santé, la beauté, et la mode, plus elles étaient insatisfaites d'un embonpoint et désiraient être minces (Ragab, 2007). Ce désir de minceur est géré par des mécanismes compensatoires tels que le fait d'initier un régime, de jeûner, de porter le voile, voire d'avoir recours à la chirurgie plastique (Ragab, 2007), et souligne les tensions auxquelles sont soumises les jeunes Égyptiennes.

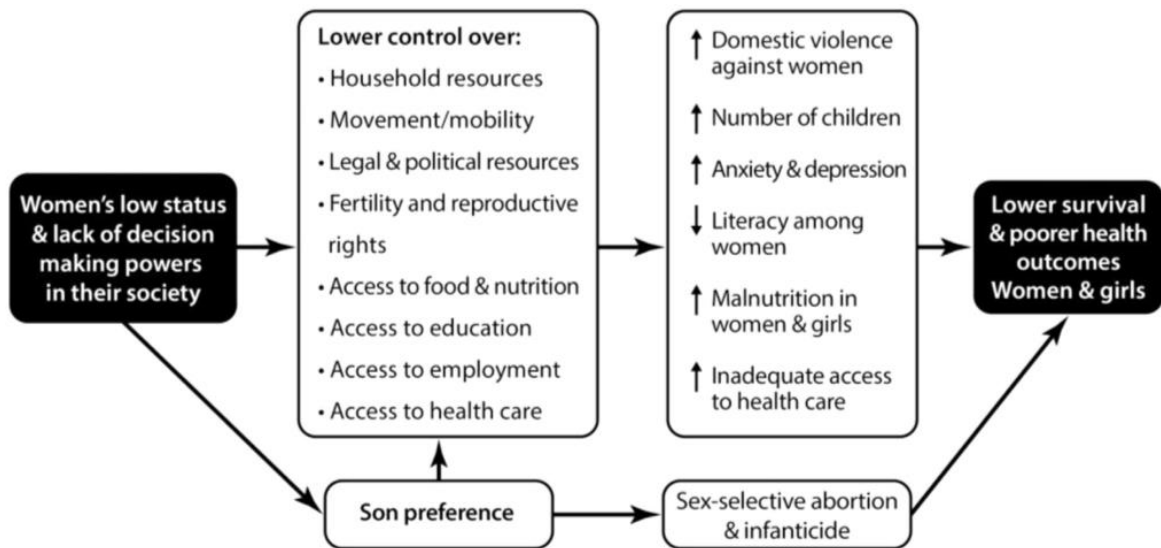


Figure 6. Répercussions d'un statut inférieur des femmes par rapport aux hommes en société sur leur santé physique et mentale.

Figure extraite de (Whitehead et al., 2016).



Figure 7. Exemples de représentations traditionnelles ou modernes de femmes dans les médias Emiratis.

L'image (a) est issue d'une série télévisée dramatique (Dubai Media Incorporated, 2011) et constitue une représentation traditionnelle des femmes. L'image (b) est issue d'un magazine de mode (Alsada, 2011) et représente une image plus moderne et émancipée de la femme (Al-Jenaibi, 2011). Les exemples et images sont issus de (Al-Jenaibi, 2011).

2.2. Risques d'inadéquation en micronutriments chez les femmes égyptiennes

D'après les données bibliographiques disponibles, le fer, la vitamine D et les folates pourraient être sous consommés par les femmes égyptiennes. L'iode, la vitamine A et le zinc étant fréquemment sous consommés dans les pays en développement (United Nations Standing Committee on Nutrition, 2010, Müller and Krawinkel, 2005, Ramakrishnan, 2002, Aguenau et al., 2019, Sommer, 2001, Nasri et al., 2004, Azizi and Mehran, 2004, Hambidge, 2000), les données disponibles en Égypte pour ces nutriments seront également examinées. Aucune donnée n'existe sur d'autres micronutriments pour les femmes égyptiennes à notre connaissance.

2.2.1. L'inadéquation en fer et le risque associé d'anémie

Risque d'anémie chez les femmes égyptiennes.

Les données sur le fer sont particulièrement sensibles car l'anémie est un problème majeur en Égypte avec près de la moitié des femmes anémiées (Tawfik et al., 2015). Une étude nationale menée dans 11 gouvernorats d'Égypte auprès de 4526 foyers dans lesquels vivaient des femmes de 20 à 49 ans révèle que 47% des femmes sont anémiées (taux d'hémoglobine < 12 g/dL), 50% présentent une déficience en fer (taux sériques de ferritine inférieurs à 11µg/L), et 25% souffrent d'une anémie par carence en fer (c'est-à-dire qu'elles avaient à la fois des taux sériques de ferritine et d'hémoglobine bas) (Tawfik et al., 2015). Des études locales confirment la forte prévalence d'anémie chez des filles plus jeunes, notamment en milieu rural : environ 30% des filles de moins de 18 ans sont anémiées en Haute-Égypte (Mousa et al., 2016) et dans le Sud du Sinaï (Yamamah et al., 2015)). Ces fortes prévalences interrogent sur les causes potentielles de ces anémies et leurs répercussions.

Origines de l'anémie

Une anémie est diagnostiquée lorsque les concentrations en hémoglobine sont inférieures à des seuils préétablis selon l'âge et le sexe des individus. L'anémie peut avoir diverses origines : apports alimentaires en fer insuffisants, besoins en fer accrus (pertes menstruelles, grossesse...), carences en micronutriments autres que le fer, malabsorption liée à un surpoids ou une obésité, ou maladies diverses (infection, inflammation ou maladie génétique) (World Health Organization, 2017). Le fer est un élément essentiel à la production (érythropoïèse) et la fonction des globules rouges, qui servent à transporter l'oxygène dans le sang. Un stock insuffisant de fer mène *in fine* à une concentration en hémoglobine plus basse des globules rouges (World Health Organization, 2017). Chez les femmes en âge de procréer, l'anémie peut générer un état de fatigue généralisé, une difficulté à se concentrer et à réaliser des efforts physiques, une perte de productivité au travail, et, quand elle est associée à une grossesse, peut avoir des répercussions sur la santé de l'enfant (prématurité, faible poids de naissance) (World Health Organization, 2017).

Apports alimentaires en fer insuffisants

Les apports en fer peuvent être estimés par des enquêtes alimentaires quantitatives, couplées avec des tables de composition précises sur la teneur en fer (idéalement en détaillant les teneurs en fer héminique et non-héminique) des aliments consommés. Les aliments riches en fer héminique sont les produits animaux (la viande rouge et le foie en particulier), tandis que les groupes alimentaires issus de produits végétaux contiennent exclusivement du fer sous forme non-héminique (légumes à feuilles vertes, graines, noix ou légumineuses par exemple). Un programme d'enrichissement de la farine utilisée pour la préparation du pain *baladi* a été lancé en 2008 par le gouvernement égyptien et le Programme alimentaire mondial (Elhakim et al., 2012). La farine était enrichie avec 30 mg/kg de fer (sous forme de sulfate ferreux) et 1,5 mg/kg de folates. Le pain produit à partir de la farine enrichie était disponible dans les boulangeries, kiosques de rue, boutiques, ou associations de développement local des quartiers les plus modestes. Les teneurs en fer et folates de la farine enrichie auraient permis d'apporter aux femmes en âge de procréer 11,4 mg de fer et 300 µg de folates par jour, *via* les 380 grammes de farine consommée quotidiennement (Elhakim et al., 2012). Ce programme d'enrichissement s'est arrêté en 2012 du fait de problèmes pour contrôler et garantir une bonne qualité des farines dans les moulins, et de l'arrêt des subventions pour financer le programme (Abdalla and Al-Shawarby, 2017). L'arrêt de ce programme d'enrichissement de la farine du pain *baladi* et le manque de données de consommation alimentaire questionnent donc les apports actuels en fer *via* l'alimentation des Égyptiennes.

Besoins en fer accrus

Lorsque le corps doit constituer des globules rouges, ses besoins en fer sont plus élevés. Ainsi, les besoins en fer augmentent pour compenser les pertes menstruelles, ou pour synthétiser le liquide placentaire lors d'une grossesse (World Health Organization, 2017). Les femmes en âge de procréer, du fait de leurs pertes menstruelles, ont typiquement des besoins en fer plus élevés que les hommes et ont donc plus de risques de présenter une anémie par carence en fer, en particulier lorsque leurs pertes sont abondantes (World Health Organization, 2017). Certaines méthodes de contraception peuvent influencer le volume des pertes menstruelles et donc les besoins en fer. La contraception orale diminue le volume des pertes menstruelles alors que l'utilisation d'un dispositif intra-utérin l'augmente (EFSA Panel on Dietetic Products Nutrition and Allergies, 2015). En Égypte, 30% des femmes mariées de moins de 50 ans utilisent un dispositif intra-utérin, 16% des femmes prennent la pilule contraceptive, et 9% utilisent des dispositifs hormonaux injectables (42% n'utilisent aucune méthode de contraception) (Egypt Ministry of Health and Population et al., 2015a).

Carences en autres micronutriments

Des carences en vitamines A, B (riboflavine, folates, B12, B6), C, D, E ou en cuivre peuvent engendrer une anémie, du fait de l'implication de ces nutriments dans le métabolisme de l'hémoglobine ou du fer (World Health Organization, 2017). La vitamine A est impliquée dans la modulation de l'érythropoïèse *via* les rétinoïdes et joue un rôle immunitaire important. Une carence en vitamine A peut donc mener à des anémies infectieuses (Semba and Bloem, 2002). Une consommation insuffisante de vitamines B peut

aussi induire une anémie, car les vitamines B jouent un rôle dans le métabolisme du fer (riboflavine (Rohner et al., 2007)), la production de l'hème (vitamine B6 (Fishman et al., 2000)), la synthèse de l'ADN, la division cellulaire et l'érythropoïèse (folates (World Health Organization, 2017) et vitamine B12 (Metz, 2008)). La vitamine C augmente la biodisponibilité du fer non-héminique et l'utilisation des réserves en fer de l'organisme (Fishman et al., 2000). Les mécanismes qui expliqueraient les liens de causalité entre une déficience en vitamine D et une concentration en hémoglobine plus basse restent assez peu compris (World Health Organization, 2017), mais ces concomitances ont été observées aussi bien chez des enfants que des adultes (Atkinson et al., 2014), et un rôle de la vitamine D est suspecté dans l'expression de l'hepcidine (une hormone contrôlant l'homéostasie du fer), particulièrement dans les maladies inflammatoires (Smith and Tangpricha, 2015). Il est donc important d'estimer les apports en micronutriments des femmes Égyptiennes.

Malabsorption du fer liée à un surpoids ou une obésité

Les individus souffrant de surpoids et d'obésité ont un risque accru de carence en fer, qui pourrait être expliqué par une production stimulée d'hepcidine, qui est produite principalement par le foie, mais aussi par le tissu adipeux. Lors d'une inflammation induite par obésité, la sécrétion d'hepcidine est stimulée, ce qui amène à séquestrer le fer sans pouvoir l'utiliser (Yanoff et al., 2007). Ce mécanisme pourrait expliquer que plus d'un cinquième (23%) des femmes enquêtées en Égypte soient anémiées malgré des stocks en fer suffisants, d'autant que des valeurs élevées en protéine réactive C (CRP) confirment la présence d'une inflammation (Tawfik et al., 2015).

Maladies diverses

Certaines maladies (malaria, infections parasitaires, cancers, virus de l'immunodéficience humaine, insuffisances cardiaques ou rénales chroniques...) peuvent induire une anémie *via* des mécanismes multiples (World Health Organization, 2017). L'absorption des nutriments ou leur métabolisme peuvent par exemple être altérés lors d'infections par des parasites intestinaux. Une inflammation (due notamment à des maladies chroniques aiguës comme les insuffisances cardiaques ou rénales) peut induire la séquestration des stocks de fer sous forme de ferritine, ou la diminution de la durée de vie et/ou de la production de globules rouges. Les maladies génétiques telles que la thalassémie bêta peuvent réduire la production d'hémoglobine et modifier la biodisponibilité du fer. En Égypte, la thalassémie bêta est l'hémoglobinopathie la plus fréquente, avec 9-10% de la population porteuse de l'anomalie génétique (El-Beshlawy et al., 1999).

2.2.2. Les risques d'inadéquation en vitamine D, folates, vitamine A, zinc et iode

La vitamine D.

Les déficiences en vitamine D sont particulièrement fréquentes chez les femmes égyptiennes, et peuvent provenir d'apports insuffisants *via* l'alimentation (les sources de vitamine D étant principalement les poissons gras, les œufs et les produits laitiers) et/ou d'une exposition insuffisante au soleil. Une étude a montré que 72% des femmes en âge de procréer étaient en déficit de vitamine D (Le Caire et Port Saïd, taux de 25 hydroxy-vitamine D sérique < 20ng/L, n=208) (60). Ces fortes prévalences se retrouvent en Égypte chez les femmes enceintes (54%), allaitantes (73%) et chez les femmes plus âgées (40-77%) (Botros et al., 2015). Bien que l'Égypte bénéficie d'un fort ensoleillement, une faible exposition au soleil du fait de barrières culturelles et sociétales mentionnées précédemment expliquerait ces fortes prévalences (premier prédicteur d'après des modèles de régression) (Botros et al., 2015). Le Caire est la deuxième mégapole la plus polluée au monde après Delhi sur la période 2011-2015 (World Health Organization, 2016a). Or la pollution de l'air réduit le passage des rayons UVB jusque l'atmosphère terrestre, et augmenterait donc les risques de déficiences en vitamine D (Hosseinpanah et al., 2010, Agarwal et al., 2002, Manicourt and Devogelaer, 2008). Le port du voile semble également altérer le statut en vitamine D. Dans cette même étude (Botros et al., 2015), les femmes voilées avaient des concentrations en vitamine D sérique significativement plus basses (16,4 ng/dL) que les femmes non voilées (23 ng/dL) et cette tendance se retrouve dans d'autres pays du Moyen-Orient (Mishal, 2001, Guzel et al., 2001). Les apports en calcium et vitamine D, estimés à l'aide d'un questionnaire sur les apports alimentaires et la prise de compléments alimentaires, ne permettaient pas de prédire les concentrations sériques en vitamine D, qui s'expliquaient plutôt par des niveaux différents d'exposition au soleil (Botros et al., 2015). Les implications d'une déficience en vitamine D sont nombreuses (contribuerait au développement de l'anémie (Atkinson et al., 2014) et à une plus grande fragilité osseuse (Lips, 2006)), d'où l'importance d'apporter un apport suffisant *via* l'alimentation afin de contrebalancer la faible exposition au soleil des femmes égyptiennes.

Les folates.

Des apports insuffisants en folates pendant la période péri-conceptionnelle et pendant la grossesse peuvent conduire à une malformation du tube neural du fœtus (Pitkin, 2007), et contribuent également au développement d'une anémie (World Health Organization, 2017). Des régimes pauvres en folates ont aussi été corrélés à une augmentation de l'incidence des cancers colorectaux (World Health Organization, 2004). Les légumes à feuilles vertes, les légumineuses et certains produits animaux (foie par exemple) sont des sources de folates. Une étude publiée en 2014 a révélé des déficiences relativement faibles en folates parmi des femmes égyptiennes en âge de procréer (14,7% des femmes de 20-49 ans avaient des taux sériques en folates < 10 nmol/L) (Tawfik et al., 2014). Cette étude s'inscrivait dans le suivi des prévalences des déficiences en fer et en folates suite au

programme d'enrichissement du pain *baladi* en fer et en folates par le gouvernement Égyptien (Elhakim et al., 2012). Comme expliqué précédemment, ce programme d'enrichissement du pain n'est plus en place aujourd'hui, et les apports en folates ainsi que les prévalences de déficience ont pu varier depuis.

La vitamine A.

Une étude au Caire portant sur 200 mères (19-39 ans) de classes sociales modestes a prouvé que 23,5% des femmes présentaient une déficience en vitamine A (taux de rétinol sérique $\leq 0,7 \mu\text{mol/L}$), et que ces taux étaient corrélés à de bas apports *via* l'alimentation (estimés à partir d'un rappel de 24 heures) (Hamdy et al., 2013). Une carence en vitamine A peut provoquer une cécité nocturne, un déficit immunitaire et contribuer au développement d'une anémie, comme expliqué précédemment. Une consommation suffisante de légumes et produits animaux riches en vitamine A est donc importante pour éviter ce risque d'inadéquation (Müller and Krawinkel, 2005).

Le zinc.

Une carence en zinc peut compliquer le déroulement d'une grossesse et induire un déficit immunitaire (Müller and Krawinkel, 2005). Une étude à Alexandrie sur 1055 femmes enceintes parue en 2014 concluait que les déficiences en zinc étaient fréquentes au sein de cette population (53% des femmes) (Naem et al., 2014). Cependant, ces résultats restent à vérifier dans d'autres régions d'Égypte et chez d'autres profils de femmes, car l'étude a été menée sur une population assez atypique par rapport aux récents changements alimentaires décrits précédemment. En effet, les femmes consommaient des régimes peu caloriques et pauvres en protéines et lipides, et les déficiences en zinc sont donc peu surprenantes car elles proviennent souvent de régimes riches en céréales, contenant peu de produits animaux (Müller and Krawinkel, 2005).

L'iode.

Le sel est enrichi en iode depuis 1996 en Égypte (Egypt Ministry of Health and Population et al., 2015b), ce qui constitue une stratégie efficace pour lutter contre les déficiences en iode (Müller and Krawinkel, 2005). Un rapport de 2015 estimait que 92,5% des foyers en Égypte utilisaient du sel enrichi à plus de 15 mg/kg (Egypt Ministry of Health and Population et al., 2015b), réduisant ainsi les risques de goitre, d'hypothyroïdie, de retard de croissance et de crétinisme (Müller and Krawinkel, 2005).

2.3. Justification et objectifs des travaux de thèse

2.3.1. Objectifs des travaux de thèse

Les jeunes femmes égyptiennes font face à des enjeux de santé publique à la fois exceptionnels et emblématiques des pays du Moyen-Orient. La forte prévalence de surpoids et d'obésité cohabite avec des déficiences en micronutriments, mais les déséquilibres alimentaires des jeunes femmes égyptiennes n'ont jusqu'ici pas été étudiés précisément à notre connaissance. Pourtant, les répercussions sur leur santé et sur celle de leurs enfants sont importantes. Il est donc déterminant de mieux comprendre les comportements alimentaires des jeunes femmes. Compte tenu des risques d'inadéquation décrits dans la partie bibliographique (pour le fer, la vitamine D et les folates à minima), on peut émettre l'hypothèse que les apports alimentaires devraient être rééquilibrés. L'Égypte ne dispose pas de recommandations alimentaires à notre connaissance (Montagnese et al., 2019). Il semble donc intéressant d'identifier des stratégies susceptibles d'améliorer la qualité de leur alimentation, *via* des modifications de leur régime alimentaire portant sur des aliments consommés localement, et, si l'environnement alimentaire ne permet pas d'assurer les apports en nutriments, *via* la reformulation d'aliments existants ou l'introduction de nouveaux produits sur le marché.

Les travaux de thèse avaient pour objectif d'analyser les déséquilibres nutritionnels des femmes égyptiennes résidant en milieu urbain, pour proposer des stratégies d'amélioration de la qualité de leur alimentation les plus acceptables possible. Les travaux de thèse ont été déclinés en 3 axes :

- (1) L'analyse des apports alimentaires et nutritionnels
- (2) L'identification de stratégies d'amélioration nutritionnelle
- (3) L'exploration de l'acceptabilité des stratégies modélisées

Une recherche transdisciplinaire utilisant des méthodes mixtes a été employée au cours de cette thèse afin de prendre en compte la complexité des composantes du régime alimentaire des femmes égyptiennes. La recherche par méthodes mixtes est une terminologie qui désigne une approche souvent suivie intuitivement par des chercheurs et qui définit l'association de méthodes quantitatives et qualitatives (Guével and Pommier, 2012).

Dans le cadre de ces travaux de thèse, les apports alimentaires et nutritionnels ont été estimés grâce à des carnets alimentaires quantifiés ; les stratégies d'amélioration nutritionnelle ont été identifiées par modélisation ; l'acceptabilité des stratégies envisagées a été testée en interrogeant les populations cibles par le biais d'enquêtes qualitatives.

2.3.2. Justification de la population étudiée

Jeunes femmes égyptiennes résidant en milieu urbain.

Les jeunes femmes égyptiennes résidant dans les villes sont particulièrement impactées par un double fardeau de malnutrition, (c'est à dire la coexistence au sein d'une population, de foyers ou d'individu, de sous-nutrition et de surpoids, d'obésité, ou de maladies non transmissibles liées à l'alimentation (World Health Organization, 2016b)), mais cette population a été peu étudiée.

Les zones urbaines sont sensiblement plus affectées par le surpoids que les zones rurales (El Ati et al., 2012). En Égypte par exemple, 88,2% des femmes sont en surpoids en milieu urbain, *versus* 82,6% en milieu rural (Egypt Ministry of Health and Population et al., 2015a). Compte tenu de l'urbanisation rapide en Égypte, il est pertinent d'étudier les comportements alimentaires dans les villes.

Une population féminine (plutôt que masculine) a été sélectionnée pour les travaux de thèse, car dans de nombreux pays du Moyen-Orient, les prévalences de surpoids et d'obésité sont plus importantes chez les femmes que chez les hommes (NCD Risk Factor Collaboration, 2017). Ecker et ses collaborateurs, dans un récent rapport de l'IFPRI (International Food Policy Research Institute), soulignaient les enjeux exceptionnels des femmes égyptiennes vis-à-vis du surpoids et de l'obésité (Ecker et al., 2016), et des analyses cliniques ont mis en évidence des déficiences en fer (Tawfik et al., 2015), vitamine D (Botros et al., 2015) et folates (Tawfik et al., 2014). Cette population est donc affectée par un double fardeau de malnutrition.

Nous avons ciblé une tranche d'âge assez jeune pour différentes raisons. D'une part, l'âge semble déterminant dans les prévalences de surpoids et d'obésité chez les femmes (Egypt Ministry of Health and Population et al., 2015a), donc il paraît pertinent de s'intéresser aux jeunes femmes en âge de procréer avant que le surpoids ne soit plus prévalent. D'autre part, un intérêt pour les questions d'alimentation semble émerger chez les jeunes femmes du Moyen-Orient, comme en témoigne le désir de minceur plus marqué chez les jeunes que chez leurs aînées (Trainer, 2010, Tlili et al., 2008, Mokhtar et al., 2001).

La période péri-conceptionnelle : fenêtre d'opportunité ?

Malgré le rôle déterminant de l'alimentation avant la grossesse sur la santé de la mère et de l'enfant, aucune étude n'a, à notre connaissance, identifié des stratégies d'amélioration nutritionnelles pour les jeunes femmes égyptiennes. Il est aujourd'hui largement admis que l'alimentation de la mère pendant la grossesse impacte la santé de la femme, l'issue de la grossesse et la santé de l'enfant à naître (Fraser and Abu-Saad, 2010, Burke et al., 2014, Baidal et al., 2016, Gernand et al., 2016, Barker, 1990, Barker, 2004). Cependant, il semble que dès le début de la période péri-conceptionnelle² (c'est à dire avant la grossesse), l'alimentation ait

² La période péri-conceptionnelle est définie comme la période allant de la pré-conception, c'est-à-dire un à deux ans avant la conception, jusqu'à l'embryo- et l'organo-génèse du fœtus (c'est-à-dire lors du premier

un rôle déterminant (Cetin et al., 2009). Par exemple, veiller à un apport suffisant en folates pendant la période péri-conceptionnelle (souvent par supplémentation) est fortement recommandé afin de prévenir les malformations du tube neural type spina-bifida (Pitkin, 2007). Bien qu'encore peu documentés chez l'humain, les apports en autres micronutriments pendant cette période semblent impacter la fertilité, l'embryogénèse et la formation du placenta (Cetin et al., 2009). Les femmes sans enfant semblent plus disposées à prendre soin de leur alimentation que les femmes avec enfants. En effet, la grossesse induit un sentiment de perte de contrôle de son corps (Hodgkinson et al., 2014) et la naissance d'un enfant diminue le temps disponible des mères pour prendre soin d'elles (McVeigh, 1997), ce qui engendre une prise de poids (Olson et al., 2003). Par ailleurs, un surpoids avant la grossesse rend plus difficile le retour à une corpulence normale après la naissance (Gunderson et al., 2004). Les jeunes femmes en âge de procréer qui n'ont pas encore d'enfants apparaissent donc comme une cible intéressante pour faire évoluer les régimes vers une alimentation contenant des aliments moins énergétiques, gras, ou sucrés et plus denses en micronutriments, et pour avoir éventuellement un impact sur les générations futures.

Le double fardeau de malnutrition se retrouve chez les enfants égyptiens.

Les données épidémiologiques suggèrent la mise en place d'un cercle vicieux entre la santé des femmes et celle de leurs enfants, pourtant les facteurs alimentaires affectant la santé des femmes sont encore méconnus. En effet, les fortes prévalences de surpoids et d'anémie observées chez les femmes se retrouvent chez les enfants : un quart des enfants de 6 mois à 5 ans sont anémiés et 15% sont en surpoids (Egypt Ministry of Health and Population et al., 2015a). La prévalence du surpoids augmente avec l'âge (un tiers des enfants de 5-19 ans sont en surpoids ou obèses) et les filles sont plus fréquemment anémiées (21%) que les garçons (18%) (Egypt Ministry of Health and Population et al., 2015a). Les déficiences en vitamine A chez les femmes enceintes se retrouvent aussi chez leurs enfants après la naissance (Hamdy et al., 2013). Ces données sur la prévalence des déficiences et du surpoids laissent penser que l'amélioration de la qualité de l'alimentation des femmes égyptiennes pourrait engendrer un cercle vertueux, en agissant positivement sur celles de leurs enfants.

Absence de données alimentaires quantifiées sur l'alimentation des femmes égyptiennes en milieu urbain.

Malgré le caractère exceptionnel et urgent des problématiques de santé des jeunes femmes égyptiennes en milieu urbain, leurs comportements alimentaires sont peu étudiés. Le double fardeau de malnutrition peut avoir des origines multiples (démographiques, culturelles, style de vie...), dont l'une est une alimentation déséquilibrée. Cependant, aucune étude n'a quantifié les consommations alimentaires des femmes égyptiennes en milieu urbain à notre connaissance. Comme décrit précédemment, les rares enquêtes alimentaires en Égypte ont été effectuées seulement chez des adolescents (Hassan et al., 2010, Tayel et al., 2013, Youssef et al., 2010).

trimestre de grossesse) CETIN, I., BERTI, C. & CALABRESE, S. 2009. Role of micronutrients in the periconceptional period. *Human Reproduction Update*, 16, 80-95.

2.3.3. Intérêts de la modélisation couplée à des analyses qualitatives pour suggérer des changements alimentaires acceptables

La modélisation de l'alimentation est une méthode mathématique qui permet d'intégrer l'ensemble des contraintes inhérentes à une alimentation durable (adéquation nutritionnelle, coût, acceptabilité, impact sur l'environnement) afin de modéliser des régimes optimaux (Burlingame et al., 2012, Daelmans et al., 2013). Cette approche a été utilisée dans ces travaux de thèse afin d'identifier un jeu de conseils alimentaires pour les jeunes femmes vivant en Égypte urbaine et de tester le potentiel de différents aliments enrichis (théoriques ou prototypes) pour améliorer les apports nutritionnels. George Stigler a été le premier, dans les années 1940, à traiter un problème mathématique complexe à l'aide de la programmation linéaire. Il cherchait à trouver la combinaison d'aliments la moins onéreuse possible qui réponde aux recommandations nutritionnelles, et a donc développé un algorithme basé sur la programmation linéaire (Dantzig, 1990). Depuis, de nombreux chercheurs ont utilisé la modélisation de l'alimentation, notamment pour identifier des régimes optimaux pouvant servir de base à l'élaboration de recommandations alimentaires (Ferguson et al., 2006, National Health and Medical Research Council, 2011, Wessells et al., 2019, Buttriss et al., 2014), ou pour comparer différents produits d'un point de vue théorique (Skau et al., 2014, Hemsworth, 2014, Frega et al., 2012, Darmon et al., 2009).

Les approches de modélisations sont bien adaptées pour identifier les changements alimentaires aussi bien au niveau des pratiques que de l'offre alimentaire mais les résultats restent théoriques et spéculatifs. En effet, l'acceptabilité des changements identifiés par modélisation dépend notamment de critères économiques, sociaux, culturels, des modes de vie ou plus simplement des préférences alimentaires de chacun. Lors du paramétrage des modèles, différents proxys d'acceptabilité sont utilisés afin d'éviter de générer des régimes optimisés trop éloignés des habitudes alimentaires. Le choix des aliments à partir desquels les régimes seront optimisés, les contraintes du modèle sur les aliments, ou les fonctions objectifs peuvent par exemple permettre de prendre en compte certains aspects des habitudes de consommation locales (*e.g.* modélisations à partir des aliments les plus fréquemment consommés uniquement, respectant des bornes minimales et maximales pour correspondre aux quantités consommées, fonctions objectifs minimisant les écarts aux fréquences de consommation de groupes alimentaires). Le soin accordé au paramétrage du modèle varie grandement d'une étude à l'autre, alors que cette étape est déterminante dans le réalisme des régimes modélisés (Gazan et al., 2018). Par exemple, au Mozambique, des régimes nutritionnellement adéquats ayant le plus faible coût possible ont été modélisés sans contrainte sur les aliments, résultant en des régimes peu diversifiés et basés principalement sur de grandes quantités d'aliments denses nutritionnellement (Parlesak et al., 2014). Dans une étude modélisant des régimes réduisant les émissions de gaz à effet de serre en Nouvelle Zélande, les aliments inclus dans différents scénarios étaient arbitrairement sélectionnés, et les régimes modélisés résultants étaient très influencés par les contraintes fixées sur les aliments (Wilson et al., 2013).

Par ailleurs, les régimes modélisés sont rarement discutés avec la population ciblée. À notre connaissance, seules quelques études de modélisation (Fahmida et al., 2015, Hlaing et al., 2015, Hotz et al., 2015, Weber et al., 2017) ont été suivies par des enquêtes qualitatives afin d'identifier les barrières et leviers à l'adoption des changements alimentaires modélisés. Les essais d'améliorations des pratiques³ sont des études qualitatives pendant lesquelles des enquêteurs se rendent sur le terrain afin d'expliquer les pratiques à adopter (sur une durée de quelques jours à plusieurs semaines) puis de discuter des barrières rencontrées lors de la phase d'essai (Dickin et al., 1997, Muehlhoff et al., 2011). Les messages sont ensuite réajustés afin de prendre en compte les barrières rencontrées, et de proposer des moyens alternatifs pour améliorer les pratiques alimentaires. Deux essais d'amélioration des pratiques ont été mis en œuvre en Birmanie (Hlaing et al., 2015) et en Indonésie (Fahmida et al., 2015) afin de tester l'acceptabilité de recommandations alimentaires formulées par modélisation (à l'aide du logiciel Optifood). Au Kenya, une enquête ethnographique a permis d'explorer la perception des recommandations alimentaires identifiées (à l'aide du logiciel Optifood) sur des aspects économiques, de praticité, d'accessibilité et de familiarité vis-à-vis des habitudes de la population (Hotz et al., 2015). En Égypte, les représentations liées à l'alimentation, à la santé ou au corps sont, à notre connaissance, peu étudiées, or cette connaissance pourrait être utile pour anticiper l'acceptabilité des changements alimentaires modélisés. Dans le cadre de cette thèse, une approche transdisciplinaire, s'inspirant de la nutrition, de modélisations mathématiques et de sciences de la consommation, a été utilisée afin d'appréhender de manière globale les déséquilibres alimentaires des femmes égyptiennes. La recherche transdisciplinaire émerge depuis quelques années comme une approche guidée par la volonté de résoudre des problématiques de terrain complexes, en combinant des disciplines et des méthodes différentes (Hadorn et al., 2008). Comme dans d'autres pays du Moyen-Orient, les déséquilibres alimentaires des femmes égyptiennes ont des origines multiples, et les stratégies envisagées pour rééquilibrer les apports doivent prendre en compte la complexité de la situation locale. Une approche mixte, combinant des données quantitatives (recueil alimentaire et prix des aliments) et qualitatives (entretiens individuels et focus groupes) à des analyses par modélisation a été utilisée pour examiner les problématiques alimentaires locales de manière transdisciplinaire, et proposer des stratégies d'amélioration basées sur des analyses théoriques (modélisations) et de terrain (échanges avec la population locale). La confrontation des solutions envisagées par modélisation aux pratiques, aspirations, contraintes et représentations des jeunes femmes égyptiennes résidant en milieu urbain nous semblait être une voie prometteuse pour optimiser les ressources alimentaires locales, affiner les solutions envisagées et favoriser leur adoption.

³ Les essais d'amélioration des pratiques sont nommés « Trial of Improved Practices (TIP) », en anglais.

3. TRAVAUX PERSONNELS

3.1. Analyse des apports alimentaires

3.1.1. Enquête alimentaire auprès d'une population âgée de 1 à 50 ans résidant en milieu urbain en Égypte

Les données alimentaires des femmes âgées de 19 à 30 ans sont issues d'une enquête plus large estimant les apports alimentaires et nutritionnels d'une population âgée de 1 à 50 ans résidant en zone urbaine en Égypte, commanditée par Danone en 2016. Nous donnons ci-après quelques éléments de contexte, de méthodologie et quelques résultats de cette enquête, qui confortent le choix des femmes comme population d'étude pour les travaux de thèse au regard des éléments évoqués précédemment.

Contexte

Peu d'études ont été conduites pour évaluer les apports alimentaires des enfants et des adultes en Égypte urbaine. En 2016, l'entreprise Danone a mis en place une enquête alimentaire de quatre jours chez des personnes âgées de 1 à 50 ans résidant en milieu urbain en Égypte, afin de mieux comprendre les comportements alimentaires et d'estimer les apports nutritionnels de cette population. Cette enquête permettait à l'entreprise d'une part de mieux connaître les contextes alimentaires d'un pays dans lequel elle est implantée, et d'autre part d'adapter l'offre et/ou la composition nutritionnelle des produits mis sur le marché en Égypte.

Différents acteurs ont été sollicités pour cette enquête alimentaire :

- Le département Science de l'Alimentation de Danone Research (Palaiseau, France) ainsi que les équipes Recherche & Innovation et Marketing de Danone Égypte (Le Caire, Égypte) ont commandité l'enquête alimentaire. Les équipes de Danone ont conçu le protocole de l'étude, formé les enquêteurs, revu la qualité des données collectées et participé à l'interprétation des données.
- Les équipes de TNS⁴ (Le Caire, Égypte) ont déployé les enquêteurs sur le terrain et transcrit (en anglais) les carnets alimentaires initialement complétés par les participants sur un support papier en Arabe.
- Le Centre d'Excellence de Recherche en Nutrition et Métabolisme (Belgrade, Serbie) a préparé une base de données des consommations alimentaires à partir des fichiers préparés par TNS (estimation des portions, contribution à la création d'une table de composition nutritionnelle des aliments égyptiens).
- J'ai été impliquée dans le contrôle de la qualité des données collectées, dans la création de la table de composition nutritionnelle des aliments égyptiens, ainsi que dans l'analyse et l'interprétation des résultats.

⁴ TNS fait partie de Kantar, un groupe de consultance qui propose aux entreprises des services d'accès aux données et des études de recherche.

Méthodologie

L'enquête alimentaire visait à obtenir un échantillon représentatif de la population résidant en zone urbaine âgée de 1 à 50 ans en termes de régions géographiques, de classes socio-économiques, de sexe et d'âge. Le protocole a été revu et approuvé par le comité d'éthique de la faculté de médecine de l'université d'Ain Shams, située au Caire.

Une soixantaine d'enquêteurs ont été répartis dans quatre régions urbaines d'Égypte (Le Caire, Alexandrie, Delta et Haute-Égypte, Figure 8) afin de réaliser du porte-à-porte de manière randomisée entre novembre 2016 et mars 2017. Une fois sur la zone à enquêter, les quartiers et rues étaient sélectionnés de manière aléatoire. Au pied de la porte des foyers, un questionnaire d'inclusion était rempli, permettant ainsi de respecter les quotas prévus en termes d'âge, de genre, de classe socio-économique et de région géographique. Les classes socio-économiques ont été stratifiées en 6 classes par un système de points basés sur le type d'emploi, les revenus, le type de logement, les équipements et le train de vie du foyer (i.e. inscription dans un club de sport, voyages en Égypte et à l'étranger). Un seul individu par foyer pouvait être interrogé. Les critères d'exclusion regroupaient le fait d'avoir participé à une autre enquête au cours des 6 derniers mois, le fait de travailler soi-même ou qu'une des personnes du foyer ou des amis proches travaillent dans le marketing, la recherche, la publicité, le journalisme ou la production de produits laitiers. Les personnes de classe socio-économique très basse étaient également exclues de l'enquête, pour des raisons liées au taux d'alphabétisation dans la classe socio-économique la plus basse en Égypte.

Unités régionales d'Égypte

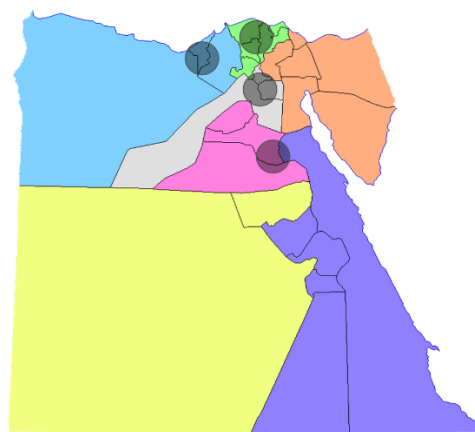


Figure 8. Unités régionales d'Égypte et régions sélectionnées pour l'enquête alimentaire

La carte a été reprise et adaptée de la carte des unités régionales réalisée par Faris El-Gwely (Faris El-Gwely, 2015)

Plusieurs documents étaient remis aux participants :

- Un questionnaire permettait aux sujets de déclarer les informations suivantes : poids (en kg), taille (en cm) et âge des sujets, consommation de compléments alimentaires (oui/non, et type de compléments consommés si oui), éducation, profession, revenu du foyer, équipements du foyer (e.g. possession de frigidaire, télévision,

ordinateurs...), habitudes de voyage en Égypte et à l'international, possession d'un abonnement à un club de sport.

- Un recueil alimentaire de quatre jours devait être rempli. Les instructions à suivre, un exemple de carnet alimentaire complété selon les habitudes locales, le carnet alimentaire à remplir sur quatre journées consécutives (incluant si possible, un jour de week-end, pour mieux représenter les habitudes alimentaires hebdomadaires), et des pages permettant de détailler les recettes consommées étaient fournis aux participants.
- Un atlas alimentaire contenait des photos de plats typiques égyptiens et d'ustensiles pour permettre aux participants d'estimer les portions consommées.
- Une « carte mémo » faisait notamment figurer la date de démarrage du recueil alimentaire, et devait être placée dans un endroit visible du foyer.
- Un formulaire de consentement fournissait des informations sur les objectifs de l'enquête.

Pour les jeunes enfants (12 ans ou moins), un adulte (par exemple les parents ou la personne en charge de l'enfant) remplissait le carnet alimentaire à la place de l'enfant, avec l'aide de ce dernier quand cela était possible. Les enfants de 13 ans ou plus remplissaient eux-mêmes les carnets alimentaires, et devaient demander à leurs parents de vérifier et/ou compléter leur carnet avec les détails appropriés (détail des recettes consommées et vérification des portions déclarées).

Les carnets alimentaires ont été chargés sur la plateforme « Diet and Asses and Plan » (Gurinović et al., 2016)⁵. Les quantités consommées étaient estimées à l'aide de l'atlas alimentaire fourni aux participants lors de l'enquête, ou avec l'atlas des Émirats Arabes Unis (Al Marzooqi et al., 2015) lorsque les données étaient incomplètes (par exemple lorsque les codes reportés par les participants ne correspondaient pas aux codes de l'atlas alimentaire fourni pendant l'enquête).

Une table de composition nutritionnelle des aliments consommés lors de l'enquête a été créée à partir de données de composition des aliments en Égypte (National Nutrition Institute, 2006) et complétée de données provenant de Serbie (Gurinović et al., 2016) et d'Inde (Longvah et al., 2017) du fait de similarités entre les aliments consommés et pour compléter les données manquantes, ainsi que de données provenant de la base FAO/INFOODS. En effet, la table de composition nutritionnelle égyptienne ne renseigne pas la composition de tous les nutriments : seules les teneurs en énergie, protéines, lipides, fibres, glucides, en certains minéraux (sodium, potassium, calcium, magnésium, fer, zinc et cuivre) et en quelques vitamines (vitamines A, thiamine, riboflavine, et vitamine C) sont renseignées. D'autre part, les aliments consommés n'étaient pas tous présents dans cette table. Les aliments ou valeurs manquantes ont donc été complétés à partir d'aliments similaires

⁵ « Diet and Asses and Plan » est une plateforme en ligne qui permet de coder et standardiser les données alimentaires collectées.

provenant d'autres tables de composition nutritionnelles, pour aboutir à une table de composition nutritionnelle contenant 649 aliments et recettes.

La qualité de la table de composition nutritionnelle générée a été vérifiée par les critères suivants : l'aliment ne devait présenter aucune valeur manquante en énergie et macronutriments ; la somme des lipides, glucides et protéines, multipliés par leur teneur en énergie, devait être égale à la valeur énergétique ($\pm 10\%$) ; les aliments d'un groupe alimentaire devaient contenir une valeur en micronutriments pour tous les micronutriments habituellement apportés par le groupe alimentaire en question. En effet, les groupes alimentaires n'apportent pas tous les mêmes nutriments. Par exemple, les minéraux sont peu présents dans les huiles et les légumes contiennent en général les vitamines hydrosolubles. Les tableaux ci-dessous indiquent quels minéraux (Tableau 1) et vitamines (Tableau 2) sont *a priori* retrouvés dans les différents groupes alimentaires. Les sources majoritaires de vitamines et minéraux parmi les groupes alimentaires ont été identifiées à partir des groupes fournissant les plus hautes teneurs en micronutriments dans la plateforme EuroFIR FoodExplorer (EuroFIR AISBL). La stratégie élaborée en collaboration avec l'équipe serbe pour distinguer les valeurs manquantes des valeurs négligeables dans la table de composition nutritionnelle est présentée Figure 9.

Une fois la table de composition nutritionnelle complétée, les teneurs en énergie et nutriments des aliments consommés ont permis d'estimer les apports énergétiques et nutritionnels de la population, et de les comparer aux recommandations populationnelles de l'Organisation Mondiale de la Santé (OMS) et de la FAO pour les macronutriments (World Health Organization and Food and Agriculture Organization of the United Nations, 2003) (Tableau 3) ainsi qu'aux recommandations nutritionnelles locales pour les minéraux et vitamines (Ministry of Health Egypt, 2004) (Tableau 4, Tableau 5). Les participants ayant des apports énergétiques moyens inférieurs au 5^{ème} percentile ou supérieurs au 95^{ème} percentile des apports énergétiques de la population étaient considérés comme sous et sur déclarants respectivement et ont été exclus de l'analyse (Rhee et al., 2015).

Tableau 1. Sources majoritaires de minéraux parmi les groupes alimentaires.

Groupe alimentaire	Calcium	Cuivre	Fer	Iode	Magnésium	Sodium	Potassium	Phosphore	Zinc
Produits laitiers	•		•	•	•	•	•	•	•
Produits à base de viande et/ou d'œufs		•	•			•		•	•
Graines, noix, fruits à coque	•	•	•		•	•	•	•	
Produits de la mer	•	•	•	•		•	•	•	
Légumes et produits contenant des légumes	•	•	•		•		•		•
Légumineuses et produits contenant des légumineuses	•	•	•		•		•	•	•
Céréales et produits céréaliers		•	•		•				•
Fruits et produits contenant des fruits	•	•			•		•		
Sucre et produits sucrés	•	•			•				
Matières grasses									

Les points indiquent la présence attendue d'un nutriment dans le groupe alimentaire considéré. Les cellules vides indiquent que le groupe alimentaire n'est *a priori* pas une source majoritaire de ce nutriment.

Tableau 2. Sources majoritaires de vitamines parmi les groupes alimentaires.

Groupe alimentaire	Thiamine	Riboflavine	Niacine	Acide pantothé-nique	Vitamine B6	Folates	Vitamine B12	Vitamine A	Vitamine C	Vitamine D	Vitamine E
Produits laitiers		•					•	•		•	•
Produits à base de viande et/ou d'œufs	•	•	•	•	•	•	•	•		•	•
Graines, noix, fruits à coque	•	•	•		•						•
Produits de la mer	•	•	•	•			•			•	•
Légumes et produits contenant des légumes	•	•		•	•	•			•		•
Légumineuses et produits contenant des légumineuses	•	•	•	•	•	•					•
Céréales et produits céréaliers	•	•		•	•						•
Fruits et produits contenant des fruits						•			•		
Sucre et produits sucrés											
Matières grasses								•			•

Les points indiquent la présence attendue d'un nutriment dans le groupe alimentaire considéré. Les cellules vides indiquent que le groupe alimentaire n'est *a priori* pas une source majoritaire de ce nutriment.

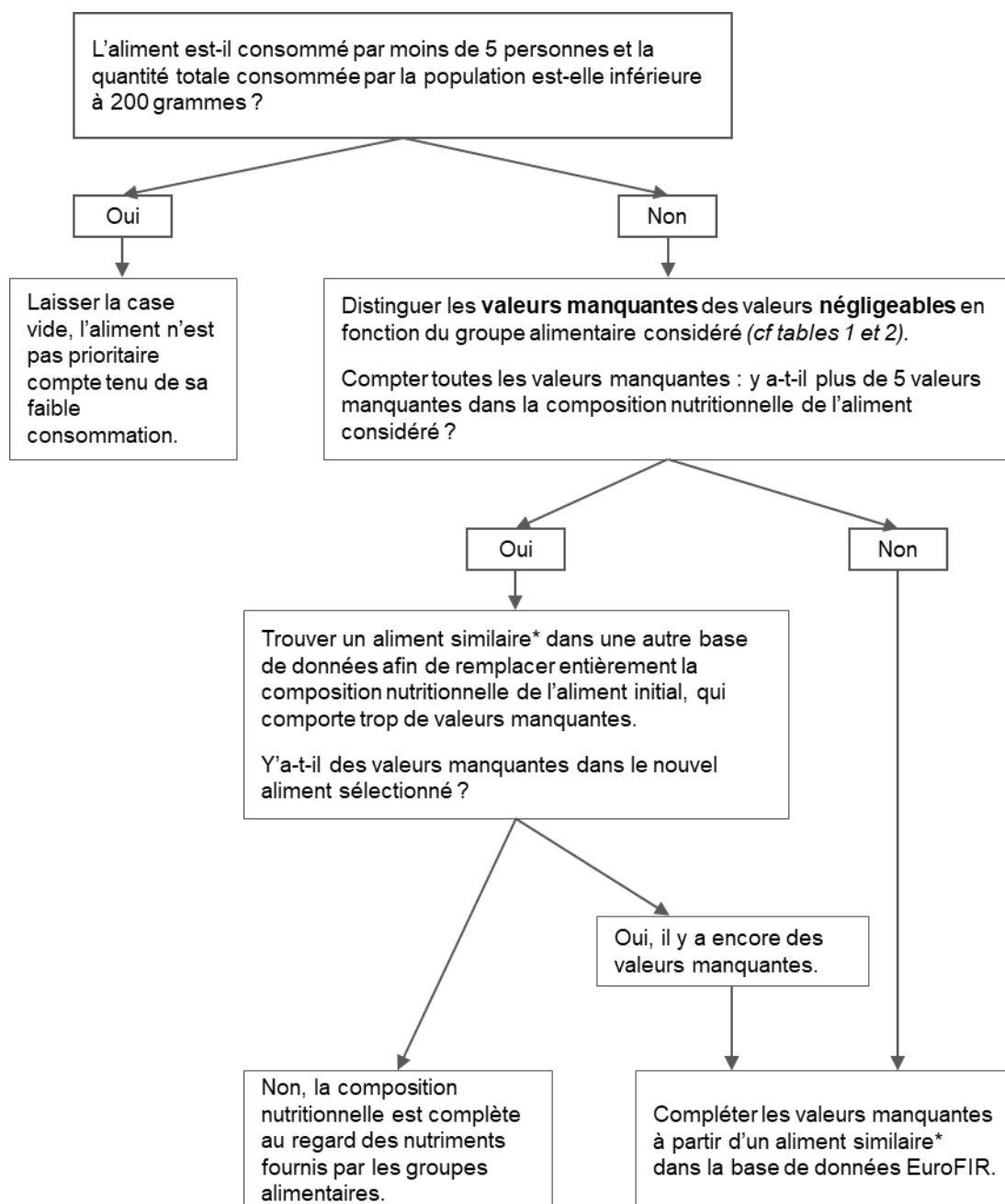


Figure 9. Stratégie suivie pour compléter les valeurs manquantes de la table de composition nutritionnelle égyptienne.

* Un aliment considéré comme similaire est un aliment avec une dénomination, un mode de préparation (cru, bouilli, grillé...) et une teneur en énergie et macronutriments comparable.

Tableau 3. Recommandations populationnelles de l'OMS et de la FAO en macronutriments.

Macronutriments	Recommandation
Glucides totaux (%ET)	55 – 75
Lipides totaux (%ET)	15 - 30
Acides gras saturés (%ET)	< 10
Protéines (%ET)	10-15
Fibres (g)	>25

%ET : Pourcentage de l'énergie totale

Tableau 4. Recommandations égyptiennes journalières en minéraux.

Groupe d'âge	Genre	Calcium (mg)	Cuivre (µg)	Fer (mg)	Iode (µg)	Magnésium (mg)	Phosphore (mg)	Potassium (g)	Sodium (g)	Zinc (mg)
1-3 ans	F	500	340	5,8-7	90	60-80	460	3	1	3-4,1
	M	500	340	5,8-7	90	60-80	460	3	1	3-4,1
4-6 ans	F	600-800	440	6,3-10	90	76-130	500	3,8	1,2	4,8-5
	M	600-800	440	6,3-10	90	76-130	500	3,8	1,2	4,8-5
7-9 ans	F	700-800	440	8,9-10	90-120	100-130	500	3,8	1,2	5-5,6
	M	700-800	440	8,9-10	90-120	100-130	500	3,8	1,2	5-5,6
10-13 ans	F	1300	700	8-14	120	220-240	1250	4,5	1,5	7,2-8
	M	1300	700	8-14,6	120	230-240	1250	4,5	1,5	8-8,6
14-18 ans	F	1300	890	15-31	150	220-360	1250	4,7	1,5	7,2-8
	M	1300	890	11-18,8	150	230-410	1250	4,7	1,5	8-8,6
19-30 ans	F	1000	900	18-29,4	150	220-310	700	4,7	1,5	7,2-9
	M	1000	900	8-13,7	150	230-400	700	4,7	1,5	8,6-11
31-50 ans	F	1000	900	18-29,4	150	220-320	700	4,7	1,5	7,2-9
	M	1000	900	8-13,7	150	260-400	700	4,7	1,5	7-11

Tableau 5. Recommandations journalières égyptiennes en vitamines.

Groupe d'âge	Genre	Vitamine A (µg RE)	Vitamine D (µg)	Vitamine E (mg)	Folate (µg)	Niacine (niacine eq, mg)	Acide pantothénique (mg)	Riboflavine (mg)	Thiamine (mg)	Vitamine B12 (µg)	Vitamine B6 (mg)	Vitamine C (mg)
1-3 ans	F	300-400	5-10	5-6	150	6	2	0,5	0,5	0,9	0,5	15-30
	M	300-400	5-10	5-6	150	6	2	0,5	0,5	0,9	0,5	15-30
4-6 ans	F	400-450	5-10	5-7	200	8	3	0,6	0,6	1,2	0,6	25-30
	M	400-450	5-10	5-7	200	8	3	0,6	0,6	1,2	0,6	25-30
7-9 ans	F	400-450	5-10	7	200-300	8-12	3-4	0,6-0,9	0,6-0,9	1,2-1,8	0,6-1	25-35
	M	400-450	5-10	7	200-300	8-12	3-4	0,6-0,10	0,6-0,9	1,2-1,8	0,6-1	25-35
10-13 ans	F	600	5-10	7,5-11	300-400	12-16	4-5	0,9-1	0,9-1,1	1,8-2,4	1-1,2	40-45
	M	600	5-10	10-11	300-400	12-16	4-5	0,9-1,3	0,9-1,2	1,8-2,4	1-1,3	40-45
14-18 ans	F	600-700	5-10	7,5-15	400	14-16	5	1	1-1,1	2,4	1,2	40-65
	M	600-900	5-10	10-15	400	16	5	1,3	1,2	2,4	1,3	40-75
19-30 ans	F	500-700	5-10	7,5-15	400	14-16	5	1,1	1,1	2,4	1,3	45-75
	M	500-900	5-10	10-15	400	16	5	1,3	1,2	2,4	1,3	45-90
31-50 ans	F	500-700	5-10	7,5-15	400	14	5	1,1	1,1	2,4	1,3	45-75
	M	500-900	5-10	10-15	400	16	5	1,3	1,2	2,4	1,3	45-90

Résultats principaux

Sur les 860 participants ayant complété au moins 3 des 4 jours de recueil alimentaire⁶, 775 participants (soit 90,1% de l'échantillon initial) ont été retenus pour l'analyse des résultats après exclusion des sous et sur déclarants. Sur ces 775 participants, 130 étaient des femmes âgées de 19 à 30 ans (soit 90,3% de l'échantillon initial de femmes de cette tranche d'âge), dont les apports alimentaires et nutritionnels ont été détaillés dans l'Article 1 (ci-dessous, (Brouzes et al., 2020)). Quelques résultats pour le reste de la population sont détaillés ci-après afin d'identifier les problématiques nutritionnelles retrouvées dans le reste de la population et de mettre en évidence les spécificités des femmes de 19-30 ans.

Concernant les apports en macronutriments, les femmes ne présentent pas de caractéristique particulière par rapport au reste de la population (Tableau 6). Quels que soient la tranche d'âge et le sexe considérés, les apports en lipides totaux et en AGS sont légèrement supérieurs aux recommandations de l'OMS. En effet, l'OMS recommande que les lipides totaux consommés constituent 15 à 30% des apports énergétiques totaux, et les AGS 10% maximum (Tableau 3). Or les apports en lipides de la population constituent 32 à 36% des apports énergétiques totaux et les apports en AGS 11 à 13%. Les apports en protéines sont supérieurs aux recommandations dans tous les groupes (entre 12 et 15% de l'apport énergétique total, alors que l'OMS recommande 5 à 10% de l'apport énergétique total). La consommation de fibres est inférieure aux 25 grammes par jour recommandés pour tous les groupes d'âge, et en particulier chez les enfants (Tableau 6).

Concernant les apports en minéraux (Tableau 7), les apports en calcium sont inférieurs aux apports recommandés (>1300 mg) pour les adolescents de 10 à 18 ans (938 à 1063 mg par jour en moyenne). Les apports en fer sont suffisants pour toute la population, excepté pour les femmes de 19-30 ans ($13,80 \pm 4,56$ mg) et de 31-50 ans ($14,13 \pm 4,65$ mg), pour qui les apports recommandés sont de 18 à 29,4 mg par jour. Tous les groupes d'âge et de sexe (sauf les filles de 7 à 9 ans) ont des apports en potassium inférieurs aux apports recommandés. Les apports en sodium dépassent d'au moins 150% les recommandations dans tous les groupes.

Concernant les apports en vitamines (Tableau 8), tous les groupes d'âge et de sexe ont des apports en vitamine D trop bas (entre 1,7 et 4,0 μ g par jour suivant les groupes) par rapport aux apports recommandés (5-10 μ g). Les apports en folates des groupes d'âge de 14 ans et plus sont inférieurs aux apports recommandés (de 319 à 377 μ g en moyenne, contre >400 μ g recommandés), y compris pour les femmes de 19-30 ans (308 ± 130 μ g). Les apports moyens en autres vitamines (vitamines A, E, niacine, acide pantothénique, riboflavine, thiamine, vitamine B6, vitamine B12, vitamine C) sont supérieurs aux recommandations pour tous les groupes d'âge et de sexe, excepté pour les filles de 10-13 ans, qui ont des apports en vitamine A légèrement inférieurs aux recommandations (589 ± 729 μ g RE *versus* 600 μ g RE recommandés).

Concernant les apports en énergie, il est difficile de commenter les résultats compte tenu du peu d'information sur le poids et la taille des participants. En effet, de nombreux participants n'ont pas déclaré leur poids et/ou leur taille ou ont renseigné des valeurs aberrantes, comme

⁶ Avant exclusion, 144 femmes étaient âgées de 19 à 30 ans sur les 860 individus interrogés.

détaillé dans l'Article 1. Compte tenu des problématiques de surpoids chez les femmes, il était primordial d'estimer les besoins en énergie afin de les comparer aux apports énergétiques observés. Dans l'Article 1, nous avons détaillé comment les valeurs de poids et de taille plausibles des hommes et des femmes âgées de 19 à 50 ans ont été utilisées pour estimer un poids et une taille pour les individus de la même tranche d'âge qui n'avaient pas déclaré ces valeurs (ou renseigné des valeurs aberrantes). Une procédure d'élimination descendante (suivant la valeur du critère d'information Akaike) a été utilisée pour identifier les paramètres socio-démographiques qui soient des prédictifs significatifs des valeurs de poids et de tailles, et imputer ainsi les valeurs manquantes ou aberrantes. Cette approche nous a permis *in fine* d'évaluer les besoins en énergie pour les femmes de 19-30 ans et de les comparer aux apports.

En résumé, les apports supérieurs aux recommandations en lipides, AGS, protéines et sodium des femmes de 19-30 ans se retrouvent dans le reste de la population. Les apports insuffisants des femmes en vitamine D, potassium et folates se retrouvent dans d'autres groupes d'âge (folates chez les plus de 14 ans), voire dans toute la population (vitamine D et potassium). La problématique spécifique aux femmes (âgées de 19 ans et plus) est d'avoir des apports insuffisants en fer. Le fer étant un élément à la biodisponibilité variable suivant la composition des régimes et le statut en fer des individus, une analyse plus fine de sa biodisponibilité a été réalisée dans le premier article. Par ailleurs, compte tenu des problématiques de surpoids et d'obésité dans le pays, les besoins en énergie ont été estimés et comparés aux apports, malgré les valeurs de poids manquantes ou aberrantes dans notre échantillon. Ces approches sont détaillées dans l'Article 1.

Tableau 6. Apports journaliers en énergie et macronutriments par groupes d'âge dans la population égyptienne de 1 à 50 ans.

Groupe d'âge	Genre	Effectif	Energie (kcal)	Glucides totaux (%ET)	Sucres totaux (%ET)	Fibres (g)	Lipides totaux (%ET)	Acides gras saturés (%ET)	Protéines (%ET)
1-3 ans	F	37	1544 ± 728	53 ± 25	21 ± 10	11 ± 7	33 ± 17	12 ± 6	14 ± 7
	M	23	1789 ± 779	53 ± 23	21 ± 9	12 ± 8	33 ± 15	13 ± 6	14 ± 6
4-6 ans	F	23	2472 ± 783	51 ± 15	15 ± 6	17 ± 7	35 ± 16	12 ± 5	14 ± 5
	M	18	2525 ± 846	51 ± 18	18 ± 7	15 ± 6	34 ± 14	11 ± 5	15 ± 5
7-9 ans	F	18	2299 ± 664	50 ± 14	16 ± 6	14 ± 5	36 ± 15	12 ± 5	14 ± 5
	M	16	2633 ± 597	51 ± 14	16 ± 7	19 ± 7	34 ± 10	12 ± 6	14 ± 4
10-13 ans	F	35	2571 ± 777	51 ± 15	13 ± 5	19 ± 7	35 ± 14	11 ± 6	14 ± 6
	M	20	2748 ± 652	54 ± 12	15 ± 6	20 ± 7	33 ± 11	11 ± 4	12 ± 3
14-18 ans	F	53	2510 ± 758	51 ± 15	16 ± 7	18 ± 9	34 ± 14	11 ± 5	14 ± 5
	M	50	2819 ± 926	51 ± 16	16 ± 7	22 ± 8	34 ± 14	11 ± 6	14 ± 6
19-30 ans	F	130	2389 ± 715	51 ± 16	16 ± 9	18 ± 8	33 ± 12	11 ± 5	15 ± 5
	M	107	2613 ± 669	53 ± 13	15 ± 7	20 ± 7	32 ± 12	11 ± 5	15 ± 4
31-50 ans	F	148	2406 ± 728	51 ± 16	16 ± 7	21 ± 10	34 ± 14	11 ± 6	15 ± 5
	M	97	2838 ± 676	51 ± 13	16 ± 7	23 ± 8	34 ± 13	11 ± 4	15 ± 4

%ET : Pourcentage de l'énergie totale

Tableau 7. Apports journaliers minéraux par groupes d'âge dans la population égyptienne de 1 à 50 ans.

Groupe d'âge	Genre	Effectif	Calcium (mg)	Cuivre (mg)	Fer (mg)	Iode (µg)	Magnésium (mg)	Phosphore (mg)	Potassium (g)	Sodium (mg)	Zinc (mg)
1-3 ans	F	37	725 ± 420	0,92 ± 0,44	8,4 ± 4,95	159 ± 91	266 ± 114	978 ± 483	2,3 ± 1,1	1569 ± 1011	6,94 ± 3,79
	M	23	827 ± 452	1,01 ± 0,5	9,52 ± 4,87	181 ± 89	310 ± 148	1076 ± 494	2,6 ± 1,2	1772 ± 1004	7,41 ± 3,65
4-6 ans	F	23	927 ± 371	1,47 ± 0,59	12,68 ± 5,01	192 ± 119	395 ± 120	1413 ± 507	3,5 ± 1,3	2724 ± 1023	10,64 ± 4,56
	M	18	1041 ± 385	1,61 ± 0,6	13,83 ± 5,75	240 ± 110	427 ± 155	1532 ± 496	3,4 ± 1,1	2858 ± 1235	10,97 ± 3,93
7-9 ans	F	18	845 ± 343	1,46 ± 0,65	12,43 ± 3,8	208 ± 122	399 ± 139	1285 ± 408	3,2 ± 0,9	2469 ± 1164	10,94 ± 5,85
	M	16	1146 ± 521	1,7 ± 0,59	14,79 ± 3,61	240 ± 102	479 ± 124	1578 ± 445	3,9 ± 1,3	3351 ± 1204	12,65 ± 3,61
10-13 ans	F	35	938 ± 331	1,48 ± 0,45	13,89 ± 4,67	227 ± 125	429 ± 130	1457 ± 496	3,7 ± 1,2	2977 ± 1187	11,33 ± 4,81
	M	20	969 ± 304	1,68 ± 0,56	15,05 ± 5,18	196 ± 64	469 ± 128	1442 ± 364	3,7 ± 1	3054 ± 974	11,05 ± 3,74
14-18 ans	F	53	985 ± 455	1,56 ± 0,61	14,13 ± 5,2	213 ± 99	460 ± 130	1399 ± 445	3,7 ± 1,5	3084 ± 1190	10,83 ± 4,2
	M	50	1063 ± 431	1,93 ± 0,78	16,98 ± 6,91	212 ± 92	524 ± 175	1557 ± 590	3,9 ± 1,4	3276 ± 1204	12,91 ± 5,65
19-30 ans	F	130	1002 ± 393	1,56 ± 0,63	13,8 ± 4,56	211 ± 98	458 ± 148	1407 ± 438	3,4 ± 1,2	2787 ± 1065	10,98 ± 3,55
	M	107	1032 ± 433	1,87 ± 1,34	16,29 ± 5,15	214 ± 89	479 ± 140	1513 ± 474	3,4 ± 1	3236 ± 1306	12,98 ± 4,58
31-50 ans	F	148	1037 ± 376	2,89 ± 13,1	14,13 ± 4,66	217 ± 102	484 ± 146	1442 ± 464	3,8 ± 1,4	3107 ± 1268	10,92 ± 3,51
	M	97	1183 ± 421	2,09 ± 1,33	17,57 ± 4,67	238 ± 113	553 ± 132	1619 ± 436	4 ± 1,2	3432 ± 1016	13,76 ± 4,18

Tableau 8. Apports journaliers vitamines par groupes d'âge dans la population égyptienne de 1 à 50 ans.

Groupe d'âge	Genre	Effectif	Vitamine A (µg RE)	Vitamine D (µg)	Vitamine E (mg)	Folates (µg)	Niacine (équivalent niacine, mg)	Acide pantothénique (mg)	Riboflavine (mg)	Thiamine (mg)	Vitamine B12 (µg)	Vitamine B6 (mg)	Vitamine C (mg)
1-3 ans	F	37	777 ± 1729	2,4 ± 3,8	6,1 ± 4,8	192 ± 94	12 ± 6,8	4,1 ± 8,9	1,3 ± 0,9	0,8 ± 0,4	3,6 ± 3,3	0,9 ± 0,5	108 ± 84
	M	23	790 ± 2069	1,7 ± 0,9	7,7 ± 4,5	224 ± 120	14,1 ± 7,7	3,1 ± 1,3	1,4 ± 0,7	0,9 ± 0,4	2,9 ± 1,6	1,0 ± 0,5	105 ± 73
4-6 ans	F	23	838 ± 1472	2,4 ± 2,9	9,8 ± 6,6	285 ± 130	19,1 ± 9,9	7,0 ± 9,7	1,6 ± 0,7	1,2 ± 0,4	5,9 ± 7,5	1,4 ± 0,7	158 ± 83
	M	18	1720 ± 3785	3,0 ± 2,3	10,6 ± 5,6	311 ± 143	23,3 ± 11,1	7,7 ± 13,1	1,9 ± 0,9	1,3 ± 0,6	7,6 ± 6,7	1,4 ± 0,5	148 ± 80
7-9 ans	F	18	845 ± 1626	2,54 ± 2,4	10,7 ± 4,5	252 ± 92	18,9 ± 8,7	3,8 ± 1,3	1,5 ± 0,5	1,1 ± 0,3	7,5 ± 8,0	1,2 ± 0,4	134 ± 64
	M	16	1955 ± 4283	2,3 ± 1,9	10,9 ± 5,9	352 ± 156	21,9 ± 7,8	13,4 ± 24,2	2,0 ± 1,2	1,4 ± 0,3	11,0 ± 18,7	1,6 ± 0,6	163 ± 92
10-13 ans	F	35	589 ± 729	2,9 ± 2,8	11,5 ± 7,0	328 ± 164	22,6 ± 12,3	7,5 ± 13,7	1,6 ± 0,7	1,4 ± 0,7	5,1 ± 4,0	1,5 ± 0,6	160 ± 94
	M	20	1057 ± 2431	3,8 ± 3,0	12,4 ± 6,4	341 ± 124	18,5 ± 6,7	4,5 ± 1,8	1,6 ± 0,8	1,4 ± 0,3	6,5 ± 10,8	1,5 ± 0,5	174 ± 87
14-18 ans	F	53	826 ± 1162	2,7 ± 2,2	12,4 ± 7,4	319 ± 154	21,1 ± 10,7	5,9 ± 7,3	1,5 ± 0,6	1,3 ± 0,4	6,0 ± 5,6	1,5 ± 0,7	168 ± 98
	M	50	1450 ± 2575	3,2 ± 3,2	14,1 ± 7,6	380 ± 162	23,7 ± 12,8	6,8 ± 11,4	1,8 ± 1,0	1,5 ± 0,6	8,5 ± 12,4	1,7 ± 0,7	154 ± 78
19-30 ans	F	130	851 ± 1279	3,3 ± 3,5	11,9 ± 6,4	308 ± 130	21,3 ± 10,8	8,5 ± 18,1	1,6 ± 0,6	1,3 ± 0,4	6,0 ± 5,6	1,5 ± 0,6	152 ± 94
	M	107	1274 ± 3452	3,2 ± 3,1	12,1 ± 5,7	337 ± 116	21,9 ± 9,1	5,7 ± 9,7	1,7 ± 0,7	1,4 ± 0,4	8,0 ± 9,9	1,5 ± 0,5	135 ± 69
31-50 ans	F	148	956 ± 1746	4,0 ± 3,8	13,5 ± 6,9	366 ± 162	22,4 ± 10,7	5,5 ± 5,6	1,6 ± 0,7	1,3 ± 0,4	6,5 ± 11,1	1,5 ± 0,7	184 ± 111
	M	97	1293 ± 2029	3,8 ± 3,9	16,0 ± 10,8	377 ± 135	24,4 ± 10,6	8,5 ± 19,0	1,8 ± 0,7	1,5 ± 0,4	8,9 ± 10,8	1,6 ± 0,6	166 96

3.1.2. Résumé des résultats pour les femmes égyptiennes âgées de 19 à 30 ans.

Contexte : En Égypte, les habitudes alimentaires ont récemment changé du fait d'une urbanisation rapide, d'un mode de vie plus sédentaire et d'altérations dans l'environnement alimentaire et sur le plan économique. Ces changements sont au moins en partie à l'origine de problèmes de santé et affectent particulièrement les femmes : l'IMC moyen des femmes en Égypte est l'un des plus hauts au monde, et 50% d'entre elles souffrent de carences en fer.

Objectifs : L'objectif de cette étude était de quantifier les apports alimentaires et nutritionnels d'une population de femmes résidant en Égypte urbaine et d'analyser en détail les apports en micronutriments, en particulier ceux fréquemment consommés en quantité inadéquate comme le fer, les folates et la vitamine D.

Méthodes : Pour cela, des femmes âgées de 19 à 30 ans résidant en zone urbaine ont été recrutées entre 2016 et 2017 (n=130). Afin d'estimer le poids et l'IMC des participantes, les données de poids et de taille collectées ont été corrigées lorsque des valeurs étaient aberrantes ou manquantes en suivant une procédure d'élimination descendante selon la valeur du critère d'information Akaike. Les besoins en énergie ont été estimés en utilisant les équations de Henry, en faisant l'hypothèse d'un bas niveau d'activité physique (valeur de 1,4). Les apports alimentaires et nutritionnels ont été estimés à partir du recueil alimentaire sur quatre jours décrit dans la section précédente (voir ci-dessus). La biodisponibilité du fer dans les régimes a été estimée en utilisant les équations d'Armah et collaborateurs. Les apports en macronutriments ont été comparés avec les recommandations populationnelles de l'OMS et de la FAO et les apports en micronutriments avec les recommandations égyptiennes. Les besoins en fer ont été estimés individuellement pour chaque participante.

Résultats : L'IMC moyen des participantes était de $27,9 \pm 4,9$ kg/m², avec un poids corporel moyen de $73,9 \pm 12,9$ kg. Les apports énergétiques (2389 ± 715 kcal/jour) étaient en moyenne au-dessus des besoins estimés (2135 ± 237 kcal/jour). Les apports en lipides (33%ET) et en AGS (11% ET) étaient légèrement au-dessus des recommandations (15-30%ET et <10%ET respectivement). Les apports en fibres étaient de 18 ± 8 g/jour (alors que les recommandations sont d'au moins 25 grammes/jour) et en sucres totaux de 98 ± 54 g/jour. Les apports en sodium (2787 ± 1065 mg/jour) étaient de quasiment plus du double des apports recommandés (<1500 mg/jour). La biodisponibilité du fer dans les régimes était basse ($9,2 \pm 1,6\%$) et 79% des femmes avaient des apports inférieurs à leurs besoins individuels. Les apports en vitamine D et folates étaient en dessous des apports recommandés pour 82 et 80% des femmes respectivement.

Conclusions : En résumé, les femmes résidant en Égypte urbaine âgées de 19 à 30 ans ont des apports alimentaires et nutritionnels caractéristiques de populations traversant une transition nutritionnelle. Leurs apports en énergie et en sodium sont trop élevés, et leurs apports en fer, vitamine D et folates sont insuffisants, avec une faible biodisponibilité du fer dans les régimes. Ces

résultats soulignent l'importance de mettre au point des stratégies d'amélioration nutritionnelle pour cette population.

Valorisation : Ce travail a fait l'objet d'un article publié dans le journal *Current Developments in Nutrition* et de deux communications affichées.

3.1.3. Article 1

(voir page suivante)



Urban Egyptian Women Aged 19–30 Years Display Nutrition Transition-Like Dietary Patterns, with High Energy and Sodium Intakes, and Insufficient Iron, Vitamin D, and Folate Intakes

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ABSTRACT

Background: Recent changes in Egyptian dietary habits can be attributed to more urban and sedentary lifestyles and to alterations in the dietary and economic context. The mean BMI of Egyptian women is one of the highest worldwide, and 50% have iron deficiency.

Objective: The aim was to quantify food and nutrient intakes of urban Egyptian women and conduct a detailed analysis of micronutrients commonly consumed in inadequate amounts, such as iron, vitamin D, and folate.

Methods: Urban Egyptian women aged 19–30 y ($n = 130$) were recruited during 2016–2017. Energy needs were estimated using the Henry equation, assuming a low physical activity level (1.4). Dietary intakes and iron bioavailability were estimated from a 4-d food diary. Macronutrient intakes were compared with WHO/FAO population goals and micronutrient intakes with Egyptian recommendations. Iron needs were determined for each subject.

Results: The mean BMI (kg/m^2) was 27.9 ± 4.9 . The mean total energy intake (TEI; 2389 ± 715 kcal/d) was significantly higher than needs (2135 ± 237 kcal/d; $P = 0.00018$). Total fat (33%TEI) and SFA (11%TEI) intakes were slightly higher than population goals (15–30%TEI and <10%TEI, respectively). Diets provided 18 ± 8 g/d of fiber, 98 ± 54 g/d of total sugars, and nearly twice the recommended sodium intake (intake: 2787 ± 1065 mg/d; recommendation: <1500 mg/d). Estimated dietary iron bioavailability was low ($9.2\% \pm 1.6\%$), and 79% of women consumed less iron than the average requirement (17.5 ± 7 mg/d). Overall, 82% and 80% of women consumed less vitamin D and folate, respectively, than recommended.

Conclusions: Egyptian women aged 19–30 y have high intakes of energy and sodium, whereas iron, vitamin D, and folate intakes are insufficient, with only low concentrations of bioavailable iron. These results call for further investigation into measures that would improve this population's diet quality. *Curr Dev Nutr* 2020;4:nzz143.

Keywords: Egypt, women, diet, nutrition, malnutrition, transition, iron, bioavailability

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Supplemental Material 1 and Supplemental Tables 1–6 are available from the "Supplementary data" link in the online posting of the article and from the same link in the online table of contents at <https://academic.oup.com/cdn/>.

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Abbreviations used: EFSA, European Food Safety Authority; ICAN, Institute of cardiometabolism and nutrition; INRAE, Institut national de recherche pour l'agriculture, l'alimentation et l'environnement; INSERM, Institut national de la santé et de la recherche médicale; MRC, Medical Research Council; SEC, socioeconomic class; TEI, total energy intake; UMR PNCA: Unité mixte de recherche physiologie de la nutrition et du comportement alimentaire; USDA, United States department of agriculture.

Introduction

The mean BMI (in kg/m^2) of Egyptian women is among the highest in the world (30.6) (1), with an 88% prevalence of overweight and obesity in those women living in urban areas (2), which is greater than observed in men or children (2–4). Approximately 50% of Egyptian women aged 20–49 y have iron deficiency and 25% have iron-deficiency

anemia (5). This coexistence of undernutrition along with overweight and obesity, known as the double burden of malnutrition (6), is also found in children (2). The situation in Egypt is not typical in that there is no clear gradient in anemia and overweight based on socioeconomic class (SEC). Anemia is almost as prevalent in the highest SEC as in the lowest (26% vs. 29%). The prevalence of overweight and obesity increases moderately with wealth (80% in the lowest SEC vs. 88% in the

highest SEC) and strongly with age in women (52% of 15- to 19-y-old girls, 75% of 20- to 29-y-old women, and 93% of 40- to 49-y-old women are overweight or obese) (2).

The high prevalence of overweight and obesity in Egypt is thought to be related to high energy intake combined with low levels of physical activity (7), especially in women, due to sociocultural factors and safety concerns (8). Recent changes in the economic environment and dietary patterns (7, 9) mean that animal products, fruits, and vegetables are expensive foods that are now consumed in larger amounts by people of higher SECs (10). These nutrient-dense foods are therefore less accessible to lower SECs. Unrefined cereals, legumes, dark-green leafy vegetables, fruits, cheese, oils, and white and red meat have been described as the pillars of the traditional Egyptian food system (9). However, new lifestyles that are emerging as a result of urbanization and longer working hours have led to reduced consumption of traditional foods and greater intakes of fast food and sugar-sweetened beverages, more frequent snacking, and consumption of the main cooked meal later in the day (9, 10).

Repeated economic crises have also weakened this food-deficit country [Egypt is one of the largest food importers worldwide (11)], and the food subsidy system may have contributed to incentivizing the consumption of calorie-rich foods (e.g., subsidized oil, bread, and sugar) (3). Egyptians traditionally consume large quantities of broad beans and sweetened black tea (9), which contain phytates and iron-binding polyphenols, respectively, both of which decrease iron bioavailability (12). In individuals with obesity, iron absorption may be further impaired due to inflammation-induced hepcidin secretion, which leads to iron sequestration (13).

Improving young women's dietary intake has the potential to impact the health of both women and future infants (14–17). The objective of this study was to quantify food and nutrient intakes in 19- to 30-y-old Egyptian women living in urban areas and to examine specifically the intake of micronutrients commonly consumed in inadequate amounts, such as iron (2, 5), vitamin D (18, 19), and folate (20).

Methods

Study design and study population

The Research Ethics Committee of Ain Shams University, Faculty of Medicine, Cairo, Egypt, approved the study protocol. Dietary data from women aged 19–30 y ($n = 130$) were extracted from a descriptive, cross-sectional survey conducted between November 2016 and March 2017 in males and females (age range: 1–50 y; $n = 860$) living in 4 urban areas in Egypt (Greater Cairo, Alexandria, Delta, and Upper Egypt), representing SECs A to D in the urban population (21). A door-to-door random-sampling methodology with a screening questionnaire was used to reach quotas for age, gender, social class, and region in order to obtain a representative sample. Interviewers randomly selected households, and 1 individual per household (selected according to age and gender quotas) was invited to participate in the study and received the study documents in Arabic, including a consent form, an information sheet, a sociodemographic questionnaire, and a 4-d food diary. Participants self-reported their height and weight, yet there were challenges in collecting these data. Briefly, some respondents were unaware of their own weight and height and provided unrealistic estimates.

Additionally, female respondents were sometimes reluctant to provide their weight (and height), especially when the interviewer was male. The research team tried to match female interviewers with female participants, but this was not always feasible. Missing or implausible values were corrected using an Akaike Information Criterion backwards elimination procedure [function “step” in R (22)] to identify a model with statistically significant predictors of height and weight values. The model that was retained included the variables “age,” “gender,” and “number of people in the household”; and a multiple imputation procedure was performed to impute missing height and weight values (“mice” package in R (23)), as detailed in **Supplemental Material 1**. The declared and imputed weight, height, and BMI values are presented in **Supplemental Table 1**.

A point system classified participants as belonging to 1 of 6 SECs (A, B, C1, C2, D, E). The point system was based on the job description of the main wage earner, the monthly household income, type of accommodation, possessions (washing machine, microwave, number of cars and value, etc.) and lifestyle (sports club membership, regular trips abroad). SEC A was the highest and class D was the lowest included in the sample. The diary was completed for 4 consecutive days, including, where possible, 1 weekend day, to better represent weekly dietary habits. The diary was completed on paper and covered the whole diet, including food and beverage intake at home and outside of the home, with detailed information on homemade recipes and dietary supplements. A photographic food atlas of portion sizes was used to estimate portion size based on pictures of typical dishes.

Quality-control checks related to food-intake data were routinely performed during data collection, and final data quality checks were done on the complete database. In addition to routine checks, 10% of data coded were cross-checked to identify and resolve discrepancies. Any issues regarding diary completeness, portion sizes, and energy and nutrient intakes were discussed among research team members to reach a consensus. Missing data, outliers, and out-of-range values were identified with energy and nutrient distributions. Among the 860 people surveyed, 144 were women aged 19–30 y, of whom 14 were excluded [due to having implausible daily energy intakes defined as being below the 5th or above the 95th percentiles (24)], leading to a study sample of 130 women, with 4 d of the diary completed (**Figure 1**).

Creation of a composite food-composition database

The 378 foods consumed by the subjects ($n = 130$) were classified into 15 main food groups and 52 subgroups, as detailed in **Supplemental Table 2**. This classification was based on the classification used in Optifood, a diet-modeling software program developed to design population-specific, food-based recommendations (25). Egyptian food-composition tables (26) were complemented with Turkish and Serbian food-composition tables (27, 28). The nutritional composition of foods such as lentils was adapted from the global food-composition table for pulses (29) and that of spices and some other foods was adapted from recently published Indian food-composition data (30). At the time of the study, the only fortification program in place in Egypt was salt iodization. As iodized salt use is very prevalent in the country [92.5% of households surveyed in a previous study used iodized salt (31)], all salt consumed was considered to be fortified with 15 ppm of iodine.

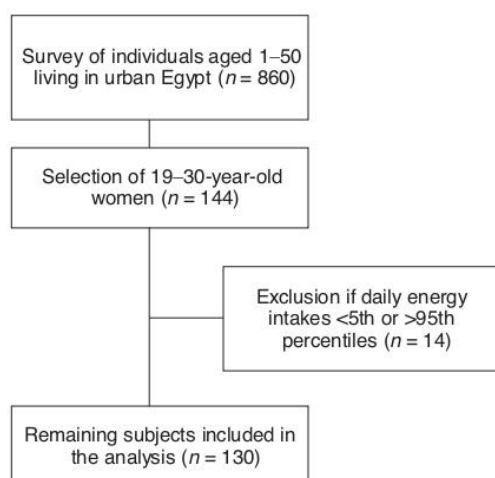


FIGURE 1 Subject selection for dietary analysis of 19- to 30-year-old Egyptian women living in urban areas.

Calculation of energy and nutrient intakes and comparison with needs and recommended intakes

Energy needs were calculated using equations for basal metabolic rate for 18- to 30-year-old women with individual reported or imputed body weight (32) and assuming a physical activity level of 1.4, corresponding to a sedentary lifestyle, for all women (33, 34). Total energy intakes (TEIs) were compared with energy needs for each woman. Nutrient intakes were calculated based on food and beverage intake only and did not include dietary supplements due to limited information on the types of supplements consumed and the low number of supplement users ($n = 8$, 6.2% of the study sample). Nutrient intakes were analyzed and compared with WHO/FAO population goals for macronutrients (35) and Egyptian recommendations for micronutrient intakes (36). For iron, mean intakes were compared with individual needs, as described in the following section.

Calculation of iron bioavailability and needs

Iron needs for premenopausal women rely mainly on basal losses, menstrual losses, and iron bioavailability (12). Bioavailable iron needs were calculated by adding basal iron losses to menstrual iron losses. Basal iron losses are estimated to be 14 $\mu\text{g}/\text{kg}$ of body weight per day (12, 37); when averaged over the entire 28-d menstrual cycle, this means that menstrual iron losses are ~ 0.56 mg/d (12). Therefore, women's iron needs were calculated as follows:

$$\begin{aligned} \text{Needs (bioavailable iron, mg/d)} &= \text{basal losses} + \text{menstrual losses (mg)} \\ &= [0.014 \times \text{body weight (kg)}] + 0.56 \end{aligned} \quad (1)$$

Iron bioavailability from diet was calculated based on intakes and bioavailability of both heme and nonheme iron from dietary intakes.

$$\begin{aligned} \text{Resultant bioavailability from diet} \\ = \frac{[\text{heme iron (mg)} \times 25\%] + [\text{nonheme iron (mg)} \times \text{nonheme iron bioavailability (\%)}]}{\text{iron intake (mg)}} \end{aligned} \quad (2)$$

Nonheme and heme iron intakes were estimated based on the content of heme and nonheme iron in each food subgroup (38, 39), as detailed in **Supplemental Table 3**. A bioavailability of 25% was assumed for heme iron intake (12, 40).

Equations from Armah et al. (41) were used to estimate nonheme iron bioavailability for each woman, as described below:

$$\begin{aligned} \text{In (nonheme iron bioavailability) (\%)} &= 6.294 - 0.709 \ln (\text{SF}) \\ &+ 0.119 \ln (\text{C}) + 0.006 \ln (\text{MFP} + 0.1) - 0.055 \ln (\text{T} + 0.1) \\ &- 0.247 \ln (\text{P}) - 0.137 \ln (\text{Ca}) - 0.083 \ln (\text{NH}) \end{aligned} \quad (3)$$

where SF is serum ferritin ($\mu\text{g}/\text{L}$); C is vitamin C (mg); MFP is meat, fish, and poultry (g); T is black tea equivalents (number of cups); P is phytate (mg); Ca is calcium (mg); and NH is nonheme iron (mg). Serum ferritin was assumed to be 15 $\mu\text{g}/\text{L}$ for all women, as approximately half of Egyptian women have a ferritin concentration < 15 $\mu\text{g}/\text{L}$ (5). Vitamin C, calcium, and meat-fish-poultry intakes were directly derived from the subjects' dietary data. As no information was available on phytate intake, a phytate intake of 1400 mg/d was assumed for all participants, which corresponds to a mixed diet with a high proportion of unrefined cereal grain products and legumes (42). Black tea equivalents were determined based on dietary data and using the approach described by Armah et al. (41) to convert the number of beverages consumed into black tea equivalents.

The total amount of iron needed could then be calculated as the bioavailable iron needs, divided by bioavailability, and a variation of 40% was assumed.

$$\begin{aligned} \text{Total amount of iron needed} &= \frac{\text{Needs (bioavailable iron, mg/d)}}{\text{Bioavailability}} \\ &\pm 40\% \end{aligned} \quad (4)$$

Statistical analysis

Data are presented as the means \pm SDs for continuous variables and as percentages for categorical variables. As energy and iron needs were calculated individually, the differences between mean intake and needs were tested using Student's *t* tests. For all other micronutrients, the differences between mean and recommended intakes were tested using Welch's 2-sample *t* tests, as the series had unequal variances. When the recommended nutrient intake was expressed as a range, the value retained for comparison was the lower bound of the recommended range. A *P*-value cutoff of 0.05 was used for statistical significance. Bonferroni corrections for simultaneous analysis were applied to micronutrients, and the null hypothesis was rejected at a significance level of $0.05/20 = 0.0025$.

Micronutrient intakes were considered "critical" when the following 2 conditions were fulfilled: 1) $>50\%$ of the sample had intakes less than the recommended amount (or needs, for iron) and 2) the mean intake was significantly lower than the recommendation ($P < 0.0025$), except for sodium (which was considered critical if the intake was significantly higher than the recommendation; $P < 0.0025$).

TABLE 1 Demographic characteristics of the 19- to 30-y-old urban Egyptian women included in this study¹

Variable	Values
Age, y	24.7 ± 3.7
Weight, ² kg	73.9 ± 12.9
Height, ² m	1.63 ± 0.12
BMI, ² kg/m ²	27.9 ± 4.9
Geographical region, % of women	
Greater Cairo	43.1
Delta	26.2
Upper Egypt	16.9
Alexandria	13.8
Socioeconomic class, % of women	
A (highest)	2.3
B	14.6
C1	19.2
C2	51.5
D (lowest)	12.3

¹Values are means ± SDs unless otherwise indicated; *n* = 130.

²Means were calculated after replacing missing or implausible height and weight values with imputed values.

Results

Population characteristics

The mean age of the women was 24.7 ± 3.7 y. Most of the participants were from Greater Cairo (43.1%), and the majority were lower middle class (51.5% of the women were from SEC C2) (Table 1). The mean reported weight was 72.2 ± 13.4 kg and the mean reported BMI was 27.6 ± 5.3 (*n* = 80; Supplemental Table 1). After replacing the missing and implausible values with imputed values (38%; *n* = 50; Supplemental Table 1), the mean weight for the 130 women was 73.9 ± 12.9 kg, and the mean BMI was 27.9 ± 4.9 (Table 1).

Energy and nutrient intakes

The mean daily total energy intake (2389 ± 715 kcal) was significantly higher (on average, 254 kcal higher; *P* = 0.00018) than daily energy needs (2135 ± 237 kcal) (Figure 2).

The mean total fat (89 ± 32 g/d; 33.4%TEI) and SFA (30 ± 13 g/d; 11.2%TEI) intakes were slightly higher than those specified by the WHO's population goals (15–30%TEI and <10%TEI, respectively) (Figure 3). Protein intake (87 ± 28 g/d; 14.6%TEI) was within the recommended range (10–15%TEI), and carbohydrate intake (307 ± 96 g/d; 51.4%TEI) was slightly below the recommended range (55–75%TEI). Approximately one-third of carbohydrates came from total sugars (98 ± 54 g/d; 16%TEI), whereas the WHO recommends a free-sugar intake of <5–10%TEI (43). Fiber intake was 18 ± 8 g/d, which is below the daily recommended intake of 25 g/d.

Mean iron, potassium, vitamin D, and folate intakes were below recommendations (Table 2). On average, women had intakes of 13.8 ± 4.6 mg iron/d, whereas their daily needs were 17.5 ± 7 mg iron/d, with 78.5% of women with inadequate intakes (iron bioavailability and needs will be discussed in detail in the following section). More than four-fifths of women consumed less vitamin D (82.3% of subjects had an intake of <5 µg/d), folate (80% of women had an intake of <400 µg/d), and potassium (82.3% had an intake of <4.7 g/d) than the recommended levels. Sodium intake (2787 ± 1065 mg/d) was nearly

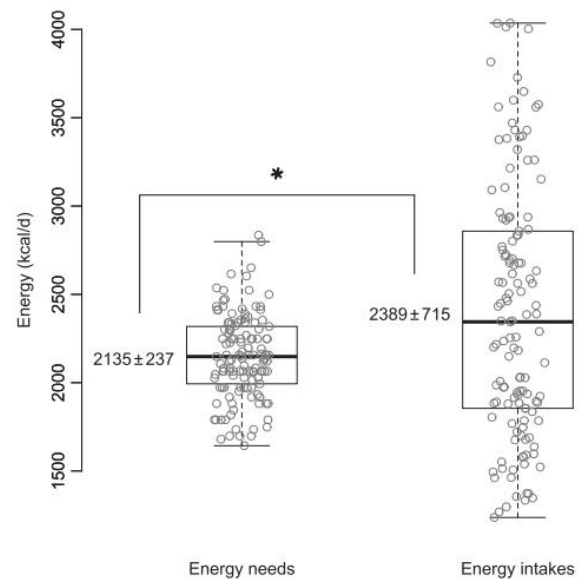


FIGURE 2 Energy needs and intakes of 19- to 30-y-old Egyptian women living in urban areas (*n* = 130). Each gray circle represents 1 woman. The mean ± SD values are presented on the left side of the boxplots. The asterisk in the center of the graph indicates that there was a significant difference in mean energy intake and needs, as determined by *t* test.

twice the recommended level, with 93.1% of participants consuming >1500 mg/d and 88% of women consuming >2300 mg/d [which is the upper limit set by the US Institute of Medicine for healthy individuals (44); data not shown]. Mean intakes were within or above recommendations for calcium, copper, iodine, magnesium, phosphorous, zinc, vitamin A, vitamin E, niacin, pantothenic acid, riboflavin, thiamin, and vitamins B-12, B-6, and C.

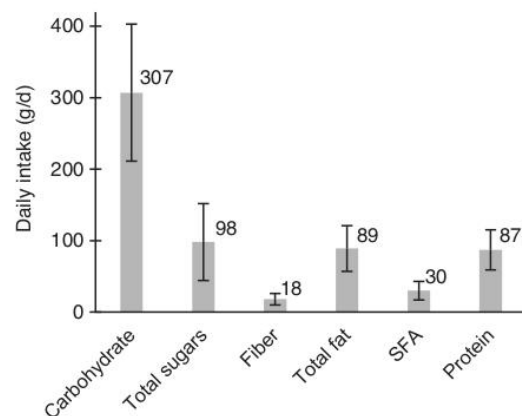


FIGURE 3 Mean daily macronutrient intake in 19- to 30-y-old urban Egyptian women (*n* = 130). Error bars displayed on the figure are standard deviations.

TABLE 2 Mean daily micronutrient intakes in 19- to 30-y-old urban Egyptian women compared with recommended intakes¹

Micronutrient	Mean \pm SD intake	Recommended intake ²	Mean of the differences ³ (95% CI)	P ⁴	Percent of women with inadequate intake ⁵
Critical micronutrients ⁶					
Iron, mg	13.8 \pm 4.6	17.5 \pm 7 ⁷	-3.7 (-4.7, -2.8)	*	78.5
Potassium, g	3.4 \pm 1.2	>4.7	-1.3 (-1.5, -1.0)	*	82.3
Sodium, mg	2787 \pm 1065	<1500	1287 (1102, 1472)	*	93.1
Folate, mg	308 \pm 130	>400	-92 (-115, -69)	*	80.0
Vitamin D, μ g	3.27 \pm 3.53	5-10	-1.73 (-2.34, -1.12)	*	82.3
Other micronutrients					
Calcium, mg	1001 \pm 392	>1000	1 (-67, 70)	0.9658	56.9
Copper, mg	1.56 \pm 0.63	>0.9	0.66 (0.55, 0.76)	*	11.5
Iodine, μ g	211 \pm 98	>150	61 (43, 78)	*	27.7
Magnesium, mg	458 \pm 148	220-310	238 (212, 264)	*	3.1
Phosphorus, mg	1406 \pm 438	>700	706 (630, 782)	*	1.5
Zinc, mg	10.98 \pm 3.56	7.2-9	3.78 (3.16, 4.39)	*	13.8
Vitamin A, μ g retinol equivalent	851 \pm 1279	500-700	351 (129, 573)	*	63.1
Vitamin E, μ g	11.89 \pm 6.36	7.5-15	4.39 (3.28, 5.49)	*	25.4
Niacin, mg niacin equivalent	21.3 \pm 10.8	14-16	7.3 (5.4, 9.2)	*	23.8
Pantothenic acid, mg	8.46 \pm 18.14	>5	3.46 (0.31, 6.61)	0.0315	68.5
Riboflavin, mg	1.55 \pm 0.59	>1.1	0.45 (0.34, 0.55)	*	23.1
Thiamin, mg	1.25 \pm 0.43	>1.1	0.15 (0.08, 0.23)	*	41.5
Vitamin B-12, μ g	6.02 \pm 5.61	>2.4	3.62 (2.65, 4.59)	*	21.5
Vitamin B-6, mg	1.45 \pm 0.61	>1.3	0.15 (0.04, 0.25)	0.0072	52.3
Vitamin C, mg	152 \pm 94	45-75	107 (91, 123)	*	6.2

¹n = 130. *P < 0.0025 (cutoff used for rejecting null hypothesis after Bonferroni correction).

²Based on nutrient intakes recommended by the Egypt Health Ministry and the WHO (36).

³The mean of differences was calculated as the mean intake minus the recommended intake, using the lower bound of the range when recommendations were expressed as ranges (magnesium; zinc; vitamins A, D, and E; niacin; and vitamin C). A positive difference indicates that mean intakes are above recommendations; a negative difference indicates that mean intakes are below recommendations.

⁴The P values shown are for Welch's 2-sample t tests comparing the intake of and requirement for all nutrients except iron, for which a Student's t test was performed to compare the intake and requirement. When recommended nutrient intakes were expressed as ranges, the lower bound of the range was used as comparison with mean intakes in statistical tests.

⁵For sodium, intakes above the recommendation are labeled as being inadequate. For all other nutrients presented, intakes below the recommendation (or below the lower bound of the range) are considered inadequate.

⁶Nutrients were identified as "critical" when >50% of women had intakes less than the recommendation and the mean intake was significantly lower than the recommendation (P < 0.0025 after Bonferroni correction), except for sodium (which was defined as critical given that >50% of women had intakes higher than the recommended amount and the mean intake was significantly higher than the recommendation).

⁷Individual iron requirements for each woman were calculated based on body weight and assuming menstrual losses of 0.56 mg/d (12). A variation in iron requirements of 40% was assumed.

Calculation of iron bioavailability, intakes, and needs

Dietary iron was consumed predominantly in nonheme form (Table 3; 12.6 \pm 4.3 mg/d of nonheme iron out of the 13.8 \pm 4.6 mg iron consumed daily). Given that nonheme iron has a bioavailability of 7.8% \pm 0.7%, and assuming a bioavailability of 25% for heme iron (12), the total iron bioavailability was 9.2% \pm 1.6%, with the variability coming from diet composition (as serum ferritin was assumed to be 15 μ g/L for all women). Dietary intake provided, on average, 1.3 \pm 0.5 mg/d of bioavailable iron, whereas the needs were 1.6 \pm 0.2 mg/d (Figure 4).

Energy and nutrient sources according to food consumption

Table 4 summarizes the contribution of the various food groups to energy, total sugars, protein, total fat, SFA, iron, potassium, sodium, folate, and vitamin D intakes. Supplemental Tables 4-6 detail the food groups and subgroups that provided all other nutrients.

The 3 food groups with the greatest contribution to mean total daily energy intake were bakery products (351 \pm 230 kcal); meat,

fish, and eggs (351 \pm 199 kcal); and dairy products (290 \pm 185 kcal). The 3 food subgroups with the highest contribution to daily total energy intake were refined grain products (e.g., rice, pasta, noodles, couscous) (265 \pm 144 kcal), bread (258 \pm 167 kcal), and sandwiches (182 \pm 248 kcal) (Supplemental Table 4).

Added sugars (25.8 \pm 19.2 g) and beverages (21.9 \pm 24.5 g) accounted for most of the total sugar intake. Meat, fish, and eggs (29.7 \pm 18.5 g); dairy products (16.9 \pm 11.5 g); and bakery products (9.5 \pm 5.9 g) were the 3 main sources of protein. Total fat was obtained primarily from meat, fish, and eggs (20.1 \pm 12.7 g); dairy products (19.6 \pm 13.9 g); and composites (mixed food groups) (8.6 \pm 9.2 g). At the subgroup level, the main sources of SFAs were white cheese (7.8 \pm 7.9 g), milk (2.8 \pm 2.8 g), and sandwiches (2.2 \pm 3.3 g) (Supplemental Table 4).

Iron was obtained primarily from meat, fish, and eggs (3.16 \pm 2.06 mg) and bakery products (2.52 \pm 1.90 mg). At the subgroup level (Supplemental Table 5), the primary iron sources were bread (1.97 \pm 1.72 mg) and legumes (1.01 \pm 1.12 mg), both of which contain only nonheme iron, as well as sandwiches (1.27 \pm 2.24 mg),

TABLE 3 Parameters for estimating nonheme iron absorption, iron intake, and iron bioavailability in 19- to 30-y-old urban Egyptian women¹

	Values
Parameters for nonheme iron absorption calculation ²	
Serum ferritin, µg/L	15
Vitamin C, mg/d	152 ± 94
Meat, fish, and poultry, g/d	158 ± 105
Black tea equivalents, number of cups/d	1.4 ± 1.0
Phytate, mg/d	1400
Calcium, mg/d	1001 ± 392
Iron intake, ³ mg/d	
Nonheme	12.6 ± 4.3
Heme	1.2 ± 1.3
Total	13.8 ± 4.6
Iron bioavailability, %	
Nonheme ²	7.8 ± 0.7
Heme ⁴	25
Resultant bioavailability from the diet ⁵	9.2 ± 1.6

¹Values are means ± SDs; n = 130. For serum ferritin, phytate intake, and heme iron bioavailability, the same values were assumed for all participants, so there is no SD.

²Nonheme iron absorption (assumed to be equal to bioavailability) was estimated using equations from Armah et al. (41).

³Intakes were calculated from the 4-d food diary of 19- to 30-y-old Egyptian women and from the proportion of heme and nonheme iron contained in animal-derived foods [Supplemental Table 3; (38, 39)].

⁴Heme iron absorption was assumed to be 25% (12).

⁵Resultant iron bioavailability from the diet was based on heme and nonheme iron intake and bioavailability.

which can contain some animal ingredients. The top 3 sources contributing to potassium intake were meat, fish, and eggs (482 ± 304 mg); potatoes (456 ± 525 mg); and vegetables (447 ± 474 mg). Dairy products (660 ± 539 mg/d; white cheese notably, with 464 ± 482 mg/d; Supplemental Table 5) and meat, fish, and eggs (424 ± 311 mg/d) were the foods that contributed most to sodium intake.

The top 3 sources of folate in the diet of Egyptian women were vegetables (54.0 ± 60.4 µg); legumes, nuts, and seeds (51.8 ± 51.4 µg); and meat, fish, and eggs (39.0 ± 35.2 µg). Nearly all vitamin D intake came from the meat, fish, and eggs group (2.65 ± 3.49 µg), with boneless fish (1.84 ± 3.39 µg), eggs (0.50 ± 0.65 µg), and poultry (0.22 ± 0.28 µg) being the main sources (Supplemental Table 6).

Discussion

A high prevalence of overweight was found in this group of 19- to 30-y-old women from urban areas of Egypt (mean BMI: 27.9 ± 4.9). This is consistent with data from the WHO reporting a mean BMI of 30.6 for Egyptian women (1) and with data from the national Demographic and Health Survey, which reported that 20- to 29-y-old Egyptian women had a mean BMI of 28.2 (2). A low level of physical activity was assumed for calculating energy needs, as previously reported in Egyptians (34, 45), which could be due to cultural and religious barriers or women's safety concerns (8, 34, 46). The food habits of these women were typical of a population undergoing nutrition transition, facing the double burden of malnutrition. Their daily energy intakes were, on average, 254 kcal greater than their needs, which can be a sufficient caloric surplus contributing to an increase in the prevalence of overweight and obesity in

the long term. The dietary data revealed unbalanced nutrient intakes, with a high intake of total sugars, SFAs, and sodium and an insufficient intake of vitamin D, folate, potassium, and iron. Data available in previous studies using biochemical measures show consistency with the insufficient intakes of iron (2, 5), vitamin D (18, 19), and folates (20) estimated in our study.

Most women (78.5%) had insufficient iron intakes, and this is consistent with the high prevalence of iron deficiency (50%) and iron-deficiency anemia (25%) in Egyptian women (5). This may be related to the relatively low consumption of heme iron-rich animal products, combined with the daily consumption of black tea and high-phytate food items such as bread, which decreases the bioavailability of nonheme iron (13.8 ± 4.6 mg/d of total iron intake, 1.2 ± 1.3 mg/d of heme iron, and nonheme iron absorbed at a rate of 7.8% ± 0.7%). Given the low number of subjects reportedly taking dietary supplements (n = 8; 6.2%), the insufficient iron intakes could be problematic at the population level, particularly for women of childbearing age. Several assumptions were made when calculating iron bioavailability. Phytate intakes were set at 1400 mg/d for all participants, based on the high consumption of legumes and bread (74 and 97 g/d, respectively). Serum ferritin, which was set at 15 µg/L based on national Egyptian data (5), is the main factor affecting nonheme iron bioavailability (41). Indeed, when iron stores are low (low ferritin concentration), less of the hormone hepcidin is released by the liver, which promotes dietary iron absorption in the gut and iron recycling in the body (47). The results from this study suggest that encouraging careful selection of heme iron-rich animal food sources, the inclusion of vitamin C-rich fruit such as citrus fruit in the diet, and decreased consumption of tea and coffee could improve both iron intake and bioavailability. Future studies warrant concurrent assessment of iron status and dietary intake in this population.

Total fats (33.4%TEI) were consumed in slight excess compared with WHO population goals (15–30%TEI), but complied with European Food Safety Authority (EFSA) and the US Institute of Medicine recommendations [20–35%TEI (48, 49)]. SFAs (11.2%TEI) were consumed in higher amounts than recommended [<10%TEI according to WHO, “as low as possible” according to EFSA (49) and US (48) recommendations], mainly due to the high consumption of white cheese (notably feta cheese, which is high in sodium and SFAs and is widely consumed in Egypt).

Approximately one-third of carbohydrate came from total sugars. Ideally, the contribution of total sugars to carbohydrate intake should be reduced, as the 2 main sources of sugars were table sugar and sugar-sweetened beverages, and the WHO recommends that only 5–10%TEI should come from free sugars (43).

In total, 93% of the women had intakes of sodium in excess of recommendations: on average, twice the recommended amount of sodium intake was consumed (2787 ± 1065 mg/d instead of 1500 mg/d) and 88% of women consumed ≥2300 mg/d. Since high sodium intake increases the risk of high blood pressure, stroke, fatal stroke, and fatal coronary heart disease, the WHO strongly recommends reducing sodium intake to <2000 mg/d (50), and the US Institute of Medicine uses an upper limit of 2300 mg/d of sodium for healthy individuals without hypertension (44). High intakes of sodium (2500–2700 mg/d) have already been highlighted in adolescents (12–18 y old) with and without hypertension from the city of Sohag (51). Reducing cheese consumption or

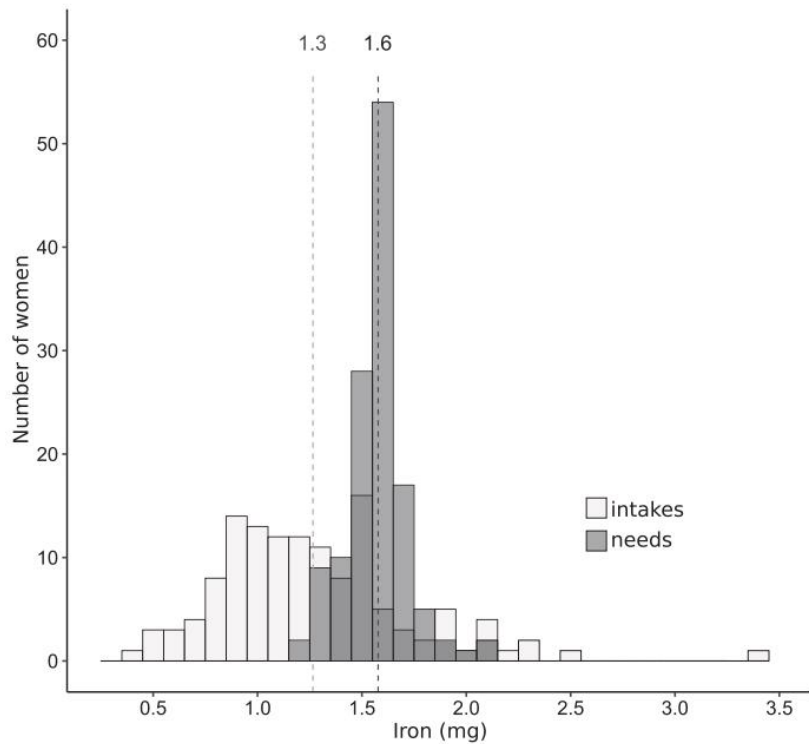


FIGURE 4 Bioavailable iron intake (light gray) and iron losses (dark gray) in 19- to 30-y-old urban Egyptian women ($n = 130$). The light-gray dashed line represents the mean intake, and the dark-gray dashed line represents the mean losses.

refraining from adding salt at the table or during cooking could help reduce sodium intake. In contrast, potassium intake was below recommendations for 82% of the women, with an average intake of 3.4 ± 1.2 g/d. It is important to note that the Egyptian recommendation for potassium intake (>4.7 g/d) is higher than the EFSA's definition of an adequate intake (3.5 g/d), and that EFSA states that a potassium intake >3.5 g/d tends to decrease the risk of stroke (52).

Vitamin D intakes were below the recommended amount for 82% of the women, which is concerning as most Egyptian women wear veils (53), so vitamin D synthesis from sun exposure is limited. Vitamin D deficiency has previously been identified as a problem in Egyptian mothers (19) and healthy Egyptian females (18) and is often related to limited sun exposure, low fish consumption, a low level of education, and a high BMI (19). Increased vitamin D intake could be encouraged by promoting direct supplementation, the introduction of vitamin D-fortified products, or the selection of appropriate vitamin D-rich foods, such as fish. Young Egyptian women could be encouraged to consume larger portion sizes and/or consume fish more frequently, with suitable advice around healthy preparation, to help increase their vitamin D intake.

Overall, 80% of the women surveyed had an insufficient folate intake. In contrast, a previous study using blood measures suggested that folate intake was less of concern, as only 14.7% of women of reproductive age (20–49 y old) had folate deficiency (serum concentrations <10 nmol/L) (20). In the current study, the main sources of

folate were vegetables (especially green leafy vegetables such as spinach or the plant *molokheya*), legumes (with a large consumption of broad beans, consumed as the traditional Egyptian dish *fuul*), and animal products. The Egyptian government launched an initiative in 2008 to increase iron and folate intake by fortifying the national (in Egyptian *baladi*) bread flour with iron and folate (54), but regrettably, the program has now ended. Tailored dietary recommendations that include good sources of folate would help women consume an adequate intake.

The main limitation of our study is linked to the self-reported nature of height and weight values collected in the study. Energy needs were estimated based on self-reported weights, where more than one-third of values were missing or implausible. In order to address this issue, we imputed missing and implausible values based on demographic data on 19- to 50-y-old men and women, and values were similar. Yet, calculated energy needs are only approximations obtained from the data available. The issues that we faced collecting self-reported height and weight highlight the importance of overcoming barriers (such as cultural or practical) in taking direct body measurements. The small sample size of our study population ($n = 130$) is another limitation, and further research on dietary practices of Egyptian women at the national level could investigate the magnitude of the nutritional imbalances. Additionally, as in any dietary survey, subjects may have misreported or changed their dietary intakes during the days of survey, and the results may not be representative of their habitual dietary intakes. Biochemical indicators of

TABLE 4 Contribution of each food group to energy, total sugars, protein, total fat, SFA, iron, potassium, sodium, folate, and vitamin D intakes in 19- to 30-y-old urban Egyptian women¹

	Energy, kcal	Total sugars, g	Protein, g	Total fat, g	SFAs, g	Iron, mg	Potassium, mg	Sodium, mg	Folate, μ g	Vitamin D, μ g
Grains and grain products	273 ± 146	0.8 ± 0.8	7.0 ± 4.2	3.6 ± 2.3	1.4 ± 0.9	0.82 ± 0.67	159 ± 109	132 ± 98	19.3 ± 22.2	0.06 ± 0.06
Bakery products	351 ± 230	12.1 ± 16.8	9.5 ± 5.9	4.3 ± 5.3	1.4 ± 2.2	2.52 ± 1.90	249 ± 159	361 ± 224	3.6 ± 5.4	0.04 ± 0.10
Potatoes	164 ± 189	0.9 ± 1.4	2.2 ± 2.5	7.1 ± 8.2	1.9 ± 2.3	0.58 ± 0.67	456 ± 525	45 ± 72	23.2 ± 26.7	0.00 ± 0.02
Legumes, nuts, and seeds	130 ± 114	0.3 ± 0.3	6.0 ± 5.6	7.0 ± 7.3	0.9 ± 1.1	1.70 ± 1.57	245 ± 230	124 ± 111	51.8 ± 51.4	0.00 ± 0.00
Dairy products	290 ± 185	9.9 ± 8.0	16.9 ± 11.5	19.6 ± 13.9	13.2 ± 9.3	0.35 ± 0.34	321 ± 228	660 ± 539	27.5 ± 17.8	0.37 ± 0.25
Meat, fish, and eggs	351 ± 199	1.0 ± 1.1	29.7 ± 18.5	20.1 ± 12.7	6.2 ± 4.6	3.16 ± 2.06	482 ± 304	424 ± 311	39.0 ± 35.2	2.65 ± 3.49
Fruits	91 ± 98	15.4 ± 17.0	1.3 ± 1.4	0.3 ± 0.4	0.0 ± 0.1	0.70 ± 0.76	364 ± 395	3 ± 3	24.8 ± 27.2	0.00 ± 0.00
Vegetables	71 ± 94	3.9 ± 5.7	2.2 ± 2.4	2.9 ± 7.3	0.4 ± 0.8	0.78 ± 0.71	447 ± 474	125 ± 152	54.0 ± 60.4	0.04 ± 0.13
Added fats	55 ± 107	0.0 ± 0.0	0.0 ± 0.0	6.2 ± 12.0	0.6 ± 1.2	0.01 ± 0.01	0 ± 0	0 ± 1	0.0 ± 0.0	0.00 ± 0.02
Added sugars	106 ± 79	25.8 ± 19.2	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.20 ± 0.44	29 ± 107	2 ± 7	0.0 ± 0.0	0.00 ± 0.00
Sweetened snack foods (candy and chocolate)	22 ± 48	2.0 ± 4.5	0.2 ± 0.6	1.2 ± 2.6	0.5 ± 1.2	0.08 ± 0.20	13 ± 29	2 ± 7	0.3 ± 0.6	0.01 ± 0.02
Beverages (non-dairy)	109 ± 116	21.9 ± 24.5	0.8 ± 0.8	0.3 ± 0.8	0.1 ± 0.2	0.66 ± 1.09	194 ± 179	130 ± 72	32.1 ± 43.1	0.00 ± 0.00
Miscellaneous ²	20 ± 83	2.1 ± 11.6	0.3 ± 1.1	0.3 ± 1.1	0.1 ± 0.5	0.16 ± 0.51	43 ± 194	264 ± 605	1.9 ± 7.5	0.00 ± 0.02
Composites (mixed food groups) ³	241 ± 262	1.8 ± 2.1	9.3 ± 10.6	8.6 ± 9.2	2.5 ± 3.3	1.74 ± 2.38	268 ± 287	337 ± 382	24.7 ± 30.2	0.09 ± 0.18
Savory snacks	115 ± 138	0.2 ± 0.6	1.5 ± 1.8	7.0 ± 8.6	0.4 ± 0.9	0.35 ± 0.42	176 ± 234	178 ± 218	5.9 ± 7.2	0.00 ± 0.02

¹Values are means ± SDs; $n = 130$.²The "Miscellaneous" group includes condiments, herbs, spices, sauces, salad dressing, jam, spreads, and sweeteners.³The "Composites (mixed food groups)" group includes main dishes, sandwiches, soups, and vegetarian dishes that were composed of ingredients from several food groups.

nutrients (e.g., serum ferritin, plasma folate, 25-hydroxyvitamin D) were not measured in this study, but these would have facilitated understanding of the validity of the results. Several assumptions on parameters impacting iron bioavailability were made based on the literature [phytate intakes (42), serum ferritin concentrations (5), menstrual losses (12)], whereas other parameters were not taken into account [e.g., contraception method (55), inflammation (13), parasite infection (12), genetic disease such as β -thalassemia (56, 57)], as data related to these factors were unfortunately not collected in our study. It would have been interesting to compare iron intakes with blood analyses (e.g., serum ferritin, hemoglobin, C-reactive protein) to better understand the root causes of anemia in our population.

The results from this study indicate that 19- to 30-y-old women living in urban Egypt have nutrition transition-like dietary patterns, with notably high energy, SFA, total sugar, and sodium intakes and insufficient iron, vitamin D, and folate intakes. In addition to the nutrient-poor and energy-rich diets reported here, the high prevalence of overweight and obesity in this population poses a greater risk for nutritional deficiencies (13) and related chronic diseases (58). Strategies are needed to increase both iron absorption and intake and to improve overall diet quality. To date, no country-specific, food-based dietary guidelines exist for Egypt (59), while traditional Egyptian foods include a range of very nutritious foods that are high in dietary fiber and low in saturated fat (60), such as legumes (broad beans, chickpeas, etc.), liver, green leafy vegetables, herbs, fruits, dates, and bread (9). The greater availability and consumption of fast foods (9) and subsidized foods (bread, oil, and sugar), which are high in calories, may have played a role in the increasing prevalence of obesity (3), suggesting that it could be helpful to fortify healthier (less caloric, more nutrient-dense) foods. Follow-up work should focus on developing food-based dietary guidelines that include local foods and investigating the potential public health benefits associated with food fortification. Improving the dietary habits of Egyptian women has the potential to improve the health of women, children, and future generations (14–17).

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Urban Egyptian women aged 19-30 years display nutrition transition-like dietary patterns, with high energy and sodium intakes, and insufficient iron, vitamin D and folate intakes. Brouzes et al.

Online Supplementary Material

Supplemental Material 1. Methods for imputing missing height and weight values to estimate energy needs of 19-30-year-old urban Egyptian women.

Due to a high number of missing or implausible demographic data, missing height and weight values were estimated following a multiple imputation approach, based on an Akaike Information Criteria (AIC) backwards elimination procedure to select a subset of demographic variables resulting in a model with statistically significant predictors. This approach was the best that could be done with the data available to estimate energy needs and compare them with energy intakes.

Over the 130 women aged 19-30yo with plausible dietary intakes, about a third did not report their weight (32.3%) or height (36.9%), while few declared implausible weight (4.6%) or height (4.6%). Therefore, demographic data of 19-50yo adults (n=535) were cleaned and analyzed. To identify implausible values, weights and heights were represented on boxplots by age and gender groups, and extreme values were studied in view on participants' age, gender and BMI (when both height and weight were provided). When there was an obvious reversal between height and weight values, the data was manually corrected (for example, if an individual declared a weight of 165 kg for 70cm of height, the data was corrected for 165cm, 70kg). The other extreme values were removed from the dataset (height <100cm, weight >140kg or < 30kg).

AIC backwards elimination procedure was performed by applying the function « step » in R [1] to demographic data of 19-50 years-old men and women who reported a **plausible** body weight and height (n=310). The "step" function performs backward elimination of non-significant effects of linear mixed model, selecting the best model based on Akaike Information Criteria (AIC), an estimator of the relative quality of statistical models. The following variables were successively tested: "gender", "age", "socio-economic class", "smoking status", "geographical region of habitation", "declared physical activity level", "household person number", and interaction between "gender" and "age". According to this procedure, the best model to estimate a weight and a height was the one including the variables "age", "gender" and "household person number". Therefore, these demographic variables were used to impute missing or implausible height and weight values, performing multiple imputation ("mice" package in R [2]), which enables to acknowledge the uncertainty in the unknown values. Mean reported and imputed height, weight and BMI values are detailed by age, gender, socio-economic and regional groups in Supplemental table 1.

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Supplemental Table 1. Missing, reported and imputed weight, height and body mass index (BMI) values in 19-50-year-old urban Egyptian men and women (n=535).

The percentage of missing height and weight values were similar across age and gender groups. People from the highest socio-economic class (class A, n=15 individuals) had the most important proportion of missing or implausible weight and height values (60%), while people from B socio-economic class provided the lowest amount of missing or implausible weight and height values (24-28% of missing data).

Variables	Count	Weights			Heights			BMI (kg/m ²)	
		Missing or implausible (%)	Reported (kg)*	Imputed (kg) α	Missing or implausible (%)	Reported (m)*	Imputed (m) α	Reported*	Imputed α
Female, 19-30yo	130	38%	72.2 ± 13.4	76.4 ± 11.9	42%	1.62 ± 0.09	1.64 ± 0.14	27.6 ± 5.3	28.9 ± 5.1
Sex									
Female	310	41%	76.9 ± 13.7	77.8 ± 11.3	46%	1.63 ± 0.08	1.65 ± 0.16	28.8 ± 5.2	29.1 ± 5.6
Male	225	43%	78.3 ± 11.2	77.3 ± 13.4	45%	1.72 ± 0.08	1.68 ± 0.16	26.8 ± 4.3	27.5 ± 5.0
Age group									
19-30yo	261	42%	73.8 ± 12.4	77.4 ± 13.5	46%	1.67 ± 0.10	1.66 ± 0.16	26.8 ± 5.0	28.5 ± 5.3
31-50yo	274	42%	81.0 ± 12.1	77.8 ± 10.9	46%	1.67 ± 0.08	1.67 ± 0.16	29.1 ± 4.6	28.4 ± 5.5
SEC									
A (highest)	15	60%	76.7 ± 8.8	88.1 ± 13.0	60%	1.69 ± 0.07	1.77 ± 0.15	26.9 ± 3.5	28.5 ± 4.9
B	86	24%	77.6 ± 11.2	77.9 ± 10.6	28%	1.67 ± 0.08	1.70 ± 0.16	27.8 ± 4.3	27.8 ± 5.0
C1	110	45%	76.5 ± 12.2	78.0 ± 10.5	49%	1.67 ± 0.08	1.67 ± 0.14	27.7 ± 4.4	28.1 ± 4.9
C2	246	46%	78.8 ± 13.9	76.2 ± 12.7	49%	1.67 ± 0.10	1.65 ± 0.16	28.7 ± 5.6	28.4 ± 5.4
D (lowest)	78	42%	75.0 ± 12.5	78.8 ± 12.8	49%	1.67 ± 0.10	1.66 ± 0.18	26.8 ± 4.3	29.4 ± 6.4
Geographical region									
Greater Cairo	244	44%	78.2 ± 12.5	76.8 ± 12.4	47%	1.66 ± 0.09	1.66 ± 0.16	28.8 ± 4.6	28.2 ± 5.2
Delta	116	38%	79.2 ± 13.9	75.3 ± 10.8	50%	1.64 ± 0.09	1.65 ± 0.14	29.1 ± 5.7	29.0 ± 5.3
Upper Egypt	86	49%	75.8 ± 15.7	80.1 ± 11.7	51%	1.67 ± 0.09	1.69 ± 0.15	27.4 ± 5.4	28.2 ± 5.2
Alexandria	89	34%	74.9 ± 8.6	80.3 ± 13.6	31%	1.72 ± 0.08	1.68 ± 0.21	25.4 ± 3.1	28.8 ± 6.7
Total	535	42%	77.5 ± 12.8	77.6 ± 12.2	46%	1.67 ± 0.09	1.67 ± 0.16	28.0 ± 4.9	28.4 ± 5.4

* Based on reported plausible weights and heights values

α Given the high proportion of missing height and weight values, an AIC backwards elimination procedure was followed to impute missing or implausible body weight and height values based on adult participants' demographic characteristics.

Supplemental Table 2: Food classification system used to describe the dietary intake of 19-30year-old urban Egyptian women.

Food group	Food subgroup
Grains & grain products	Wholegrain products (brown rice, corn, barley) Refined grain products (rice, pasta, noodles, couscous) Enriched noodles
Bakery products	Wholegrain bread Bread Sweetened bakery products
Potatoes	Potatoes
Legumes, nuts & seeds	Legumes ¹ Nuts, seeds, and unsalted products Salted nuts and seeds
Dairy products	Milk Flavored milk Fortified milk Yoghurt, plain or sweetened Sweetened dairy desserts ² Cream White cheese Hard cheese
Meat, fish & eggs	Red meat Poultry Eggs Processed meat Fish without bones Small, whole fish, with bones Seafood Organ meat
Fruits	Vitamin C-rich fruits (citruses, pineapple, strawberries...) ³ Other fruits
Vegetables	Vitamin A-source vegetables (jews mallow, onion spring...) ⁴ Vitamin C-rich vegetables (cabbage, peas, spinach...) ³ Other vegetables (eggplants, green beans...)
Added fats	Vegetable oil Butter, ghee, margarine
Added sugars	Sugar Honey, molasses
Sweetened snack foods (candy and chocolate)	Sweet snack foods (candy and chocolate)

¹ The “legumes” subgroup includes cooked beans, peas and lentils.

² Sweetened dairy desserts include ice cream, milkshakes, rice pudding and *salep*.

³ Vitamin C-rich fruits and vegetables are defined as those containing ≥ 18 mg/100 g of vitamin C in the form in which they are eaten. Vitamin C-rich fruits and vegetables are not included here if they are categorized as vitamin A sources.

⁴ Fruit and vegetable sources of vitamin A are defined as those containing ≥ 120 RE/100 g (or ≥ 60 RAE/100 g) in the form in which they are eaten. Fruit and vegetable sources of vitamin A are included in this group even if they are also vitamin C-rich.

Supplemental Table 2. *Continued*

Food group	Food subgroup
Beverages (non-dairy)	Brewed tea, herbal infusions (w/wo sugar or milk) Brewed coffee (w/wo sugar or milk) Juice, nectar - Vitamin C-rich ⁵ Juice, nectar – Other Sodas Low calorie drinks Water
Miscellaneous	Condiments, herbs, spices Sauces, salad dressing Jam, spread Artificial sweetener
Composites (mixed food groups)	Main meal recipes ⁶ Sandwiches ⁷ Soups Vegetarian recipes ⁸
Savory snacks	Savory snacks, salted, spiced, fried, pickles

⁵ Vitamin C-rich juices or nectars are defined as those containing ≥ 9 mg/100 g of vitamin C.

⁶ Main dishes are defined as dishes containing an animal protein source (meat, fish or eggs) as well as grains, legumes or vegetable products.

⁷ The “sandwiches” subgroup includes grain products with fillings such as sandwiches, pizzas, burgers or savory pies. As sandwiches were the predominant food consumed from this subgroup, it is referred to as “sandwiches”.

⁸ Vegetarian recipes include dishes containing vegetables and/or legumes and/or grain products.

Supplemental Table 3. Percentage of heme iron from animal-derived food subgroups, and food items and references used.

Food subgroups	Food items	Percentage of heme iron (%)	Reference
Fish without bones	Catfish, grilled	27.9	[1]
	Fish fingers, breaded, fried	27.1	[1]
	Fried mackerel	25	[1]
	Gilt-head bream fish with tomatoes sauces and olives	27.1	[1]
	Herring, smoked	25	[1]
	Mackerel fish	25	[1]
	Mackerel, smoked	25	[1]
	Mullet, fried	25	[1]
	Salty kipper, fish	25	[1]
	Sea bass, grilled	27.1	[1]
	Tilapia, fried in oil	27.1	[1]
	Tilapia, grilled	27.1	[1]
	Tuna, in oil, canned	25	[1]
Organ meat	Alexandrian style liver	78	[2]
	Calf, offal, raw	83	[2]
	Fried camel liver with green pepper	78	[2]
	Fried chicken liver	24.2	[1]
	Giblets, fried on onion	28	[2]
	Lamb, liver, raw	70	[2]
	Liver chicken	24.2	[1]
	Liver in bran, fried	24.2	[1]
	Pate, liver, canned	24.2	[1]
Poultry	Breaded chicken	28	[2]
	Chicken breast meat with skin	28	[2]
	Chicken breast, fillet, breaded, fried	28	[2]
	Chicken meat, breast, with skin, boneless	28	[2]
	Chicken meat, breast, without skin, boneless	28	[2]
	Chicken with onion	28	[2]
	Chicken, cooked in water	28	[2]
	Chicken, drumstick, without skin, boneless	35	[2]
	Chicken, fried	28	[2]
	Chicken, leg, flesh and skin, raw	30	[2]
	Chicken, pieces, fried	28	[2]
	Chicken, roasted	28	[2]
	Chicken, thigh, raw	30	[2]
	Duck with freekeh	28	[2]
	Duck, baked	28	[2]
	Fried rabbit	52	[2]
	Griddled chicken breast	28	[2]
	KFC, Chicken leg	28	[2]
	Minced chicken meat steak	28	[2]
	Pigeon, fried	28	[2]
	Rabbit meat, back and leg	52	[2]
	Rabbit, poached	52	[2]
	Stuffed chicken with freekeh	28	[2]
	Turkey, roasted	35	[2]
	Veal, cooked in water	83	[2]
	Veal, roasted	83	[2]

Supplemental Table 3. *continued*

Food subgroups	Food items	Percentage of heme iron (%)	Reference
Processed meat	Chicken pate	9	[1]
	Luncheon meat, beef	19	[1]
	Pastrami	19	[1]
	Rissole- Kofta bulgur and meat	19	[1]
	Sausage, beef,	19	[1]
	Sausage with sauce	32	[1]
	Sausage, hot dog type, chicken	32	[1]
Red meat	Beef steak, fried	78	[2]
	Beef, cooked, with tomato	78	[2]
	Beef, medium fat, raw	78	[2]
	Beef, minced	78	[2]
	Beef, rump	78	[2]
	Buffalo, meat	78	[2]
	Camel, meat	78	[2]
	Goulash - beef meat	78	[2]
	Hamburger, beef	78	[2]
	Meat balls in tomato sauce	78	[2]
	Meat stew with onion and tomato	78	[2]
	Meat, beef- poached and roasted	78	[2]
	Minced meat steak, lamb and beef	74	[2]
	Minced meat, beef, stir fried	78	[2]
	Mixed grilled meat	78	[2]
	Mutton, grilled	70	[2]
	Poached beef meat	78	[2]
	Rissole - Kofta meat	78	[2]
	Stew, beef in onion	78	[2]
	Tomato sauce with minced beef meat	78	[2]
Seafood	Calamari, fried	11	[1]
	Crabs	11	[1]
	Mussel	27	[1]
	Seafood, mix	11	[1]
	Shrimp, fried	11	[1]
	Shrimps, grilled	11	[1]
	Small shrimp, raw	11	[1]
Small, whole fish, with bones	Sardine, canned	25	[1]
	Sardine, fried	25	[1]
	Sardine, grilled	25	[1]
	Sardine, in oil, canned	25	[1]

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Supplemental Table 4: Food consumed and contribution of foods to energy and macronutrient intakes in 19-30-year-old urban Egyptian women (n=130).

Food groups and subgroups	Amount (g)	Energy (kcal)	Carbohydrate (g)	Total sugar (g)	Fiber (g)	Total fat (g)	SFA (g)	Protein (g)
Grains & grain products	204 ± 111	273 ± 146	53.0 ± 28.7	0.8 ± 0.8	2.1 ± 1.4	3.6 ± 2.3	1.4 ± 0.9	7.0 ± 4.2
Refined grain products (rice, pasta, noodles, couscous)	202 ± 112	265 ± 144	51.6 ± 28.2	0.8 ± 0.8	2.0 ± 1.3	3.6 ± 2.3	1.4 ± 0.9	6.7 ± 4.1
Enriched noodles	1 ± 8	5 ± 32	1.0 ± 6.0	0.0 ± 0.2	0.0 ± 0.3	0.1 ± 0.4	0.0 ± 0.1	0.2 ± 1.2
Whole grain products (brown rice, corn, barley)	1 ± 7	2 ± 24	0.4 ± 4.6	0.0 ± 0.1	0.1 ± 0.6	0.0 ± 0.2	0.0 ± 0.0	0.1 ± 0.8
Bakery products	123 ± 77	351 ± 230	67.6 ± 42.8	12.1 ± 16.8	1.6 ± 1.0	4.3 ± 5.3	1.4 ± 2.2	9.5 ± 5.9
Bread	97 ± 64	258 ± 167	52.8 ± 34.4	2.3 ± 1.5	1.1 ± 0.8	1.5 ± 1.6	0.2 ± 0.6	8.0 ± 5.2
Sweetened bakery products	26 ± 43	93 ± 148	14.8 ± 24.2	9.8 ± 16.7	0.4 ± 0.6	2.9 ± 4.9	1.2 ± 2.1	1.6 ± 2.4
Whole grain bread	0 ± 1	0 ± 3	0.1 ± 0.6	0.0 ± 0.0	0.0 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.1
Potatoes	84 ± 103	164 ± 189	22.2 ± 25.8	0.9 ± 1.4	2.5 ± 2.9	7.1 ± 8.2	1.9 ± 2.3	2.2 ± 2.5
Legumes, nuts & seeds	82 ± 83	130 ± 114	9.0 ± 8.7	0.3 ± 0.3	4.0 ± 3.9	7.0 ± 7.3	0.9 ± 1.1	6.0 ± 5.6
Legumes [⊠]	74 ± 84	85 ± 92	8.0 ± 8.8	0.2 ± 0.2	3.5 ± 4.0	3.4 ± 3.9	0.4 ± 0.4	4.1 ± 4.7
Salted nuts and seeds	6 ± 10	32 ± 57	0.9 ± 1.6	0.1 ± 0.2	0.4 ± 1.0	2.6 ± 4.6	0.4 ± 0.7	1.2 ± 2.1
Nuts, seeds, and unsalted products	2 ± 9	13 ± 53	0.1 ± 0.6	0.0 ± 0.1	0.2 ± 0.7	1.0 ± 4.3	0.2 ± 0.8	0.7 ± 2.9
Dairy products	241 ± 158	290 ± 185	11.3 ± 9.4	9.9 ± 8.0	0.1 ± 0.1	19.6 ± 13.9	13.2 ± 9.3	16.9 ± 11.5
Milk	128 ± 126	80 ± 78	5.7 ± 5.6	6.0 ± 5.9	0.0 ± 0.0	4.4 ± 4.3	2.8 ± 2.8	4.4 ± 4.3
White cheese	48 ± 47	133 ± 131	0.5 ± 0.6	0.2 ± 0.8	0.0 ± 0.0	11.2 ± 11.4	7.8 ± 7.9	7.4 ± 7.3
Yoghurt, plain or sweetened	41 ± 69	27 ± 44	2.4 ± 4.1	2.3 ± 4.0	0.0 ± 0.1	1.2 ± 2.1	0.8 ± 1.4	1.4 ± 2.4
Sweetened dairy desserts	10 ± 26	12 ± 33	2.0 ± 5.8	0.9 ± 2.5	0.0 ± 0.1	0.3 ± 0.7	0.2 ± 0.4	0.4 ± 1.0
Hard cheese	9 ± 19	35 ± 78	0.3 ± 0.6	0.1 ± 0.2	0.0 ± 0.0	2.4 ± 5.2	1.5 ± 3.3	3.2 ± 7.4
Flavored milk	5 ± 25	4 ± 18	0.4 ± 2.0	0.4 ± 1.9	0.0 ± 0.1	0.2 ± 0.7	0.1 ± 0.5	0.2 ± 0.9
Fortified milk	0 ± 2	0 ± 1	0.0 ± 0.1	0.0 ± 0.1	0.0 ± 0.0	0.0 ± 0.1	0.0 ± 0.0	0.0 ± 0.0
Cream	0 ± 1	0 ± 2	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.2	0.0 ± 0.1	0.0 ± 0.0
Meat, fish & eggs	189 ± 109	351 ± 199	12.2 ± 11.6	1.0 ± 1.1	0.9 ± 0.8	20.1 ± 12.7	6.2 ± 4.6	29.7 ± 18.5
Poultry	64 ± 67	110 ± 112	6.4 ± 10.6	0.6 ± 0.9	0.5 ± 0.8	4.0 ± 5.3	1.3 ± 1.9	11.8 ± 13.6
Fish without bones	42 ± 53	85 ± 105	3.5 ± 6.0	0.1 ± 0.2	0.2 ± 0.3	5.0 ± 6.1	1.1 ± 1.3	6.6 ± 8.5
Red meat	35 ± 62	66 ± 119	1.0 ± 2.5	0.3 ± 0.7	0.1 ± 0.3	4.6 ± 8.4	1.7 ± 3.1	5.4 ± 9.4
Eggs	31 ± 40	52 ± 69	0.5 ± 0.9	0.0 ± 0.1	0.0 ± 0.1	3.6 ± 4.8	1.0 ± 1.3	3.8 ± 4.8
Processed meat	8 ± 20	25 ± 62	0.3 ± 1.0	0.0 ± 0.0	0.0 ± 0.0	2.1 ± 5.2	0.9 ± 2.2	1.2 ± 3.0
Organ meat	6 ± 18	9 ± 28	0.4 ± 1.3	0.0 ± 0.1	0.1 ± 0.3	0.6 ± 1.9	0.1 ± 0.8	0.7 ± 1.8
Seafood	1 ± 8	2 ± 15	0.0 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 1.4	0.1 ± 0.8	0.1 ± 0.8
Small, whole fish, with bones	1 ± 6	2 ± 19	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 1.6	0.1 ± 0.7	0.1 ± 1.2
Fruits	153 ± 159	91 ± 98	22.3 ± 24.5	15.4 ± 17.0	1.6 ± 2.2	0.3 ± 0.4	0.0 ± 0.1	1.3 ± 1.4
Other fruits	78 ± 101	57 ± 72	14.3 ± 18.2	10.7 ± 13.7	0.9 ± 1.5	0.2 ± 0.2	0.0 ± 0.0	0.6 ± 0.8
Vitamin C-rich fruits (citruses, pineapple, strawberries)	75 ± 95	34 ± 45	7.9 ± 11.0	4.7 ± 6.8	0.7 ± 1.3	0.2 ± 0.2	0.0 ± 0.0	0.7 ± 0.8

Supplemental Table 4. *continued*

Food groups and subgroups	Amount (g)	Energy (kcal)	Carbohydrate (g)	Total sugars (g)	Fibers (g)	Total fat (g)	SFA (g)	Protein (g)
Vegetables	179 ± 167	71 ± 94	9.9 ± 12.3	3.9 ± 5.7	2.4 ± 2.8	2.9 ± 7.3	0.4 ± 0.8	2.2 ± 2.4
Vitamin C-rich vegetables (cabbage, peas, spinach...)	85 ± 115	31 ± 50	6.1 ± 9.8	1.7 ± 2.7	1.2 ± 1.8	0.4 ± 1.0	0.1 ± 0.2	1.0 ± 1.5
Other vegetables (eggplants, green beans...)	81 ± 87	33 ± 75	3.3 ± 5.8	2.0 ± 4.1	1.0 ± 1.5	2.0 ± 7.1	0.3 ± 0.8	1.0 ± 1.6
Vitamin A source vegetables (carrots, dark leafy vegetables...)	13 ± 24	7 ± 13	0.6 ± 1.1	0.2 ± 0.5	0.1 ± 0.4	0.4 ± 0.9	0.0 ± 0.0	0.2 ± 0.4
Added fats	6 ± 12	55 ± 107	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	6.2 ± 12.0	0.6 ± 1.2	0.0 ± 0.0
Vegetable oil	5 ± 11	47 ± 99	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	5.3 ± 11.1	0.6 ± 1.2	0.0 ± 0.0
Butter, ghee, margarine	1 ± 4	9 ± 34	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	1.0 ± 3.9	0.0 ± 0.3	0.0 ± 0.0
Added sugars	27 ± 20	106 ± 79	25.8 ± 19.2	25.8 ± 19.2	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
Sugar	23 ± 18	96 ± 73	23.4 ± 17.8	23.4 ± 17.8	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
Honey, molasse	3 ± 10	10 ± 30	2.4 ± 7.4	2.4 ± 7.4	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
Sweetened snack foods (candy and chocolate)	4 ± 9	22 ± 48	2.5 ± 5.5	2.0 ± 4.5	0.0 ± 0.1	1.2 ± 2.6	0.5 ± 1.2	0.2 ± 0.6
Beverages (non-dairy)	1815 ± 936	109 ± 116	23.7 ± 25.9	21.9 ± 24.5	0.2 ± 0.4	0.3 ± 0.8	0.1 ± 0.2	0.8 ± 0.8
Water	1218 ± 745	0 ± 0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
Brewed tea, herbal infusions (w/wo sugar or milk)	291 ± 233	4 ± 7	0.4 ± 1.1	0.1 ± 0.6	0.1 ± 0.3	0.1 ± 0.3	0.0 ± 0.0	0.4 ± 0.4
Sodas	130 ± 192	55 ± 81	11.8 ± 17.6	11.8 ± 17.6	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.1
Brewed coffee (w/wo sugar or milk)	88 ± 113	5 ± 27	0.8 ± 4.6	0.5 ± 3.8	0.0 ± 0.0	0.1 ± 0.7	0.1 ± 0.2	0.1 ± 0.4
Juice, nectar - Vitamin C-rich	73 ± 123	36 ± 64	8.5 ± 15.2	7.3 ± 13.5	0.1 ± 0.1	0.1 ± 0.2	0.0 ± 0.0	0.3 ± 0.5
Juice, nectar - Other	14 ± 45	9 ± 29	2.2 ± 6.8	2.1 ± 6.5	0.0 ± 0.2	0.0 ± 0.1	0.0 ± 0.0	0.0 ± 0.1
Low calory drinks	1 ± 10	0 ± 0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
Miscellaneous	12 ± 39	20 ± 83	4.0 ± 18.9	2.1 ± 11.6	0.4 ± 1.2	0.3 ± 1.1	0.1 ± 0.5	0.3 ± 1.1
Condiments, herbs, spices	5 ± 23	11 ± 79	2.3 ± 18.0	1.1 ± 11.0	0.3 ± 1.2	0.1 ± 0.4	0.0 ± 0.0	0.2 ± 1.1
Sauces, salad dressing	5 ± 26	3 ± 12	0.4 ± 2.4	0.1 ± 0.3	0.0 ± 0.2	0.1 ± 0.8	0.0 ± 0.1	0.0 ± 0.2
Jam, spread	2 ± 7	4 ± 20	0.9 ± 4.0	0.9 ± 3.9	0.0 ± 0.1	0.1 ± 0.7	0.0 ± 0.5	0.0 ± 0.2
Diet sweetener	0 ± 3	1 ± 12	0.3 ± 3.3	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
Composites (mixed food groups)	134 ± 133	241 ± 262	31.7 ± 35.4	1.8 ± 2.1	1.9 ± 2.3	8.6 ± 9.2	2.5 ± 3.3	9.3 ± 10.6
Sandwiches	73 ± 101	182 ± 248	23.9 ± 33.1	1.2 ± 1.9	1.1 ± 1.7	6.5 ± 8.7	2.2 ± 3.3	6.9 ± 10.0
Main meal recipes	24 ± 48	28 ± 57	2.8 ± 6.2	0.2 ± 0.4	0.2 ± 0.5	1.4 ± 3.1	0.2 ± 0.5	1.1 ± 2.2
Vegetarian recipes	18 ± 47	19 ± 50	3.1 ± 8.4	0.2 ± 0.5	0.3 ± 0.7	0.5 ± 1.3	0.0 ± 0.1	0.6 ± 1.6
Soups	18 ± 46	13 ± 34	1.8 ± 5.0	0.1 ± 0.5	0.3 ± 1.0	0.3 ± 0.8	0.1 ± 0.2	0.7 ± 1.9
Savory snacks	26 ± 29	115 ± 138	11.8 ± 14.5	0.2 ± 0.6	0.6 ± 0.8	7.0 ± 8.6	0.4 ± 0.9	1.5 ± 1.8

‡ The "legumes" subgroup includes cooked beans, peas and lentils.

* The "sandwiches" subgroup includes grain products with fillings such as sandwiches, pizzas, burgers or savory pies. As sandwiches were the predominant food consumed from this subgroup, it is referred to as "sandwiches".

Supplemental Table 5: Contribution of foods to minerals intakes in 19-30-year-old urban Egyptian women (n=130).

Food groups and subgroups	Calcium (mg)	Copper (mg)	Iodine (µg)	Iron (mg)	Magnesium (mg)	Sodium (mg)	Phosphorus (mg)	Potassium (mg)	Zinc (mg)
Grains & grain products	38 ± 24	0.18 ± 0.11	10 ± 6	0.82 ± 0.67	36 ± 24	132 ± 98	90 ± 58	159 ± 109	0.62 ± 0.56
Refined grain products (rice, pasta, noodles, couscous)	37 ± 24	0.17 ± 0.10	10 ± 6	0.74 ± 0.57	35 ± 22	132 ± 98	85 ± 51	153 ± 103	0.58 ± 0.52
Enriched noodles	0 ± 3	0.00 ± 0.00	0 ± 0	0.06 ± 0.34	1 ± 5	0 ± 2	3 ± 20	3 ± 20	0.03 ± 0.16
Whole grain products (brown rice, corn, barley)	0 ± 3	0.00 ± 0.03	0 ± 1	0.02 ± 0.20	1 ± 8	0 ± 1	2 ± 25	3 ± 32	0.01 ± 0.17
Bakery products	44 ± 32	0.24 ± 0.23	2 ± 5	2.52 ± 1.90	24 ± 20	361 ± 224	141 ± 88	249 ± 159	1.65 ± 1.06
Bread	33 ± 25	0.13 ± 0.10	1 ± 3	1.97 ± 1.72	15 ± 10	319 ± 208	116 ± 79	194 ± 136	1.46 ± 1.02
Sweetened bakery products	11 ± 20	0.11 ± 0.21	2 ± 4	0.55 ± 0.84	9 ± 17	41 ± 71	25 ± 38	55 ± 81	0.18 ± 0.28
Whole grain bread	0 ± 1	0.00 ± 0.00	0 ± 0	0.00 ± 0.04	0 ± 0	1 ± 10	0 ± 2	0 ± 2	0.00 ± 0.00
Potatoes	16 ± 17	0.07 ± 0.08	2 ± 4	0.58 ± 0.67	17 ± 21	45 ± 72	68 ± 78	456 ± 525	0.26 ± 0.30
Legumes, nuts & seeds	51 ± 63	0.22 ± 0.19	5 ± 5	1.70 ± 1.57	51 ± 47	124 ± 111	109 ± 97	245 ± 230	1.00 ± 0.89
Legumes [□]	24 ± 27	0.13 ± 0.15	5 ± 5	1.01 ± 1.12	28 ± 32	93 ± 104	67 ± 78	196 ± 229	0.58 ± 0.67
Salted nuts and seeds	27 ± 61	0.07 ± 0.12	0 ± 2	0.58 ± 1.23	16 ± 29	31 ± 59	30 ± 53	36 ± 64	0.29 ± 0.54
Nuts, seeds, and unsalted products	0 ± 3	0.02 ± 0.09	0 ± 0	0.11 ± 0.44	7 ± 27	1 ± 2	11 ± 47	13 ± 50	0.12 ± 0.47
Dairy products	419 ± 307	0.04 ± 0.04	71 ± 47	0.35 ± 0.34	34 ± 21	660 ± 539	368 ± 249	321 ± 228	1.71 ± 1.05
Milk	146 ± 142	0.01 ± 0.01	29 ± 30	0.07 ± 0.07	14 ± 14	55 ± 54	115 ± 113	189 ± 187	0.59 ± 0.58
White cheese	108 ± 112	0.02 ± 0.04	29 ± 33	0.12 ± 0.21	8 ± 8	464 ± 482	130 ± 129	34 ± 34	0.54 ± 0.51
Yoghurt, plain or sweetened	51 ± 87	0.00 ± 0.00	10 ± 17	0.04 ± 0.07	5 ± 8	19 ± 32	40 ± 68	64 ± 109	0.23 ± 0.39
Sweetened dairy desserts	9 ± 25	0.00 ± 0.01	1 ± 4	0.03 ± 0.08	2 ± 4	4 ± 12	9 ± 23	15 ± 41	0.05 ± 0.15
Hard cheese	100 ± 228	0.00 ± 0.00	1 ± 3	0.08 ± 0.19	4 ± 10	116 ± 272	70 ± 163	10 ± 23	0.28 ± 0.63
Flavored milk	6 ± 28	0.00 ± 0.01	1 ± 4	0.01 ± 0.05	1 ± 4	2 ± 12	5 ± 24	8 ± 42	0.02 ± 0.12
Fortified milk	0 ± 2	0.00 ± 0.00	0 ± 0	0.00 ± 0.02	0 ± 0	0 ± 1	0 ± 0	1 ± 6	0.00 ± 0.01
Cream	0 ± 1	0.00 ± 0.00	0 ± 0	0.00 ± 0.00	0 ± 0	0 ± 1	0 ± 1	0 ± 1	0.00 ± 0.00
Meat, fish & eggs	53 ± 42	0.21 ± 0.28	80 ± 75	3.16 ± 2.06	40 ± 30	424 ± 311	319 ± 187	482 ± 304	2.99 ± 2.41
Poultry	8 ± 10	0.04 ± 0.05	29 ± 42	0.85 ± 0.97	17 ± 18	173 ± 201	125 ± 135	196 ± 208	0.71 ± 0.88
Fish without bones	20 ± 32	0.04 ± 0.07	17 ± 26	0.54 ± 0.76	8 ± 13	67 ± 108	65 ± 87	110 ± 144	0.18 ± 0.31
Red meat	5 ± 10	0.04 ± 0.14	22 ± 55	0.68 ± 1.35	9 ± 21	70 ± 135	52 ± 91	104 ± 184	1.27 ± 2.23
Eggs	16 ± 20	0.03 ± 0.04	9 ± 16	0.55 ± 0.81	3 ± 4	37 ± 72	51 ± 65	35 ± 50	0.34 ± 0.43
Processed meat	1 ± 1	0.01 ± 0.03	0 ± 0	0.18 ± 0.43	1 ± 4	55 ± 137	9 ± 24	16 ± 40	0.23 ± 0.56
Organ meat	1 ± 2	0.05 ± 0.21	1 ± 3	0.34 ± 0.97	2 ± 7	17 ± 51	14 ± 38	17 ± 49	0.25 ± 0.72
Seafood	0 ± 4	0.00 ± 0.01	1 ± 9	0.01 ± 0.07	0 ± 0	1 ± 11	1 ± 9	1 ± 11	0.00 ± 0.00
Small, whole fish, with bones	2 ± 16	0.00 ± 0.00	1 ± 5	0.02 ± 0.13	0 ± 2	4 ± 29	3 ± 21	2 ± 19	0.01 ± 0.11
Fruits	33 ± 40	0.09 ± 0.09	1 ± 1	0.70 ± 0.76	27 ± 30	3 ± 3	31 ± 32	364 ± 395	0.05 ± 0.11
Other fruits	6 ± 8	0.06 ± 0.07	0 ± 0	0.42 ± 0.55	18 ± 24	1 ± 1	17 ± 21	227 ± 291	0.03 ± 0.07
Vitamin C-rich fruits (citruses, pineapple, strawberries)	27 ± 38	0.03 ± 0.04	1 ± 1	0.28 ± 0.36	8 ± 10	2 ± 2	14 ± 17	136 ± 178	0.02 ± 0.06

Supplemental Table 5. *continued*

Food groups and subgroups	Calcium (mg)	Copper (mg)	Iodine (µg)	Iron (mg)	Magnesium (mg)	Sodium (mg)	Phosphorus (mg)	Potassium (mg)	Zinc (mg)
Vegetables	50 ± 43	0.07 ± 0.09	6 ± 7	0.78 ± 0.71	21 ± 22	125 ± 152	56 ± 56	447 ± 474	0.36 ± 0.37
Vitamin C-rich vegetables (cabbage, peas, spinach...)	17 ± 25	0.04 ± 0.06	4 ± 6	0.31 ± 0.42	11 ± 15	65 ± 101	28 ± 40	194 ± 264	0.18 ± 0.27
Other vegetables (eggplants, green beans...)	23 ± 28	0.03 ± 0.05	2 ± 3	0.32 ± 0.41	9 ± 13	40 ± 112	24 ± 28	229 ± 300	0.16 ± 0.21
Vitamin A source vegetables (carrots, dark leafy vegetables...)	9 ± 18	0.00 ± 0.01	1 ± 3	0.15 ± 0.29	2 ± 3	20 ± 45	4 ± 8	24 ± 43	0.03 ± 0.05
Added fats	0 ± 0	0.00 ± 0.00	0 ± 0	0.01 ± 0.01	0 ± 0	0 ± 1	0 ± 0	0 ± 0	0.00 ± 0.00
Vegetable oil	0 ± 0	0.00 ± 0.00	0 ± 0	0.01 ± 0.01	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0.00 ± 0.00
Butter, ghee, margarine	0 ± 0	0.00 ± 0.00	0 ± 0	0.00 ± 0.00	0 ± 0	0 ± 1	0 ± 0	0 ± 0	0.00 ± 0.00
Added sugars	1 ± 2	0.04 ± 0.14	0 ± 0	0.20 ± 0.44	5 ± 18	2 ± 7	0 ± 0	29 ± 107	0.02 ± 0.05
Sugar	0 ± 0	0.00 ± 0.00	0 ± 0	0.07 ± 0.05	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0.00 ± 0.00
Honey, molasse	1 ± 2	0.04 ± 0.14	0 ± 0	0.13 ± 0.44	5 ± 18	2 ± 7	0 ± 0	29 ± 107	0.02 ± 0.05
Sweetened snack foods (candy and chocolate)	7 ± 16	0.02 ± 0.04	0 ± 0	0.08 ± 0.20	2 ± 4	2 ± 7	12 ± 28	13 ± 29	0.08 ± 0.18
Beverages (non-dairy)	191 ± 103	0.16 ± 0.22	3 ± 3	0.66 ± 1.09	150 ± 85	130 ± 72	40 ± 36	194 ± 179	0.58 ± 0.37
Water	144 ± 88	0.02 ± 0.16	0 ± 0	0.01 ± 0.05	127 ± 77	103 ± 62	0 ± 0	0 ± 0	0.07 ± 0.04
Brewed tea, herbal infusions (w/wo sugar or milk)	28 ± 28	0.11 ± 0.13	3 ± 2	0.37 ± 1.00	11 ± 13	5 ± 8	5 ± 8	51 ± 43	0.42 ± 0.33
Sodas	4 ± 6	0.00 ± 0.00	0 ± 0	0.01 ± 0.07	0 ± 0	13 ± 20	19 ± 29	9 ± 13	0.01 ± 0.07
Brewed coffee (w/wo sugar or milk)	6 ± 10	0.00 ± 0.01	0 ± 1	0.03 ± 0.04	6 ± 9	4 ± 6	6 ± 8	37 ± 59	0.03 ± 0.06
Juice, nectar - Vitamin C-rich	7 ± 12	0.03 ± 0.05	0 ± 1	0.17 ± 0.30	5 ± 9	4 ± 14	8 ± 14	86 ± 145	0.03 ± 0.06
Juice, nectar - Other	2 ± 6	0.00 ± 0.01	0 ± 0	0.07 ± 0.37	1 ± 4	0 ± 1	2 ± 8	13 ± 52	0.01 ± 0.05
Low calory drinks	0 ± 0	0.00 ± 0.00	0 ± 0	0.00 ± 0.00	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0.00 ± 0.00
Miscellaneous	15 ± 80	0.03 ± 0.13	16 ± 38	0.16 ± 0.51	5 ± 18	264 ± 605	7 ± 24	43 ± 194	0.04 ± 0.10
Condiments, herbs, spices	13 ± 79	0.02 ± 0.13	16 ± 38	0.13 ± 0.40	4 ± 15	245 ± 583	5 ± 20	33 ± 187	0.03 ± 0.09
Sauces, salad dressing	1 ± 5	0.00 ± 0.01	0 ± 1	0.02 ± 0.12	1 ± 5	19 ± 75	2 ± 9	9 ± 39	0.01 ± 0.02
Jam, spread	1 ± 4	0.00 ± 0.01	0 ± 0	0.01 ± 0.04	0 ± 3	0 ± 0	1 ± 4	2 ± 8	0.00 ± 0.03
Diet sweetener	0 ± 0	0.00 ± 0.00	0 ± 0	0.00 ± 0.00	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0.00 ± 0.00
Composites (mixed food groups)	73 ± 92	0.16 ± 0.19	13 ± 18	1.74 ± 2.38	34 ± 38	337 ± 382	134 ± 158	268 ± 287	1.38 ± 1.60
Sandwiches	60 ± 90	0.11 ± 0.18	8 ± 16	1.27 ± 2.24	21 ± 32	260 ± 359	100 ± 148	164 ± 238	1.06 ± 1.52
Main meal recipes	6 ± 13	0.01 ± 0.03	3 ± 8	0.16 ± 0.33	4 ± 9	26 ± 59	14 ± 28	47 ± 97	0.12 ± 0.27
Vegetarian recipes	3 ± 7	0.01 ± 0.03	2 ± 5	0.12 ± 0.34	4 ± 12	27 ± 76	10 ± 27	26 ± 64	0.09 ± 0.26
Soups	4 ± 13	0.02 ± 0.05	1 ± 3	0.19 ± 0.57	4 ± 11	23 ± 77	10 ± 28	30 ± 93	0.11 ± 0.32
Savory snacks	12 ± 17	0.05 ± 0.06	0 ± 0	0.35 ± 0.42	12 ± 14	178 ± 218	31 ± 36	176 ± 234	0.23 ± 0.28

‡ The "legumes" subgroup includes cooked beans, peas and lentils.

* The "sandwiches" subgroup includes grain products with fillings such as sandwiches, pizzas, burgers or savory pies. As sandwiches were the predominant food consumed from this subgroup, it is referred to as "sandwiches".

Supplemental Table 6: Contribution of foods to vitamins intakes in 19-30-year-old urban Egyptian women (n=130).

Food groups and subgroups	Vitamin A (ug RE)	Vitamin D (ug)	Vitamin E (mg)	Folates (ug)	Niacin Eq (mg)	Pantothenic acid (mg)	Riboflavin (mg)	Thiamin (mg)	Vitamin B12 (ug)	Vitamin B6 (mg)	Vitamin C (mg)
Grains & grain products	26 ± 26	0.06 ± 0.06	0.30 ± 0.43	19.35 ± 22.19	1.1 ± 1.2	0.30 ± 0.17	0.05 ± 0.05	0.14 ± 0.11	0.05 ± 0.16	0.09 ± 0.06	3 ± 3
Refined grain products (rice, pasta, noodles, couscous)	26 ± 26	0.06 ± 0.06	0.30 ± 0.43	15.73 ± 12.22	0.9 ± 0.9	0.29 ± 0.16	0.04 ± 0.03	0.12 ± 0.06	0.05 ± 0.16	0.08 ± 0.04	3 ± 3
Enriched noodles	0 ± 0	0.00 ± 0.00	0.01 ± 0.03	3.21 ± 19.30	0.1 ± 0.7	0.00 ± 0.01	0.01 ± 0.04	0.02 ± 0.10	0.00 ± 0.00	0.00 ± 0.02	0 ± 0
Whole grain products (brown rice, corn, barley)	0 ± 0	0.00 ± 0.00	0.00 ± 0.02	0.41 ± 4.70	0.1 ± 0.5	0.00 ± 0.05	0.00 ± 0.01	0.00 ± 0.03	0.00 ± 0.00	0.00 ± 0.04	0 ± 0
Bakery products	1 ± 5	0.04 ± 0.10	0.51 ± 0.58	3.60 ± 5.35	0.3 ± 0.5	0.34 ± 0.22	0.12 ± 0.08	0.22 ± 0.18	0.03 ± 0.06	0.09 ± 0.06	0 ± 1
Bread	0 ± 0	0.01 ± 0.04	0.22 ± 0.24	1.09 ± 3.52	0.1 ± 0.2	0.29 ± 0.19	0.09 ± 0.06	0.20 ± 0.17	0.01 ± 0.03	0.07 ± 0.05	0 ± 0
Sweetened bakery products	1 ± 5	0.03 ± 0.09	0.29 ± 0.49	2.47 ± 4.21	0.3 ± 0.4	0.06 ± 0.10	0.03 ± 0.05	0.02 ± 0.04	0.03 ± 0.05	0.02 ± 0.02	0 ± 1
Whole grain bread	0 ± 0	0.00 ± 0.00	0.00 ± 0.01	0.05 ± 0.51	0.0 ± 0.0	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0 ± 0
Potatoes	9 ± 23	0.00 ± 0.02	0.37 ± 0.44	23.17 ± 26.67	1.7 ± 2.0	0.28 ± 0.32	0.04 ± 0.04	0.08 ± 0.10	0.00 ± 0.01	0.26 ± 0.30	17 ± 22
Legumes, nuts & seeds	2 ± 5	0.00 ± 0.00	1.83 ± 2.20	51.80 ± 51.37	1.5 ± 1.4	0.21 ± 0.22	0.05 ± 0.04	0.13 ± 0.13	0.00 ± 0.00	0.10 ± 0.09	5 ± 6
Legumes	2 ± 5	0.00 ± 0.00	1.30 ± 1.54	46.59 ± 52.19	1.0 ± 1.1	0.20 ± 0.22	0.04 ± 0.04	0.09 ± 0.11	0.00 ± 0.00	0.07 ± 0.08	5 ± 6
Salted nuts and seeds	0 ± 0	0.00 ± 0.00	0.32 ± 0.74	4.29 ± 7.74	0.3 ± 0.7	0.00 ± 0.01	0.01 ± 0.01	0.02 ± 0.04	0.00 ± 0.00	0.03 ± 0.06	0 ± 0
Nuts, seeds, and unsalted products	0 ± 0	0.00 ± 0.00	0.21 ± 1.50	0.92 ± 4.05	0.2 ± 0.9	0.01 ± 0.04	0.00 ± 0.01	0.02 ± 0.08	0.00 ± 0.00	0.00 ± 0.01	0 ± 0
Dairy products	90 ± 74	0.37 ± 0.25	0.60 ± 0.43	27.49 ± 17.85	2.7 ± 2.1	0.43 ± 0.44	0.52 ± 0.33	0.09 ± 0.06	1.10 ± 0.74	0.09 ± 0.07	2 ± 2
Milk	39 ± 38	0.12 ± 0.13	0.11 ± 0.11	13.08 ± 13.35	1.0 ± 1.1	0.38 ± 0.43	0.22 ± 0.22	0.05 ± 0.05	0.57 ± 0.56	0.06 ± 0.06	1 ± 2
White cheese	17 ± 38	0.18 ± 0.19	0.35 ± 0.35	7.55 ± 9.42	1.5 ± 1.7	0.02 ± 0.08	0.19 ± 0.19	0.01 ± 0.01	0.22 ± 0.22	0.00 ± 0.01	0 ± 0
Yoghurt, plain or sweetened	10 ± 19	0.03 ± 0.05	0.04 ± 0.06	3.85 ± 6.51	0.1 ± 0.2	0.00 ± 0.03	0.06 ± 0.10	0.01 ± 0.02	0.13 ± 0.23	0.01 ± 0.02	0 ± 1
Sweetened dairy desserts	2 ± 5	0.00 ± 0.01	0.01 ± 0.03	0.97 ± 2.73	0.1 ± 0.2	0.02 ± 0.07	0.01 ± 0.03	0.01 ± 0.01	0.03 ± 0.08	0.00 ± 0.01	0 ± 0
Hard cheese	21 ± 46	0.02 ± 0.05	0.09 ± 0.19	1.79 ± 3.92	0.0 ± 0.0	0.00 ± 0.00	0.04 ± 0.08	0.00 ± 0.01	0.13 ± 0.29	0.01 ± 0.02	0 ± 0
Flavored milk	1 ± 5	0.00 ± 0.03	0.00 ± 0.02	0.21 ± 1.18	0.0 ± 0.2	0.00 ± 0.03	0.01 ± 0.04	0.00 ± 0.01	0.02 ± 0.09	0.00 ± 0.01	0 ± 0
Fortified milk	0 ± 0	0.00 ± 0.01	0.00 ± 0.00	0.04 ± 0.40	0.0 ± 0.0	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0 ± 0
Cream	0 ± 0	0.00 ± 0.00	0.00 ± 0.01	0.00 ± 0.02	0.0 ± 0.0	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0 ± 0
Meat, fish & eggs	450 ± 1096	2.65 ± 3.49	3.04 ± 2.15	38.96 ± 35.22	8.7 ± 8.5	1.49 ± 1.08	0.40 ± 0.34	0.15 ± 0.11	4.40 ± 5.48	0.35 ± 0.30	6 ± 12
Poultry	10 ± 18	0.22 ± 0.28	0.51 ± 0.87	7.33 ± 9.18	4.1 ± 7.1	0.53 ± 0.71	0.08 ± 0.10	0.06 ± 0.07	0.21 ± 0.26	0.15 ± 0.26	1 ± 6
Fish without bones	3 ± 7	1.84 ± 3.39	1.20 ± 1.60	2.50 ± 3.80	1.6 ± 2.4	0.21 ± 0.32	0.04 ± 0.06	0.03 ± 0.04	0.76 ± 1.76	0.05 ± 0.08	0 ± 1
Red meat	1 ± 4	0.03 ± 0.05	0.39 ± 1.00	2.36 ± 4.81	1.7 ± 3.0	0.09 ± 0.15	0.06 ± 0.12	0.03 ± 0.06	0.99 ± 1.74	0.05 ± 0.09	1 ± 3
Eggs	51 ± 66	0.50 ± 0.65	0.74 ± 1.02	16.09 ± 20.70	0.5 ± 0.9	0.38 ± 0.49	0.10 ± 0.13	0.02 ± 0.02	0.36 ± 0.46	0.04 ± 0.05	0 ± 1
Processed meat	0 ± 0	0.03 ± 0.10	0.03 ± 0.07	0.54 ± 2.41	0.3 ± 0.7	0.04 ± 0.09	0.02 ± 0.04	0.01 ± 0.02	0.27 ± 0.69	0.01 ± 0.04	0 ± 0
Organ meat	386 ± 1099	0.00 ± 0.02	0.10 ± 0.51	9.99 ± 28.59	0.5 ± 1.3	0.24 ± 0.68	0.10 ± 0.28	0.01 ± 0.03	1.73 ± 4.95	0.04 ± 0.11	3 ± 10
Seafood	0 ± 0	0.01 ± 0.08	0.03 ± 0.24	0.04 ± 0.29	0.1 ± 0.5	0.00 ± 0.02	0.00 ± 0.00	0.00 ± 0.00	0.02 ± 0.19	0.00 ± 0.01	0 ± 0
Small, whole fish, with bones	0 ± 0	0.02 ± 0.17	0.04 ± 0.41	0.11 ± 0.88	0.0 ± 0.3	0.00 ± 0.03	0.00 ± 0.01	0.00 ± 0.00	0.05 ± 0.43	0.00 ± 0.01	0 ± 0
Fruits	9 ± 12	0.00 ± 0.00	0.19 ± 0.35	24.83 ± 27.25	0.2 ± 0.4	0.04 ± 0.11	0.07 ± 0.07	0.10 ± 0.11	0.00 ± 0.00	0.06 ± 0.14	43 ± 51
Other fruits	1 ± 2	0.00 ± 0.00	0.14 ± 0.31	5.58 ± 7.73	0.1 ± 0.2	0.02 ± 0.09	0.04 ± 0.05	0.03 ± 0.04	0.00 ± 0.00	0.05 ± 0.11	8 ± 10
Vitamin C-rich fruits (citruses, pineapple, strawberries)	8 ± 12	0.00 ± 0.00	0.05 ± 0.15	19.26 ± 22.92	0.1 ± 0.2	0.02 ± 0.05	0.03 ± 0.04	0.06 ± 0.09	0.00 ± 0.00	0.01 ± 0.03	36 ± 47

Supplemental Table 6. *continued*

Food groups and subgroups	Vitamin A (ug RE)	Vitamin D (ug)	Vitamin E (mg)	Folates (ug)	Niacin Eq (mg)	Pantothenic acid (mg)	Riboflavin (mg)	Thiamin (mg)	Vitamin B12 (ug)	Vitamin B6 (mg)	Vitamin C (mg)
Vegetables	127 ± 166	0.04 ± 0.13	1.38 ± 2.99	54.02 ± 60.40	1.1 ± 1.3	0.40 ± 0.43	0.08 ± 0.08	0.09 ± 0.09	0.00 ± 0.02	0.15 ± 0.16	39 ± 54
Vitamin C-rich vegetables (cabbage, peas, spinach...)	43 ± 69	0.01 ± 0.04	0.51 ± 0.84	26.59 ± 38.57	0.6 ± 1.0	0.20 ± 0.30	0.03 ± 0.05	0.04 ± 0.06	0.00 ± 0.02	0.08 ± 0.12	26 ± 50
Other vegetables (eggplants, green beans...)	18 ± 27	0.02 ± 0.12	0.83 ± 2.82	22.32 ± 37.50	0.4 ± 0.6	0.18 ± 0.21	0.03 ± 0.05	0.03 ± 0.05	0.00 ± 0.00	0.06 ± 0.08	10 ± 12
Vitamin A source vegetables (carrots, dark leafy vegetables...)	67 ± 127	0.00 ± 0.03	0.03 ± 0.06	5.11 ± 8.73	0.0 ± 0.2	0.01 ± 0.04	0.01 ± 0.02	0.02 ± 0.03	0.00 ± 0.00	0.02 ± 0.04	3 ± 5
Added fats	1 ± 4	0.00 ± 0.02	2.06 ± 4.32	0.00 ± 0.01	0.0 ± 0.0	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0 ± 0
Vegetable oil	0 ± 0	0.00 ± 0.00	2.03 ± 4.31	0.00 ± 0.00	0.0 ± 0.0	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0 ± 0
Butter, ghee, margarine	1 ± 4	0.00 ± 0.02	0.03 ± 0.13	0.00 ± 0.01	0.0 ± 0.0	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0 ± 0
Added sugars	0 ± 0	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.0 ± 0.0	0.00 ± 0.01	0.00 ± 0.01	0.00 ± 0.01	0.00 ± 0.00	0.00 ± 0.01	0 ± 0
Sugar	0 ± 0	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.0 ± 0.0	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0 ± 0
Honey, molasse	0 ± 0	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.0 ± 0.0	0.00 ± 0.01	0.00 ± 0.01	0.00 ± 0.01	0.00 ± 0.00	0.00 ± 0.01	0 ± 0
Sweetened snack foods (candy and chocolate)	0 ± 0	0.01 ± 0.02	0.03 ± 0.09	0.26 ± 0.63	0.2 ± 0.4	0.00 ± 0.00	0.01 ± 0.02	0.01 ± 0.02	0.02 ± 0.04	0.01 ± 0.01	0 ± 0
Beverages (non-dairy)	10 ± 28	0.00 ± 0.00	0.09 ± 0.23	32.07 ± 43.14	1.1 ± 0.8	0.15 ± 0.21	0.07 ± 0.06	0.07 ± 0.13	0.01 ± 0.02	0.02 ± 0.04	24 ± 39
Water	0 ± 0	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.0 ± 0.0	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0 ± 0
Brewed tea, herbal infusions (w/wo sugar or milk)	0 ± 1	0.00 ± 0.00	0.00 ± 0.02	12.90 ± 10.45	0.6 ± 0.5	0.00 ± 0.01	0.03 ± 0.03	0.03 ± 0.12	0.00 ± 0.01	0.01 ± 0.01	0 ± 2
Sodas	0 ± 0	0.00 ± 0.00	0.00 ± 0.00	0.01 ± 0.07	0.0 ± 0.0	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0 ± 0
Brewed coffee (w/wo sugar or milk)	0 ± 0	0.00 ± 0.00	0.00 ± 0.01	0.51 ± 1.17	0.3 ± 0.4	0.05 ± 0.13	0.02 ± 0.04	0.00 ± 0.01	0.00 ± 0.00	0.00 ± 0.00	0 ± 0
Juice, nectar - Vitamin C-rich	10 ± 28	0.00 ± 0.00	0.06 ± 0.22	14.00 ± 25.23	0.2 ± 0.5	0.09 ± 0.18	0.02 ± 0.04	0.03 ± 0.07	0.00 ± 0.02	0.01 ± 0.04	23 ± 39
Juice, nectar - Other	0 ± 0	0.00 ± 0.00	0.02 ± 0.08	4.66 ± 28.46	0.0 ± 0.0	0.00 ± 0.01	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.01	0 ± 1
Low calory drinks	0 ± 0	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.0 ± 0.0	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0 ± 0
Miscellaneous	1 ± 9	0.00 ± 0.02	0.10 ± 0.40	1.90 ± 7.47	0.1 ± 0.2	0.01 ± 0.03	0.00 ± 0.01	0.00 ± 0.01	0.00 ± 0.01	0.01 ± 0.03	1 ± 3
Condiments, herbs, spices	0 ± 2	0.00 ± 0.02	0.02 ± 0.06	1.60 ± 7.25	0.0 ± 0.1	0.00 ± 0.01	0.00 ± 0.01	0.00 ± 0.01	0.00 ± 0.01	0.01 ± 0.03	1 ± 3
Sauces, salad dressing	0 ± 1	0.00 ± 0.00	0.05 ± 0.25	0.12 ± 0.49	0.0 ± 0.1	0.01 ± 0.02	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.01	0.00 ± 0.02	0 ± 0
Jam, spread	1 ± 9	0.00 ± 0.00	0.03 ± 0.31	0.18 ± 1.62	0.0 ± 0.0	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0 ± 1
Diet sweetener	0 ± 0	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.0 ± 0.0	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0 ± 0
Composites (mixed food groups)	122 ± 699	0.09 ± 0.18	1.31 ± 1.71	24.75 ± 30.16	1.9 ± 2.3	4.65 ± 18.21	0.12 ± 0.20	0.13 ± 0.16	0.41 ± 1.27	0.14 ± 0.15	8 ± 10
Sandwiches *	92 ± 696	0.06 ± 0.14	0.77 ± 1.40	14.53 ± 25.79	1.1 ± 1.8	0.23 ± 0.37	0.09 ± 0.20	0.08 ± 0.13	0.32 ± 1.22	0.08 ± 0.13	3 ± 6
Main meal recipes	13 ± 71	0.03 ± 0.12	0.40 ± 1.04	4.12 ± 9.61	0.4 ± 1.0	4.36 ± 18.23	0.01 ± 0.03	0.02 ± 0.04	0.08 ± 0.35	0.03 ± 0.06	3 ± 8
Vegetarian recipes	3 ± 7	0.00 ± 0.00	0.07 ± 0.21	3.23 ± 7.81	0.2 ± 0.4	0.03 ± 0.08	0.01 ± 0.02	0.02 ± 0.04	0.00 ± 0.00	0.01 ± 0.04	1 ± 2
Soups	14 ± 45	0.00 ± 0.00	0.06 ± 0.24	2.87 ± 9.06	0.2 ± 0.6	0.03 ± 0.10	0.01 ± 0.02	0.02 ± 0.05	0.01 ± 0.04	0.01 ± 0.04	1 ± 2
Savory snacks	1 ± 7	0.00 ± 0.02	0.08 ± 0.16	5.93 ± 7.15	0.7 ± 0.9	0.16 ± 0.21	0.01 ± 0.02	0.04 ± 0.05	0.00 ± 0.01	0.08 ± 0.11	5 ± 7

‡ The "legumes" subgroup includes cooked beans, peas and lentils. * The "sandwiches" subgroup includes grain products with fillings such as sandwiches, pizzas, burgers or savory pies. As sandwiches were the predominant food consumed from this subgroup, it is referred to as "sandwiches".

3.2. Elaboration de stratégies d'amélioration nutritionnelle par modélisation

3.2.1. Démarche générale

Devant les déséquilibres nutritionnels observés chez les femmes égyptiennes âgées de 19-30 ans, la deuxième étape de ces travaux de thèse a été de modéliser des stratégies d'amélioration nutritionnelle. Compte tenu des fortes contraintes économiques impactant le budget alimentaire des foyers égyptiens (Kenawy and Fathy Abd-El Ghany, 2011), une étude de prix des aliments a été réalisée au Caire afin d'identifier les groupes alimentaires les plus chers et de ne modéliser que des stratégies d'amélioration nutritionnelle qui soient abordables économiquement. Une fois les informations de prix des aliments collectées, des modifications de régimes ont été testées par modélisation en utilisant le logiciel Optifood (développé par la London School of Hygiene and Tropical Medicine en partenariat avec l'OMS et le projet « Food and Nutrition Technical Assistant III »). Des jeux de conseils alimentaires permettant d'améliorer l'adéquation nutritionnelle à partir d'aliments consommés localement ont d'abord été modélisés, puis l'introduction d'aliments (théoriques ou prototypes) enrichis *a minima* en fer a été testée.

3.2.2. Etude du prix des aliments au Caire

Méthodologie.

Le protocole de l'étude a été mis au point en collaboration avec une agence locale qui propose des services de recherche terrain (entreprise « PHI Market Research ») et avec les équipes de Danone Égypte. L'enquête a eu lieu entre février et mars 2018, soit un an après l'enquête alimentaire.

La liste des aliments à couvrir par cette enquête de prix a été établie à partir des carnets alimentaires des jeunes femmes de 19-30 ans (Brouzes et al., 2020). Le prix des ingrédients composant les recettes consommées a aussi été collecté afin de calculer le prix des recettes fait-maison. Les marques et formats à sélectionner ont été définis en demandant à 50 femmes de classe socio-économique moyenne⁷ résidant au Caire de consigner pendant une semaine tous les produits alimentaires achetés dans un carnet, en février 2018. Quatre quartiers du Caire typiques des régions d'habitation des classes socio-économiques moyennes ont été sélectionnés pour l'enquête (quartiers d'Ain Shams, Imbabah, Shubra et Maryouteya, Figure 10). Dans chaque quartier, des supermarchés ainsi que des points de vente traditionnels (petites boutiques et marchés en plein air) ont été visités. Les points de vente traditionnels étaient localisés sur des routes très passantes ou dans des quartiers résidentiels, où les prix sont souvent plus bas. Les enquêteurs notaient pour chaque aliment

⁷ En 2018, la classe moyenne représentait 39% de la population d'Égypte. Leurs revenus étaient principalement issus de salaires mensuels (plutôt que des revenus ponctuels). Les classes moyennes s'approvisionnent préférentiellement dans de petites boutiques plutôt que dans de grands hypermarchés. PHI KNOWLEDGE 2018. Socio-economic classes in Egypt - Renovated. Cairo, Egypt: PHI Market Research.

la marque, la forme (par exemple cru, cuit, séché), le poids net et le prix de l'aliment. Des photos de l'étalage ont été prises quand cela était possible. Un aperçu de la base de données collectée est disponible Figure 11. Ces informations ont ensuite permis d'estimer le prix des aliments par 100 grammes d'aliment comestible, c'est-à-dire une fois le poids des déchets alimentaires (épluchures et noyaux des produits végétaux, ossements, arêtes ou coquilles des produits animaux) et les modifications liées à la préparation de l'aliment estimées (pertes ou gain d'eau liés à la cuisson par exemple). Pour cela, les conversions fournies dans l'atlas alimentaire des Émirats Arabes Unis et le manuel photos pour l'estimation des quantités SU.VI.MAX ont été utilisés (Al Marzooqi et al., 2015, Herberg et al., 1994). Le prix des recettes a été estimé à partir du prix et des quantités de chaque ingrédient composant les recettes. Le prix par portion a été estimé à partir des portions médianes déclarées par les femmes de 19 à 30 ans dans l'enquête alimentaire, pour chaque aliment.

Le coût journalier des régimes alimentaires a été estimé en croisant les informations de prix des aliments avec les données de consommation issues de l'enquête alimentaire pour les femmes de 19 à 30 ans. Lorsqu'un prix n'était pas renseigné pour un aliment consommé, le prix moyen du sous-groupe alimentaire auquel appartenait l'aliment a été utilisé. Ce cas de figure n'a concerné qu'un petit nombre d'aliments, qui étaient très peu consommés dans l'enquête alimentaire et qui n'ont pas été inclus dans l'enquête de prix des aliments compte tenu de leur faible consommation (nous souhaitons modéliser des régimes alimentaires excluant les aliments faiblement consommés, c'est-à-dire consommés par moins de 5% de la population), et pour des raisons liées au temps et à l'amplitude des recherches qu'aurait nécessité une collecte de prix exhaustive.



Figure 10. Quartiers du Caire sélectionnés pour réaliser l'enquête de prix des aliments.

Résultats.

Les résultats montrent que des variations de prix peuvent être observées entre les différents points de vente et au sein d'un même quartier. Les supermarchés sont les lieux d'approvisionnement les plus chers comparés aux points de vente traditionnels, qui proposent des aliments à des prix en moyenne $6,8 \pm 14,8\%$ moins chers qu'en supermarché ; néanmoins la déviation standard importante témoigne de la grande variabilité des prix au sein d'un même quartier ou type de point de vente. Parmi les quartiers visités, Imbabah est le quartier avec les points de vente traditionnels proposant les prix les plus bas en moyenne ($-11,3 \pm 9,7\%$ par rapport aux prix des supermarchés) et Maryouteya celui avec les prix les plus proches de ceux collectés en supermarchés ($0,8 \pm 21,3\%$ moins cher en moyenne, Figure 12).

Le groupe des produits « Viande, poisson et œufs » (« Meat, fish & eggs ») a le plus haut prix moyen par portion ($10,1 \pm 7,9$ EGP), suivi par les aliments composites (« Composite, mixed food groups », $5,2 \pm 5,4$ EGP) qui incluent des sandwiches, pizzas, et plats composites. Le groupe divers (« Miscellaneous ») était le groupe avec la plus grande variabilité des prix par portion, ce qui s'explique par la présence d'épices et de condiments ayant des prix très variables (poivre, autour de 32 EGP/100g *versus* vinaigre, 0,6 EGP/100g, données non présentées). Les groupes alimentaires les moins chers par portion étaient les sucres ajoutés ($0,9 \pm 1,1$ EGP), les produits à base de pommes de terre ($1,0 \pm 0,3$ EGP), les matières grasses ($1,4 \pm 0,8$ EGP), les légumes ($1,4 \pm 1,5$ EGP) et les snacks salés ($2,2 \pm 1,6$ EGP) (Figure 13). A l'échelle des sous-groupes alimentaires, la viande rouge, les poissons et le fromage à pâte dure étaient les sous-groupes les plus chers par portion (Figure 14).

Le coût moyen des régimes journaliers était de 42 livres égyptiennes par jour, avec une forte variabilité entre les participantes, comme représenté Figure 15.











Sample n°	Food to sample	Description	Brand	Food form	Pack	Portion	Weight	Unit	Price in modern trade (EGP)	Price in traditional trade (EGP)				Picture
										Shubra	Ain Shams	Maryoutya	Imbahah	
1	Olive oil	Liquid olive oil virgin	Borges	Liquid oil	Glass bottle	1	250	mL	49,95	52,00	51,50	52,50	50,00	
2	Olive oil	Liquid olive oil virgin	Eliada	Liquid oil	Plastic bottle	1	500	mL	70,95	72,00	68,25	75,00	70,00	
3	Olive oil	Liquid olive oil virgin	Afia	Liquid oil	Plastic bottle	1	500	mL	75,95	76,00	78,00	77,50	74,00	
4	Olive oil	Liquid olive oil virgin	Olivia	Liquid oil	Glass bottle	1	250	mL	36,75	38,00	37,25	37,00	36,75	
5	Olive oil	Liquid olive oil virgin	Wadi food	Liquid oil	Plastic bottle	1	250	mL	52,00	54,00	52,50	53,00	52,00	
6	Olive oil	Liquid olive oil virgin	Khoshala	Liquid oil	Glass bottle	1	250	mL	33,95	35,00	36,25	36,00	34,00	
1	Biscuit	Tea biscuit	Shorty	Ready to eat	plastic wrap	24	80	g	3,50	4,00	3,00	3,75	3,50	
2	Biscuit	Tea biscuit	Bisco Misr	Ready to eat	plastic wrap	12	40	g	2,00	2,00	2,50	2,50	2,00	
3	Biscuit	Vanilla biscuit	Oreo	Ready to eat	plastic wrap	3	28,5	g	2,00	2,00	2,25	2,50	2,00	
4	Biscuit	Cacao biscuit	Biskrem	Ready to eat	plastic wrap	2	36	g	2,00	2,50	3,00	3,00	2,00	

Figure 11. Aperçu de la base de données des prix des aliments au Caire.

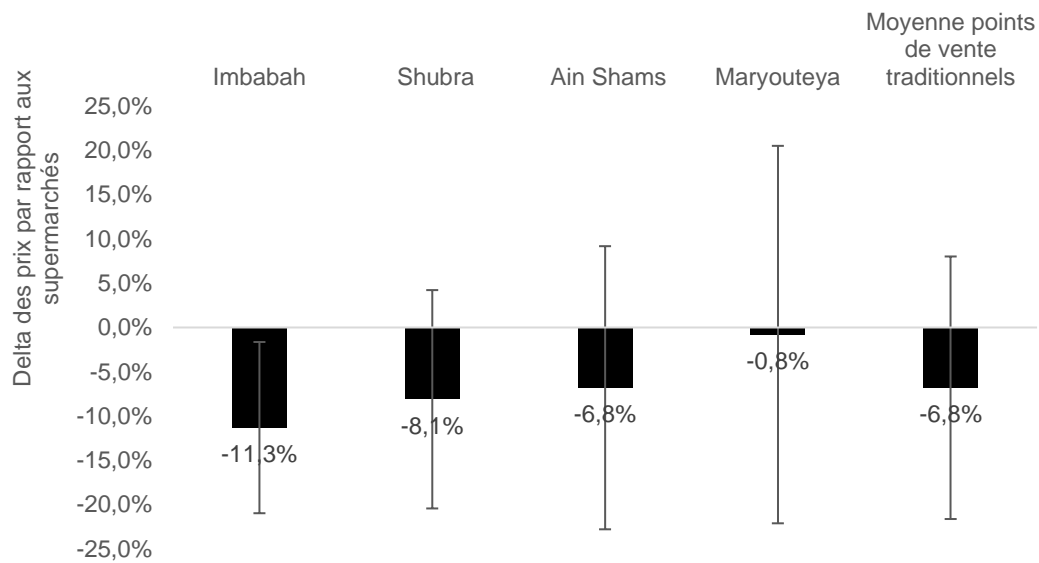


Figure 12. Différence de prix des aliments entre les supermarchés et les points de vente traditionnels, en moyenne et par quartier.

Les barres d'erreurs correspondent à plus ou moins la déviation standard.

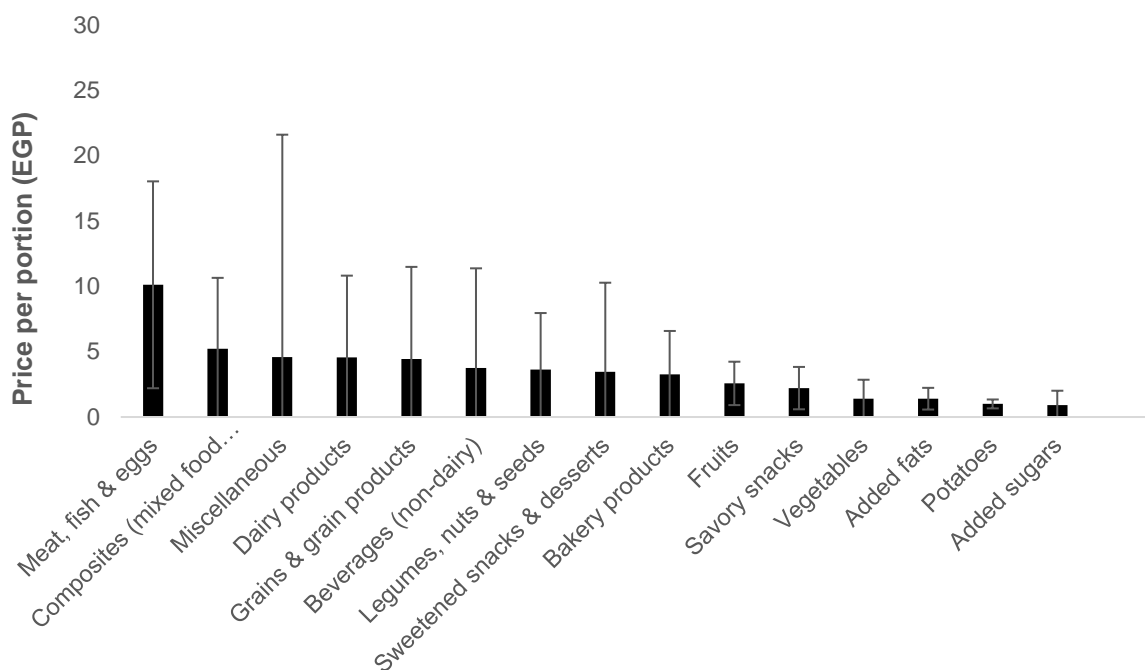


Figure 13. Prix moyen par portion des groupes alimentaires.

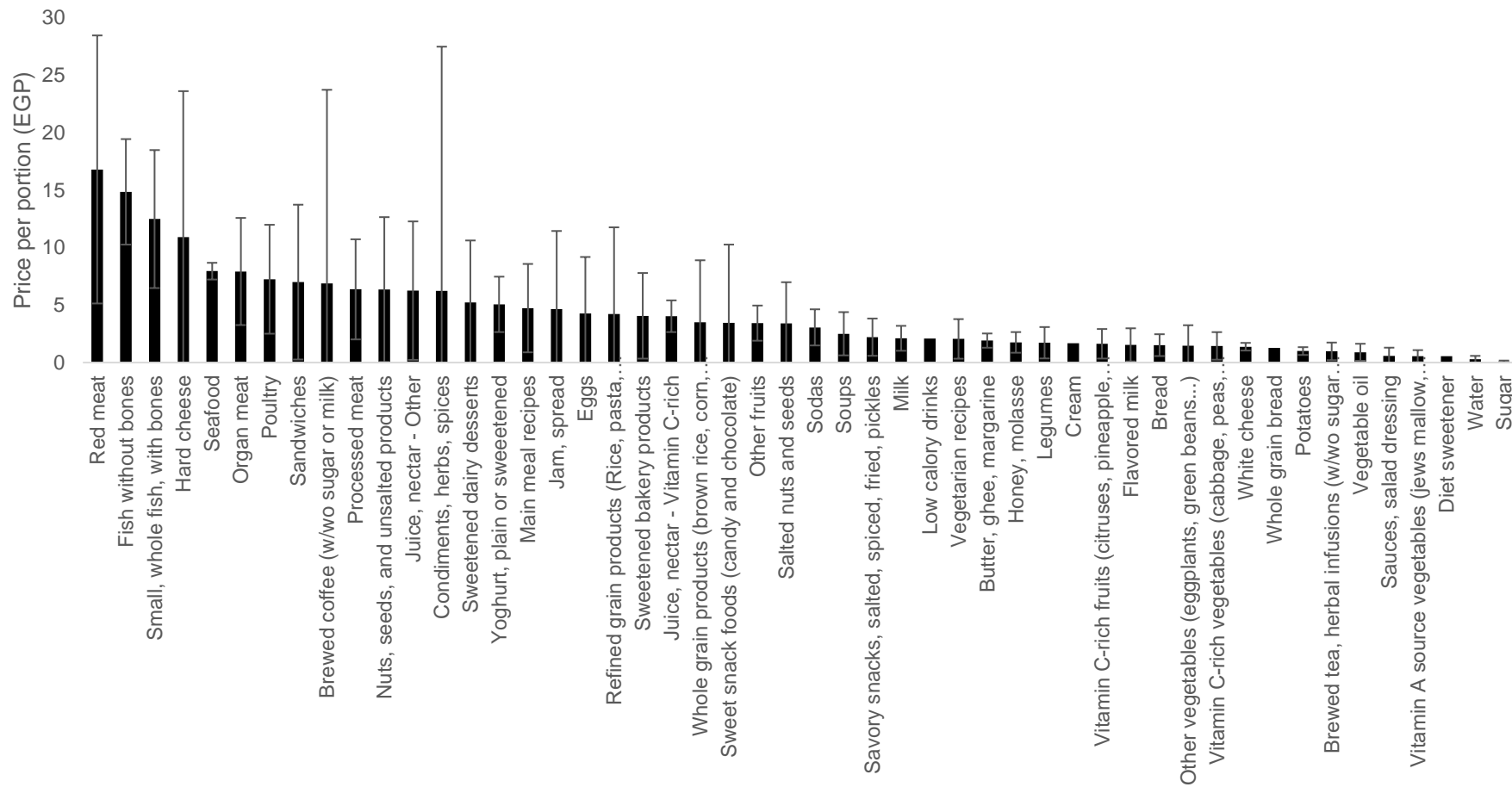


Figure 14. Prix moyen par portion des sous-groupes alimentaires

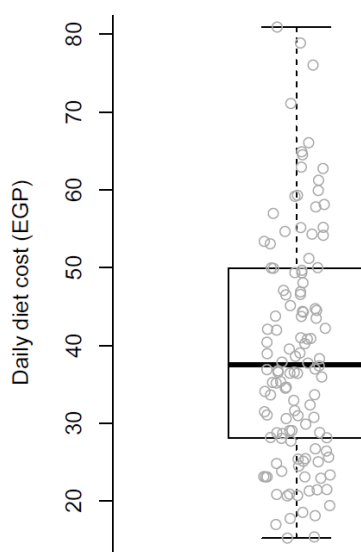


Figure 15. Coût moyen du régime alimentaire des femmes de 19 à 30 ans en Égypte urbaine (n=130)

La barre horizontale en gras représente la médiane. Les parties externes horizontales de la boîte représentent les premier (en bas) et troisième (en haut) quartiles. Les tirets horizontaux situés à l'extrémité des lignes pointillées représentent les valeurs minimales (tout en en bas) et maximales (tout en haut).

3.2.3. Présentation d'Optifood

Le principe et les équations mathématiques régissant Optifood ont été décrites en détail dans de précédentes publications (Ferguson et al., 2006, Daelmans et al., 2013). Nous donnons ici quelques éléments qui permettront d'éclairer l'Article 2 quant au fonctionnement du logiciel, en illustrant avec quelques exemples de résultats de ces travaux de thèse.

Optifood utilise des données alimentaires quantitatives (données de consommation, table de composition nutritionnelle et prix des aliments)⁸ afin de modéliser des régimes alimentaires nutritionnellement adéquats et abordables pour une population donnée. Ce logiciel a été principalement utilisé pour des populations confrontées à des situations de sous-nutrition résidant en région rurale, comme par exemple dans certaines régions d'Asie du Sud Est (Fahmida et al., 2015, Hlaing et al., 2015, Fahmida et al., 2014, Ferguson et al., 2015a) et d'Afrique Centrale (Hemsworth, 2014, Hotz et al., 2015, Ferguson et al., 2015b, Ferguson et al., 2015c, Ngala et al., 2015, de Jager et al., 2019, Kumwenda et al., 2014). Plus

⁸ Dans ces travaux, les données quantitatives utilisées étaient les données de consommation des femmes âgées de 19 à 30 ans, la table de composition nutritionnelle de aliments utilisée dans l'enquête, et le prix des aliments collectés au Caire.

rarement, cette interface a permis de tester les impacts nutritionnels et économiques de l'introduction de produits d'intervention enrichis dans les régimes alimentaires (Skau et al., 2014, Kumwenda et al., 2014). Optifood repose sur la programmation linéaire et multi-objectifs (« *linear and goal programming* » en anglais). Ces méthodes mathématiques permettent d'identifier des combinaisons d'aliments qui obéissent à un jeu de contraintes définies par l'utilisateur tout en minimisant la valeur d'une (programmation linéaire) ou plusieurs (programmation multi-objectifs) fonctions simultanément. La programmation *linéaire* peut par exemple servir à estimer la teneur minimale en fer assurée par un jeu de conseils (parfois appelés « recommandations ») alimentaires. La programmation *multi-objectifs* permet quant à elle de générer des régimes qui minimisent la déviation par rapport à des objectifs nutritionnels, d'acceptabilité et de coût (Ferguson et al., 2006).

Le logiciel est organisé en quatre modules qui permettent de définir et vérifier les paramètres des régimes modélisés, puis de tester différentes stratégies d'amélioration nutritionnelle (Figure 16). Nous décrivons ci-dessous le fonctionnement de chacun des modules afin de compléter les données de méthodes fournies dans l'Article 2.

Module I : Paramétrage et vérification du logiciel.

Caractéristiques de la population étudiée : La population d'étude est d'abord définie. La tranche d'âge (*e.g.* 19-30 ans) et le sexe (*e.g.* féminin) doivent être sélectionnés et correspondre à un jeu de recommandations nutritionnelles homogène⁹. La localisation de l'étude (*e.g.* Égypte urbaine) peut éventuellement être précisée. Le poids corporel moyen et le niveau d'activité physique estimé peuvent être renseignés pour que le logiciel propose une estimation des besoins en énergie à couvrir par les régimes modélisés, ou l'utilisateur peut renseigner directement un besoin en énergie en kilocalories (dans notre cas, 2135 kcal/j). L'utilisateur choisit ensuite un jeu de recommandations nutritionnelles à atteindre pour la population d'étude. Les paramètres nutritionnels considérés dans Optifood sont l'énergie (exprimée en kcal), les protéines (g), les lipides (g), la vitamine A (deux unités possibles : µg RE et µg RAE), la vitamine C (mg), la thiamine (mg), la riboflavine (mg), la niacine (mg), la vitamine B6 (mg), les folates (µg), la vitamine B12 (µg), le calcium (mg), le fer (mg) et le zinc (mg). Les autres nutriments ne sont pas pris en compte. La redondance de la vitamine A (selon l'unité) permet de modéliser un nutriment additionnel, mais il n'est pas possible de modéliser d'autres nutriments supplémentaires en raison du manque de flexibilité de l'interface. Dans ces travaux, la vitamine D a été choisie comme nutriment additionnel compte-tenu des

⁹ Le jeu de recommandations nutritionnelles doit correspondre à l'âge et au sexe de la population étudiée. Ainsi, l'utilisateur doit diviser la population en sous-populations si elle regroupe des personnes d'âge et de sexe ayant différents besoins nutritionnels. Des jeux de recommandations nutritionnelles préétablis sont disponibles dans Optifood (ces jeux sont basés sur les recommandations de la FAO et de l'OMS) mais l'utilisateur peut aussi définir son propre jeu de recommandations.

apports insuffisants des femmes constatés dans l'enquête alimentaire. Le coût maximal des régimes modélisés peut être paramétré (dans notre cas, 42 EGP/jour).

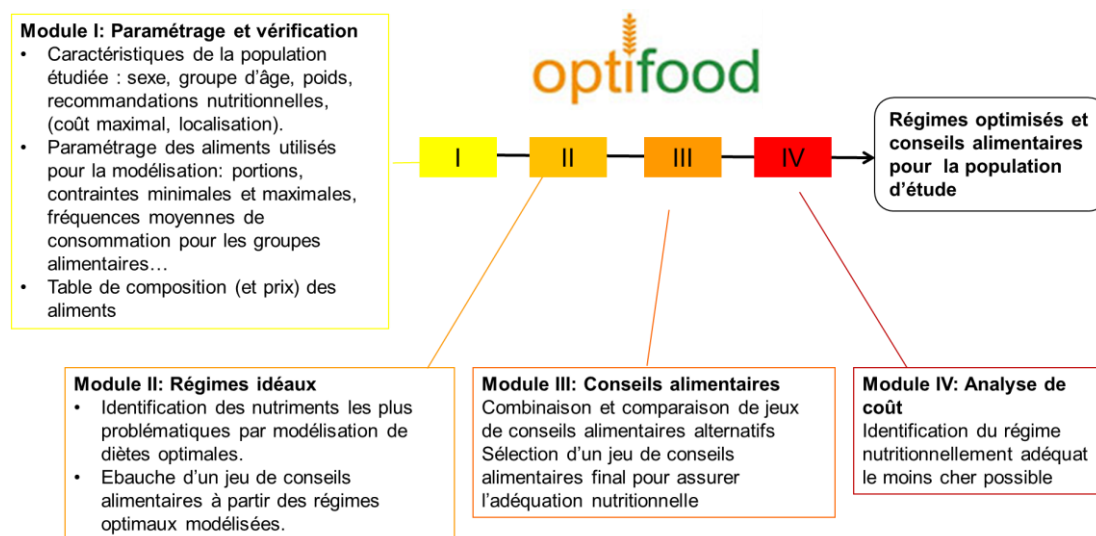


Figure 16. Présentation des différents modules d'Optifood.

Paramétrage des aliments utilisés pour la modélisation : Pour modéliser des scénarios aussi réalistes que possible, il est primordial de partir de données quantitatives collectées auprès de la population d'étude. L'utilisateur établit la liste des aliments à partir desquels il souhaite modéliser des régimes optimaux en fonction des régimes locaux (pour ce travail, il s'agissait des aliments consommés par plus de 5% de la population). Les tailles de portions des aliments modélisés sont établies à partir des données de consommation (quantité médiane consommée par acte alimentaire¹⁰ par exemple). Des contraintes minimales et maximales de fréquence de consommation sont fixées pour tous les aliments, sous-groupes et groupes alimentaires afin de modéliser des régimes aussi réalistes que possible. Nous avons par exemple choisi d'utiliser les 10^{ème} et 90^{ème} percentiles de fréquence de consommation comme bornes inférieures et supérieures pour les sous-groupes et groupes alimentaires. Les fréquences moyennes de consommation des groupes alimentaires (calculées sur toute la population pour mieux rendre compte de la diversité des pratiques) sont également renseignées. Ces dernières servent de proxy d'acceptabilité pour un des régimes modélisés dans le module II d'Optifood. La table de composition nutritionnelle des aliments (donnant les teneurs nutritionnelles pour 100g) ainsi que le prix des aliments (également à renseigner par 100 grammes d'aliment comestible) sont chargées dans le logiciel.

¹⁰ La portion pour chaque aliment est calculée à partir des consommateurs de l'aliment en question uniquement et non pas à partir de toute la population, car cela réduirait drastiquement les portions et serait peu représentatif des pratiques alimentaires.

Vérification des paramètres : Une fois les contraintes minimales et maximales définies pour les aliments, sous-groupes et groupes alimentaires, l'utilisateur doit vérifier leur compatibilité. Le logiciel détecte par exemple si la somme des fréquences maximales de consommation d'aliments d'un même groupe n'atteint pas la fréquence maximale indiquée pour le groupe alimentaire en question, et invite si besoin l'utilisateur à ajuster les paramètres. Cette étape de vérification des paramètres est cruciale pour s'assurer que la modélisation de régimes optimaux sera possible (parfois les paramètres choisis pour les modèles sont incompatibles) et que les résultats ne seront pas trop éloignés des habitudes de consommation de la population étudiée.

Module II : Modélisation de régimes avec la meilleure adéquation nutritionnelle possible

Le deuxième module d'Optifood utilise la programmation multi-objectifs afin de modéliser deux régimes se rapprochant le plus possible des objectifs fixés (nutritionnels, économiques et éventuellement d'acceptabilité), en minimisant la somme des écarts aux objectifs. Cette étape de modélisation permet de tester si les aliments disponibles localement suffisent à couvrir les recommandations nutritionnelles.

L'un des régimes inclut simplement des objectifs nutritionnels et économiques (régime « No Food Pattern »), tandis que l'autre (régime « Food Pattern ») ajoute également un objectif d'acceptabilité afin de se rapprocher des pratiques alimentaires de la population (minimisation de l'écart aux fréquences moyennes de consommation des groupes alimentaires). Le régime « No Food Pattern » dispose donc de plus de flexibilité que le régime « Food Pattern » pour trouver une combinaison d'aliments couvrant les recommandations nutritionnelles (Figure 17).

Module II d'Optifood

Deux régimes maximisant l'adéquation nutritionnelle sont modélisés, pouvant dévier (No Food Pattern) ou non (Food Pattern) des fréquences de consommation moyennes des groupes alimentaires.

- Le régime « **No Food Pattern** » n'a pas d'objectif lié aux habitudes de consommation, et doit donc seulement rester entre les contraintes minimales et maximales de fréquences de consommation des groupes alimentaires (**zone entre les lignes bleues**).
- Le régime « **Food Pattern** » inclut comme objectif de se rapprocher le plus possible des fréquences moyennes de consommation des groupes alimentaires (**en vert**).

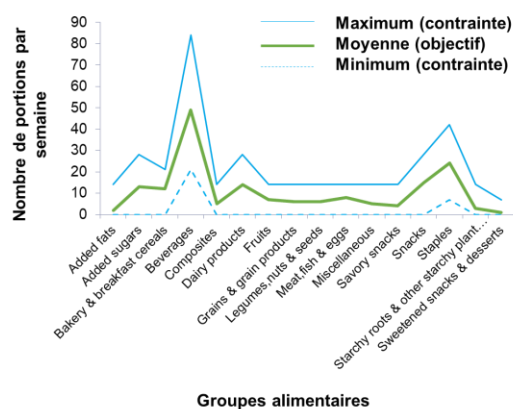


Figure 17. Contraintes et objectifs d'acceptabilité à respecter par les deux régimes optimaux modélisés dans le Module II d'Optifood.

Si plusieurs combinaisons d'aliments permettent d'atteindre toutes les recommandations nutritionnelles, Optifood les discrimine en sélectionnant celle avec le plus bas coût, ou à défaut avec la plus faible teneur en protéines (les protéines étant traditionnellement les nutriments les plus chers).

Lorsque les régimes optimaux modélisés n'atteignent pas les recommandations nutritionnelles, c'est que l'environnement alimentaire ne le permet pas non plus. Les nutriments pour lesquels les recommandations n'ont pas été atteintes dans le régime « Food Pattern » (et éventuellement aussi dans le régime « No Food Pattern ») peuvent être considérés comme « limitants » (voire « problématiques ») pour le contexte géographique et la population considérés. En effet, si ces combinaisons optimales d'aliments ne permettent pas d'atteindre les recommandations nutritionnelles, c'est que les nutriments ne peuvent pas être apportés en quantités suffisantes par les aliments consommés localement (et ce même en s'éloignant des pratiques alimentaires observées, pour le régime « No Food Pattern »).

Les régimes optimaux modélisés par le Module II d'Optifood pour les femmes égyptiennes dans ces travaux sont présentés à titre d'exemple dans le Tableau 9. On voit par exemple que le régime s'éloignant des pratiques alimentaires de la population (régime « No Food Pattern ») inclut 14 portions par semaine de fruits et 21 portions par semaine de légumes, alors que celui respectant des objectifs liés aux fréquences moyennes de consommation des groupes alimentaires (régime « Food Pattern ») n'introduit que 6 et 9 portions de fruits et légumes par semaine respectivement. L'analyse de ces régimes (en étudiant notamment les aliments au sein de chaque groupe alimentaire composant les régimes modélisés et l'adéquation nutritionnelle des deux régimes optimaux) permet d'élaborer une ébauche de jeu de conseils alimentaires. Ces ébauches de conseils alimentaires sont testées, enrichies, combinées et finalisées en utilisant le troisième module d'Optifood.

Tableau 9. Nombre de portions de chacun des groupes alimentaires inclus dans les régimes optimaux générés par le Module II d'Optifood pour les jeunes femmes égyptiennes âgées de 19 à 30 ans.

Food groups	"No Food Pattern" diet (number of servings per week)	"Food Pattern" diet (number of servings per week)
Fruits	14	6
Vegetables	21	9
Legumes, nuts & seeds	14	5
Grains & grain products	0	6
Bakery & breakfast cereals	21	12
Starchy roots & other starchy plant foods	7	3
Meat, fish & eggs	8	8
Dairy products	0	14
Composites (mixed food groups)	9	5
Beverages (non-dairy)	56	50
Added fats	0	2
Added sugars	1	14
Sweetened snacks & desserts	7	1
Savory snacks	1	3
Miscellaneous	14	5

Module III : Elaboration de jeux de conseils alimentaires

Les régimes modélisés avec le Module II donnent une bonne idée des changements alimentaires nécessaires à la couverture des recommandations nutritionnelles. Cependant, ces régimes correspondent à des combinaisons d'aliments très spécifiques, et ne peuvent être promus tels quel pour des raisons d'acceptabilité. Le Module III d'Optifood permet de combiner et tester différents conseils alimentaires inspirés des régimes modélisés avec le Module II afin de trouver un jeu de conseils qui soit à la fois le plus généraliste possible (on évite les conseils sur des aliments très spécifiques, et on préfère les conseils sur des groupes ou sous-groupes alimentaires) et le plus robuste possible d'un point de vue nutritionnel.

La robustesse des jeux de conseils alimentaires est testée par une série de modélisations qui minimisent la teneur en chacun des nutriments tout en respectant un jeu de contraintes sur des aliments, groupes ou sous-groupes alimentaires. Par exemple, la robustesse pour les folates du conseil « consommez 1 portion de légumineuses par jour et 2 portions de légumes par jour » est testée par la modélisation d'une combinaison d'aliments avec la plus petite teneur en folates possible incluant une portion de légumineuses et deux portions de légumes par jour. Un autre régime est généré avec les mêmes contraintes, mais minimise ensuite la teneur en vitamine C, puis en vitamine A, puis en chacun des nutriments pris en compte dans Optifood. Si les teneurs minimales garanties par les conseils alimentaires sont trop faibles (par exemple, en dessous de 70% des recommandations nutritionnelles), les

jeux de conseils sont rejetés et d'autres combinaisons sont testées pour assurer une meilleure adéquation nutritionnelle.

Optifood permet de combiner et tester automatiquement plus d'une centaine de jeux de conseils alimentaires générés à partir de huit conseils alimentaires individuels¹¹. L'utilisateur doit donc composer un jeu de conseils en sélectionnant 8 conseils (ou moins) inspirés des régimes modélisés avec le Module II. La possibilité de combinaisons est immense et repose sur les choix de l'utilisateur, puisque celui-ci spécifie la nature des conseils alimentaires à combiner (groupes, sous-groupes alimentaires ou aliments spécifiques) et teste différentes fréquences de consommation à recommander. Il y a, comme souligné par d'autres analyses de modélisation, mille et une façons d'atteindre les objectifs fixés (Maillot et al., 2017). Cette étape est donc fastidieuse et nécessite la génération de tableaux récapitulant les teneurs minimales en nutriments assurées par les différentes combinaisons de conseils, afin de les comparer objectivement. La combinaison la plus prometteuse est retenue, c'est-à-dire celle qui assure le mieux l'adéquation nutritionnelle (c'est-à-dire pour un maximum de nutriments) avec idéalement un nombre limité de conseils, portant plutôt sur des groupes ou sous-groupes alimentaires plutôt que sur des aliments spécifiques, et avec un coût le plus faible possible. Des exemples de jeux de conseils alimentaires testés et comparés dans le cadre de ces travaux sont présentés dans le Tableau 10. Le jeu de conseils alimentaire retenu est illustré par la Figure 18, et est détaillé dans l'Article 2.

¹¹ Seulement huit conseils alimentaires peuvent être combinés simultanément pour des raisons de limites de puissance de calcul du logiciel. Néanmoins, cette limite peut être contournée car un conseil alimentaire peut englober plusieurs contraintes sur différents aliments, sous-groupes et groupes alimentaires (autrement dit, un conseil alimentaire peut en englober plusieurs).

Tableau 10. Exemples d'analyses par minimisation des teneurs en micronutriments pour des jeux de conseils alimentaires testés pour les femmes égyptiennes âgées de 19 à 30 ans dans le Module III d'Optifood.

Sets of dietary advice tested with minimization analyses ^{1, 2, 3.}	Calcium	Vitamin C	Thiamin	Riboflavin	Niacin	Vitamin B-6	Folate	Vitamin B-12	Vitamin A	Vitamin D	Iron	Zinc
Grain7 - MFE8 - Tilapia2 - Liver1 - Cookedlegumes7 - Broadbeans4 - Veg21 - Fruits14 - Milk7 - Yog7 - Tahini7	89	142	61	108	62	72	57	281	216	110	38	93
Grain7 - RedMeat2 - Eggs4 - Tilapia2 - Liver1 - Cookedlegumes7 - Veg21 - Fruits14 - Milk7 - Yog7 - Tahini7	90	132	57	114	70	75	60	337	231	123	40	108
Grain7 - Bread7 - RedMeat2 - Eggs4- Tilapia2 - Liver1 - Cookedlegumes7 - Veg21 - Fruits14 - Milk7 - Yog7 - Tahini7	90	132	57	116	70	76	60	337	231	123	40	110
Grain7 - MFE14 - Eggs4- Tilapia2 - Liver1 - Cookedlegumes7 - Veg21 - Fruits14 - Milk7 - Yog7 - Tahini7	90	132	59	117	61	75	60	305	231	124	40	99
Grain7 - RedMeat2 - Poultry 2- Eggs4- Tilapia2 - Liver1 - Cookedlegumes7 - Veg21 - Fruits14 - Milk7 - Yog7 - Tahini7	90	132	58	115	72	76	61	339	231	124	40	111
Grain7 - RedMeat2 - Eggs4 - Tilapia2 - Liver1 - Cookedlegumes7 - Veg21 - Fruits14 - Milk7 - Yog7 - Tahini7 - Molasses7	91	132	59	119	70	75	60	337	231	123	49	112
Grain7 - RedMeat1 - Eggs4- Tilapia2 - Liver1 - Cookedlegumes7 - Veg21 - Fruits14 - Milk7 - Yog7 - Tahini7	90	132	56	112	64	73	60	317	231	123	39	101
Grain7 - MFE14 - Tilapia2 - Liver1 - Cookedlegumes7 - Veg21 - Fruits14 - Milk7 - Yog7 - Tahini7	88	132	59	111	61	75	54	305	216	112	40	99
Grain7 - RedMeat2 - Poultry2- Eggs4- Fish2 - Liver1 - Cookedlegumes7 - Veg21 - Fruits14 - Milk7 - Yog7 - Tahini7	85	131	55	111	68	70	61	316	228	32	38	106
Grain7 - Eggs4- Tilapia2 - Liver1 - Cookedlegumes7 - Veg21 - Fruits14 - Milk7 - Yog7 - Tahini7	89	132	55	110	58	72	60	296	231	123	38	94

¹ Les conseils alimentaires sont testés par des analyses minimisant successivement les teneurs en micronutriments de régimes, respectant des contraintes sur des groupes, sous-groupes alimentaires ou aliments spécifiques, modélisant les jeux de conseils.

² Les chiffres accolés aux aliments correspondent aux fréquences recommandées testées. Par exemple, Grain7 indique que la consommation de 7 produits céréaliers par semaine a été testée. Les abréviations ou acronymes suivants ont été utilisés: Grain, grains and grains products ; MFE, Meat fish eggs ; Tilapia, fish *tilapia* ; Cookedlegumes, cooked legumes, Broadbeans, broad beans ; Veg, vegetables ; Yog ; Yoghurt ; RedMeat, red meat.

³ Les résultats sont exprimés en pourcentage d'atteinte des recommandations.

⁴ Les cellules en vert indiquent que le jeu de conseils alimentaires testé assure 70% ou plus de la recommandation pour un nutriment.

Module IV : Analyse de coût

Le dernier module d'Optifood utilise la programmation linéaire afin de calculer le coût minimal d'une combinaison d'aliments couvrant les recommandations nutritionnelles. Ce dernier module peut être utilisé à des fins de plaidoyer, par exemple pour dénoncer le fait qu'une alimentation nutritionnellement adéquate coûte plus cher que le revenu moyen de la population étudiée, mais n'a pas été utilisé dans ces travaux.

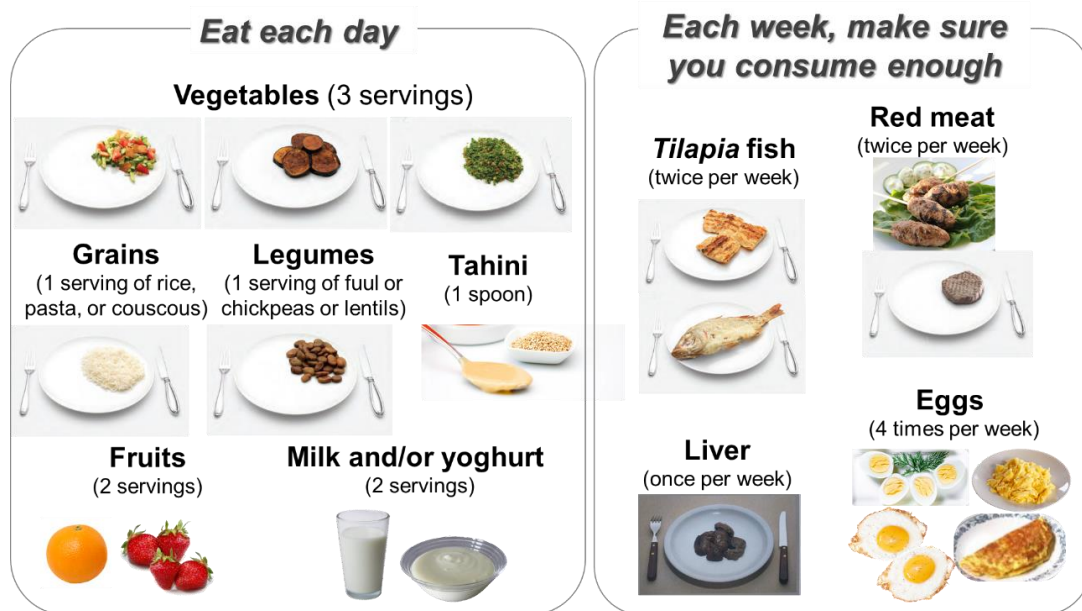


Figure 18. Illustration du jeu de conseils alimentaires retenu suite aux analyses réalisées avec Optifood.

Les images sur des assiettes sont issues des atlas alimentaires des Émirats Arabe Unis (légumes, aubergines et taboulé, pour les légumes, riz pour les produits céréaliers, fèves pour les légumineuses, poisson entier et en filet, steak pour la viande rouge) (Al Marzooqi et al., 2015) ou français (foie) (Hercberg et al., 1994). Les autres images (tahini, orange, fraises, lait, yaourt, kofta, œufs) sont des images libres de droit issues de banques d'images (flickr, paxabay, pixnio, wikimedia commons).

3.2.4. Résumé des stratégies nutritionnelles modélisées pour les femmes de 19-30 ans

Contexte : Au Moyen-Orient, les récents changements dans les modes de vie et la transition nutritionnelle ont abouti à un double fardeau de malnutrition. En Égypte, 50% des femmes sont carencées en fer et 88% sont en surpoids dans les zones urbaines. Leurs apports alimentaires sont trop riches en énergie et sodium, et insuffisants en fer, vitamine D et folates, et ces déséquilibres soulignent l'importance de la mise au point de stratégies pour améliorer l'adéquation nutritionnelle.

Objectifs : Cette étude avait pour objectif de modéliser des stratégies permettant d'assurer l'adéquation nutritionnelle pour une population de femmes âgées de 19 à 30 ans résidant en zone urbaine en Égypte, en identifiant des changements économiquement abordables dans leurs pratiques alimentaires et si besoin dans l'offre de produits enrichis (en fer notamment).

Méthodes : Les données de consommation alimentaire des femmes de 19-30 ans résidant en Égypte urbaine (décrites précédemment dans l'Article 1) ont été complétées par des données sur le prix des aliments. Pour cela, une étude a été mise en place dans des supermarchés et points de vente traditionnels typiques de ceux fréquentés par les classes moyennes au Caire, afin d'estimer le coût des régimes. Des analyses par programmation linéaire et multi-objectifs (réalisées avec le logiciel Optifood) ont été réalisées afin d'identifier les « nutriments limitants », et d'estimer si les aliments consommés localement (*i.e.*, consommés par >5% des femmes dans l'enquête alimentaire) pouvaient en théorie assurer l'adéquation nutritionnelle à un prix raisonnable (*i.e.*, inférieur au coût moyen de l'alimentation des femmes). Des analyses complémentaires ont été réalisées afin de s'assurer que les changements alimentaires modélisés n'excédaient pas les recommandations en AGS, sucres et sodium. Le potentiel de plusieurs produits enrichis pour améliorer l'adéquation nutritionnelle a aussi été testé.

Résultats : Les résultats des modélisations montrent que le fer est un nutriment limitant, car la couverture des apports recommandés en fer ne peut pas être assurée lorsque des objectifs d'acceptabilité des régimes sont introduits dans les modèles (c'est-à-dire lorsque le logiciel essaie de rester au plus près des fréquences moyennes de consommation des groupes alimentaires). La consommation journalière de fruits (2 portions), légumes (3 portions), légumineuses (1 portion), produits céréaliers (1 portion), lait ou yaourt (2 portions), tahini (1 cuillère à café), ainsi que des choix spécifiques dans le groupe « viande, poisson & œufs » (chaque semaine, deux portions de viande rouge, 2 portions de poisson, une portion de foie et quatre portions d'œufs) permettraient d'assurer l'adéquation nutritionnelle pour 11 des 12 nutriments modélisés, mais pas pour le fer. Parmi les produits enrichis testés, le riz, l'eau, le pain, le lait et le yaourt enrichis (en fer notamment) permettaient de garantir plus de 60% des apports en fer recommandés lorsque ces aliments étaient inclus dans un jeu de conseils alimentaires.

Conclusions : Un jeu de conseils alimentaires basé sur des aliments locaux permet en théorie d'atteindre la plupart des recommandations nutritionnelles, excepté pour le fer, pour lequel l'adéquation est difficilement atteignable sans produit enrichi. L'acceptabilité des stratégies d'amélioration nutritionnelle modélisées doit être évaluée avant de promouvoir ces changements alimentaires aux jeunes femmes égyptiennes.

Valorisation : Ce travail a fait l'objet de 3 communications orales et 3 communications affichées. Un article est également en cours de soumission dans le journal *The Journal of Nutrition*, dont la version la plus récente est présentée ci-après.

3.2.5. Article 2

Local foods can ensure nutrient adequacy except for iron in urban Egyptian women – results from diet modeling analyses

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Accronyms

EAR: Estimated average requirement

FAO: Food and Agriculture Organization

RNI: Recommended nutrients intake

SFAs: saturated fatty acids

TEI: total energy intake

WHO: World Health Organization

Conflict of Interest and Funding Disclosure

Danone Nutricia Research funded the study. CB' salary was funded by Danone. AL, R B-S and HK are Danone employees. SYS, YGEG and ND do scientific consulting for Danone. EF did scientific consulting for Danone Nutricia Research in 2016. DT is an Associate Editor of the Journal of Nutrition and played no role in the journal's evaluation of the manuscript, he has no conflict of interest.

ABSTRACT

BACKGROUND. Nutrition transition and recent changes in lifestyle in Middle Eastern countries have resulted in the double burden of malnutrition. In Egypt, 88% of urban women are overweight and obese and 50% are iron-deficient. Their energy, sugar and sodium intakes are excessive, while intakes of iron, vitamin D and folate are inadequate.

OBJECTIVE. This study aimed to formulate affordable dietary advice based on locally consumed foods and possibly fortified products to ensure adequate nutrient intakes for urban Egyptian women.

METHODS. Food intakes were assessed using a 4-day food diary collected from 130 urban Egyptian women aged 19-30 years. Food prices were collected from modern and traditional markets typically used by middle socio-economic classes in Cairo to calculate diet cost. Linear and goal programming analyses (Optifood software) were used to identify "limiting nutrients" and to assess whether locally consumed foods (i.e. consumed by >5% of women) could theoretically ensure nutrient adequacy at an affordable cost (i.e. \leq the mean diet cost), while meeting recommendations for saturated fatty acids, sugars and sodium. The potential of fortified foods for improving intakes of micronutrients, was also assessed.

RESULTS. Iron was the most limiting nutrient. Daily consumption of fruits, vegetables, milk or yoghurt, meat-fish-eggs and tahini (sesame paste) would likely ensure adequate intakes for 11 out of 12 micronutrients modeled. Among fortified foods tested for inclusion in dietary advice, iron-fortified rice, milk, water, bread or yoghurt were promising to ensure the iron intakes of these women covered >60% of their iron recommendation.

CONCLUSIONS. A set of dietary advice based on locally consumed foods can theoretically ensure requirements for most nutrients are covered, except iron, for which adequacy is harder to achieve without fortified products. The acceptability of the dietary changes modeled needs evaluation before promoting them to young Egyptian women.

Keywords: Egyptian women; linear programming; dietary advice; fortification; iron.

INTRODUCTION

In Middle Eastern countries, changes in lifestyle and dietary patterns over the last decades (1-3) have resulted in a marked increase in overweight, obesity (4, 5) and metabolic disorders (6, 7). In Egypt, women are particularly affected by a double burden of malnutrition, characterized by a high prevalence of overweight and obesity (88% in urban areas) coexisting with iron-deficiency (50% of women) (8, 9). A previous dietary survey showed that the dietary patterns of 19-30-year-old urban Egyptian women displayed those typical of nutrition transition, with high intakes of energy and sodium, and inadequate intakes of iron, vitamin D and folate (10). In these diets iron is mainly found in the less efficiently absorbed non-heme iron form (10, 11).

Diet modeling, using linear and goal programming analyses, is a robust approach for identifying specific and affordable dietary changes to improve nutrient adequacy (12). Optifood is a diet modeling software (13) developed to formulate and test dietary changes for children (14-19) and adults (20, 21). It can also be used to model the potential impact of interventions such as the use of fortified products (21-23). While Optifood has been used extensively in contexts of undernutrition (infants and young children from low-income countries in rural areas of Asia and Africa) (14, 16-18, 22-25), it has not been used in urban settings facing the double burden of malnutrition.

The objective of this study was to use the Optifood software to identify affordable dietary advice based on locally-consumed foods for young, middle-class urban Egyptian women and to theoretically assess if fortified foods could help to meet nutrient adequacy in this population.

METHODS

Dietary data and market survey data

Dietary data from women aged 19-30y (n=130) was extracted from a descriptive cross-sectional survey conducted between November 2016 and March 2017 in males and females (age range: 1-50y; n=860) living in four urban areas in Egypt (Greater Cairo, Alexandria, Delta and Upper Egypt) (10, 26). The dietary data consisted of a 4-day food diary and were used to define the model parameters. Most of these women were from the lower-middle income classes (51.5%), from Greater Cairo (43.1%), and had a high prevalence of overweight or obesity (75.3% overweight or obese; mean BMI: 27.9 ± 4.9 kg/m²) (10).

Food prices were collected between February and March 2018 in five different supermarkets covering East and West Cairo and twenty traditional shops in middle class residence areas (districts of *Shubra*, *Ain Shams*, *Maryouteya* and *Imbabah*). In each district, prices were collected from one shop on a main road and four shops located away from the main road to capture location-specific price variability (i.e. prices tend to be higher on the main roads than off them). Brands and package sizes sampled were selected based on data provided by fifty middle-class female respondents from Cairo (recruited in addition to the previous dietary survey) who detailed the brands and formats of the food items that they purchased in the past week. For each food item, the brand, price, and net weight were recorded, and a picture was taken. The subsidized price of the national bread (in Egyptian, *baladi* bread) was selected because the target population was middle class women. For each food item, the price per 100 grams of edible product was calculated using yield factors in the Food Atlas from the United Emirates (27) or, when the item was not found, from France (28). The price per 100 grams of each recipe was calculated based on the amount and price of each ingredient used in the recipe. The food composition database used to calculate the energy and nutrient content of modeled diets was based on the Egyptian food composition database with imputed values from the Turkish (29), Serbian (30) and Indian (31) food composition databases when food or nutrients values were missing. The study protocol was fully approved by The Research Ethics Committee of Ain Shams University, Faculty of Medicine, Cairo, Egypt.

Diet modeling analyses: nutritional, economic and acceptability parameters

The data were analyzed using the Optifood software (version 4.0, 16.0, June 2016) (13, 14) using nutritional, economic and acceptability parameters presented in **Supplemental Table 1**. Goal (Module II) and linear programming (Module III) analyses (14) were used to identify "problem nutrients" and model nutritious and affordable dietary advice, with or without fortified products.

The energy content of modeled diets (2135 kcal) was the mean energy requirement (ER) for the studied population, obtained from the mean basal metabolic rate (BMR) multiplied by a Physical Activity Level (PAL) of 1.4 (which corresponds to the sedentary lifestyle assumed for this population (32, 33)). The mean BMR was calculated using the Henry equations (34) and the mean weight of the women surveyed (i.e., 73.9 kg) (10). The protein and fat content of the modeled diets were compared with the World Health Organization (WHO) and the Food and Agriculture Organization (FAO) population goals for macronutrients (35). Recommended nutrients intakes (RNIs) from the Egyptian Ministry of Health were used as goals in the goal programming analyses for calcium, vitamin C, thiamin, riboflavin, niacin, vitamin B6, folate, vitamin B12, vitamin A, vitamin D and zinc (the lower bound of Egyptian RNIs were used when RNIs were expressed as a range) (36). The Egyptian RNI for iron for women of childbearing age is to consume 18-29.4mg/d of iron. Yet

findings from a previous study showed that iron bioavailability in the diets of Egyptian women is low (i.e., $9.2 \pm 1.6\%$ iron absorption (10)), which led us to select the upper bound of the recommended range, which is also in line with WHO iron recommendations with an iron bioavailability at 10% (i.e. 29.4mg/d) (11). The model constraint on maximum diet cost per week was defined as the mean diet cost, for Egyptian women, which was estimated using the food consumption data from the survey of 19-30y Egyptian women, and price data from the market survey (daily diet cost of 42 EGP). Acceptability parameters included the model goals on food groups (i.e. average number of servings per week) and constraints on the number of servings per week of food items, food subgroups and food groups. These acceptability constraints were based on observed dietary patterns from the survey of 19-30y women, as detailed in **Supplemental Tables 1 & 2**. The list of foods included in the model were the foods consumed by $\geq 5\%$ of the 130 women. Some non-nutritive foods like chewing-gums or artificial sweetener were removed from the list of foods. Serving sizes were based on median quantities per serving among women who consumed these foods.

Identification of problem and limiting nutrients from the foods locally consumed

Goal programming analyses (done with Optifood Module's II (14)), were run to identify the most nutritious, affordable and acceptable combinations of foods, from those commonly consumed. These analyses helped to determine whether 12 micronutrients (calcium, iron, zinc, vitamin A, thiamin, riboflavin, niacin, vitamin B6, folates, vitamin B12, vitamin C and vitamin D) could be consumed in sufficient amounts using combinations of locally consumed-foods within a realistic budget. The two "best diets" achievable given the list of foods and the parameters entered were modeled. One of these "best diets" modeled (called the "Food pattern diet") aimed to achieve the RNIs as well as food pattern goals (i.e. the objective function aimed at minimizing deviations below the RNIs, *and* minimizing deviations both below and above the population average number of servings for each food group). The other "best diet" modeled (called the "No food pattern diet") only had nutrient goals, but no food pattern goals. Both diets remained within the dietary boundaries for food patterns (14) and diet cost, set as constraints in the model (**Supplemental Tables 1 & 2**). In this study, nutrients that did not meet RNIs in the "Food Pattern diet" but achieved them in the "No food pattern diet" were defined as "*limiting nutrients*". Nutrients that remained below the RNIs in both best diets were defined as "*problem nutrients*".

Formulation and testing of dietary advice from locally consumed foods

A second set of analyses (done with Optifood Module's III (14)) compared alternative sets of dietary advice that could potentially improve nutrient adequacy. Hundreds of sets of dietary advice were tested and combined, based on the nutrient-dense food groups, food subgroups or food items selected in the Module II best diets. To select the final set of dietary advice among the hundreds modeled, sets were discriminated based on nutritional criteria as well as practical aspects. The nutritional criteria were of two kinds. First, linear programming models were run that successively minimized the content of each nutrient modeled while applying minimum constraints to ensure the food combination respected the dietary advice tested (13, 14). In other words, these analyses modeled scenarios, for each nutrient, in which people would pick the least nutrient dense foods for that nutrient while following the dietary advice.

Only sets performing >70% RNI for the highest of number of nutrients among those modeled (i.e. vitamin C, thiamin, riboflavin, niacin, vitamin B6, folate, vitamin B12, vitamin A, vitamin D calcium, iron and zinc) in minimization analyses were selected for the rest of the analyses. Then, sets were discriminated based on their average content in nutrients not modeled in Optifood (i.e. total sugars, dietary fiber, saturated fatty acids (SFAs), sodium, potassium, phosphorous, magnesium, iodine, copper and vitamin E). The average contribution of non-modeled nutrients was estimated using the Excel software (as detailed in **Supplemental Material 1**). Finally, the “simplicity” of the sets of dietary advice discriminated the remaining sets, favoring sets with the lowest number of advice and the less specific sets of advice: advice on a food group was prioritized over one on a food subgroup, which was prioritized over one on a food item to increase food choice flexibility and accommodate individual food preferences.

Acceptability indicators

Components of the final set of dietary advice retained (i.e. food groups, subgroups and food items included in the final set of dietary advice) were compared with “acceptability indicators”, in order to identify potential difficulties of the targeted population for following the set of dietary advice modeled. These “acceptability indicators” were based on the results of the dietary and market surveys and on the nature of the advice (i.e. food group versus food subgroup versus food item). The following indicators were considered: mean observed frequency of consumption over the 4-days of dietary record; percentage of women consuming each modeled food (or food subgroup or group) at least once in 4-days; and cost per serving (calculated as detailed in **Supplemental Material 2**). The assumptions behind these acceptability indicators were that it would be difficult to recommend the consumption of food items, subgroups, or groups that were only occasionally consumed (i.e. acceptability could be low if the recommended frequency of consumption was more than double the observed frequency of consumption). Similarly, if only a low percentage of women were consuming the recommended food group, subgroup or item, its adoption might be more difficult. Advice that encompassed a range of foods (i.e. advice on food group or food subgroups) are simpler and allow more flexibility on food choice than advice on very specific food items.

Modeling the impact of modifying the food environment

In the final set of analyses, to simulate modifications in the food environment, the food list was expanded to include foods that were good sources of “problem nutrients” but were not currently consumed by the population. Eight theoretical fortified foods (*baladi* bread, beans, rice, spread cheese, milk, yoghurt with cereal toppers, yoghurt highly fortified and water, **Table 1**) were therefore tested. Maximum frequencies of consumption and serving sizes were derived from dietary data of similar non-fortified foods consumed (10). The levels of the “limiting” or “problem” nutrients in the fortified foods were based on successful trials from the literature on other populations or from pilot products under development at the time of the survey. Prices modelled, for the fortified foods, were identical to those modelled for the non-fortified foods. These fortified foods were successively included in the list of foods available, one by one, to check whether their introduction in the previous set of dietary advice (made out of non-fortified foods only) would improve nutrient adequacy and acceptability indicators in minimization analyses (Optifood Module’s III (14)). More specifically, we assessed whether the inclusion of fortified foods would result in a simpler and more

affordable set of dietary advice, by systematically reducing the number of recommendations, starting by the most expensive ones.

RESULTS

Identification of problem and limiting nutrients

For all nutrients, 100% of RNIs were covered in the Module II “No food pattern diet”, indicating that there was no problem nutrient. In other words, locally consumed foods can in theory be combined to cover RNIs, when deviation from average food group patterns is allowed in the modelled food combination. Iron was the only limiting nutrient identified, because less than 80% of the iron goal was covered in the “Food pattern diet” (which is the food combination aiming to stay as close as possible to the population’s average food group patterns). All other nutrients reached or exceeded their respective goals (**Figure 1**).

Formulation and testing of dietary advice from locally consumed foods

Among the hundreds of sets of dietary advice tested, four performed similarly in the Module III minimization analyses (sets presented in **Supplemental Table 3**). Yet, the average nutrient content of these 4 sets of dietary advice on nutrient not modeled in Optifood revealed that one of them (set number 2) was more balanced than the others. As an example, the set number 3 including 7 servings of molasses had the highest average iron content (19.0 mg/d) but also the highest sugar content (84 g/d). Similarly, the set number 1 including the recommendation to consume 14 servings of foods from the group “meat, fish & eggs” had the second highest average iron content (17.9 mg/d) but also high amounts of protein (82 g/d) and fats (76 g/d) compared to the recommended intakes (53-80g/d of protein and 36-71g/d of fats) (**Supplemental Table 4**). Therefore, among these four sets of dietary advice, the second set was selected for further analyses because it was the best set for improving iron intakes while not exceeding total sugars, fats or sodium recommendations (**Supplemental Tables 3 and 4**). This selected set of dietary advice included vegetables (3 times per day), legumes and grains (once per day for each), tahini (a sesame paste commonly used as dressing for salads, meals, or desserts in Egypt, once per day), milk or yoghurt (twice per day), fruits (twice per day), Nile fish (also known as *Tilapia*) and red meat (twice per week for each), liver (once per week) and eggs (4 times per week) (**Table 2**). The acceptability indicators showed that, for this set of dietary advice, the modeled numbers of servings per week were above their observed average frequency of consumption: vegetables (21 servings per week modeled against 8.7 servings per week observed), yoghurt (consumed only 1.8 times per week on average), fruits (6.4 servings per week on average, while 14 servings per week were modeled), tahini (consumed only 0.5 times per week in the dietary survey) and all animal food products (*Tilapia* fish, red meat, liver, and eggs) at least doubled the observed frequencies per week. The selected set of dietary advice included expensive (i.e. red meat and Nile fish) and infrequently consumed foods (less than 50% of the women consumed yoghurt, Nile fish, tahini and liver). Yet, this set of dietary advice was the best set to improve nutrient adequacy for as many nutrients as possible, including non-modeled nutrients (**Table 3**). Following this set of advice, a woman would consume on average 1573 kcal of the estimated 2135 kcal per day required, which leaves a gap of 562 kcal of energy for other (potentially less healthy) foods, and for macronutrients, a gap, of on average 119 to 225 g of carbohydrate, and 6g of fiber. The dietary advice ensures on average the recommended intakes for vitamin D (7.9 µg/day) and folate (407 µg/day), which were insufficiently consumed in the mean

observed diet (vitamin D: $3.3 \pm 3.5\mu\text{g}/\text{day}$, folate: $308 \pm 130\mu\text{g}/\text{day}$) (10). The average iron content, for the set of dietary advice, is also higher than the observed intakes, yet it does not achieve the RNI ($13.8 \pm 4.6 \text{ mg}$ ($47 \pm 16\%$ RNI) in observed intakes, *versus* 16.4 mg (56% RNI) on average in the dietary advice). In addition to the sub-optimal level of iron, this set of dietary advice does not fully meet the recommended intakes for potassium (average content from the dietary advice: 3.2 g , recommended: $\geq 4.7 \text{ g}$). For all other nutrients modeled, this set of dietary advice would ensure adequate intakes for most women in the population, without exceeding upper tolerable limits.

Impact of including iron-fortified foods in the food environment

With no fortified food, the selected set of dietary advice modeled from locally consumed foods “ensured” only 40% of the iron RNI, 57% of the thiamin RNI and 60% of the folate RNI in the Module III minimization analyses. These minimization analyses corresponded to analyses of the worst-case scenario, i.e. when the lowest nutrient dense foods among a recommended group or subgroup are picked. For the remaining 9 out of 12 micronutrients modeled, 70% or more of their RNIs were covered (**Table 4**). Minimization analyses (Module III) with fortified products showed that the consumption of *baladi* bread (3 times per day), rice (4 times per week), milk (10 times per week), a highly fortified yoghurt (once a day) and water (3 times per day) would likely reduce the percentage of population at risk of inadequate iron intakes, because the lowest intake, in the simulated intake distribution, increased from 40% (without fortified products) to 61-85% of the iron RNI (**Table 4**). Including a recommendation on the highly-fortified yoghurt (once per day) or iron-fortified water (3 times per day) enabled to remove red meat from the sets of dietary advice (**Table 5**), which was the most expensive recommended item per serving in the set of recommendation based on locally consumed foods only (**Table 2**).

DISCUSSION

A previous dietary survey showed that about 80% of the young urban Egyptian women included in the study had an inadequate intake for iron, folate and vitamin D (10). The present results, using diet modelling, indicate that the percentage of women with these inadequate intakes can be reduced by combining locally available nutritious foods and iron-fortified products. Iron was the only limiting nutrient ($<80\%$ of its RNI) in the Module II food combination using average local food consumption patterns, whereas the RNIs for folate and vitamin D could be achieved in this modelled diet. Achieving 100% of the iron RNI in this women population required to deviate from the population’s average food patterns (Module II, “No Food Pattern diet”).

It was difficult to formulate a set of dietary advice ensuring sufficient iron intakes (i.e. at least 70% of iron RNI) without exceeding sugar, protein or fat RNIs. Indeed, the analyses of the four best sets of dietary advice designed with Optifood’s Module III illustrated that including 7 servings of molasses or 14 servings of foods from the group “meat, fish & eggs” would increase iron intakes but also induce high sugar (for molasses) or protein and fat intakes (with the recommendations to consume weekly 14 servings of foods from the group “meat, fish & eggs”) respectively. The set of dietary advice retained, which improved micronutrient intakes with moderate fat, sugar and sodium content, lead to consume fruits, vegetables, milk or yoghurt, and tahini (the sesame paste) daily, and to consume red meat twice a week, liver once a week, fish twice a week, and eggs four times per week. Successful adoption of this set of dietary advice would result in a low percentage of

women with inadequate intakes for 11 out of 12 micronutrients modeled, but iron would remain problematic. This modeled set of dietary advice is in line with international food-based recommendations (FAO, WHO, USDA) (37-39) and partially aligns with the recent recommendations from EAT-Lancet commission (Willett et al, 2019) promoting, for the general population, an increase in fruits, vegetables, legumes and nuts and a decrease in sweetened products but also red meat. In the present study, the advice on red meat contributes to meet the high iron needs of women of childbearing age by increasing the bioavailability of iron in these Egyptian diets (10, 40, 41).

Optifood was originally created to develop nutritious and affordable population-specific food-based recommendations to improve, for at least 12 nutrients, dietary nutrient adequacy. In Egypt, underconsumption of key micronutrients coexists with over-consumption of total fat, SFAs, sugars and sodium (10). Even though Optifood's unique way of testing the robustness of dietary advice, by minimizing the nutrient content of each modeled nutrient, is powerful, the software cannot be used to model all nutrients (including SFAs, sugars and sodium), which may be of importance in countries facing nutrition transitions. The current study addressed these limitations by externally calculating a weighted average, for the total sugar, SFAs and sodium contribution from the dietary advice to the total diet, and used this information to both select a set of dietary advice from amongst alternatives and ensure the advice would not contradict recommendations to limit intakes of these nutrients. Thus, Optifood can be used in combination with simple calculations to guide the formulation of dietary advice in countries facing the nutrition transition.

Despite the robustness of diet modeling, the acceptability of the selected set of dietary advice is questionable from several perspectives. First, the dietary advice includes two specific and monotonous recommendations (i.e. consuming Nile fish twice a week and tahini once a day). The remaining set of dietary advice allows flexibility in food choices i.e., recommends consuming foods from several food groups and subgroups, which should increase their acceptability. Second, the dietary advice recommends increasing the consumption of foods or foods from specific food groups/sub-groups, which except for grains and legumes, is more than twice the mean observed frequencies of consumption. Third, the dietary advice includes expensive food items (i.e. red meat, Nile fish and yoghurt) that might be unrealistic for low-middle class people, although this constraint is tempered by the low overall cost of the dietary advice compared with observed diet costs. Fourth, the acceptability of some recommendations might be low for different reasons (palatability, convenience, habits, medical condition...) (42-44), because few women reported consuming liver (17%), tahini (18%), Nile fish (25%), red meat (44%) and yoghurt (44%) over the four days of assessment in the dietary survey.

The results of this study underlined the advantages of including iron-fortified products in a set of dietary advice for increasing iron adequacy for young urban Egyptian women and possibly simplifying a set of dietary advice. Indeed, the eight fortified products tested enabled to increase iron adequacy, from 40% of the RNI with no fortified product, to 45 or 85% RNI when iron-fortified spread cheese or iron-fortified rice were included, respectively. These results underline the relevance of iron-fortified products for young women living in Egypt, even if the performances of the iron-fortified products tested strongly rely on all parameters defined. Fortification levels in this study were based on successful trials from the literature on other populations, or from feasible pilot products. Of course, the high level of fortification of rice (8,9 mg/100g) probably explains the

performance in both modeling analyses (85% of iron RNIs ensured with a set of dietary advice including fortified rice) and the clinical trial on women in Mexico from which this product was inspired (45). The high maximum frequency of consumption allowed for the iron and folate enriched Baladi bread (21 times per week) was derived from observed consumption of Baladi bread (10), and provided an opportunity to introduce large amounts of this fortified food in the diets modeled (3 servings per day covering 62% of the iron RNI when included in a set of dietary advice). Some fortified products not only had the advantage of increasing iron adequacy, but also of simplifying the set of dietary advice. This was the case for the highly fortified yoghurt, which ensured at least 61% of iron RNI when included in a simpler set of advice (i.e. red meat, eggs, other dairy products, grains and fruits could be theoretically removed). Further studies could confirm the potential of the fortified foods modeled and help to select the best one, once their feasibility on technical and logistic aspects is confirmed.

The modeling analyses highlighted the changes required *in theory* in food practices and in the food supply (notably iron-fortified products), yet the acceptability and risks of the strategies modeled need to be investigated. As an example, Egyptian women consume more tap water than bottle water, and more milk than yoghurt, which suggests a fortified milk might be more acceptable, for more women, than alternative new fortified products. The risks of fortifying foods which are usually bought and consumed by all household members (such as rice, bread and milk), however, should be evaluated to ensure fortification would not put other household member at risk of exceeding upper tolerable limits, for the fortified nutrient(s). Bread, which is widely consumed (40), is a potential vector for iron fortification but the past initiative from the Egyptian government, World Food Program and GAIN (46) showed it was challenging to implement at the national level. The program was stopped because of technical issues (problems with blenders and difficulties for controlling the quality of the fortified flour), lack of funding (funds ended in 2012) and public health concerns regarding iron over-load (9-10% of Egyptians carry the beta-thalassemia genetic trait) (47, 48). Modeling analyses are useful to better understand what dietary changes are best to promote, and which fortified products could be relevant. However, these results do not document the compliance of consumers with the dietary changes modeled, including the consumption of new fortified products that are not yet in the market and imply new purchase and consumption habits. Previous studies combined Optifood analyses with trials of improved practices (16) or focused ethnographic studies (17), highlighting the importance of going back to the target population to determine whether the dietary advice is realistic and identify ways to refine it.

In conclusion, this study used diet modeling to identify nutritious and affordable dietary advice for a population facing nutrition transition. A set of dietary advice was modeled from locally consumed foods, which if followed should ensure a low percentage of young urban Egyptian women would be at risk of inadequate intakes of all nutrients modelled except iron. Several iron-fortified products were thus identified as relevant options to improve iron intakes. Yet, the acceptability of the dietary advice selected to improve nutrient adequacy should be evaluated and refined with the targeted population. This tailored set of dietary advice could then be promoted to reduce the percentage of young urban Egyptian women at risk of inadequate intakes of multiple micronutrients (10). Additional research is also needed to identify appropriate food vehicles and

fortification levels to address iron deficiency in this population (8), because our analyses indicate iron-fortified foods are needed to ensure adequate iron intakes in this population.

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Authors' contribution: The authors' contributions were as follow: CB and AL designed the food price study, CB analyzed the food price data collected and created the database for diet modeling analyses. CB, AL, DT, ND and RB-S decided of the modeling analyses to perform. CB conducted the diet modeling analyses. EF provided expertise on the Optifood software. HK, SYS and YGEG provided guidance on modeling parameters and results. All authors were involved in the interpretation of the results. CB, AL, DT, ND and EF wrote the paper. All authors read and approved the final manuscript.

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TABLES

Table 1. The serving size and iron content of iron-fortified foods tested for 19-30 year-old Egyptian women.

Iron-fortified foods	Serving size (g)	Iron content (mg/100g)	Iron content (mg/serving)	Rationale for fortification level
Baladi bread fortified with iron and folates	50 *	4.4	2.2	Based on the former fortification program of baladi bread in Egypt (Elhakim et al., 2012)
Beans (cooked as fuul), fortified with iron	140 *	4.3	6.0	Based on the iron content of biofortified beans evaluated in a randomized controlled trial with women from Rwanda (Haas et al., 2016)
Rice (cooked), fortified with iron	250 *	8.9	22.3	Based on the iron content of rice fortified with microencapsulated, micronized iron pyrophosphate evaluated in a randomized controlled trial on women from Mexico (Hotz et al., 2008)
Spread cheese, fortified with iron	60 *	2.7	1.6	15% of the safety boundaries for certification in Egypt (18mg/100g) (Ministry of Health Egypt, 2004)
Milk, fortified with iron	200 *	2.7	5.4	15% of safety boundaries for certification in Egypt (18mg/100g) (Ministry of Health Egypt, 2004)
Yoghurt, non-fortified (100g) + cereals fortified with iron and other micronutrients (15g)	115 +	3.0	3.4	Iron content of non-fortified yoghurt, plus cereals fortified with multiple micronutrients (nutritional data from a package label of local fortified cereal, "Temmy's Nutrifit Bran flakes")
Yoghurt, highly fortified (iron and other micronutrients)	140 α	5.8	8.1	In each serving contains 100% of the Estimated Average Requirement (EAR) for micronutrients with frequent deficiencies in women of reproductive age (iron, zinc, B9, B12) (Bill & Melinda Gates Foundation, 2016) and addition of other micronutrients in lower amounts (vitamin C (80% EAR) vitamin A (50% EAR), vitamin D (45% EAR), vitamins E, K, B1, B2, B3, B6 (all at 33% EAR), calcium (80% EAR), phosphorous, copper, selenium and iodine (all at 33% EAR))
Water, fortified with iron	200 #	1.2	2.4	Based on the iron content of iron-fortified drinking water evaluated in a large-scale intervention study on preschool children from Brazil (Beinner et al., 2005)

* Serving sizes are based on median serving sizes declared by women aged 19-30 years in the dietary survey (Brouzes et al., 2020) .

▫ Serving size estimate of a pilot product.

+ Suggested serving size of cereals is based on visuals from a food atlas (Hercberg et al., 1994).

Serving size of a glass of water.

Table 2. Indicators of acceptability for the modeled set dietary advice retained

Food	Best modeled dietary advice using locally consumed foods		Acceptability indicators			
	Recommended number of servings per week	Serving size* (g)	Mean observed frequency of consumption per week ^a	Women consuming (%) ^a	Cost per serving (EGP) [⊥]	Group and sub-group (G) or food item (I)
Vegetables	21	≈120	8.7	92	1	G
Legumes	7	≈120	4.2	76	2	G
Grains & grains products	7	≈250	5.7	96	2	G
Milk (m) or Yoghurt (y)	14	183 (m) 125 (y)	5.2 (m) 1.8 (y)	77 (m) 44 (y)	2 (m) 4 (y)	G
Fruits	14	≈140	6.4	80	2	G
Tahini (sesame paste)	7	30	0.5	18	1	I
Nile fish (Tilapia)	2	280	0.4	25	12	I
Red meat	2	≈205	1.1	44	15	G
Liver	1	115	0.3	17	2	G
Eggs	4	95	2.0	63	3	G

* Serving sizes are based on median serving sizes, for foods as eaten, from the dietary survey (Brouzes et al., 2020). For food groups (and subgroups), the average serving size was calculated by averaging the median serving size of all food items of the same food group (or subgroup) and weighting it by the number of consumers in this food group (or subgroup).

^a Mean observed frequency of consumption and percentage of women consuming each recommended food were estimated based on reported intakes of all women in the dietary survey (Brouzes et al., 2020).

[⊥] Cost per serving was calculated from a market survey conducted in 2018 – 2019 in Cairo to collect food prices, and median serving sizes declared in 2016-2017 dietary survey.

Table 3. Daily energy and nutrient content of the observed diet and the set of dietary advice selected, as the best set using locally available non-fortified foods, in comparison with recommended intakes and safety limits ^{||}.

Energy and nutrient values (unit per day)	Mean observed intake \pm SD	Dietary advice's mean nutrient content	Recommended intake	Safety limits *	Difference between mean nutrient content of dietary advice and recommended intake
Energy (kcal)	2389 \pm 715	1573	2135 [□]	NA	- 562
Carbohydrate (g)	307 \pm 96	175	294-400 [⊥]	NA	- [119-225]
Total sugars (g) [∨]	98 \pm 54	52	<53 [#]	NA	< >
Fibers (g) [∨]	18 \pm 8	19	\geq 25 [⊥]	NA	-6
Total fat (g)	89 \pm 32	67	36-71 [⊥]	NA	< >
SFAs (g) [∨]	30 \pm 13	18	<24 [⊥]	NA	< >
Protein (g)	87 \pm 28	69	53-80 [⊥]	NA	< >
Calcium (mg)	1001 \pm 392	1041	\geq 1000	NA	< >
Copper (mg) [∨]	1.6 \pm 0.6	1.5	\geq 0.9	5	< >
Iron (mg)	13.8 \pm 4.6	16.4	\geq 29.4 [§]	50 †	- 13
Iodine (μ g) [∨]	211 \pm 98	185	\geq 150	600	< >
Potassium (g) [∨]	3.4 \pm 1.2	3.2	\geq 4.7	NA	- 1.5
Magnesium (mg) [∨]	458 \pm 148	379	220-310	NA	< >
Sodium (mg) [∨]	2787 \pm 1065	1261	<1500	NA	< >
Phosphorous (mg) [∨]	1406 \pm 438	1241	\geq 700	NA	< >
Zinc (mg)	11.0 \pm 3.6	10.5	7.2-9	25	< >
Vitamin A (μ g RE)	851 \pm 1279	1668	500-700	3000	< >
Thiamin (mg)	1.3 \pm 0.4	1.1	\geq 1.1	NA	< >
Riboflavin (mg)	1.6 \pm 0.6	1.7	\geq 1.1	NA	< >
Niacin equivalents (mg)	21.3 \pm 10.8	16.4	14-16	900 °	< >
Vitamin B6 (mg)	1.5 \pm 0.6	1.4	\geq 1.3	25	< >
Folate (μ g)	308 \pm 130	407	\geq 400	1000	< >
Vitamin B12 (μ g)	6.0 \pm 5.6	9.6	\geq 2.4	NA	< >
Vitamin C (mg)	152 \pm 94	189	45-75	NA	< >
Vitamin D (μ g)	3.3 \pm 3.5	7.9	5-10	100	< >
Vitamin E (mg) [∨]	11.9 \pm 6.4	12.3	7.5-15	300	< >

^{||} Energy and nutrient content of the set of dietary advice was estimated using the average serving size and nutrient content of its recommended food groups, subgroups and food items,, as detailed in **Supplemental Material 1**.

[∨] Nutrient not modeled in Optifood.

[□] Recommended energy intake estimated from the mean basal metabolic rate (Henry, 2005), calculated from the mean body weight of the women surveyed (73.9 kg), and multiplied by a Physical Activity Level (PAL) of 1.4.

[⊥] Macronutrients recommended intakes are based on WHO/FAO population goals: Carbohydrate 55-75% total energy intake (TEI); Fibers > 25g/day; Total fat 15-30%TEI; SFAs < 10%TEI, Protein 10-15%TEI (World Health Organization and Food and Agriculture Organization of the United Nations, 2003).

[#] No recommendation exists on total sugars intakes. Since free sugars should be limited to 5-10%TEI (World Health Organization, 2015), we assumed that total sugars intakes should be limited to \leq 10%TEI.

⁺ Recommendations for all micronutrients except iron are based on Egyptians RNIs for 19-30 year-old women (Ministry of Health Egypt, 2004).

[§] For iron, a bioavailability of approximately 10% is assumed (10), therefore leading to a RNI of 29.4 mg/day (World Health Organization, 2004b).

^{*} Safety limits are based on the European food safety authority reports (European Food Safety Authority, 2018). *NA* indicates that no safety limit was defined for the given nutrient (European Food Safety Authority, 2018).

[†] Safety limit for iron is based on temporary guidance level suggested by Rasmussen et al.(49) since no value was provided by the European food safety authority.

° Safety limit for niacin is expressed in nicotinamide (900 nicotinamide per day).< > This symbol indicates that the dietary advice's mean nutrient content is within or above the daily recommended nutrient intakes and is below safety limit (when applicable).

Table 4. Minimum nutrient content (expressed as % of the RNIs) and cost of the sets of dietary advice tested, including or not fortified foods (outputs of minimization analyses performed in Module III).

	Nutrients modeled in Optifood (% RNI)												Cost (EGP/d)
	Calcium	Iron	Zinc	Vitamin A	Thiamin	Riboflavin	Niacin	Vitamin B6	Folate	Vitamin B12	Vitamin C	Vitamin D	
Set of dietary advice based on locally consumed non-fortified foods only *	90	40	+	+	57	+	70	75	60	+	+	+	22
Sets of dietary advice including one fortified food (number of servings per week) **:													
<i>Baladi</i> bread (21)	96	62	+	+	95	+	70	83	75	+	+	+	22
Beans, cooked as <i>fuul</i> (7)	92	56	+	+	65	+	78	76	65	+	+	+	21
Rice (4)	86	85	+	+	56 α	+	64 α	68 α	44 α	+	+	+	20
Spread cheese (7)	97	45	+	+	61	+	94	75	61	+	+	+	23
Milk (10)	84	65	+	+	57	+	75	77	60	+	+	+	19
Yoghurt, non-fortified + cereals, fortified (7)	89	51	+	+	76	+	76	76	79	+	+	+	22
Yoghurt, highly fortified (7)	85	61	+	+	61	78	70	84	119	+	+	+	15
Water (21)	95	63	94	+	59 #	+	58 #	75	60	+	+	+	21

Cells are shaded in grey when the value is below 70% of the RNI.

+ \geq 99% of RNI.

* The set of dietary advice modeled from consumed foods only (no fortified food) is the following: vegetables (3 times per day), legumes, grains and tahini (once per day for each), milk/yoghurt and fruits (twice per day for each), Nile fish and red meat (twice per week for each), liver (once per week) and eggs (4 times per week).

** The sets of dietary advice including fortified products could vary slightly from the one modeled with consumed food only as detailed in **Table 5**.

α The minimized values for thiamin, niacin, vitamin B6 and folate for the set of dietary advice including fortified rice are lower than those for the set made of non-fortified foods only, presumably, because of the removal of "legumes". Legumes had to be removed because of the energy constraint.

The minimized values for thiamin and niacin for the set of dietary advice with fortified water are lower than those for the set made of non-fortified food only, because red meat was removed from this set of dietary advice.

Table 5. Comparison of sets of dietary advice including or not fortified products

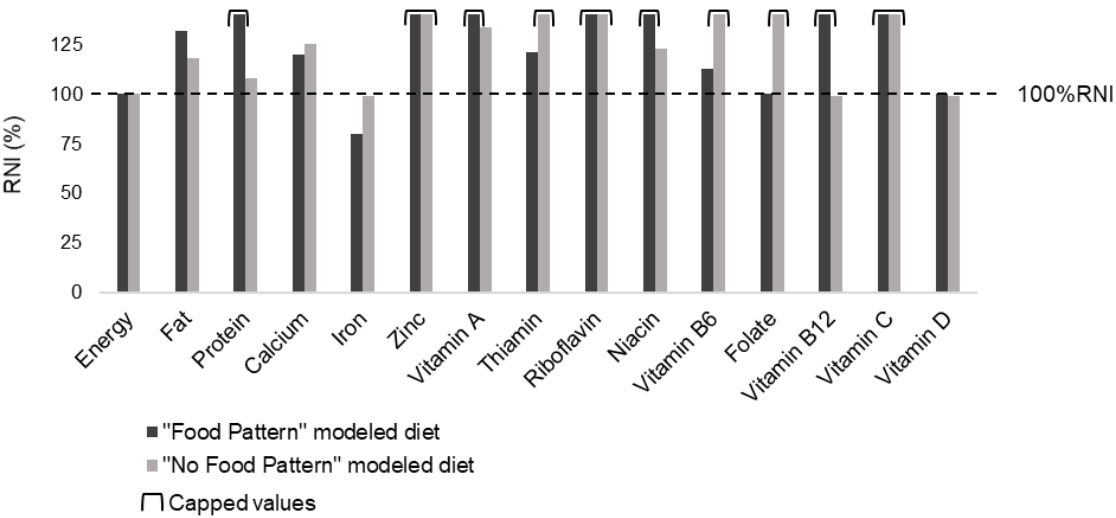
Fortified foods * number of servings per week	Non-fortified foods: number of servings per week included in the sets of dietary advice									
	Vegetables	Legumes	Grains & grain products	Milk or Yoghurt	Fruits	Tahini	Nile fish (Tilapia)	Red meat	Liver	Eggs
No fortified food ^a	21	7	7	14	14	7	2	2	1	4
<i>Baladi</i> bread * 21	"	"	"	"	"	"	"	"	"	"
Beans (cooked as <i>fuu</i>) * 7	"	0	"	"	"	"	"	"	"	"
Rice *4	"	0	"	"	"	"	"	"	"	"
Spread cheese * 7	"	"	"	"	"	"	"	"	"	"
Milk * 10	"	"	"	0	"	"	"	"	"	"
Yoghurt, non-fortified + cereals, fortified * 7 "	"	"	"	7	"	"	"	"	"	"
Highly-fortified yoghurt * 7	"	"	0	0	0	"	"	0	"	0
Water * 21	"	"	"	"	"	"	"	0	"	"

^a "No fortified food" represent the best modeled set of dietary advice identified from locally consumed, non-fortified foods only.

" Same number of servings per week than when no fortified food was included in the set of dietary advice (first line of this table, "No fortified food").

FIGURES

Figure 1. Energy and nutrient content of the 2 best possible diets modeled with Optifood from locally-consumed foods, for the diet that did not include goals for food groups (“No Food Pattern” diet, in light grey) or the diet that included goals to achieve the population’s median food group patterns (“Food Pattern” diet, in dark grey). Nutrient values were capped when they exceeded 135% of RNIs, to allow a better graphical visualization of nutrients below 100% RNIs in these 2 best possible modeled diets.



Local foods can ensure nutrient adequacy except for iron in urban Egyptian women – results from diet modeling analyses, Brouzes et al.

SUPPLEMENTAL MATERIAL & DATA

Supplemental Material 1. Average contribution of non-modeled nutrients in the sets of dietary advice

Since it is not possible to set parameters on all nutrients in Optifood (only 3 macronutrients and 12 micronutrients modeled), we checked that the set of dietary advice modeled ensured adequate levels for other nutrients, not modeled in Optifood: total sugars, fibers, SFAs, sodium, potassium, phosphorous, magnesium, iodine, copper and vitamin E. The nutrient content provided by the set of dietary advice was estimated from the mean nutrient content of each “component” of the set of dietary advice multiplied by the recommended number of servings and the serving size.

$$\text{Average nutrient content of the dietary advice} = \sum_{i=1}^n \frac{\text{Nutrients}_i}{100} * \text{Servings}_i * \text{Portion}_i$$

Where i is one of the 1 to n component of the set of dietary advice (i.e. recommended food item, food subgroup or group). Nutrients_i is the mean energy and nutrient content (expressed in unit per 100 grams of edible product) of this component i , Servings_i is the recommended number of servings; Portion_i is the serving size (in grams), estimates based on the intake data from the dietary survey. Serving size of food groups (and subgroups) that were included in a set of dietary advice, gathering l food items k , was calculated as the mean serving size of the food items in this food group (or subgroup) weighted by the number of consumers of each food item among the food group or subgroup.

$$\text{Portion}_i = \sum_{k=1}^l \frac{\text{Portion}_k * \text{ConsumersFood}_k}{\text{ConsumersGroup}_i}$$

With Portion_i the average serving size of food group (or subgroup) i , Portion_k the median serving size among consumers of food item k among 19-30 yo women, ConsumersFood_k the number of subjects who declared consuming >0g of the food item k during the four days of dietary record, and ConsumersGroup_i the number of subjects who declared consuming >0g of the food group during the dietary survey.

When a set of dietary advice included specific food items (e.g. “*Tilapia fish*” or “*Alexandrian style liver*”), Nutrients_i was simply the energy and nutrient content of this food item (data from the food composition table). When the set of dietary advice included food groups or subgroups (e.g. “*Fruits*”) regrouping m food items (e.g. “*Banana*”, “*Orange*”, “*Strawberry*”, “*Mango*”), its mean energy and nutrient content was calculated as the mean energy and nutrient content of each food group or subgroup, weighted by the number of consumers of each food item among the food group or subgroup.

$$\text{Nutrients}_i = \sum_{j=1}^m \frac{\text{NutrientsFood}_j * \text{ConsumersFood}_j}{\text{ConsumersGroup}_i}$$

With NutrientsFood_j the energy and nutrient content of food item j , ConsumersFood_j the number of subjects who declared consuming >0g of the food item j during the four days of dietary record, and ConsumersGroup_i the number of subjects who declared consuming >0g of the subgroup or group during the dietary survey.

The average nutrient content of the set of dietary advice was then compared with recommended nutrient intakes (or population goals for macronutrients) and upper toxicological limits, when applicable.

Supplemental Material 2. Estimation of the cost of food groups and subgroups included in the sets of dietary advice modeled as an indicator of acceptability.

As an indicator of acceptability, the cost of each component of the final set of dietary advice was estimated.

The average cost of the i recommended food groups and subgroups was estimated based on the cost of food items included in the given food groups (or subgroups) and the number of consumers of each item among this food group (or subgroup).

$$Cost_i = \sum_{k=1}^l \frac{Cost_k * ConsumersFood_k}{ConsumersGroup_i}$$

With $Cost_i$ the average cost of food group (or subgroup) i , $Cost_k$ the cost of food item k , $Consumers Food_k$ the number of subjects who declared consuming >0g of the food item k during the four days of dietary record, and $Consumers Group_i$ the number of subjects who declared consuming >0g of the food group during the dietary survey.

Supplemental Table 1. Parameters for modeling the “best diets” (Optifood’s Module II, goal programming analyses) and for testing sets of dietary advice (Optifood’s Module III, linear programming analyses)

Category	Parameter (unit)	Value	Rationale	Setting for modeling the “best diets” (Optifood Module II, goal programming)	Setting for testing sets of dietary advice (Optifood Module III, linear programming)
Nutrition	Energy (kcal/d)	2135	Henry et al. for BMR calculation (Henry, 2005). Physical activity level of 1.4 assumed (Food and Agriculture Organization et al., 2004) and mean body weight of 73.9 kg.	Equality constraint	Equality constraint
	Protein (g/d)	67	12.5% total energy intake (World Health Organization and Food and Agriculture Organization of the United Nations, 2003)	Goal	Minimization*
	Fat (%TEI/d)	30	Upper bound of population goals (15-30% total energy intake) (World Health Organization and Food and Agriculture Organization of the United Nations, 2003)	Goal	Minimization*
	Calcium (mg/d)	1000	Egyptian RNIs (Ministry of Health Egypt, 2004)	Goal	Minimization*
	Iron (mg/d)	29.4	Egyptian RNIs (Ministry of Health Egypt, 2004) #	Goal	Minimization*
	Zinc (mg/d)	7.2	Egyptian RNIs (Ministry of Health Egypt, 2004) □	Goal	Minimization*
	Vitamin A (µg retinol equivalent/d)	500	Egyptian RNIs (Ministry of Health Egypt, 2004) □	Goal	Minimization*
	Thiamin (mg/d)	1.1	Egyptian RNIs (Ministry of Health Egypt, 2004)	Goal	Minimization*
	Riboflavin (mg/d)	1.1	Egyptian RNIs (Ministry of Health Egypt, 2004)	Goal	Minimization*
	Niacin (mg/d)	14	Egyptian RNIs (Ministry of Health Egypt, 2004) □	Goal	Minimization*
	Vitamin B6 (mg/d)	1.3	Egyptian RNIs (Ministry of Health Egypt, 2004)	Goal	Minimization*
	Folates (µg dietary folates equivalent/d)	400	Egyptian RNIs (Ministry of Health Egypt, 2004)	Goal	Minimization*
	Vitamin B12 (µg/d)	2.4	Egyptian RNIs (Ministry of Health Egypt, 2004)	Goal	Minimization*
	Vitamin C (mg/d)	45	Egyptian RNIs (Ministry of Health Egypt, 2004) □	Goal	Minimization*
Vitamin D (µg/d)	5	Egyptian RNIs (Ministry of Health Egypt, 2004) □	Goal	Minimization*	
Economic	Cost (EGP/d)	42	Mean observed diet cost for 19-30yo Egyptian women.	Upper constraint	Minimization*

□ Since zinc, vitamin A, niacin, vitamin C, and vitamin D RNIs were expressed as a range by the Egyptian minister of Health and WHO (Ministry of Health Egypt, 2004), the lower bound of the range was taken as goal in this study.

For iron, a bioavailability of approximately 10% was assumed (World Health Organization 2004, Brouzes, Darcel et al. 2020)

* Module III runs successive minimization analyses for each nutrient and cost (Ferguson et al., 2006)

Supplemental Table 1 - **continued**

Category	Parameter (unit)	Value	Rationale	Setting for maximization analyses (Optifood Module II, goal programming)	Setting for minimization analyses (Module III, linear programming)
Acceptability	Minimum for each food group (number of servings per week)	See suppl. Table 2	10th percentile among the whole population	Lower constraint	Lower constraint
	Average servings for each food group (number of servings per week)	See suppl. Table 2	Mean number consumptions per week of each food group, among all women surveyed	Goal (only in the "Food Pattern" diet)	-
	Maximum for each food group (number of servings per week)	See suppl. Table 2	90 th percentile among the whole population	Upper constraint	Upper constraint
	Minimum for each food subgroup (number of servings per week)	See suppl. Table 2	10th percentile of frequency of consumption reported by the consumers of each food subgroup	Lower constraint	Lower constraint
	Maximum for each food subgroup (number of servings per week)	See suppl. Table 2	90th percentile of frequency of consumption reported by the consumers of each food subgroup	Upper constraint	Upper constraint
	Minimum for each food item (number of servings per week)	See suppl. Table 2	10th percentile of frequency of consumption reported by the consumers of each food item	Lower constraint	Lower constraint
	Maximum for each food item (number of servings per week)	See suppl. Table 2	90th percentile of frequency of consumption reported by the consumers of each food item	Upper constraint	Upper constraint
Draft set of dietary advice	Dietary advice (number of servings per week of food groups, subgroups and/or food items included in the draft set tested)	See Table 2 or Suppl table 3	Selected based on the Module II diets	-	Lower constraints

Supplemental Table 2. Groups, subgroups and food items parameters used for diet modeling analyses performed with Optifood

Food groups	Food subgroups	Food items	Group parameters (servings per week)			Subgroup parameters (servings per week)		Food items parameters (servings per week and serving size)		
			Min ¹	Average ²	Max ¹	Min ¹	Max ¹	Min ¹	Max ¹	Serving size (g) ¹
Grains & grain products			0	6	14					
	Refined grain products (rice, pasta, noodles, couscous)					0	14			
		Rice, white, long-grain, cooked						0	7	290
		Rice with broken vermicelli						0	7	303
		Pasta with tomato sauce						0	14	221
		Egyptian rice dish - Sayadia						0	7	196
		Bechamel pasta						0	14	266
Bakery products			0	12	21					
	Bread					0	21			
		Bread, Baladi (Egyptian bread)						0	21	50
		Bread, Shami, Shamy						0	14	60
		Bread, French, Fino						0	14	80
		Crackers						0	12	31
		White wheat bakers roll						0	14	114
	Sweetened bakery products					0	7			
		Basbusa, Basbuosa & Harissa, dessert						0	7	86
		Chocolate cake						0	9	86
		Fancy fruit cake						0	7	86
		Filled tea biscuit, chocolate coated						0	7	32
		Sandwich, halva (halawa tehenya), on Shamy bread						0	7	120
		Tea biscuits						0	7	48
		Waffles						0	7	32
Potatoes			0	3	7					
	Potatoes					0	7			
		Potato, fried in oil						0	7	184
		Potato, baked						0	14	184
		Potato puree						0	7	88

Supplemental Table 2 – continued

Food groups	Food subgroups	Food items	Group parameters (servings per week)			Subgroup parameters (servings per week)		Food items parameters (number of servings per week and serving size)		
			Min ¹	Average ²	Max ¹	Min ¹	Max ¹	Min ¹	Max ¹	Serving size (g) ¹
Legumes, nuts & seeds			0	5	14					
	Legumes					0	14			
		Broad bean stewed, <i>Fuul</i>						0	7	140
		Falafel						0	7	80
	Unsalted nuts and seeds					0	1			
		Pumpkin seeds, peeled, dried						0	7	40
	Salted nuts and seeds					0	7			
		Nuts and seeds, mix						0	7	50
		Peanut, oil-roasted, salted						0	7	30
		Sesame butter, paste						0	7	30
Dairy products			0	14	28					
	Milk					0	14			
		Milk sterile 3.5% milk fat						0	14	200
	Flavored milk					0	1			
		Cacao drink, with milk, sweetened, prepared						0	14	50
	Yoghurt, plain or sweetened					0	7			
		Yoghurt fruit, strawberry						0	7	150
		Yoghurt, 3.2% milk fat						0	7	130
	Sweetened dairy desserts					0	1			
		Rice pudding, with milk						0	7	196
		Salep, Sahlab drink						0	7	196
	Hard cheese					0	7			
		Cheese, cheddar						0	7	60
		Cheese, parmezan						0	7	24
	White cheese					0	14			
		Cheese processed, spreadable						0	7	60
		Cheese, cottage (Kareesh, Karish)						0	7	40
		Cheese, feta						0	14	50
		Cheese, white, fresh, unripened, full milk						0	14	60

Supplemental Table 2 – continued

Food groups	Food subgroups	Food items	Group parameters (servings per week)			Subgroup parameters (servings per week)		Food items parameters (number of servings per week and serving size)							
			Min ¹	Average ²	Max ¹	Min ¹	Max ¹	Min ¹	Max ¹	Serving size (g) ¹					
Meat, fish & eggs	Red meat	Minced meat, beef, stir fried	0	8	14	0	7	0	7	146					
		Poached beef meat						0	7	216					
		Rissole - Kofta meat						0	7	300					
	Poultry	Chicken breast, fillet, breaded, fried				0	7	0	7	146					
		Chicken, cooked in water						0	7	102					
		Chicken, pieces, fried						0	7	155					
		Chicken, roasted						0	7	102					
		Griddled chicken breast						0	7	146					
		Eggs						0	7	Egg, white, fried	0	12	120		
	Egg, whole, boiled	0				7	70								
	Fish without bones	Catfish, grilled				0	7	0	7	200					
		Tilapia, fried in oil						0	7	222					
		Tuna, in oil, canned						0	7	140					
	Organ meat	Alexandrian Style Liver				0	1	110							
	Processed meat	Luncheon meat, beef				0	7	0	7	48					
								0	7	48					
	Fruits	Vitamin C-rich fruits (citruses, pineapple, strawberries...) 3					0	6	14	0	14	Lemon	0	7	54
						Mandarine, Tangerine						0	7	100	
						Orange						0	14	148	
Strawberry			0	7	108										
			0	7	108										
Other fruits		Apple, whole, raw	0	7	0	14				170					
		Banana			0	11				180					
		Grape			0	7				200					

Supplemental Table 2 – continued

Food groups	Food subgroups	Food items	Group parameters (servings per week)			Subgroup parameters (servings per week)		Food items parameters (number of servings per week and serving size)		
			Min ¹	Average ²	Max ¹	Min ¹	Max ¹	Min ¹	Max ¹	Serving size (g) ¹
Vegetables			0	9	21					
	Vitamin A-source vegetables ⁴					0	7			
		Carrot						0	7	44
		Jews mallow dish						0	7	110
		Watercress						0	7	30
	Vitamin C-rich vegetables ³					0	14			
		Cabbage rolls						0	7	227
		Salad, egyptian (cucumber, salad and tomatoes)						0	7	60
		Pepper, green						0	7	100
		Tomato, raw						0	11	161
	Other vegetables					0	14			
		Cucumber, raw						0	14	118
		Fried pickled eggplant						0	7	146
		Green bean stew						0	8	203
		Lettuce						0	7	100
		Onion						0	7	112
		Peas with carrots in tomato sauce						0	10	186
		Spinach, cooked						0	10	167
		Zucchini with tomato						0	14	65
Added fats			0	2	7					
	Vegetable oil					0	7			
		Oil, sunflower, refined						0	14	15
	Butter, ghee, margarine					0	1			
		Ghee						0	7	17

Supplemental Table 2 – continued

Food groups	Food subgroups	Food items	Group parameters (servings per week)			Subgroup parameters (servings per week)		Food items parameters (number of servings per week and serving size)		
			Min ¹	Average ²	Max ¹	Min ¹	Max ¹	Min ¹	Max ¹	Serving size (g) ¹
Added sugars			0	14	28					
	Sugar					0	28			
		Sugar, white						0	28	10
	Honey, molasse					0	1			
		Honey						0	11	30
		Molasses						0	7	45
Sweet snack foods (candy and chocolate)			0	1	7					
	Sweet snack foods (candy and chocolate)					0	7			
		Halva, sesame						0	7	55
		Milk chocolate						0	7	28
Beverages			21	50	91					
	Brewed coffee (w/wo sugar or milk)					0	7			
		Coffee instant, 3 in 1, beverage						0	7	200
		Coffee instant, classic, beverage						0	14	200
	Brewed tea, herbal infusions (w/wo sugar or milk)					0	21			
		Tea black- beverage						0	21	200
		Tea herbal- Mint- beverage						0	9	200
		Tea with milk, beverage						0	7	200
	Juices & nectars, vitamin C-rich 5					0	7			
		Lemonade						0	7	225
		Nectar, mango						0	7	235
		Orange juice, fresh						0	7	200

Supplemental Table 2 – continued

Food groups	Food subgroups	Food items	Group parameters (servings per week)			Subgroup parameters (servings per week)		Food items parameters (number of servings per week and serving size)		
			Min ¹	Average ²	Max ¹	Min ¹	Max ¹	Min ¹	Max ¹	Serving size (g) ¹
Miscellaneous	Juices & nectars, other					0	1			
		Apple juice						0	7	230
	Sodas					0	7			
		Coca-Cola						0	14	330
	Water					14	56			
		Water, still, Nestle						0	28	100
		Water, tap						0	56	250
			0	5	14					
	Condiments, herbs, spices					0	14			
		Black pepper, ground						0	14	0.5
		Cumin seeds						0	7	0.5
		Garlic						0	7	16
		Parsley, leaf, raw						0	7	6
		Salt, marine						0	14	0.5
	Sauces							0	1	
	Tomato, ketchup							0	25	10
Jams							0	1		
	Jam, strawberry							0	7	38
Savory snacks					0	3	7			
	Savory snacks, salted, spiced, fried, pickles						0	7		
	Mixed pickles							0	7	56
	Olive, ripe, raw							0	7	25
	Popcorn							0	7	40
	Potato, chips, all sorts							0	7	47
	Salty sticks							0	10	60
	Snacks, sesame sticks, salted							0	7	80

Supplemental Table 2 – continued

Food groups	Food subgroups	Food items	Group parameters (servings per week)			Subgroup parameters (servings per week)		Food items parameters (number of servings per week and serving size)		
			Min ¹	Average ²	Max ¹	Min ¹	Max ¹	Min ¹	Max ¹	Serving size (g) ¹
Composites (mixed food groups)			0	5	14					
	Main meal recipes ⁶					0	7			
		Moussaka						0	7	180
		Rice with chicken						0	7	243
		Spagetti Bolognaise						0	7	196
		Taro stew						0	7	216
		Tray of potato with chicken, baked						0	7	264
	Sandwiches ⁷					0	7			
		Sandwich, broad bean in Baladi bread						0	7	140
		Sandwich, burger						0	8	400
		Sandwich, falafel, in Baladi (Egyptian) bread						0	7	110
		Sandwich, fried potatoes, Egyptian (baladi) bread						0	7	157
		Sandwich, Roumy (Ras) cheese, in French bread						0	7	150
		Sandwich, with breaded chicken breast in French bread						0	13	350
		Sandwich, with feta cheese in Baladi bread						0	7	150
		Sandwiches, shawerma meal						0	7	290
		Feteer meshaltet, layered pastry						0	7	120
		Pizza						0	7	237
	Vegetarian recipes ⁸					0	1			
		Koshary, Koshari						0	7	250
		Potato with tomato sauce						0	7	140
	Soups					0	1			
		Chicken soup						0	7	253
		Lentil, yellow, soup						0	7	200

Supplemental Table 2 – **continued**

¹ Minimum and maximum number of servings per week for all food groups, subgroups and food items, as well as serving sizes were defined as constraints in the modeling analyses. Optifood could adjust food quantities in the output modeled diets by playing on frequencies of consumption per week, but serving remain constant

² The average number of servings per week for food groups is used as a proxy of acceptability for some analyses with Optifood. It was used as a goal in a first series of analyses modeling the best possible diets minimizing deviation from nutrient, cost and acceptability goals.

³ Vitamin C-rich fruits and vegetables are defined as those containing ≥ 18 mg/100 g of vitamin C in the form in which they are eaten. Vitamin C-rich fruits and vegetables are not included here if they are categorized as vitamin A sources.

⁴ Fruit and vegetable sources of vitamin A are defined as those containing ≥ 120 RE/100 g (or ≥ 60 RAE/100 g) in the form in which they are eaten. Fruit and vegetable sources of vitamin A are included in this group even if they are also vitamin C-rich.

⁵ Vitamin C-rich juices or nectars are defined as those containing ≥ 9 mg/100 g of vitamin C.

⁶ Main meal recipes are defined as dishes containing an animal protein source (meat, fish or eggs) as well as grains, legumes or vegetable products.

⁷ The “sandwiches” subgroup includes grain products with fillings such as sandwiches, pizzas, burgers or savory pies. As sandwiches were the predominant food consumed from this subgroup, it is referred to as “sandwiches”.

⁸ Vegetarian recipes include dishes containing vegetables and/or legumes and/or grain products.

Supplemental Table 3. Composition of the 4 best sets of dietary advice modeled, which performed similarly in the minimization analyses (Optifood's Module III)

Number of servings per week	Set of dietary advice n°			
	1	2	3	4
Grains	7	7	7	7
Fruits	14	14	14	14
Vegetables	21	21	21	21
Milk and/or yoghurt	14	14	14	14
Tahini	7	7	7	7
Legumes	7	7	7	7
Broad beans	-	-	-	4
Meat, fish and eggs	14	-	-	8
Eggs	4	4	4	-
Fish, tilapia	2	2	2	2
Liver	1	1	1	1
Red meat	-	2	2	-
Molasses	-	-	7	-

⌞ The recommended number of servings of these food subgroups are included in the recommended number of servings of the group "Meat, fish and eggs" (e.g. "14 servings of "meat, fish and eggs", including 4 servings of eggs, 2 servings of fish, tilapia and 1 serving of liver per week, for the set of dietary advice n°1)

⌞ The recommended number of servings for Broad beans is included in the number of servings of Legumes (i.e., 7 servings of legumes per week, including 4 servings of broad beans)

Supplemental Table 4. Average nutrient content of the 4 best sets of dietary advice modeled, which performed similarly in the minimization analyses (Optifood's Module III) *

Set of dietary advice n°	1	2	3	4	Recommended intake
	Average energy and nutrient values (unit per day)				
Energy (kcal)	1742	1573	1699	1542	2135 ^α
Carbohydrate (g)	181	175	206	177	294-400 [⊥]
Total sugars (g) ^γ	52	52	84	52	<53 [#]
Fibers (g) ^γ	19	19	19	20	≥25 [⊥]
Total fat (g)	76	67	67	61	36-71 [⊥]
SFAs (g) ^γ	21	18	18	17	<24 [⊥]
Protein (g)	82	69	69	70	53-80 [⊥]
Calcium (mg)	1074	1041	1054	1038	≥1000
Copper (mg) ^γ	1.7	1.5	2.3	1.6	≥0.9
Iron (mg)	17.9	16.4	19.0	16.3	≥29.4 [§]
Iodine (μg) ^γ	207	185	185	177	≥150
Potassium (g) ^γ	3342	3162	3792	3247	≥4.7
Magnesium (mg) ^γ	395	379	487	388	220-310
Sodium (mg) ^γ	1506	1261	1301	1345	<1500
Phosphorus (mg) ^γ	1401	1241	1241	1265	≥700
Zinc (mg)	10.8	10.5	10.8	9.6	7.2-9
Vitamin A (μg RE)	2167	1668	1668	1935	500-700
Thiamin (mg)	1.2	1.1	1.1	1.1	≥1.1
Riboflavin (mg)	1.9	1.7	1.7	1.7	≥1.1
Niacin equivalents (mg)	21	16	16	18	14-16
Vitamin B6 (mg)	1.6	1.4	1.4	1.5	≥1.3
Folate (μg)	441	407	407	404	≥400
Vitamin B12 (μg)	12.1	9.6	9.6	10.2	≥2.4
Vitamin C (mg)	193	189	189	194	45-75
Vitamin D (μg)	9.6	7.9	7.9	8.3	5-10
Vit E (mg) ^γ	14.1	12.3	12.3	10.7	7.5-15

* Cells are shaded in grey when the average nutrient content differs from recommendations.

^γ Nutrient not modeled in Optifood

^α Recommended energy intake estimated from the mean basal metabolic rate (Henry 2005), calculated from the mean body weight of the women surveyed (73.9 kg), and multiplied by a Physical Activity Level (PAL) of 1.4 (Brouzes, Darcel et al. 2020).

[⊥] Based on WHO/FAO population goals: Carbohydrate 55-75%TEI; Fibers > 25g/day; Total fat 15-30%TEI; SFAs < 10%TEI, Protein 10-15%TEI (World Health Organization and Food and Agriculture Organization of the United Nations 2003).

[#] No recommendation exists on total sugars intakes. Since added sugars should be limited to 5-10%TEI (World Health Organization 2015), we assumed that total sugars intakes should be limited to ≤10%TEI.

⁺ Recommendations for all micronutrients except iron are based on Egyptians RNIs for 19-30-year-old women (Ministry of Health Egypt 2004).

[§] For iron, a bioavailability of 10% is assumed, therefore leading to a RNI of 29.4 mg/day (World Health Organization 2004, Brouzes, Darcel et al. 2020).

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3.3. Acceptabilité des stratégies d'amélioration nutritionnelle identifiées

3.3.1. Contexte et objectifs de l'étude

Bien que les analyses par modélisation aient été paramétrées à l'aide de données locales de consommation, il n'est pas possible de prédire l'acceptabilité des stratégies modélisées. Des indicateurs quantitatifs permettent d'anticiper les réticences potentielles à la consommation d'aliments relativement chers (comme la viande rouge ou le poisson) ou consommés dans des fréquences ou des quantités inférieures à celles recommandées (ce qui concernait tous les aliments recommandés sauf les produits céréaliers et les légumineuses). Mais les barrières et leviers qui empêcheraient ou faciliteraient l'adoption du jeu de conseils alimentaires modélisé ne peuvent être identifiés que par une évaluation directe d'acceptabilité auprès des populations locales concernées.

Les études qualitatives comme les focus groupes et les entretiens individuels permettent de collecter avec des moyens humains et financiers limités des données sur les perceptions des individus (Saks and Allsop, 2012). Les focus groupes sont des groupes de discussions constitués généralement d'un modérateur et de 6 à 10 individus sollicités pour réagir sur un service ou un produit. Cette technique permet d'évaluer les perceptions collectives des utilisateurs potentiels. Les focus groupes nécessitent la rédaction préalable d'un guide de discussion qui permet au modérateur de structurer et d'orienter les échanges en vue d'aborder les différentes facettes à explorer. Les entretiens individuels semi-directifs sont par définition des entretiens réalisés par un enquêteur avec un seul participant à la fois. Ces entretiens individuels fournissent, *via* les expériences personnelles de la personne interrogée, des informations sur ses aspirations, ses contraintes (liées à son mode de vie par exemple) et ses représentations du produit ou service concerné (Saks and Allsop, 2012).

Dans ces travaux, 18 entretiens individuels ont été réalisés au domicile des femmes et 9 focus groupes (regroupant un total de 62 femmes) ont été organisés dans les locaux de PHI Market Research, qui sont équipés d'une vitre sans teint et de microphones. Ces études ont fourni des informations sur les perceptions positives et négatives associées à chacun des aliments, sous-groupes ou groupes alimentaires recommandés (en allant plus loin que les indicateurs quantitatifs tels que le prix et les fréquences de consommation observées décrits dans l'Article 2) et les types de barrières et leviers à prendre en considération pour promouvoir le jeu de conseils alimentaires. L'approche et les résultats obtenus sont décrits dans l'Article 3 ci-après.

3.3.2. Résumé des résultats de l'étude d'acceptabilité

Contexte : Les fortes prévalences de déficiences en fer (50%) et de surpoids (88% en zone urbaine) sont associés à des déséquilibres nutritionnels chez les femmes égyptiennes. Des conseils alimentaires spécifiques, formulés par modélisation, ont montré leur potentiel pour améliorer l'adéquation nutritionnelle des jeunes femmes résidant en zone urbaine. Cependant, l'acceptabilité de ces changements alimentaires doit être examinée.

Objectifs : L'objectif de cette étude était de décrire les perceptions des jeunes femmes résidant en Égypte urbaine à propos d'un jeu de conseils alimentaires préalablement mis au point par modélisation.

Méthodes : Des entretiens semi-directifs (n=18) et des focus groupes (n=62) ont été conduits au Caire avec un total de 80 femmes de classe moyenne âgées de 18 à 35 ans (étudiantes, femmes actives, femmes au foyer). Les bénéfices et inconvénients perçus pour chacun des aliments (ou groupes et sous-groupes d'aliments) inclus dans le jeu de conseils alimentaires ont été examinés. Les barrières et leviers à l'adoption de meilleures pratiques alimentaires ont été classifiés suivant les thèmes majeurs émergeant des discussions.

Résultats : Les résultats des entretiens et focus groupes montrent que la promotion du jeu de conseils alimentaires se heurterait à des perceptions positives et négatives pour chacun des aliments (ou groupes et sous-groupes d'aliments) recommandés. Par exemple, d'après les participantes, la consommation de fruits, légumes, lait ou yaourt aurait des bénéfices notables sur l'aspect des cheveux, des ongles et de la peau, alors le goût des légumes était critiqué. Les leviers pour adopter de meilleures pratiques alimentaires regroupaient la recherche de bénéfices esthétiques (par exemple. Le contrôle du poids corporel, une peau nette, des dents blanches, des ongles forts, une chevelure épaisse et soyeuse) et psychologiques (comme le fait d'améliorer leur confiance en elles ou l'image qu'elles ont d'elles-mêmes). Cependant, leur comportement curatif (c'est à dire le fait de ne pas mettre en place d'action préventive pour éviter des problèmes de santé), des contraintes liées à leur mode de vie (par exemple le fait que la plupart des étudiantes et femmes actives consomment leur repas hors-domicile) et des aspects socio-culturels ou économiques (*e.g.* la commensalité, le prix élevé de la viande rouge) peuvent constituer des barrières à l'adoption du jeu de conseils modélisé.

Conclusions : La motivation des jeunes femmes égyptiennes à suivre un jeu de conseils alimentaires repose sur des considérations hédoniques, pratiques et économiques, mais aussi sur la recherche de bénéfices esthétiques et psychologiques découlant des changements alimentaires à réaliser. La promotion de changements alimentaires pratiques, abordables, et améliorant l'adéquation nutritionnelle doit souligner les bénéfices d'une meilleure alimentation avec des messages adaptées à cette population.

Valorisation : Ce travail a fait l'objet d'une communication affichée. Un article est en cours de soumission dans le journal *Public Health Nutrition*, dont la version la plus récente est présentée ci-après.

3.3.3. Article 3

Women's concerns about dietary recommendations relate to taste, affordability, convenience, aesthetics and self-confidence: a qualitative evaluation in Egypt.

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ABSTRACT

OBJECTIVES: the acceptability of dietary recommendations in young urban Egyptian women that have the potential to improve iron intakes and nutrient adequacy.

DESIGN: Individual interviews and focus groups were conducted in Cairo. Perceived benefits and downsides for each recommended food were examined. Barriers and boosters for improving dietary practices were classified into major emerging themes.

SUBJECTS: 80 middle-class women aged 18-35 years (students, active women, and housewives).

RESULTS: Promoting the recommended foods would be met with both positive and negative feedback (e.g. positive impact of fruit, vegetables, milk or yoghurt consumption on hair, nails and skin appearance, bad taste of vegetables). Boosters for improving dietary practices included the pursuit of aesthetical (e.g. attaining/maintaining body shape, clear skin, bright teeth, strong nails, silky and thick hair) and psychological (e.g. improved self-confidence and self-esteem) benefits. Yet the "curative behavior" of the population targeted (i.e. changing dietary practices only when they face a serious issue), some life-stage related factors (e.g. students and active women consuming most of their meals out-of-home) and sociocultural and economic factors (e.g. social gatherings, high price of red meat) can constitute barriers for implementing a set of dietary recommendations.

CONCLUSION: The willingness of young urban Egyptian women to follow dietary recommendations relies on palatability, convenience and affordability, but also on the pursuit of aesthetic and psychological benefits. The communication of dietary advice should emphasize the benefits of healthier dietary choices with population-specific messages.

Keywords: Egyptian women, Dietary advice, Iron-deficiency anemia, Dietary practices, Motivations, Acceptability

INTRODUCTION

Young women from urban Egypt are in a context of nutrition-transition with high prevalence of overweight, excessive energy and sodium intakes, and insufficient iron, vitamin D and folate intakes ⁽¹⁾. Half of women in Egypt are iron-deficient ⁽²⁾, 72% are vitamin D deficient ⁽³⁾ and

15% folate deficient ⁽⁴⁾. Women are more affected than men by overweight and obesity (42.5% of women are obese versus 23.5% of men) ⁽⁵⁾. The urban female population has a particularly high prevalence of overweight and obesity (88%) ⁽⁶⁾, and their body mass index (BMI) increases with age, with values of 26.2 kg/m² and 32.4 kg/m² for women aged 15-19 and 40-49, respectively ⁽⁶⁾.

Using the Optifood software, we conducted a modeling analysis to develop a set of dietary recommendations based on locally consumed foods and fortified products, in an effort to improve nutrient adequacy while keeping costs affordable, for urban Egyptian women aged 19-30 years ⁽⁷⁾. Based on our analysis, we suggested dietary modifications that increase the consumption of fruit, vegetables, milk/yoghurt, and tahini (a sesame paste), specific food choices in the meat-fish-eggs category (e.g. red meat, Tilapia fish), and iron-fortified products ⁽⁷⁾. However, eating behavior is driven by a multitude of factors ⁽⁸⁻¹²⁾, and the acceptability of adopting these recommendations needs to be evaluated by the target population ⁽¹³⁾.

Interestingly, Middle Eastern beauty standards have evolved in younger generations—potentially paving the way to guide food choices. Female plumpness is traditionally perceived as “a sign of social status and [...] a cultural symbol of beauty, fertility and prosperity” ⁽¹⁴⁾; however, women today aspire to have a thinner physique. Studies conducted in the 2000s showed that school girls (aged 11 to 19 years from Egypt ⁽¹⁵⁾), and women (aged 18-52 years from Tunisia ⁽¹⁶⁾) prefer thin to normal body sizes compared plumpness. Similarly, young women from the United Arab Emirates expressed social pressure from their friends, families, and husbands to have a thin silhouette, while their grandparents still idealize female fatness ⁽¹⁷⁾. In Egypt, numerous advertisements promote weight loss, plastic surgery, skin treatments, and make-up to transform women’s bodies (more than men’s) so that they may “become responsible for their own happiness, marital happiness, and family harmony” ⁽¹⁸⁾.

Aside from the aforementioned the aesthetic drivers related to body weight, the life-stage of young urban Egyptian women, as well as economic constraints, possibly affect their willingness to improve their dietary practices and adopt the proposed set of dietary recommendations. Recent food price inflation in Egypt has resulted in a larger share of household income (about 40%) allocated to food ⁽¹⁹⁾. Additionally, young adulthood is a period of increased risk for weight gain, due to the major lifestyle changes that occur at this life-stage ⁽²⁰⁻²⁴⁾; these include the transition from student to working professional, leaving the family home, or getting married.

The present study aims to investigate the acceptability of our modeled dietary recommendations based on the food perception and willingness to change eating habits ⁽⁷⁾, in a population of 18-35 year old urban, middle-class Egyptian women (from students to young mothers), using a qualitative approach.

METHODS

Recruitment and study population

Middle class women living in Cairo were randomly contacted by phone through PHI Market Research’s¹² database and recruiters’ network. Women of target age (18-35 years) were asked if

¹² PHI Market Research is a research agency based in Cairo, with premises dedicated for focus groups (e.g. room with one-way mirror and microphones)

they were interested and available to participate in the study, and questioned about their socio-economic background. Exclusion criteria included any involvement of their relatives in the health or marketing sectors, or participation to another group discussion or interview in the same field in the past six months. Socio-economic class was assessed based on both the participant's (and her head of household's) educational attainment level, and her lifestyle (traveling habits inside Egypt and abroad, gym or club membership, brands usually bought, shops visited for groceries...) using an index adapted to the Egyptian context. Vouchers from one of the biggest supermarkets in Egypt were provided as incentives. The study was designed to conform with the European general data protection regulation. Notably, all participants were informed of the objectives of the study and gave their consent to the processing of their personal data, and answers were de-identified by pseudonymization.

Focus groups and individual interviews.

To investigate the acceptability of the our modeled dietary recommendations, a total of 80 middle class women, who were either university students, working women, housewives, with or without children, were recruited for focus group discussions (n=62) and individual interviews (n=18), as presented in **Table 1**. All studies were conducted in Egyptian Arabic by study moderators with experience in qualitative methods, using the following techniques: spontaneous associations, projective scenarios, and life narrative methods ^(25, 26).

Focus groups. Focus groups were used to encourage discussions and collective reactions rather than single opinions ^(25, 26); they were conducted on PHI market research's premises with women of comparable life-stages in each group: two focus groups were held with students in their 1st of 2nd year of college, two with students in their 3rd of 4th year of studies, two with married women and three with mothers; focus groups run with non-student women were conducted among both unemployed from employed women (**Table 1**). Moderators used a discussion guide (available in **Supplementary material 1**) to orientate conversation; they investigated the factors that encouraged or discouraged participants to mind what they eat with probing questions on the physical and psychological characteristics of peers that do not pay attention to what they eat. Afterwhich, the set of dietary recommendations was presented to the group as a diet plan created for a woman who would like to pay closer attention to what she eats. It was presented as a one-page illustration with pictures of recommended portion sizes, including: at least daily portions of vegetables (3 servings), grain or grain products (at least 1 serving), legumes (1 serving), tahini (1 spoon), fruit (2 servings), milk and/or yoghurt (2 servings), and weekly portions of local fish (*tilapia*, twice per week), red meat (twice per week), liver (once per week) and eggs (4 times per week) (**Figure 1**). Then, the factors that encouraged and discouraged participants to follow this set of recommendations were collectively discussed. Participants' awareness of the signs and symptoms of iron-deficiency anemia was also assessed using easily recognizable images showing the possible consequences of iron-deficiency anemia, such as fatigue, altered work performance, dizziness, pale skin, coldness in hands or feet, pain in the chest, hair loss, and brittle nails ^(27, 28) (**Figure 2**). Finally, the acceptability of introducing existing and theoretical iron-fortified products into the diet was discussed, since these products would help to increase iron intake ⁽⁷⁾.

Individual interviews. Individual semi-structured interviews were conducted to explore participants' dietary practices, and awareness of their body and health, with open-ended questions; this type of survey allows researchers to pursue the emergent themes of the interviewees' discussion ^(25, 26). Interviews were held at each participant's homes, lasted about two hours, and were conducted following the discussion guide presented in **Supplementary material 2**. Women were asked to narrate their typical eating habits throughout the day, to answer reflective questions (e.g. how would they define themselves based on what they eat, what would they give thumbs up and down for...) and to describe their lifestyles, habits, personality traits, and the appearance of a woman who they consider "very healthy" as well as a woman they consider "less healthy".

Data transcription and analysis

All focus group discussions and individual interviews were blindly transcribed in Arabic, and then translated into English by nine research assistants from PHI market research, so that both Arabic and non-Arabic speaking researchers could thoroughly read the transcripts. The quality of the Arabic and English-translated transcripts was checked by the research coordinator from PHI, who speaks both English and Arabic. Analyses began by splitting Arabic transcripts into pre-established themes in an Excel file for each of the recommended foods from the set of dietary recommendations, including the barriers and boosters for improving eating habits. Results were compared across socio-economic classes and profiles. Emerging themes were noted and explored throughout the analyses. The same task was concurrently conducted by non-Arabic speaking researchers, based on the English transcripts. Emerging themes from both teams were discussed collectively—in an effort to jointly analyze participants' perceptions our recommended foods, and the barriers and boosters that arose from the conversations.

RESULTS

The results did not differ across socio-economic classes and are therefore presented together.

Barriers and boosters for the recommended foods

All foods from the set of modeled dietary recommendations were perceived both positively and negatively by interviewees (Table 2). Perception related to either the consequences consuming the food (taste or effect on the body) or the characteristics of the food (convenience and price).

Perceived benefits. Positive perceptions of the recommended foods were related to: i) taste and satiability, ii) nutritional value, iii) perceived physical or physiological (i.e., health) benefits, and iv) convenience and affordability.

For taste and satiability, women described that they enjoy consuming several of the recommended foods, in particular fruit, grains, tahini, and liver. Legumes (*"It lasts in the stomach for long time."* (FG4)) and grains (*"I don't feel full without it."* (FG1)) were appreciated for their satiability.

The vitamin and mineral content of several of the recommended foods were cited as beneficial, although women sometimes had only approximative knowledge about it nutrient content. For example, fruit and vegetables were perceived as a source of vitamins, iron (and sometimes calcium) (*"Bananas have iron it is a source of antioxidants, kiwi, it decreases the amount of salt in the body, lemon as well contains vitamin C, cantaloupe it's good for the memory"* (I3))

while legumes, eggs, and red meat were cited as a source of protein (*"Beans contain protein which is very important to body."* (I7)). Milk and yoghurt were cited as a source of calcium (*"Yogurt like milk are very important and full of calcium"* (I1)) and fish was described to be rich in *"phosphorus"* (FG7) and *"omega 3"* (I1).

Participants repeatedly mentioned the benefits of some of the recommended foods on external physical aspects. For example, a participant stated that consuming *"anything green [...] gives you a good complexion"* (I7) while another mentioned that red meat *"builds muscles"* (FG9). Participants linked the physical benefits that they would get from some foods to certain nutrients that they thought these foods contained. For example, a student stated that milk and yoghurt *"include calcium"*, and *"are beneficial for teeth and nails. For hair also [...]"* (FG1), while another linked the vitamin content of vegetables to strengthening hair: *"vitamins will help improve the hair follicle itself. It will make it healthier and make it grow more."* (ID6).

Several of the recommended foods were perceived to have physiological and health benefits. Fish consumption, for example, was thought to improve cognitive capacity (*"If the pregnant woman eats fish, the baby will have sharp intelligence."* (FG7)), while milk and yoghurt would *"strengthen the bones"* (FG4). Interestingly, the physiological benefits of fortified products were highlighted for children, but not for adults. For example, a mother mentioned that *"kids get so active before swimming training"* (FG5) when consuming fortified products, and a student explained that children *"get teeth so fast"* when consuming fortified milk (FG2). Among the recommended foods, fruit and yoghurt were perceived as *"full of good effects and benefits"* (I6), even if the precise effects were not always clear (they *"impact [the] body internally"* (I6)). Some foods were also readily associated with improving anemia, such as liver, red meat or vegetables (*"Anybody who has anemia or lack of blood should eat liver."* (FG3), *"Meat contains protein and fix anemia."* (I1), *"[...] strengthen our body and protect us from anemia"* (I5)).

Participants highlighted the ease of use/preparation for several of the recommended foods, particularly liver (*"You could just cook it so quickly and make sandwiches for kids [...]"* (FG5)), fruit (*"I eat fruit as a snack and for dinner."* (FG6)) and yoghurt (*"We can eat it [yoghurt] as an alternative for the dinner."* (FG4)). Finally, women also stressed the affordability of several recommended foods, including grains (*"Price is reasonable and it is varied."* (FG8)), legumes (*"a cheap alternative for protein"* (FG3)), liver, and eggs (*"the cheapest animal protein we can buy."* (FG3)).

Perceived drawbacks. Reluctance to consume certain foods included in the dietary recommendations were largely linked to i) poor palatability and digestibility, ii) fear of weight gain or of health issues related to fat content, and iii) safety concerns and affordability.

Women had negative opinions about the taste of vegetables: *"Bad taste."* *"Boring."* *"Not many people love them."* (FG2). The smell and taste of eggs was also mentioned as a deterrent (*"I don't like its taste."* (FG3), *"It stinks as well."* (FG5)). Difficulties in digesting some of the recommended foods were also mentioned. According to some participants, the consumption of beans *"harms the colon"* (FG1), red meat is *"hard to be digested"* (FG2) and *"many people have allergy against lactose"* (FG7). Participants also expressed their worry of weight gain when consuming grain products (*"They make people fat, as my friends who want to gain weight, they keep eating carbs."* (FG6)) and tahini (*"It causes extra weight."* (FG5)). The negative impact of red

meat on the cardiovascular system was also mentioned by participants, who feared that it "*forms fats on heart*" (FG2) or "*makes cholesterol*" (FG9).

Food safety concerns was raised for red meat, liver, fish and vegetables. For example, mothers were apprehensive about the origin of meat: "*it might not be beef at all. It is easy for fraud makers.*" (FG7). Liver was perceived as "*a center of poisons in body*" containing "*bad blood*" (FG4). Students raised concern over fish sourced from the contaminated water of the Nile river: "*Because the Nile is polluted, and it might harm the fish itself.*" (FG2). Some participants were worried that vegetables were sprayed with chemicals ("*For me I am so worried about vegetables which are processed with insecticides and so on, which is really harmful*" (FG6)). Processed foods such as pasteurized milk and iron-fortified foods were also negatively perceived. Women believed, for example, that "*preservatives are added [to pasteurized milk] through machines to last longer*" (FG7), and that iron-fortified products are "*not beneficial like the natural one*" (FG4). Finally, the price of fruit, milk, yoghurt, and red meat were said to be too costly. Mothers explained that they would reduce the quantity of fruit purchased because of price: "*You may be obliged to get only 1 kilo instead of more because it is expensive*" (FG5).

Barrier and boosters for improving dietary practices

The factors that encouraged or discouraged participants to improve their dietary practices were classified into four major emerging themes: aesthetic, psychological, life-stage, and sociocultural and economic factors (Table 3).

Aesthetic factors. Women repeatedly mentioned following a diet or consuming specific foods in the pursuit of aesthetic benefits.

Aesthetic benefits refer to all positive effects on the external physical appearance, such as attaining or maintaining an ideal body shape, clear skin, bright teeth, strong nails, or silky and thick hair. For example, a woman recounted starting a diet because she wanted her "*appearance to look good, to look just right*" (I3). Another participant stated: "*I eat a lot of cucumber, rocca and parsley as they are making me have a fresher skin*" (I7). Statements linking specific foods with notable effects on skin, hair, nails, and teeth were frequent. **Table 2** reports that eight out of 12 of the recommended foods were perceived to have aesthetic benefits (fruit, vegetables, tahini, fish, eggs, fortified foods, milk and yoghurt). Yet, a lack of quick and tangible effects after changing dietary practices was cited as discouraging ("*I don't find a result in the first days*" (FG9)). Participants declared they would rather use cosmetic masks and creams to transform their appearance, rather than change their eating habits. For example, one woman explained: "*I eat a lot of fats, so my face will not look healthy, so I will try to compensate that with masks and creams and medicines*" (I6). Other women who were satisfied with their current physique, would not change their dietary practices.

Psychological factors. Several psychological factors (i.e. mental state and/or motivations) were identified as boosters for better dietary practices. Participants expressed their wish to improve their self-confidence and physical appearance. For example, a participant recounted: "*I did lose much weight. I liked myself so much. I had very high self-confidence. I was able to wear anything I want.*" (I17). This increased self-confidence was recognized in interactions with others—as one participant explained when describing a "*very healthy*" woman: "*this is reflected on how she deals*

with people." (I6). Participants described feelings of self-guilt regarding their current dietary practices, that encouraged them to eat healthier foods, in addition to the food they usually consumed: "Because I eat snacks and fried food and stuff that could be not very good, I make sure to eat something good and healthy every day" (I6). Fear of disease was said to motivate healthier eating habits in some participants: "Eating healthy will make the body organs survive more." (I2).

Conversely, the discussions revealed several psychological barriers to adopting the proposed set of dietary recommendations. First, participants explicitly mentioned difficulty resisting tempting foods (which are often energy-dense, and high in sugar, fat and salt): "Because of the weak willingness [...], loving a type of food makes us violate the nutrition system." (FG2). Food cravings seemed difficult to control for some participants: "Sometimes I crave for it and I like to try many things like waffles, like Nutella, like brownies, I like to try new things this in addition to the regular Konaffa¹³ and the regular pastries." (I3). Moreover, participants clearly described "curative behavior"—i.e. a tendency to rarely (or never) take preventative action to reduce the risk of disease in the future. For example, a participant explained that she would wait to face a problem before considering changing her dietary practices: "This is how I deal with everything, I wait till it is totally damaged and then go fix it. In my teeth or health or anything." (I3). Finally, participants reported distaste for healthier food choices, a barrier for their uptake: "The healthy food [...] like vegetables will not taste as good as the fast food." (FG2).

Life-stage related factors. Factors related to the life-stage of participants (i.e. time and access to healthy food choices) were reported to encourage participants to improve their eating habits.

Among these boosters, having a target related to a wedding or a job opportunity were reportedly motivated participants to change dietary practices and lose weight: "She started a nutrition system and gym as her wedding day is coming." (FG4); "She needs to lose weight because there is a target like applying for a job." (FG4). Getting married also seemed to have dietary implications. According to participants, spending more time in the household and learning to cook for their husbands reduced fast food consumption. For example, a participant stated: "Before getting married I was eating outdoors all the time and eating fast food, however after marriage, I am keen to prepare food at home." (FG5). Family planning and getting pregnant were reported to positively impact dietary choices; participants mentioned they "will need vitamins and calcium" (I13) during this specific life-stage. Dietary guidance from a physician aimed to address a medical issue was reported to encourage participants to pay closer attention to what they ate: "The doctor advised me to eat a lot of food that contain iron and taking vitamins to increase the hemoglobin in my body" (FG8).

Several barriers were linked to the life-stage of the participants. Students and working women often consumed their meals out-of-home, where healthy meals are not readily available (see paragraph on sociocultural and economic aspects below). Our dietary recommendations were seen as time consuming, could be only home-made, and were unrealistic for some students and working women: "She may be working and doesn't have much time to eat healthy food. She is eating outdoors mostly." (FG5). Participants who were not solely responsible for shopping for, and

¹³ Konaffa is a traditional dessert from Middle East made of thin noodles and cream cheese, soaked in a sweet syrup.

preparing, food reported being so as a barrier for implementing the dietary recommendations in their daily routine: *"My mother is the one responsible for cooking so I eat what she cooks as she can't cook for the family plus an additional meal for me every day"* (I4). Similarly, participants responsible for preparing meals for their husbands (who preferred "tasty" meals) also reported difficulty: *"My husband eats tasty food and since we are together, I can't stay on a diet for a long time because I can't resist what he's eating everyday"* (I2). Finally, motherhood as was reported to discourage participants from following the dietary recommendations; working mothers explained that children are main priority for many women, who have little time to dedicate to themselves: *"She cares for her children more than herself. She is busy with life."* (FG8).

Sociocultural and economic factors. Egypt's environment and cultural norms (grouped together in this paper as "sociocultural and economic factors") can act as both barriers and boosters for improving dietary practices.

First, the positive social perception of the thin body type in younger generations seemed to motivate participants to adopt healthier eating habits. One participant described discrimination that young, overweight women can face in Egypt: *"All people criticize her as she is still young. All her friends seem so slim and she is so obese."* (FG5). Some participants mentioned turning to social media for advice on how live up to these beauty standards: *"I'm following some influencers and models. I try to do what they are doing hoping to achieve anything"* (I13). Issues around food safety in Egypt were reported to encourage participants to eat fewer meals out-of-home: *"My mom [...] gets scared from food outside. She thinks it is untrusted [...], unclean, not cooked the way she does it."* (I6). "Healthy" foods were seen as synonymous with "home-made" foods by some participants: *"Healthy food means homemade food because it's guaranteed and we know how it's cooked and what does it include"* (I7).

Yet, other sociocultural and economic factors specific to Egypt discourage healthier dietary practices. First, social gatherings with family and friends often entail eating large food quantities of poor nutritional value: *"Most of time I'm with my friends outside so we like to eat chips or chocolate as an entertainment"* (I6). Second, the recent inflation in food prices in Egypt has caused economic barriers to access, explained by a group of mothers: *"You know that in last 10 days of the month we have no money, and you are finding out how to make your meal! [laughing]"* (FG5). Some foods from our set of dietary recommendations were perceived as expensive. Finally, the limited places in Egypt serving healthy food options was reported as another barrier: *"It takes me time to find a good place that offers healthy food when outside with friends"* (I3).

DISCUSSION

This study revealed that life-stage, sociocultural, and economic factors, as well as a general lack of proactive behavior to prevent health issues, were barriers to adopting healthier dietary recommendations for young urban women in Egypt. However, conversely, the aesthetic and psychological benefits of such recommendations seemed to encourage them to adopt healthier eating habits.

Food choices for Egyptian women seem to be driven by palatability, and socio-economic factors, and by expected benefits to health (e.g. strong teeth and bones), functional abilities (e.g.

memory, muscular strength) and beauty (such as hair and nails). The participants reactions to our dietary recommendations showed that, even when these recommendations are based on local foods, and robust modeling analysis that consider local dietary patterns, its acceptability is not guaranteed. Our results confirm that implementing dietary recommendations is far from easy^(29, 30), and that food choices are driven not only by taste, nutritional value and healthfulness, but also cost⁽³¹⁻³³⁾ and other socio-cultural factors⁽³⁴⁻³⁷⁾.

Following our dietary recommendations was seen as a means to lose weight or to improve the appearance of hair, nails or skin—which would therefore improve self-esteem, mood and social interactions. The importance of physical appearance in this population is apparent in advertising specially targeting women, which indicate that taking care of one's body is a way to reach "happiness" and "harmony"⁽¹⁸⁾. These results suggest that behavior change communication oriented around aesthetic benefits could motivate women to initiate recommended dietary changes, at least in the short term. However, the risk of misinforming consumers (who have little nutritional knowledge) with this type of communication needs to be considered. Besides, potential benefits on hair⁽³⁸⁾, nails⁽³⁹⁾ skin⁽⁴⁰⁾ or other physical attributes must be clearly proven upstream. The increasing appeal of the thin body type to young Middle Eastern women⁽¹⁵⁻¹⁸⁾ confirms that dietary practices are topics of interest for young Egyptian women. Yet, the development of eating disorders in Northern countries shows the potential extremes of encouraging weight loss^(41, 42). and communication campaigns addressing these issues must be conducted with caution

Several barriers preventing the adoption of healthier dietary practices were mentioned by participants and must be overcome. The palatability of vegetables was criticized by many participants; while in contrast, fast food restaurants were depicted as providing appealing and tasty items, although unhealthy. This association between "unhealthy" and "tasty" has already been highlighted⁽⁴³⁾ and underlines the importance of making healthy food choices as appealing as "unhealthy" ones. Other identified disadvantages were linked to the fattening potential of some of the recommended foods (grain products and tahini) or to the poor digestibility of others (legumes, red meat, and dairy products). Improving awareness on adequate portion size and providing practical tips for improving the digestibility when preparing legumes, could help address these concerns. The life-stage of women appeared to play a determining role in the adoption of healthier dietary practices. As an example, students and working women reported having little time to prepare meals and eating most of their meals out-of-home. Given the rising availability of cheap and ultra-processed foods in Egypt's streets (as in many other low to middle income countries⁽⁴⁴⁾) and the struggle for finding healthy options out-of-home, following a set of dietary recommendations requires anticipating what is needed to prepare home-made meals, and extra time.

Food safety concerns over animal products (red meat, liver, and fish) and skepticism about processed foods (iron-fortified foods and dairy products) were barriers for consuming these items. This sanitary context in Egypt could provide an opportunity to promote home-made and healthy recipes from the recommended foods, since "*home-made*" is readily associated to "*healthy*" by some participants. Iron adequacy could be enhanced by the consumption of iron-fortified products and/or red meat, which contain primarily heme iron, a more bioavailable form than non-heme iron^(7, 45-47). Despite the described benefits of red meat for treating anemia and building muscle mass,

the participants complained about its high price, its potential for causing weight gain and difficulty in digesting it. Similarly, women underlined the direct health benefits of enriched, commercialized products by trustworthy brands (especially for children) but expressed doubts about their real iron-content and synthetic nature, confirming the general distrust in ultra-processed foods ^(48, 49). Strategies to improve the acceptability of these iron-rich foods are needed to reduce the risks of iron-deficiency in this population.

In conclusion, this study sheds a new light on eating behaviors in young women in urban Egypt—a population that is rarely studied, despite the important nutritional issues they face ^(1, 50). This study helped to identify perceptions about the recommended foods and elucidated the factors barriers and boosters to improving dietary habits in this population. Multicomponent interventions, tailored to the population and cultural norms, and potentially using mobile application technology, should be considered for promoting any set of dietary recommendations since they can promote sustainable behavior changes and improve health outcomes ⁽⁵¹⁻⁵³⁾.

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TABLES

Table 1. Number of participants recruited for interviews and focus groups. The codes in brackets refer to the interview ("I", from 1 to 18) and focus group ("FG", from 1 to 9) number. The symbol "-" refers to lower middle socio-economic class, and the symbol "+" to upper middle class.

Participants' profile	Activity	Socio-economic class	Number of participants interviewed individually	Number of participants in focus groups
Female students, not married, no child	1st and 2nd year of college	-	2 (I4, I12)	7 (FG1)
"	"	+	2 (I9, I10)	7 (FG2)
"	3rd and 4th year of college	-	1 (I11)	7 (FG3)
"	"	+	1 (I1)	7 (FG4)
Women not married, with no child	Working	-	1 (I5)	0
"	"	+	2 (I3, I8)	0
"	Unemployed	-	2 (I7, I13)	0
"	"	+	1 (I6)	0
Married women, with no child	Working	-	2 (I14, I16)	0
"	"	+	1 (I18)	7 (FG9)
"	Unemployed	-	1 (I15)	5 (FG6)
"	"	+	2 (I2, I17)	0
Mothers	Working	-	0	8 (FG8)
"	Unemployed	+	0	14 (FG5, FG7)
Total			18	62

Table 2. Perceived benefits and downsides of the foods included in the set of dietary advice.

Recommended foods	Perceived benefits	Perceived downsides
Vegetables	<p>Healthy: "Vegetables are healthy in everything." (FG1) "This group is the most vital and healthy because vegetables are very healthy and fruit are the same." (ID117)</p> <p>Source of vitamins and iron: "It will give you the vitamins that your body needs and doesn't take from anywhere else." (I6) "Tomato has iron. And also eggplant." (FG1) *</p> <p>Positive impact on external physical aspects (skin and hair notably): "Like parsley, like leafy vegetables, cucumber, anything green and it gives you a good complexion." (I7) "Eating salad now will make a difference to your health, and skin, and hair. [...] It will increase your skin brightness [...]. All girls now have a problem with hair splitting and hair fall, so vitamins will help improve the hair follicle itself. It will make it healthier and make it grow more." (I6)</p> <p>Positive impact on physiological healthy features (anemia, cognitive function, immunity): "I just know that vegetables are good for our bodies. [...] It strengthens our body and protects us from anemia. My mom always tells me to eat salad to help me. [...] It doesn't make you feel weak or not focusing" (I5) "You must eat lots of salads. [...] it will give you the vitamins that your body needs and doesn't take from anywhere else. It will also increase your body energy." (I6)</p>	<p>Bad taste: "Bad taste.[...] Not many people love them.[...] I don't like all sorts of vegetables." (FG2) "The kids don't love it. [...] and we neither. I don't like it." (FG7)</p> <p>Boring: "There is no creativity in cooking vegetables." (FG8) "Boredom" (FG5)</p> <p>Contain chemicals: "I am so worried from vegetables which are processed with insecticides and so on, which are really harmful" (FG6) "It could include chemicals. Vegetables are not like before. They have also pesticides." (FG4)</p>
Legumes	<p>Source of protein: "Beans contain protein which is very important to body." (I7) "It contains protein, it contains carbohydrates. The vegetal protein is the best." (FG2)</p> <p>Satiating: "It lasts in the stomach for long time." (FG4) "It saturates the hunger." (FG2)</p> <p>Cheap: "It is a cheap alternative for protein." (FG3)</p>	<p>Hard to digest: "They are heavy, I feel tired when I eat a lot of it. [...] It harms the colon." (FG1) "It is not proper for colon. [laughing]" (FG5)</p>

	<i>"Most of poor people eat it because it is cheap" (IDI13)</i>	
Grains & grains products	<p>High appeal: <i>"They are the best things ever, I love them! Pasta... They make me happy" (FG6)</i></p> <p><i>"I like it. My favorite meal!" (FG9)</i></p> <p>Essential component of diet: <i>"It's essential with any food I eat" (I11)</i></p> <p><i>"They are essential [...]. I don't feel full without it, it is essential in any meal." (FG1)</i></p> <p>Satiating: <i>"It makes me feel full." (FG4)</i></p> <p><i>"I don't feel full without it." (FG1)</i></p> <p>Affordable: <i>"It has no cons. Price is reasonable and it is varied." (FG8)</i></p> <p><i>"Baladi bread can be afforded by all classes of the society." (I7)</i></p>	<p>Induce weight gain: <i>"They make people fat, as my friends who want to gain weight, they keep eating carbs" (FG6)</i></p> <p><i>[talking about Egyptian bread] "it gives energy because of carbohydrates, but if you eat a lot of it, it will increase your weight" (I10)</i></p>
Milk or Yoghurt	<p>Healthy: <i>"Healthy. Light on stomach." (FG7)</i></p> <p><i>"Milk and yogurt have many benefits" (FG2)</i></p> <p>Useful for external physical aspects (teeth, nails, and hair): <i>"They [milk and yoghurt] include calcium, they are beneficial for teeth, and nails. For hair also." (FG1)</i></p> <p><i>"I don't drink milk. My hair is falling badly because of that." (I17)</i></p> <p>Positive impact on physiological functions (bones strength, metabolism, immunity): <i>"They strengthen the bones because it contains calcium [...] It helps in burning fats, yoghurt with lemon burns fats." (FG4)</i></p> <p><i>"Good for kids." [...] "Immunity." (FG7)</i></p> <p>Helps digesting: <i>"Yoghurt is like milk. [...] It's for any pain in the stomach." (I3)</i></p> <p><i>"They comfort the stomach. [...] It helps the body to be relaxed" (FG2)</i></p> <p>Alternative for dinner: <i>"Yogurt is a light meal and it saturates the stomach." (FG2)</i></p> <p><i>"Before I sleep. [...] Alternative for dinner" (FG6)</i></p> <p>Contains calcium: <i>"Yogurt like milk are very important and full of calcium" (I1)</i></p> <p><i>"They strengthen the bones because it contains calcium and it benefits the skin, teeth and nails." (FG4)</i></p>	<p>Not adequate for people with lactose intolerance: <i>"Many people have allergy against lactose." (FG2)</i></p> <p><i>"There are persons who have allergy from lactose. [...] It could cause diarrhea" (FG9)</i></p> <p>Processed: <i>[talking about pasteurized milk] "It is not fresh and packed. Preservatives are added through machines to last longer." (FG7)</i></p> <p><i>"It might include preservatives" (FG5)</i></p> <p>Expensive: <i>[the cons of milk and yoghurt are] "their expensive prices." (FG7)</i></p> <p><i>"the high prices" (FG7).</i></p>

Fruit	<p>Tasty: <i>"It's nice, entertaining. It has [...] good taste. I'm enjoying eating it."</i> (FG2)</p> <p><i>"They make us happy, all people love fruit"</i> (FG7)</p> <p>Improves notably external physical aspects due to water and vitamin content: <i>"Cherries are good for the skin. The watermelon contains high percentage of water, which makes the skin fresh and wet and soft. [...] It provides vitamins for skin and face."</i> (FG2)</p> <p><i>"The natural fruit are so healthy for body, hair, nails and skin."</i> (FG3)</p> <p>Impacts positively physiological health features: <i>"I think it is the only thing that goes into my body and has full good effect and benefits. [...] It will impact my body internally. It can help fight something from what fats do to my body".</i> (I6)</p> <p><i>"Bananas has iron it is a source of antioxidants, kiwi it decreases the amount of salt in the body, lemon as well contains vitamin C, cantaloupe it's good for the memory, I read about all that, [...] on the Internet."</i> (I3) *</p> <p>Healthy snacks, which can constitute an alternative for dinner: <i>"Fruit are an alternative for dinner. It is light meal at night."</i> (FG9)</p> <p><i>"I eat fruit as a snack and for dinner."</i> (FG6)</p> <p>Healthier sugar: <i>"It's an alternative for sugary stuff."</i> (FG2)</p> <p><i>"I can replace the chocolates with fruit. [...] Fruit have good taste, light calories, so there are alternative to sweets."</i> (FG2)</p> <p>Natural: <i>"They don't include preservatives, they are healthy."</i> (FG3)</p> <p><i>"They are fresh and natural"</i> (FG2)</p>	<p>Expensive: <i>"It is expensive. Yes, it is not cheap [...]. You may be obliged to get only 1 kilo instead of more because it is expensive"</i> (FG5).</p> <p><i>"I might not find fruit salad or something like that. It might be expensive when I find it."</i> (FG3)</p>
Tahini	<p>Tasty: <i>"I adore it. I love it besides chicken and fish"</i> (FG3)</p> <p><i>"It gives good taste. It is like appetizer."</i> (FG9)</p> <p>Can be consumed in different ways (sauce for sweet & savory dishes, appetizer...): <i>"I like it so much; I could make it as a side dish besides French fries. It is proper to be eaten with molasses. We make Tahina salad with</i></p>	<p>Induces weight gain: <i>"It causes extra weight. [...] Yes, I think so, especially if one would eat it directly with a spoon. It will be so fatty due to the sesame."</i> (FG5)</p> <p><i>"Sesame makes us gain weight."</i> (FG1)</p>

grilled food and fish, yes, it is a side dish in so many meals.” (FG5)

“Tahini salad, tahini with honey, beans with tahini... There are dishes which need it.” (FG9)

Notable benefits on external physical aspects (hair & skin) due to sesame oil: *“It contains sesame oils. [...] It is important for skin and hair. [...] For the skin freshness, it helps in the excretion process. It causes hair freshness.” (FG3)*

“Sesame oil is so beneficial. [...] It benefits the hair. [...] It makes the hair long.” (FG2)

<p>Nile fish (Tilapia)</p>	<p>Notable benefits on external appearance (skin, hair): <i>“It is beneficial for the skin and hair. The Asian people eat fish a lot, that’s why their skin is fresh and white.” (FG2)</i></p> <p><i>“It gives me a tight complexion, especially after a fish meal” (I7)</i></p> <p>Enhances cognitive capacities: <i>“It increases the intelligence. We eat it during exams. It benefits the memory as well.” (FG2)</i></p> <p><i>“If the pregnant woman eats fish, the baby will have sharp intelligence.” (FG7)</i></p> <p>Impact on other physiological features (muscles, metabolism): <i>“I feel that my body is light, my muscles are relaxed.” (I7).</i></p> <p><i>“It provides the body with energy and make it active. It gives it power. It makes me strong” (FG4)</i></p> <p>Light and easily digested: <i>“The fish is light on the stomach, it’s meat without fats.” (FG2)</i></p> <p><i>“It’s easy to digest” (FG1)</i></p> <p>Source of unsaturated fatty acids and phosphorus: <i>“Phosphorus, omegas” (FG7)</i></p> <p><i>“Fish is good in preventing Alzheimer, it contains phosphor and omega 3” (I1)</i></p>	<p>Safety concerns: <i>“It is preferred not to eat a lot from this kind [talking about Tilapia] because this type of fish is extracted from the Nile river. And the Nile’s water is not so clean. Because the Nile is polluted, and it might harm the fish itself. [...] The Nile river isn’t open and it ends in Egypt, so all wastes come to us.” (FG2)</i></p> <p><i>“I have to eat fish in Alex and port Sa’ed or from any person who prepares it here fresh.” (FG9)</i></p>
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<p>Red meat</p>	<p>Builds muscle and body: <i>“It is a source of protein, it builds the muscles. It is good for who wants to gym.” (FG3)</i></p> <p><i>“It enhances muscles, the body needs it. It increases power, and calories.” (FG9)</i></p> <p>Good for treating anemia: <i>“Meat contains protein and fix anemia.” (I1)</i></p> <p><i>“It renovates our body cells and hormones, like red blood cells.” (FG6)</i></p>	<p>Fatty: <i>“It forms fats on heart.” (FG2)</i></p> <p><i>“Meat is important, it gives energy but makes cholesterol.” (I3)</i></p> <p>Sanitary issues: <i>“We can suffer from germs and bacterial infection if it is not well done.” (FG9)</i></p> <p><i>“If you see the red in the meat after being cooked this is bad, because this mean it is</i></p>
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	<p><i>under cooked. It gives you stomach ache and it give you an upset stomach.” (I7)</i></p> <p>Mistrust in origin: <i>“The source of meat is important. We see the Sudanese and frozen meat. We become afraid of eating it [...]. It might cause diseases in the stomach. [...] Yes, it might not be beef at all. It is easy for fraud makers. [...] the meat was donkey meat.” (FG7)</i></p> <p><i>“There is no trusted place for buying it now.” (FG8)</i></p> <p>Not easily digested: <i>“Eating too much of it causes gout. It harms the uric acid rate. It is hard to be digested.” (FG2)</i></p> <p><i>“It is heavy on stomach.” (FG3)</i></p> <p>Expensive: <i>“It is expensive.” (FG8)</i></p> <p><i>“We can switch to something else if we don’t afford to buy meat” (FG3)</i></p>
<p>Liver</p> <p>Tasty: <i>“I like it so much. I like the one which is sold on the street. [...] It is delicious.” (FG1)</i></p> <p><i>“It’s delicious” (FG7)</i></p> <p>Convenient to prepare: <i>“It is a very quick meal to prepare. You could just cook it so quickly and make sandwiches for kids, so it is suitable in case of taking it in trips.” (FG5)</i></p> <p><i>“It’s easy and quick to be prepared” (FG7)</i></p> <p>Good for treating anemia (because of iron or blood content): <i>“Liver is beneficial for many organs in the body. It compensates the body with iron for those who suffer from anemia. Anybody who has anemia or lack of blood should eat liver.” (FG3)</i></p> <p><i>“It has iron, it is good for anemia, especially when it is uncooked.” (FG7)</i></p> <p>Affordable: <i>“It has a reasonable price” (FG3).</i></p> <p><i>“Reasonable prices [...]. One kilo of liver for me is better than one kilo of meat.” (FG7)</i></p>	<p>Sanitary issues: <i>“A lot of countries export liver to Egypt because it is a center of poisons in body because it absorbs the poisons in body. It contains bad blood, which contains poison.” (FG4)</i></p> <p><i>“If don’t trust its source you should not buy it. It is not always available fresh.” (FG8)</i></p>
<p>Eggs</p> <p>Cheap source of protein: <i>“Eggs are the cheapest animal protein we can buy.” (FG3)</i></p> <p><i>“It’s an alternative for protein” (FG8)</i></p> <p>Positive impact on bones, muscles, skin, hair: <i>“The yolk in the egg is beneficial for hair. And the white part is beneficial for skin while eating it. The white part is beneficial for the muscles. It strengthens it. The gym practitioners eat it a lot.” (FG2)</i></p>	<p>Bad taste and smell: <i>“I don’t like its taste. I eat the yolk only not the white part of the egg.” (FG3)</i></p> <p><i>“It stinks as well. [...] But there is a solution for that we are adding some vinegar while boiling eggs, and you would add black pepper after boiling so you will never find any stink in it.” (FG5)</i></p>

	<i>"it is very useful for young kids due to the portion of protein and calcium, which is useful for their bones." (FG5) *</i>	Raise cholesterol: <i>"Eggs increase the cholesterol. It is not healthy for heart; we have not to eat it daily." (FG4)</i> <i>"It increases the cholesterol in blood." (FG7)</i>
Iron-fortified foods	<p>Notable health benefits, especially for kids (vitality, teeth): <i>"You will notice that on your kids. You may notice that they get teeth so fast. [...] it is credible because kids get so active before swimming training." (FG5)</i></p> <p><i>"I see that the Nido powder milk is credible regarding the support of iron in it. [...] because it is produced for kids." (FG2)</i></p> <p>Trustworthy when produced by well-known brands: <i>"We believe them [fortified products] from known brands [...] as brand are trusted. They want to compete with other companies so they increase them." (FG8)</i></p> <p><i>"It could be true. It depends on the brand and on its credibility." (FG1)</i></p> <p>Trustworthy if advised</p> <ul style="list-style-type: none"> - by health care professionals: <i>"If physicians are sure of that and would tell me it is fine." (FG5) "The physicians will be better. Yes nutrition physicians." (FG4)</i> - by influencers through social media or TV: <i>" "Green apple" show on MBC and Mona Radamis[#]. I trust her." (FG9). "Social medias, [...] bloggers, or like Mourad Makram[▫]." (FG4)</i> 	<p>Processed and artificial, not natural: <i>"I feel that it is just advertising. In addition the powder milk is not beneficial like the natural one." (FG4)</i></p> <p><i>"It is not natural. It is written on it that the juice is extracted from something and this thing doesn't contain iron." (FG2)</i></p> <p>Mistrust in some products: <i>"I think they do that in order to attract consumer, as it has vitamins." (FG1)</i></p> <p><i>"I feel that they cheat me." (FG8)</i></p>

* These sentences show that knowledge of foods' nutrient content can be approximative, as these foods are not natural sources of the mentioned nutrients.

[#] Mona Radamis is a nutritionist communicating on social medias and TV shows in Egypt.

[▫] Mourad Makram is a TV presenter and actor in Egypt.

Table 3: Barriers and levers for improving dietary practices.

Type	Levers	Barriers
<p>Aesthetic aspects</p>	<p>Will to get clear skin, bright teeth, strong nails, or silky and thick hair: <i>"I eat a lot of cucumber, rocca and parsley as they are making me have a fresher skin."</i> (I7) <i>"I have to take care of myself to avoid this. I was upset when I saw the brush that contains hair. I will be upset if I lose my hair."</i> (FG3)</p> <p>Will to control body shape: <i>"I wanted my body to be in harmony and symmetric on the overall [...], I wanted my appearance to look good, to look just right."</i> (I3) <i>"When you want to dress in a certain way and you can't do it because of your body you will be motivated to change that."</i> (FG6)</p>	<p>Lack of quick and tangible effects on esthetic aspects when changing dietary practices: <i>"In the beginning we are enthusiasm and then we miss it. [...] There is no quick result."</i> (FG1) <i>"There is no enough willing. [...] I don't find a result in the first days."</i> (FG9)</p> <p>Preference to use external masks and creams than to change dietary practices: <i>"My life is not fully healthy so I want to compensate that with creams and masks [...]. For example I eat a lot of fats, so my face will not look healthy, so I will try to compensate that with masks and creams and medicines."</i> (I6) <i>"I like salty food so I drink green tea to remove toxic from the body, and I like to do masks for my skin and hair."</i> (I10)</p> <p>No will to change their external appearance: <i>"I'm not looking forward to change anything in my body as I'm very satisfied with how I look currently."</i> (I6) <i>"My weight is good I just want to keep my body in shape."</i> (I6)</p>
<p>Psychological considerations</p>	<p>Wish to restore self-confidence through better external appearance (beautiful skin, fit body) and attitude towards other people: <i>"I did lose much weight. I liked myself so much. I had very high self-confidence. I was able to wear anything I want."</i> (I17) <i>"[A healthy woman] is psychologically stable because her eating is right and her sleep is right and all her life system is right. So, this is reflected on how she deals with people."</i> (I6)</p> <p>Wish to decrease guilt towards their dietary practices: <i>"Because I eat snacks and fried food and stuff that could be not very good, I make sure to eat something good and healthy every day."</i> (I6) <i>"I take care of eating vegetables because it contains vitamins that are beneficial for the body, so I do not eat everything bad."</i> (I18)</p>	<p>Low motivation to resist to temptations: <i>"Because of the weak willingness [...], loving a type of food makes us violate the nutrition system."</i> (FG2) <i>"Sometimes I crave for it and I like to try many things like waffles, like Nutella, like brownies, I like to try new things this in addition to the regular konaffa and the regular pastries."</i> (I3)</p> <p>Curative behavior: <i>"This is how I deal with everything, I wait till it is totally damaged and then go fix it. In my teeth or health or anything."</i> (I3) <i>"I'm overweight, and I am supposed to follow a regime because if I don't I may not get pregnant, Because I suffer from a lot of fat that clots the uterus and oocytes and honestly, I don't care. [...] If Allah wants anything for me it will be."</i> (I10)</p>

	<p>Fear of disease: <i>"The more you eat fats, you damage something in your body. So, eating healthy will make the body organs survive more."</i> (I2)</p> <p><i>"I don't like it [vegetables] but I eat it for the sake of its benefits."</i> (I6)</p>	<p>Healthy considered as tasteless: <i>"The healthy food [...] like vegetables will not taste as good as the fast food."</i> (FG2)</p> <p><i>"When I was on a diet, I was very depressed because I was feeling that I'm prevented from everything I love and what I eat is tasteless."</i> (I4)</p>
Life-stage related factors	<p>Target related to an event to come (wedding, job): <i>"My auntie is a little bit fat and I told her to lose weight [...]. And she started a nutrition system and gym as her wedding day is coming."</i> (FG4)</p> <p><i>"She needs to lose weight because there is a target like applying for a work."</i> (FG4)</p> <p>Marriage implying a higher consumption of home-made food (versus out-of-home food): <i>"Before getting married I was eating outdoors all the time and eat fast food, however after marriage, I am keen to prepare food at home and my husband shall come to find home food ready."</i> (FG5)</p> <p><i>"At first I used not to know how to cook at all. My mom didn't teach me anything. Then I got married and my husband loves eating so much."</i> (I17)</p> <p>Family planning (baby) inducing healthier food choices: <i>"After few years we will be married and have babies so we will need vitamins and calcium."</i> (I13)</p> <p><i>"I was very keen on my health and my food during pregnancy time. [...] I was keen to drink milk and eat honey to avoid anemia. I was really careful about food which includes iron."</i> (FG5)</p> <p>Need to follow doctors' dietary guidance for a medical issue (anemia, pregnancy...): <i>"The doctor advised me to eat a lot of food that contain iron and taking vitamins to increase the hemoglobin in my body."</i> (FG8)</p> <p><i>"To have a healthy baby, as my doctor say to me "strong body equal strong baby."</i> (I14)</p>	<p>Students and working women eat mostly outside home and lack time: <i>"She may be working and doesn't have much time to eat healthy food. She is eating outdoors mostly."</i> (FG5)</p> <p><i>"I think at our age, as college students, doesn't suit applying such system, [...] because most of the day we are outside home."</i> (FG2)</p> <p>Somebody else is in charge of cooking: <i>"My mother is the one responsible for cooking so I eat what she cooks as she can't cook for the family plus an additional meal for me every day."</i> (I4)</p> <p><i>"We call her [my mom] at work in school because she works in a nearby school and ask. If she is coming, we would ask her to bring us breakfast with her."</i> (I5)</p> <p>Husband's desire for heavy and tasty food: <i>"My husband eats tasty food and since we are together, I can't stay on a diet for a long time because I can't resist what he's eating every day."</i> (I2)</p> <p><i>"I got married and my husband loves eating so much. [...] He adores fatty food."</i> (I17)</p> <p>Mothers cannot dedicate time for themselves: <i>"She cares for her children more than herself. She is busy with life. She is busy with her tasks not for herself."</i> (FG8)</p> <p><i>"Definitely she has children that's why she can't give herself full attention, she can't focus with her health fully."</i> (I7)</p>

Sociocultural and economic aspects	<p>Social valuation of thin body figures in younger generations: <i>"I was used to see pictures of ladies, young ladies who looked really good, wonderful figures. I was always impressed and I was dreaming of having the same figure one day."</i> (I3)</p> <p><i>"One of my neighbors was seeking to lose weight because of other people criticizing. [...] All people criticize her as she is still young. All her friends seem so slim and she is so obese."</i> (FG5)</p> <p>Social media providing dietary tips: <i>"I'm following a group on Facebook where they always post tips and advices for a thicker and longer hair."</i> (I1)</p> <p><i>"I'm following some influencers and models. I try to do what they are doing hoping to achieve anything."</i> (I13)</p> <p>Cooking home-made is a habit due to sanitary insecurity: <i>"Healthy food means homemade food because it's guaranteed and we know how it's cooked and what does it include."</i> (I7)</p> <p><i>"If we are going to eat from outside, it will be just once or something because my mom doesn't like us to eat out a lot. [...] She gets scared from food outside. She thinks it is untrusted, [...] unclean, not cooked the way she does it."</i> (I6)</p>	<p>Healthy & nutritious food perceived as expensive: <i>"You know that in last 10 days of the month we have no money, and you are finding out how to make your meal! [laughing]"</i> (FG5)</p> <p><i>« Some people will not be able to afford buying fish and meat twice per week. Also, to buy two types of fruit every day. [...] Most of Egyptian people are middle class and government employees. »</i> (FG3)</p> <p>Healthy food less available when eating out-of-home: <i>"It takes me time to find a good place that offers healthy food when outside with friends."</i> (I3)</p> <p><i>"Fast food and food outside home are plenty with fats, [...] which give us diseases we don't know about."</i> (I6)</p> <p>Social gathering prompting overconsumption: <i>"Most of time I'm with my friends outside so we like to eat chips or chocolate as an entertainment."</i> (I6)</p> <p><i>"I might want to eat healthy food such as vegetables, but the surroundings love fast food and nuts."</i> (FG3)</p>
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FIGURES

Figure 1: Illustration used during focus groups to present the set of dietary advice modeled from local foods. The pictures of plates are taken from food atlas of the United Arab Emirates (vegetables, eggplants, tabbouleh, rice, broad beans, whole fish and fish fillet, steak) ⁽⁵⁴⁾ and France (liver, ⁽⁵⁵⁾) to represent the recommended portion sizes in the previous diet modeling study ⁽⁷⁾. The other pictures also represent estimates of recommended portion sizes for tahini, fruit, milk, yoghurt, a commonly consumed form of red meat (*kofta*) and eggs (pictures free of use extracted from the following image banks: flickr, paxabay, pixnio, wikimedia commons).

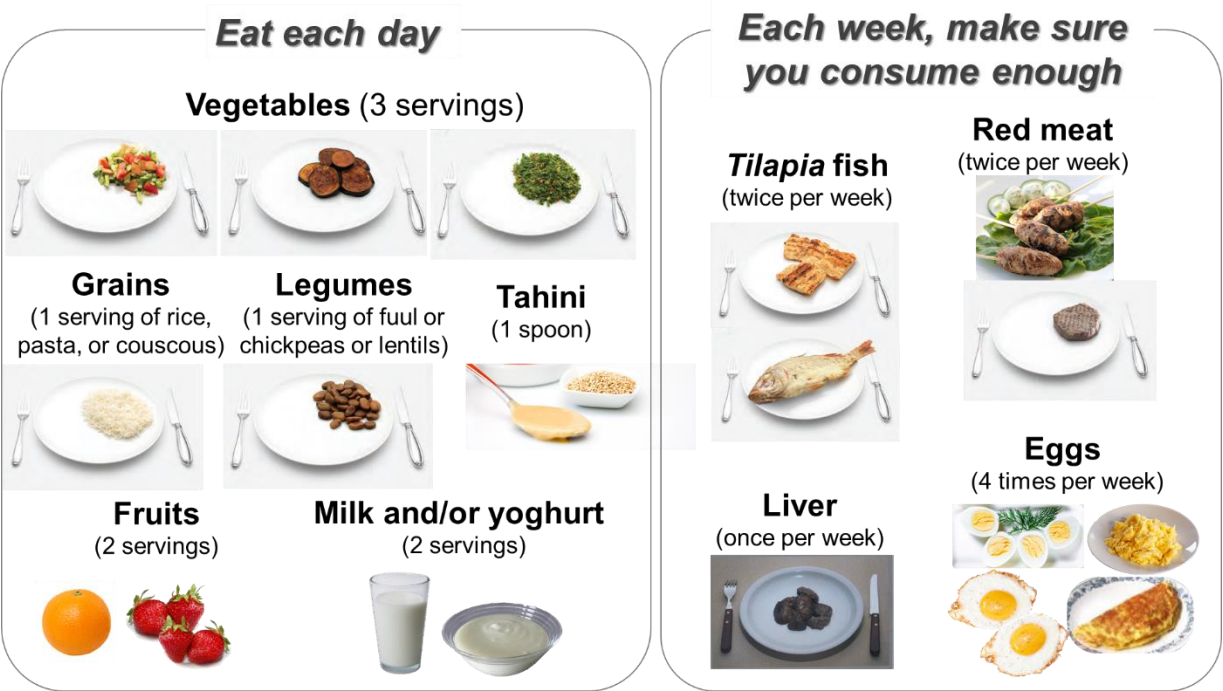
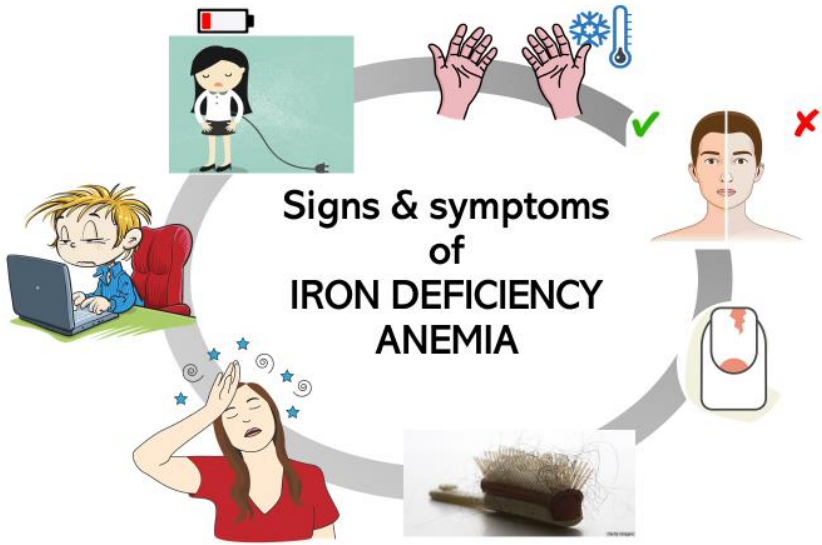


Figure 2: Illustration used during focus groups to test awareness and knowledge about signs and symptoms of iron-deficiency anemia. This illustration was created based on signs and symptoms listed by the UK National Health Service and the American Society of Hematology ^(27, 28).



Women’s motivations to follow dietary advice include taste, affordability and convenience but also aesthetic and self-confidence concerns. Results from a qualitative study in Egypt.

SUPPLEMENTAL MATERIAL

Supplemental Material 1. Discussion guide for focus groups

This discussion guide (DG) was designed for the moderators of the focus groups. Questions to be asked by moderator are on the right side of the DG. **ALL BOLD AND CAPITAL LETTER COMMENTS** are instructions for the moderator which should be strictly followed.

Introduction	Points below are just a reminder for the moderator to set up the rules of the discussion.
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Research purpose	<p>THANK RESPONDENT FOR HER TIME</p> <p>INTRODUCE SELF & PHI</p> <p>EXPLAIN WHAT MARKET RESEARCH- PURPOSE IS AND REASON FOR COMING.</p>
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You will now take part to a group of discussion about food and dietary habits, because we are trying to improve dietary habits of women. Indeed, we know that good food habits are key for good health, so we wonder how to promote some food advice, and what kind of healthy products could be adapted for women. Today we organize these groups of discussion with you, because we think that the best people to help us improve advice and products for Egyptian women are Egyptian women! So please feel free to tell us everything that you think and feel, it will be very helpful to improve advice and products for Egyptian women.

EXPLAIN THE REASON FOR TAPE/ VIDEO RECORDING

ASK RESPONDENTS TO TURN THEIR MOBILES TO THE SILENT MODE.

ASK RESPONDENT TO SPEAK OUT LOUD FOR RECORDING.

Section 1:	Warm Up
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Introduction	<p>1. OK, now I would like to get to know you. Could you tell me more about yourselves please? I will be listening to you one by one only in the introduction, and then we will be discussing things together but not in order. Could you tell me your name, your marital status, what you do, and anything else you would like us to know about you. MODERATOR TO GIVE TIME FOR INTRODUCTION</p>
Warm-up: role of food in life	<p>2. Ok, that is really great... now I would like to know you better and to break the ice between us to have a fruitful discussion together. If I asked you about the role of food in your life! What could it be? What do you prefer to eat? How do you feel when you eat something you love? Do you think that you all now have something in common? Cool let’s start.</p>

Section 2:	Food recommendations understanding
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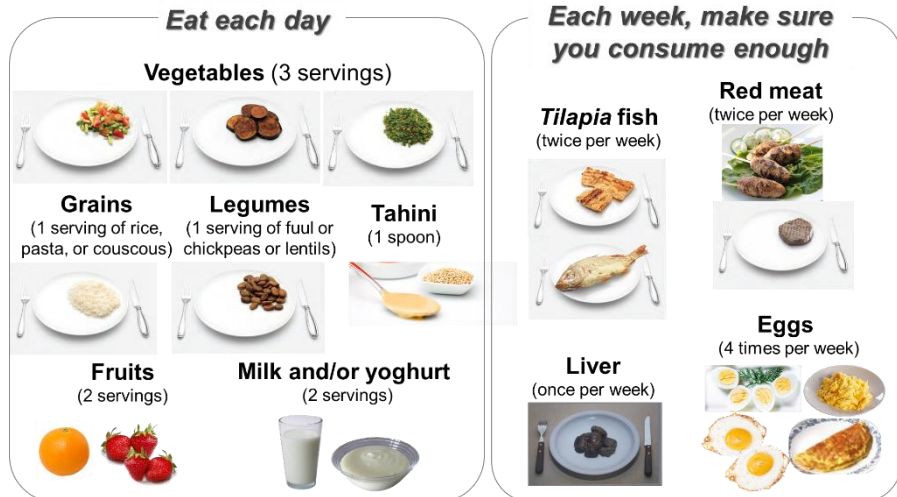
Understanding “taking care of what they eat”	<p>Today we will be talking about many things and doing many exercises that I hope you will like.</p> <p>3. If I told you that I met a woman who says that she takes care of what she eats. I am very curious to know from you, what could that mean? What exactly is she eating to describe herself this way? I am still confused, so what would be not taking care of what we eat mean?</p>
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Triggers & barriers for changing food habits	<p>4. Okay... Now we have 2 girls who are totally different from each other, the 1st girl wants to change her food habits/ (Heya 3ayza tezabat aklaha) and the other girl doesn't want to change anything.</p> <p>a. Let's think of the 1st girl a little bit.... What could be all the reasons that makes her want to change her food habits? What else? What makes you say that? PROBE FULLY TO ARRIVE AT ALL REASONS. PROMPT IF NOT MENTIONED BY ASKING:</p> <ul style="list-style-type: none"> • Some people told me that the reasons for changing her food eating habits could be related to health. Could you tell me more about that please? • Could anemia be a reason for her to change her eating habits? <p>ASK SAME QUESTIONS FOR WEIGHT MANAGEMENT, EXTERNAL BEAUTY ASPECTS (HAIR, SKIN, NAILS...?)</p> <p>b. And for the 2nd girl... what could be all the reasons that makes her doesn't want to change anything? What else? What made you say that?</p>
Changes could be done	<p>5. Great, let's have all the mentioned reasons earlier in details to advice the girl who wants to change her food habits. MODERATOR TO HAVE THE CUE CARDS ON THE TABLE AND ASK THE BELOW ON EACH CASE/REASON.</p> <p>a. Let's start by "mention reason" what could be all the things that she needs to change for this case? What made you say that?</p> <p>b. What would be your advice to her? What made you say that?</p> <ul style="list-style-type: none"> ▪ In your opinion if she succeeded in applying this change, what would be all the factors that helped her to achieve this? <p>If she did not succeed in changing her habits, what could be all the barriers that made her stop?</p>

Section 3: Food-based recommendations evaluation

Spontaneous associations towards the eating plan	<p>6. I have with me a list of food types that I want to say out loud and you tell me what comes to your mind when you hear it. MODERATOR TO READ OUT LOUD EACH FOOD TYPE SEPARATELY IN THE LIST BELOW. TRY TO GET EMOTIONAL AND FUNCTIONAL ASSOCIATIONS IN ADDITION TO POSITIVES AND NEGATIVES IF ANY.</p> <ul style="list-style-type: none"> • Vegetables • Fruit • Legumes (beans) • Milk & yoghurt • Tahini • Grains / carbohydrates • Red meat (beef) • Fish • Eggs • Liver <p>7. Great, lets now have a look at an eating plan that a girl did before and I will ask you few questions. LEAVE THE PLAN ON THE TV SCREEN FOR PARTICIPANTS</p>
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TO READ AND GO BACK TO WHENEVER NEEDED.



Triggers & barriers for the FBR

8. Looking at that eating plan, tell me what was going through your minds? Is there any food item that surprised you in this list? What made you say that?

MODERATOR TO PROBE FOR:

- **CLARITY**
- **QUANTITY**
- **PERCEIVED HEALTHINESS**
- **PRACTICABILITY (COOKING TIME, COULD BE EATEN ONLY IN PARTICULAR SETTINGS, AFFORDABILITY...)**

9. What is the purpose of this plan in your opinion?

- First, what could be all the reasons that made a girl follow such a diet? What else? What made you say that? **FOR EACH MENTIONED REASON, UNDERSTAND HOW THIS DIET COULD HELP.**
- What could be all the reasons that prevent a girl to follow this diet?
- What could be the barriers for not following this eating plan? **MENTION EACH FOOD SEPARATELY.**

Profile

10. And how can you describe this girl? **MODERATOR TO PROBE FOR:**

- **BODY**
- **AGE**
- **CHARACTER**
- **PERSONALITY**
- **HEALTH WISE**

11. What does she want to reach by following this diet?

Changes in the food-based recommendations

12. Let's imagine that you have the authority to change this eating plan to achieve a better health for this girl, what would you like to change? What made you say that?

MODERATOR TO PROBE FOR:

- **VARIETY**
- **QUANTITY**
- **FOOD TYPE**
- **ORDER OF FOOD/ TIMING**
- **AFFORDABILITY**

Would you like to add anything to this plan or a habit to be done for a healthier eating lifestyle? What could it be? What made you say that?

Likes & dislikes towards the eating plan 13. Let's imagine that each of you are going to follow this plan.

- How would that make you feel?
- What would be the thing that you like the most in this plan?
- What is the thing that you would not like in this plan?
- What would be the impact of this plan on you? **PROBE FOR HEALTH, BODY WEIGHT, MOOD, AND BEAUTY ASPECTS. FOR EACH MENTION, UNDERSTAND WHAT MADE THEM BELIEVE SO.**

Section 4: Iron rich foods and iron-fortified products evaluation

Fortified products awareness 14. In the supermarket, we see a lot of products that are fortified. I am interested to know from you, do you buy or consume any fortified products? What made you say that?

Fortified products credibility 15. If there is a company producing fortified products, what could be all the things that could make people believe that the product is really fortified? What else? What made you say that?

16. Are there certain vitamins or minerals that are more credible when added to products than others? What made you say that?

Iron deficiency in women 17. Ok, now I want to talk about iron for a while. Do we as Egyptian females, suffer from iron deficiency? How serious is this in your opinion? Is it something common or not?

18. Do men need more iron than women according to you? Why?

Foods rich in Iron 19. I am very interested to know the food types that are rich in iron, what are they? What else?

- a. Do you usually consume these foods?
 - If **YES**, what made you consume them?
 - If **NO**, what prevented you to try them?

b. What is the benefit of consuming such types of food on the body?

Iron fortified products awareness 20. Are there any products in the market with iron fortification? Do you use any? What made you say that?

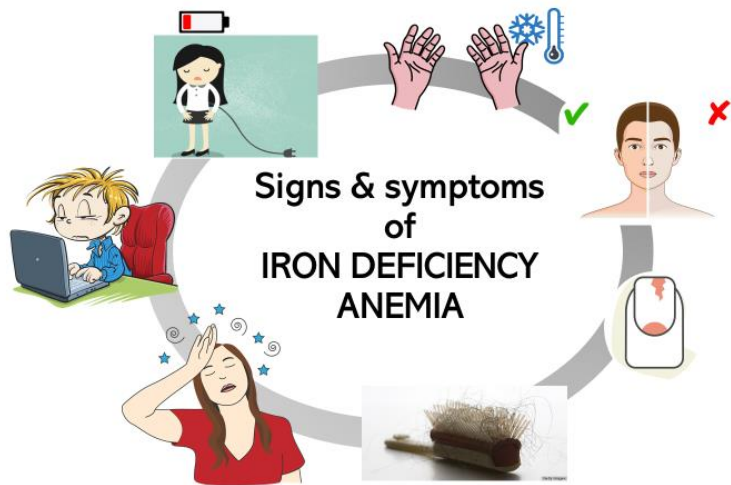
- If **YES**, what made you try them?
- If **NO**, what prevented you to try them?

Consumer profile 21. If there is a product in the market that is fortified with Iron, would that be of any interest in your opinion to females like you? What made you say that?

22. Who are the people who really care about buying fortified products in your opinion?

Section 5: Anemia awareness & Iron-fortified foods evaluation

Setting the ground 23. OK, now I will show you a picture, and you will tell me what you understand of it.



Iron deficiency anemia signs	<p>24. What are the signs of iron-deficiency anemia according to you?</p> <p>Does this happen to you?</p> <p>How do you know that you have iron deficiency anemia? What are the symptoms?</p>
	<p>MODERATOR TO PROBE FOR</p> <ul style="list-style-type: none"> - FATIGUE (TIRED AND WEAK), LETHARGY, PHYSICAL CAPACITY (STAMINA) - WORK PERFORMANCE - DIZZINESS, FREQUENT HEADACHES, PAIN IN THE CHEST - PALE SKIN - COLDNESS IN HANDS OR FEET - HAIR LOSS - BRITTLE NAILS
Profile	<p>25. How did you feel when you saw the picture? Why?</p> <p>26. Who is most at risk of iron deficiency anemia according to you?</p>
Iron fortified product communication	<p>MODERATOR TO PROBE FOR</p> <ul style="list-style-type: none"> - BABIES - PREGNANT OR BREASTFEEDING WOMEN - WOMEN WHO MENSTRUATE, PARTICULARLY IF MENSTRUAL PERIODS ARE HEAVY. <p>27. Now that you have all this information in mind, if you were responsible of launching a new iron-fortified product for young women, what could it be?</p> <ul style="list-style-type: none"> c. What made you chose that? d. How would you make young women believe in it? What made you say that?
Reactions & willingness to buy on each of the mentioned products	<p>MODERATOR TO PROBE FULLY TO ARRIVE TO COMMUNICATIONS THAT WOULD BE THE MOST EFFECTIVE FOR IMPACTING YOUNG WOMEN (e.g. REDUCING ANAEMIA? BENEFITS ON ENERGY /STAMINA? BEAUTY-RELATED BENEFITS? BENEFITS FOR THE FUTURE BABY? OTHERS?)</p> <p>28. Now I will tell you some iron-fortified concepts that I need you to tell me your opinion about.</p> <p>29. Our client wonders if the following foods could be of interest for young women in Egypt</p> <ul style="list-style-type: none"> o Water fortified with iron o Flavored water fortified with iron o A flavored spoon-able yoghurt fortified with iron o A flavored drinkable yoghurt fortified with iron o A flavored milk fortified with iron o A spreadable cheese fortified with iron o Baladi bread that is fortified with iron o Rice fortified with iron o Broad beans (fuul) fortified with iron <p>a. Let's start with the iron-fortified water.</p> <ul style="list-style-type: none"> - What do you think about fortifying bottle water with iron? - Would you buy and drink such fortified water? Why? <p>QUESTIONS TO BE REPEATED FOR ALL PRODUCTS BELOW</p> <p>b. Let's now think about a flavored water, like a healthy soda, that would also be fortified with iron.</p> <p>c. What about a flavored yoghurt that would be fortified with iron?</p>

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- d. What about a flavored yoghurt fortified with iron that would be drinkable (to eat on the go)?
 - e. What about a flavored milk fortified with iron?
 - f. What about having some white spread cheese fortified with iron?
 - g. What if the bread or the rice or broad beans would be sold fortified with iron? If you had the choice between fortified and non-fortified bread, rice and/or broad beans, which one would you buy and eat? Why?

Ranking

30. Please now vote for the food you would most likely buy and consume if fortified with iron and let's put them in order of appeal and acceptance.

THANK RESPONDENTS FOR ATTENDING

Supplemental material 2. Discussion guide for individual interviews, in home visits

Questions to be asked by moderator below are on the right side of the discussion guide. **ALL BOLD AND CAPITAL LETTER COMMENTS** are instructions for the moderator that have to be followed strictly.

Introduction	
Research Purpose	<p>I would like to start by thanking you for agreeing to participate in this study with us.</p> <p>Allow me first to start by introducing myself. I am</p> <p>Our company is called PHI for market research.</p> <p>Are you familiar with Market research? Let me tell you all about it... Market research is a simple tool through which marketers get to know about their consumers, you, your opinion about their different products, advertisements, packaging or services etc. are of great value for them...</p> <p>So as you see, we act like middlemen between consumers and manufacturers. This is the only service we offer. We are not an advertisement agency or a sales agency, we do not market any product and we do not work with a particular company. We deal with any company that wishes to know more about its consumers' opinions.</p> <p>We do not always work on products and services, sometimes we go meet people just to understand their habits, their habits about different things like for example, media habits, transportation habits, or eating habits.</p> <p>Today we are interested to know the Egyptian females eating habits. The real ones. In research there are no right and wrong questions. Because people are different. I can like a cup of tea that you hate, just because I take two spoons of sugar and you drink it with milk and no sugar for example. No one is right nor wrong it's a matter of preference and relevance.</p> <p>So today we are very interested to know from you, your real eating habits. Thinking about it, you can very well say this is a service for you at the end of the day as it ensures that anything new you see in the market or a new advertisement would be something more relevant to you and something you really need or like.</p> <p>Please remember that the only way we can reach this is by being very honest in our opinions. Your opinion is what matters. There is nothing in particular that I'm trying to know other than your opinion and the reality. There are no right or wrong answers; as long as it is your opinion or habit, this is what matters. No matter what you do, or what you wish you would want to do.</p> <p>Before we start I would like to take your permission for a number of things</p>
Reasons for Audio Recording	<p>I would like first to take your permission for audio recording. The main purpose for audio recording is that during the session I would not get a chance to keep note of everything and I would really like to have everything you say recorded as it is very important for me not to lose any of your valuable opinions. Even if I try to write down everything, I will not manage to do it and the session will not flow as smoothly.</p>
Section 1	
Warm Up	
Introduction	<ol style="list-style-type: none">1. OK, I would like to get to know you. Could you tell me more about yourself please... your name, your marital status, what you do, and anything else you would like us to know about you. MODERATOR TO GIVE TIME FOR INTRODUCTION
Typical day	<ol style="list-style-type: none">2. Ok, that is really great... now I would like to know you better. Could you tell me how does your day pass by from the time you wake up till the time you go

to sleep? **MODERATOR NOT TO GIVE A LOT OF TIME FOR THIS QUESTION, IT IS JUST TO MAKE THEM START OPENING SUBJECTS**

Section 2

Their eating habits

Understanding meals and snacking habits

Ok, as we mentioned at the beginning, we will be talking about your eating habits, so let's talk more about that

3. Before going into the details of what you eat, I am interested to know from you how many meals do you eat per day? What makes you do that?
 - Do you have average times for each meal? If yes: What times? What makes you eat at these times?
 - **FOR EACH OCCASION ASK: In this occasion "MENTION OCCASION", where would you usually be? Who would you be with? UNDERSTAND IF THEY CONSUME THIS MEAL INSIDE OR OUTSIDE HOME AND TAKE NOTE OF THAT. ALSO UNDERSTAND IF THEY EAT FOOD FROM HOME OR BUY IT FROM OUTSIDE.**

4. OK, now I got to know when you eat a meal, and when do you snack and where and with who? Let's talk about each eating occasion for a while
 - **MENTION EATING OCCASION (MEAL OR SNACKING)** tell me more about what you eat in that time, not the things you would love to be eating? **MODERATOR TO MAKE SURE THEY ARE SAYING THE TRUTH-COULD REFER TO THE PICTURES IF YOU FELT THEY ARE TRYING TO MAKE AN IDEAL SCENARIO FOR ANY REASON.**
 - **REPEAT FOR ALL WHAT THEY EAT DURING THE DAY.**
 - **THROUGH OUT THE DISCUSSION UNDERSTAND SOME LIFESTYLE HABITS LIKE WHEN THEY WAKE UP AND WHEN THEY GO TO SLEEP.**

Their feeling when they saw what they eat

5. Great, now I have here all the things you said you consume throughout the day, have a look at it and tell me how do you feel about it? What made you say that? Is there anything you would like to say about it? What made you say that?

Thumbs up

6. If you were to give yourself thumbs up for things that you said you consume throughout the day, and the habits you do (**REFER TO ANY MENTIONS OF SPORTS, SLEEPING AND WAKING UP TIME...ETC**) what would that be? What made you say that? **UNDERSTAND CLEARLY WHY THEY CHOSE THESE THINGS AND THEIR IMPACT.**

Thumbs down if any

7. Will there be anything that you would like to give yourself thumbs down? **IF YES:** what would that be? What made you say that? **UNDERSTAND CLEARLY WHY THEY SAID THAT AND ITS IMPACT**

How would people react to their eating habits

8. If someone passed by coincidence and heard what you consume throughout the day without seeing you, and understood your lifestyle, what will they say? **UNDERSTAND PERCEPTION ABOUT THE PERCEIVED ATTITUDE, LIFESTYLE, CHARACTER AND BODY IMAGE**
 - a. How will they perceive your body weight?
 - Overall health and wellness?
 - Age?
 - Social class?

-
- b. How do you feel about that?
- Things they cannot change even if they know that by the book it is not the best practice**
9. There are things that we do, and by the book we might know that they are not the best practice, but what we do is what is really relevant to our lifestyle and situation, so what I mean is that, what is good for me, might not be good for you, and both might not be what the book says, but they are the best for us.
- a. Based on that, I would like to know what are the things that you do and you cannot change even if you know that by the book it is not the best practice? What made you say that? How difficult it is to change that? How would that make you feel based on your lifestyle?
- b. Is there anything you would like to change in your diet and you feel you could change it? **IF YES:** what is that? What made you want to change that in specific? What makes you not able to change so far? What made you say that?
- Things they can change (if any) but did not so far**
- How they define themselves based on what they eat**
10. How would you define your own self when it comes to the food you currently eat? Will that have an effect later on in any way on your health and wellness, or its effect is instant?
- Perceptions about eating different types of food in different life stages**
11. In general do you think that we should be eating in a different way in different life-stages, i.e. kids should be eating more of or less of something, adults, elders and so on, or this is not true? What made you say that? **IF SHE SAID YES: UNDERSTAND WHAT ARE THE THINGS THAT ARE IMPORTANT IN EACH LIFE-STAGE**
12. **ASK HER AS A PROBING TECHNIQUE TO MAKE SURE OF THE PREVIOUS ANSWER:** in this life stage that you are in, are there things that you make sure you consume or not consume? What makes you do that? **UNDERSTAND WHAT IN THAT THING THAT MAKES HER KEEN TO CONSUME IT, AND REASONS FOR THINGS THAT MAKES HER NOT WANT TO CONSUME IT.**
- For married females-understand their eating habits of this life stage and its impact as a mother to be**
13. **IF SHE IS MARRIED ASK:** I see you are married and have no children, am I right? Great, tell me more about this life-stage, is there anything you need to do as a preparation for a mother to be? What made you say that?
- a. Are there things that you care about when it comes to the fact that you are married and one day you will become a mother? **UNDERSTAND WHAT ARE THE THINGS SHE IS DOING OR PLANNING TO DO IN THE STAGE WHEN SHE DECIDES SHE IS READY TO BE A MOTHER.**
- b. Is your health related to your child's health in any way? What made you say that? Could you explain to me more your opinion?

Section 3

Health & Eating habits understanding

NOTES FOR THE MODERATOR: TAKE ENOUGH TIME IN THIS SECTION AS IT IS OF HIGH IMPORTANCE. TRY TO UNDERSTAND THE IMPACT OF ALL THE GOOD OR NOT SO GOOD HABITS ON THE BODY (HEALTH AND WELLNESS) AND HOW IT HAS AN IMPACT ON THE PERSON.

Understanding health signs	health	OK, now let's talk more on a general level.
		<p>14. I will start by asking you about health. Imagine we have two women, everyone agrees that one of them is healthier than the other. Tell me what are all the things that make them agree and say that this is a very healthy woman? What else? What made you say that? PROBE FULLY TO ARRIVE AT ALL THE SIGNS THAT REFLECT HEALTH –FROM THE APPEARANCE.</p> <ul style="list-style-type: none"> a. How would the lifestyle of a healthy women be? UNDERSTAND THE HEALTHY LIFESTYLE. b. In your opinion, could she look like this but still not be healthy internally? c. What are the things that she should do to stay healthy? What else? What made you say that?
Unhealthy signs		<p>15. What about the other woman, why are they saying she is not as healthy as the first one, and here I do not want us to repeat the opposite of what we said, but more explain how different she is</p> <ul style="list-style-type: none"> a. How would the lifestyle of a less healthy women be? b. Could she look like this but could actually be healthy from inside? What made you say that? c. What are the habits that would be better for her to stop in order to become healthier?
Meaning of "caring about self"	"caring about self"	<p>16. Interestingly I hear another word which is "a woman caring about herself" in your opinion, how different is that from being healthy? If you were to choose something to be said about you behind your back, would it be a healthy woman or a woman caring about herself? What made you say that?</p>
Understanding their lifestyle & behavior	more &	<p>17. The fact is, women have different eating habits and different behaviors. The question is, what are your behaviors? What are the lifestyle behaviors that can affect your health?</p> <p>UNDERSTAND THEIR LIFESTYLE AND BEHAVIORS</p> <ul style="list-style-type: none"> i. Wake up time ii. Sleeping time iii. The right number of sleeping hours iv. How many meals v. What is the time for each meal? vi. Role of sports in their life
How do they see themselves?		<p>FOR ALL THE ABOVE UNDERSTAND OF THIS IS SOMETHING THEY ARE HAPPY WITH OR NOT. AND REASONS.</p> <p>18. Great I will draw here a woman, consider her the healthier women we have been speaking about, and on the other side the women who is less healthy. I want you to place yourself beside the one you feel is close to you, you can also put it in the middle if you feel you are equally close to both. REPEAT FOR THE WOMEN CARING ABOUT HERSELF AND UNDERSTAND REASONS</p>
Impact of food on being healthy or not		<p>19. I want to know from your opinion, how would food contribute to a person being healthy or not. Let's imagine that we have a thermometer that will measure the importance of food in a person's health, you have mentioned many other things like playing sports or sleeping well, but I want to know the role of food in being healthy. Where would you place food here on this line that represents a thermometer, the higher you go, the more important it is, the lower you go the less important it is. SEE WHERE SHE PLACES IT AND</p>

ASK: What made you put it in that place? **EXPLAIN WHERE WAS IT PUT FOR RECORDING**

- Reasons for dieting**
Challenges when dieting
End result
20. I am interested to know from you, have you ever made a diet before? **IF YES ASK:**
- a. What made you want to diet? What else? Was there a certain diet that you were following? What were your feelings before you decided to diet? **PROBE FULLY TO UNDERSTAND THE EMOTIONAL EXPERIENCE BEFORE DECIDING TO DIET**
 - b. What were your main challenges during that time? **UNDERSTAND ROLE OF HAVING DIFFERENT MEALS THAN THE FAMILY, IMPACT ON BUDGET, FEELINGS WHILE ON DIET, THE OVERALL MOOD...ETC**
 - c. Did you reach your goal? How did that make you feel? **IF NOT:** what could have happened to make you reach your goal?

Section 4 **Meaning of "good food" & "eating well"**

- Understanding "Good food"** 21. I want you to tell me more about good food. Give me examples of good food. **UNDERSTAND ALL THE ATTRIBUTES THAT MAKES GOOD FOOD, GOOD**
- "Eating well"** 22. What does "eating well" mean to you? **MODERATOR TO UNDERSTAND ALL ATTRIBUTES THAT MAKE THEM THINK OF ANY KIND OF FOOD AS GOOD FOOD/ EATING WELL**
- "Healthy food"** 23. What about healthy food, tell me when would you consider any type of healthy food? **MODERATOR TO UNDERSTAND ALL ATTRIBUTES THAT MAKE THEM THINK OF ANY KIND OF FOOD AS HEALTHY FOOD.** Ok, now give me examples of healthy food.
- Profile of woman able to eat good and healthy food and reasons behind doing so**
Profile of woman NOT able to eat good and healthy food and reasons behind NOT doing so
24. Imagine that we had two women, one eats healthy and good food and the other doesn't eat so good nor so healthy food.
- a. Tell me in your opinion, who would be the women who eats good and healthy food? **ASK FOR AGE, LIFESTYLE, MARITAL STATUS, AGE, LIFESTAGE, SOCIAL CLASS.** What makes her able/willing to eat good and healthy food? What else? What made you say that?
 - b. And who would be the woman who eats less of good and healthy food? **ASK FOR AGE, LIFESTYLE, MARITAL STATUS, AGE, LIFE STAGE, SOCIAL CLASS.** What makes her not able to eat good and healthy food? What else? What made you say that?

Section 5 **Understanding more about how they see their appearance & bodies**

- Choosing their body figure and talking about how they feel about it**
- Let's talk about you for a while.
25. If you had a chance to change anything about your body... will there be anything that you would like to change or not? **IF YES:** what will that thing be? What made you say that? How does it make you feel today as we speak? How would you feel if it changed?
- Understanding role of food**
26. Currently if you were to describe how you feel about your body, what would you say? Was food a reason for the shape of your body in any way? What made you say that? Could it be a reason for a better body shape? What made you say that?
27. What about the other things like your hair for example?
- How would you describe it?

- How satisfied or dissatisfied are you with it?
- What are the challenges you face?
- Are there certain types of food that could help with this problem/ challenges?

REPEAT FOR SKIN, NAILS AND OTHER ATTRIBUTES CITED

Section 6

Understanding the perceptions about different types of foods

Grouping the items

28. Ok great, I have with me some food types that I would love to put here on the table **MODERATOR TO PLACE CUE CARDS WITH ONE FOOD TYPE WRITTEN ON EACH ON THE TABLE IN-FRONT OF THE PARTICIPANT.**

ITEMS TO BE LISTEN ON CUE CARDS

- Eggs
- Chicken
- Red meat (e.g. : Kofta)
- Liver
- Bolty fish
- Fruit
- Vegetables
- Dark green leafy vegetables such as Molokhia
- Fuul (broad beans)
- Yoghurt
- Milk
- Baladi bread
- Tahini (sesame paste)
- Hard cheese
- White cheese (e.g. feta)

**Name for each group
Positives and negatives
of each groupf**

29. I want you to look at these different types of food and divide them into groups, where each group would have any common factor in your mind that is common between the items in this group. You can group them based on emotional feelings towards these types of food or things that are functional like their benefit for example things we feel from the head, vs things we feel from the heart, you are the boss. Do whatever you want, just make sure that the ones together are together for a reason that is common between them. A group can have as many items as you want or even one item, if you see it so different, and you can make as many groups as you want. **MODERATOR TO ENSURE CLARITY OF EXERCISE. LEAVE ENOUGH TIME TO PARTICIPANT FOR GROUPING FOODS– READ OUT LOUD THE GROUPS FOR RECORDING AND THEN ASK:**

- a. I am interested to give a name for each group that you have **READ OUT THE GROUPED ITEMS AND ASK:**
 - i. What would you name this group? What in the group made you give them this name?
 - ii. What would be all the positive of this group?
 - iii. What about its negatives?

b. REPEAT FOR OTHER GROUPS

-
- Group ranking in terms of frequency of consumption** 30. If I asked you to rank these items in order of how close they are to you in your eating habits, how will you rank them, where the first one would be the one you consume the most, and the last would be the one that you consume the least. **UNDERSTAND REASONS FOR RANKING – DO THEY CONSUME IT AS IT IS THE CHEAPEST, THE MOST LOVED, THE MOST AVAILABLE OR EASIEST TO PREPARE FOR EXAMPLE**
- Understanding each item (Reasons for consumption, good and bad things in each item, benefit of eating it, ease of preparation)** 31. Ok, great, let's talk about each item now separately but very quickly
- a. Do you eat it? **IF THEY DO NOT CONSUME IT UNDERSTAND REASONS FOR THAT AND STILL ASK THE UNDERLINED QUESTIONS BELOW**
 - b. When do you eat it?
 - c. How many times per day /week/ month?
 - d. How do you eat it? With who?
 - e. What are the good things about this item? **UNDERSTAND THEIR IMPACT ON HEALTH**
 - f. What are the bad things?
 - g. Do you think this food could benefit or harm the body in any way?
 - h. **FOR TYPES OF FOOD THAT NEEDS PREPARATION ASK:** On a scale from 1 to 10 how easy or difficult it is to prepare this item?
- How will they convince someone with this diet** 32. If you were responsible for promoting this diet to women like you, how would you recommend it for them, what will be the things that you will tell them to really make them convinced or willing to think about following this diet?
- Message related to beauty benefit vs message related to health benefit** 33. Some people I sat with told me they would think of talking about the beauty benefits of each item, like it will make your hair grow faster, or your skin glow, or have the right shape and so on, and others thought of communicating it with health benefits like for example saying that it will make you stronger, no anemia...etc.
- a. In your opinion, which way of communication would be better and would grab more females like you?
 - b. Out of 20 women your age how many will get attracted to the message communicating the external effect (Beauty benefit) and how many will be attracted to the message communicating the internal effect (health benefit)? What made you say that?

THANK RESPONDENTS FOR THEIR TIME

What is your age? Height? Weight?

4. DISCUSSION ET PERSPECTIVES

4.1. Discussion

La méthodologie transdisciplinaire adoptée dans ces travaux a combiné des approches s'inspirant de la nutrition, de la modélisation et des sciences de la consommation pour éclairer plusieurs aspects de l'alimentation des femmes égyptiennes en milieu urbain. L'enquête alimentaire a permis de quantifier les apports des jeunes femmes et de mettre en évidence des déséquilibres nutritionnels. Les analyses par modélisation ont permis d'identifier des solutions pour améliorer la qualité de l'alimentation *via* des changements théoriques dans les pratiques et des modifications dans l'offre de produits. Les enquêtes qualitatives ont révélé des barrières et leviers à l'adoption de ces solutions et fournissent des pistes pour améliorer le jeu de conseils alimentaires identifié et le rendre plus acceptable. Les résultats de chacun de ces travaux ont déjà été individuellement discutés dans les discussions des articles. Dans cette partie sont discutées les similarités des problématiques nutritionnelles identifiées pour les jeunes femmes résidant en Égypte urbaine avec d'autres populations. Nous comparerons les stratégies nutritionnelles modélisées avec les recommandations alimentaires et nous discuterons les barrières et leviers identifiés dans les enquêtes qualitatives.

4.1.1. Cohérence des résultats de l'enquête alimentaire

Le surpoids et les risques de carences en fer, folates et vitamine D s'observent aussi à l'échelle nationale.

La coexistence de surpoids et de risques d'inadéquation en micronutriments constatée dans ces travaux est cohérente avec les données nationales égyptiennes. Nos résultats sont issus d'une étude réalisée avec un petit échantillon de femmes qui résidaient exclusivement en zone urbaine (130 femmes de 19-30 ans dans l'enquête alimentaire) et ne peuvent en aucun cas représenter la population générale en Égypte, qui vit à 57% en zone rurale (United Nations, 2018). Malgré les difficultés rencontrées pour collecter le poids et la taille des participantes¹⁴, ces travaux ont permis d'établir que les femmes interrogées étaient en surpoids. L'IMC moyen était de $27,9 \pm 4,9$ kg/m², ce qui est proche de l'IMC moyen de 28,2 kg/m² mesuré à l'échelle nationale pour les femmes âgées de 20 à 29 ans (Egypt Ministry of Health and Population et al., 2015a) et cohérent avec les fortes prévalences de surpoids et d'obésité observées dans les régions urbaines (88%) comme rurales (83%) (Egypt Ministry of Health and Population et al., 2015a). Par ailleurs, les apports insuffisants en folates, fer et vitamine D observés dans notre enquête sont cohérents avec les statuts trop bas en folates, fer et vitamine D au niveau national pour respectivement 15, 50 et 72 % des femmes (Tawfik et al., 2015, Tawfik et al., 2014, Botros et al., 2015). Les apports insuffisants en ces micronutriments sont très probablement à l'origine de carences dans la population de notre

¹⁴ L'IMC des participantes a été estimé à partir de données déclaratives qui ont été corrigées ou complétées par un modèle prédictif lorsque les valeurs étaient manquantes ou aberrantes. En effet, la collecte des données de poids et de taille s'est heurtée à diverses difficultés, comme par exemple la réticence des participantes à communiquer ces données, ou à la présence de valeurs aberrantes ou manquantes. L'Article 1 décrit la méthode de prédiction des valeurs de poids et de taille utilisée.

étude, bien que l'absence d'analyses sanguines ne nous permette pas de l'affirmer avec certitude.

Les apports en énergie des femmes interrogées sont plus bas que ceux observés dans la littérature.

Les apports en énergie des femmes étaient en moyenne trop élevés (+ 254 kcal) par rapport aux besoins estimés (apports : 2389 ± 715 kcal/jour ; besoins : 2135 ± 237 kcal/jour). Compte tenu des faibles niveaux d'activité physique (Musaiger et al., 2013, Musaiger and Al-Hazzaa, 2012), ce surplus énergétique peut contribuer à une prise de poids au cours du temps. Cependant, les apports énergétiques estimés dans nos travaux sont moins élevés que d'autres valeurs disponibles de la littérature (paragraphe « Disponibilité élevée des calories alimentaires »). En effet, la disponibilité des calories par jour en Égypte est d'environ 3000 kcal par personne (Musaiger, 2011) et des populations plus jeunes déclaraient des apports caloriques de plus de 2700 kcal par jour (2713 ± 322 kcal/jour pour des adolescentes de 17-18 ans en surpoids issues de classes socio-économiques inférieures (Youssef et al., 2010) ; 3268 ± 1464 kcal/jour chez des filles de 13-18 ans obèses (Hassan et al., 2010)). Ces différences peuvent provenir de multiples sources. D'une part, il s'agit de données de disponibilité des calories alimentaires (quantités de denrées alimentaires produites et importées dans le pays) et non de données de consommation. D'autre part, les populations étudiées par Youssef, Hassan et leurs collaborateurs sont des adolescentes, qui ont des besoins plus importants que les adultes du fait d'une dépense énergétique d'activité *a priori* plus élevée (et il n'est donc pas surprenant qu'elles consomment plus d'énergie). Il est aussi possible que les participantes de notre étude aient sous-déclaré leurs apports, ce qui est un biais classique des rappels alimentaires, en particulier chez les personnes en surpoids ou obèses (Klesges et al., 1995, Prentice et al., 1996, Briefel et al., 1997). Néanmoins, la sous-déclaration semble moins marquée chez les femmes égyptiennes comparativement aux femmes américaines, comme le montre une étude comparative des sous-déclarantes aux Etats-Unis et en Égypte : seulement 10% des femmes égyptiennes déclarent des apports énergétiques inférieurs à des seuils définis comme plausibles, contre environ un tiers des femmes américaines (Harrison et al., 2000). D'autres hypothèses pourraient être envisagées pour expliquer les différences entre les valeurs énergétiques citées dans la littérature et les apports estimés dans cette enquête, comme par exemple une répartition inégale des calories entre les membres d'un foyer, ou un gaspillage alimentaire.

Des liens de causalité possibles entre surpoids et risque de carences en micronutriments ?

Les liens entre surpoids et déficiences en micronutriments sont encore loin d'être évidents en Égypte comme ailleurs. Les prévalences de surpoids et d'obésité ont tendance à augmenter plus rapidement dans les régions où les déficiences en micronutriments sont fréquentes, et les sujets obèses présentent plus fréquemment une carence en nutriments

(antioxydants¹⁵, vitamines A, B et D, zinc, fer et calcium notamment). Cependant, la relation de causalité n'est pas clairement établie et pourrait être bidirectionnelle (García et al., 2009, Cepeda-Lopez et al., 2010, Lefebvre et al., 2014, Pereira-Santos et al., 2015). En effet, ces carences pourraient avoir des effets sur le métabolisme de l'insuline et de la leptine. A l'inverse, les apports en nutriments peuvent être insuffisants une fois rapportés à la masse corporelle des sujets obèses. Le métabolisme des micronutriments peut aussi être altéré par l'obésité (García et al., 2009, Cepeda-Lopez et al., 2010, Stoffel et al., 2019, Yanoff et al., 2007). Pour le fer par exemple, il est aujourd'hui clair que l'obésité aggrave le risque de carence en fer du fait des répercussions d'une inflammation sur le métabolisme de l'hepcidine (Yanoff et al., 2007). Pour la vitamine D, la plus grande incidence de carence chez les sujets obèses pourrait provenir d'une séquestration de cette vitamine liposoluble dans les tissus adipeux, et une carence en vitamine D pourrait aussi favoriser la production de tissu adipeux *via* une différenciation excessive de pré-adipocytes en adipocytes (Wortsman et al., 2000, Wood, 2008, Pereira-Santos et al., 2015). Ces hypothèses soulignent l'importance d'une alimentation suffisamment riche en micronutriments (notamment pour éviter d'altérer le métabolisme de l'insuline et de la leptine) et d'apports énergétiques adaptés à la dépense énergétique et en particulier au niveau d'activité physique pratiqué. L'identification d'un jeu de conseils alimentaires orientant les jeunes femmes égyptiennes vers une alimentation plus dense en micronutriments résoudrait les carences en micronutriments et pourrait contribuer à réduire (ou du moins stabiliser) la prévalence de surpoids, si les apports en énergie sont également adaptés.

Le double fardeau de malnutrition des femmes égyptiennes se retrouve dans d'autres contextes internationaux.

Le double fardeau de malnutrition n'est pas une problématique spécifique des femmes égyptiennes en milieu urbain, car il se retrouve dans d'autres populations en transition nutritionnelle.

Le surpoids et l'obésité sont devenues des problématiques mondiales qui concernent toutes les tranches d'âge et de sexe, bien que la prévalence reste prépondérante pour les femmes et varie suivant les régions du monde (Egypt Ministry of Health and Population et al., 2015a, NCD Risk Factor Collaboration, 2017). Ainsi, les prévalences d'obésité les plus élevées chez les femmes sont retrouvées aux Etats-Unis (20,7%), dans les pays d'Afrique du Nord et du Moyen-Orient (17,2%), dans les pays de l'ex Union Soviétique et d'Europe Centrale (15,4%) et dans les pays d'Amérique Latine et des Caraïbes (9,6%). En revanche, la situation des femmes en Asie du Sud et en Afrique Sub-saharienne semble assez éloignée de celles

¹⁵ Les antioxydants revus par les Garcia et collaborateurs regroupent la vitamine E (α -tocophérol), la vitamine C (acide ascorbique), le β -carotène et le sélénium (GARCÍA, O. P., LONG, K. Z. & ROSADO, J. L. 2009. Impact of micronutrient deficiencies on obesity. *Nutrition Reviews*, 67, 559-572.).

des femmes égyptiennes car elles souffrent rarement d'obésité (0,1% et 2,5% respectivement) (Martorell et al., 2000).

Les risques de carences en micronutriments constatés pour les femmes égyptiennes (fer, vitamine D et folates) se retrouvent dans de nombreuses régions du monde et en particulier dans les pays en développement (United Nations Standing Committee on Nutrition, 2010, Müller and Krawinkel, 2005, Ramakrishnan, 2002). Alors que les carences en vitamine A et en iode semblent progressivement diminuer à l'échelle mondiale (et en Égypte), l'anémie persiste, avec au moins 500 millions de femmes anémiées dans le monde (United Nations Standing Committee on Nutrition, 2010). Près d'un quart des femmes d'Amérique Latine et des Caraïbes et 45% des femmes d'Asie et d'Afrique sont anémiées (United Nations Standing Committee on Nutrition, 2010), ce qui est proche de la prévalence observée en Égypte (50% (Tawfik et al., 2015)). Palacios et Gonzalez confirment la généralisation des carences en vitamine D dans le monde y compris dans les pays qui disposent d'un fort ensoleillement comme l'Égypte, et soulignent l'importance du problème pour les jeunes filles et les femmes du Moyen-Orient (Palacios and Gonzalez, 2014). Les déficiences en folates semblent être un problème de santé publique dans des régions du monde autres que l'Égypte, mais la rareté des données et le manque de représentativité des études existantes ne permettent pas d'établir des tendances régionales (McLean et al., 2008).

Pour conclure, on constate que les femmes du Moyen-Orient, d'Afrique du Nord, d'Amérique du Sud et des Caraïbes sont, comme en Égypte, à la fois touchées par de fortes prévalences de surpoids et d'obésité et des risques de carences en micronutriments (fer et vitamine D *a minima*). Plus spécifiquement, le surpoids accompagné d'anémie est une problématique commune à d'autres pays en développement traversant une transition nutritionnelle comme le Mexique et le Pérou (Eckhardt et al., 2008). Ce constat souligne la difficulté à couvrir les besoins en fer des femmes dans les pays en transition nutritionnelle malgré des apports énergétiques suffisants, voire excessifs.

4.1.2. Cohérence des stratégies d'amélioration nutritionnelle modélisées

Une revue de bibliographie sur les méthodologies permettant de modéliser des régimes alimentaires durables (Article 4, disponible en annexe) a été rédigée en parallèle des travaux de thèse (Gazan et al., 2018). Nous reprendrons dans cette partie certains éléments de cette revue que nous étayerons à la lumière de récentes recommandations alimentaires pour discuter de la cohérence des stratégies d'amélioration nutritionnelle identifiées dans ces travaux.

Le fer, nutriment limitant.

Les résultats des analyses par modélisation ont montré qu'il était difficile de subvenir aux besoins en fer des femmes égyptiennes compte tenu des aliments consommés localement et des contraintes économiques. Le fer a déjà été identifié comme un nutriment

« problématique », c'est-à-dire un nutriment pour lequel les recommandations ne peuvent pas être atteintes à partir des aliments locaux tels que consommés par la population. Des études (réalisées avec Optifood) ont montré que les recommandations en fer étaient inatteignables pour des enfants et des femmes d'Asie du Sud-Est et du Kenya, même en maximisant l'adéquation nutritionnelle dans les régimes modélisés (Ferguson et al., 2015b, Ferguson et al., 2015a, Ferguson et al., 2015c, Fahmida et al., 2014)¹⁶. Au Mozambique, le fer et certaines vitamines du groupe B (riboflavine, acide pantothénique) étaient contraignants car l'atteinte des recommandations nutritionnelles impactait grandement le coût des régimes modélisés (Frega et al., 2012). Nos résultats sont donc cohérents avec un ensemble d'études utilisant la modélisation qui prouvent qu'atteindre les recommandations nutritionnelles pour tous les nutriments simultanément est un défi difficile à relever (Gao et al., 2006, Maillot and Drewnowski, 2012, Maillot et al., 2013) d'autant plus lorsque des contraintes de coût sont imposées (Darmon et al., 2003, Darmon et al., 2002, Wilde and Llobrera, 2009, Gazan et al., 2018).

Le jeu de conseils alimentaires modélisés est cohérent avec les recommandations alimentaires internationales

Le jeu de conseils alimentaires modélisé est globalement cohérent avec les recommandations alimentaires élaborées par des organismes internationaux (FAO, OMS, Département de l'Agriculture des Etats-Unis) (Food and Agriculture Organization and World Health Organization, 2019, World Health Organization, 2018, US Department of Health Human Services and US Department of Agriculture, 2015) et celles récemment publiées par la commission du EAT-Lancet (Willett et al., 2019). Ces recommandations s'accordent pour proposer une augmentation de fruits, légumes, légumineuses et noix et une réduction des consommations de produits sucrés et de viande rouge. Nos résultats montrent que des changements similaires seraient nécessaires pour les femmes égyptiennes afin d'améliorer l'adéquation nutritionnelle tout en respectant des contraintes de coût (forte augmentation des fruits, légumes, légumineuses et produits laitiers et consommation d'une variété de produits du groupe « viande, poisson, et œufs »). Cependant, les quantités du groupe « viande poisson et œufs » et de légumineuses recommandées dans nos travaux (169 g par jour du groupe « viande, poisson et œufs »¹⁷ et 120 g/j de légumineuses) sont plus importantes que les quantités du régime du EAT-Lancet (84 g/j du groupe « viande, poisson

¹⁶ Les analyses maximisant l'adéquation nutritionnelle étaient réalisées dans le Module II d'Optifood.

¹⁷ Le jeu de conseils alimentaires modélisé pour les femmes égyptiennes aboutit à la consommation **hebdomadaire** de deux portions de viande rouge, deux portions de poisson *Tilapia*, une portion de foie et quatre portions d'œufs. Ramenées à des quantités **journalières**, ces conseils correspondent à 59 g de viande rouge, 80 g de poisson, 16 g de foie et 54 g d'œufs par jour, soit 169 g/j de produits du groupe « viande, poisson et œufs ».

et œufs »¹⁸ et 75 g/j de légumineuses). Pourtant, la recommandation en fer n'est que partiellement couverte par le jeu de conseils alimentaires modélisé (40% dans les analyses minimisant la teneur en fer, et 65% dans les analyses estimant la teneur moyenne en fer du jeu de conseils), ce qui souligne la difficulté à couvrir les besoins en fer des femmes en âge de procréer. La réduction de viande rouge recommandée par les différents organismes internationaux est bien sûr à moduler en fonction des consommations actuelles des populations à l'échelle régionale. Le rapport du EAT-Lancet souligne par exemple que la consommation de viande rouge devrait être réduite dans les pays d'Amérique du Nord, d'Europe, d'Asie centrale, d'Amérique Latine et des Caraïbes, alors qu'elle devrait être augmentée dans les pays d'Asie du Sud-Est. Les pays du Moyen-Orient et d'Afrique du Nord sont proches des quantités recommandées par le EAT-Lancet. Nos résultats sont donc cohérents avec ces recommandations générales, puisque d'une part, les changements à réaliser consistent en une augmentation de la consommation de fruits, légumes et légumineuses et d'autre part, nos résultats soulignent l'importance d'adapter les conseils alimentaires aux besoins spécifiques des populations locales. En l'occurrence, les besoins importants en fer des femmes en âge de procréer et la biodisponibilité réduite du fer du fait de la composition des régimes en Égypte nécessite un apport suffisant de produits animaux.

Une des forces de notre étude est d'avoir pris en compte le coût de l'alimentation dans les analyses par modélisation. En effet, la dimension économique occupe une place centrale dans la définition d'un régime alimentaire durable d'après la FAO (un régime alimentaire durable étant à la fois nutritionnellement adéquat, abordable économiquement, culturellement acceptable et respectueux de l'environnement) (Burlingame et al., 2012). Une récente étude confirmait l'importance de la prise en compte des facteurs économiques en démontrant par exemple que le régime de référence proposé par le EAT-Lancet (qui été conçu sans considérations financières) n'est pas abordable économiquement pour 1,58 milliards de personnes (Hirvonen et al., 2020). Cette étude souligne donc la plus-value de modéliser des régimes alimentaires avec des contraintes économiques, comme nous l'avons fait dans ces travaux. A l'inverse, aucune donnée environnementale n'étant disponible pour les aliments consommés en Égypte, nous n'avons pas pu prendre en compte cette dimension dans nos travaux. Compte tenu de l'impact environnemental important de la production de viande rouge (Willett et al., 2019), on peut émettre l'hypothèse que le jeu de conseils alimentaires aurait différé si les émissions de gaz à effets de serre, l'utilisation des terres ou la consommation d'eau avaient été intégrés dans le modèle (moins de viande rouge par exemple) (Gazan et al., 2018). Si des données sur l'impact environnemental des aliments consommés en Égypte venaient à paraître, il serait intéressant de modéliser des régimes

¹⁸ Le régime de référence proposé par le EAT-Lancet contient 14 g de viande rouge, 29 g de volaille, 13 g d'œufs et 28 g de poisson par jour, soit 84 g/j d'aliments du groupe « viande, poisson et œufs » (WILLETT, W., ROCKSTRÖM, J., LOKEN, B., SPRINGMANN, M., LANG, T., VERMEULEN, S., GARNETT, T., TILMAN, D. & DECLERCK, F. 2019. The Lancet Commissions Food in the Anthropocene: the EAT-Lancet Commission on healthy diets from sustainable food systems.).

alimentaires riches en fer, abordables économiquement, acceptables culturellement et à faible impact environnemental.

4.1.3. Discussion des barrières et leviers identifiés par l'étude d'acceptabilité

Étant donné les spécificités d'âge (18-35 ans), de lieu de résidence (Le Caire uniquement) et de niveau socio-économique (classe moyenne) considérées dans les études qualitatives, nos résultats ne prétendent pas être représentatifs de la population féminine en Égypte. Cependant, malgré les faibles effectifs mobilisés pour les focus groupes (n=62) et les entretiens individuels (n=18), nous sommes arrivés à une certaine convergence des informations, c'est-à-dire que nous retrouvions les mêmes types de réponses dans les entretiens.

Les contraintes de temps et d'accessibilité sont répandues

L'inaccessibilité économique et géographique d'aliments sains ainsi que le manque de temps pour préparer des repas équilibrés sont des barrières qui ont été évoquées par les femmes interrogées dans ces travaux. Ces résultats sont assez peu surprenants, car les aliments denses nutritionnellement sont souvent plus chers que les aliments plus énergétiques et à faible densité nutritionnelle (Darmon and Drewnowski, 2015). Le manque de temps et d'accessibilité de produits sains sont par ailleurs des obstacles classiques à la mise en place d'habitudes alimentaires équilibrées. A titre de comparaison, dans la population européenne, le prix est le deuxième facteur le plus influent sur les choix alimentaires (après la qualité et la fraîcheur du produit) et le manque de temps est la barrière la plus fréquente (Lappalainen et al., 1998). La notion de déserts alimentaires, qui qualifie l'inaccessibilité géographique et économique des aliments frais et denses nutritionnellement (comme les produits animaux et les fruits et légumes) a été largement étudiée aux Etats-Unis (Council, 2009, Walker et al., 2010). Une étude sur l'accessibilité aux aliments frais dans les quartiers urbains d'Égypte permettrait de déterminer si ces environnements sont des déserts alimentaires similaires à ceux observés aux Etats-Unis. Des exemples de repas hors domicile proposés par les enseignes présentes sur les lieux d'étude ou de travail constitueraient par ailleurs des moyens simples pour rendre le jeu de conseils alimentaires plus applicable. Enfin, suggérer des recettes rapides à préparer à partir des aliments recommandés permettrait de contourner certaines barrières liées au manque de temps.

Les barrières et leviers psychologiques illustrent le tiraillement des femmes entre envies impulsives et objectifs long-terme.

Les barrières et leviers psychologiques identifiés dans ces travaux rappellent de manière assez nette les conclusions de plusieurs auteurs, qui ont montré que les comportements alimentaires sont gouvernés par des considérations liées à la santé raisonnées et orientées vers un but (système « réflexif »), mais aussi par des déterminants hédoniques et psycho-affectifs (système « impulsif ») (Hofmann et al., 2008, Metcalfe and Mischel, 1999, Strack and Deutsch, 2004). Les souhaits des femmes de diminuer les risques

pour leur santé, d'acquiescer une meilleure confiance en elles et de réduire leur culpabilité vis-à-vis de leur alimentation constituent des considérations relativement long-terme et abstraites qui les motiveraient à appliquer le jeu de conseils. À l'inverse, leur recherche de plaisir alimentaire par la consommation d'aliments gras, salés ou sucrés, leur comportement curatif plutôt que préventif et leur perception négative des aliments « sains » illustrent la difficulté à résister aux envies impulsives. L'équilibre entre systèmes réflexif et impulsif fait partie des déterminants du comportement alimentaire, et il est donc nécessaire d'identifier des stratégies pour promouvoir le jeu de conseils alimentaires qui satisfont les désirs de palatabilité tout en permettant de contribuer aux objectifs long-terme de bien-être physique et psychologique.

Les motivations esthétiques des femmes : un levier mobilisable ?

L'importance des préoccupations esthétiques des femmes constatée dans nos travaux rejoint des observations montrant que la plupart des publicités liées aux soins du corps dans les médias égyptiens sont destinées aux femmes, en les invitant à prendre en main leur futur et leur bonheur *via* leur apparence externe (Ghannam, 2008). En Indonésie, où la culture du voile et la tradition de ne pas découvrir excessivement son corps et son visage existent également, il a aussi été constaté que les femmes musulmanes de classe moyenne essayaient de maintenir une silhouette fine, apportaient un grand soin à leur peau, portaient des accessoires de mode et apportaient un soin particulier à leur maquillage (Listyani et al., 2018), ce qui renforce l'idée que l'apparence physique est une préoccupation importante pour cette population.

Les bénéfices esthétiques potentiels perçus révèlent d'une part les aspirations des femmes à des corpulences plus fines (comme en témoigne par exemple la peur de prendre du poids en consommant des produits céréaliers ou du tahini), et d'autre part leurs attentes à propos de caractéristiques corporelles liées à leur peau, cheveux, ongles et dents (comme le montrent les impacts supposés des fruits et légumes sur ces aspects). L'aspiration des femmes à des corpulences fines est une tendance dans différents pays de la région d'Afrique du Nord et du Moyen-Orient (Tlili et al., 2008, Ragab, 2007, Trainer, 2010). Si cet idéal de minceur peut apparaître comme un levier pour motiver les femmes à adopter des régimes alimentaires moins énergétiques (et nutritionnellement plus denses), le développement de troubles du comportement alimentaire (anorexie, boulimie) chez les jeunes femmes dans le monde souligne à l'inverse les dérives et risques potentiels de ce type de communication (Hesse-Biber et al., 2006, Betz et al., 2019).

Les préoccupations des jeunes femmes pour leurs cheveux, leur peau, leurs dents et leurs ongles pourraient *a priori* constituer des leviers pour communiquer autour du jeu de conseils alimentaires. Le développement récent de la nutri-cosmétique, qui mobilise les motivations esthétiques pour promouvoir la consommation de compléments alimentaires, est un témoin de la prise de conscience de l'impact (fondé ou non) des nutriments ingérés sur le corps (Dini and Laneri, 2019). Une communication sur l'importance d'une alimentation suffisamment riche en micronutriments pour maintenir diverses caractéristiques corporelles pouvant être associées à une bonne santé pourrait donc augmenter la motivation des

femmes à appliquer le jeu de conseils modélisé, mais ces bénéfices doivent être clairement démontrés au préalable.

La motivation à changer est déterminante.

Les barrières et leviers liés au suivi du jeu de conseils alimentaires peuvent être articulés en déterminants individuels (motivations personnelles, aspects hédoniques, émotions, perception des normes, connaissances) et contextuels (habitudes, accessibilité géographique et économique, temps, commensalité, normes) comme résumé par la Figure 19. Bien qu'il s'agisse d'un processus complexe et dépendant de facteurs cognitifs et psycho-affectifs ou externes à l'individu, la motivation des femmes à suivre le jeu de conseils alimentaires est primordiale. Cette motivation passe par la perspective de bénéfices sur la « santé » au sens large (telle que définie par l'OMS), c'est-à-dire « un état de bien-être physique, mental et social complet » (World Health Organization, 1948). Dans nos études, les bénéfices « santé » perçus pouvaient être esthétiques (apparence physique de la peau, des cheveux, des ongles, des dents ou encore le poids corporel), psychologiques (bien-être et meilleure confiance en soi) ou physiologiques (traitement ou prévention de maladies) (Figure 19). Le rôle central de la motivation (parfois appelée « intention ») a été analysé par plusieurs auteurs (Triandis, 1979, Ajzen, 1991, Michie et al., 2011). Chez des consommateurs britanniques et tchèques, la motivation des participants à manger sain constituait le premier déterminant des comportements alimentaires et avait une influence plus grande que les barrières physiques rencontrées telles que le manque de temps ou le coût des produits (Michaelidou et al., 2012). La motivation liée à des conséquences long-terme sur la santé semble être renforcée par un meilleur état psychologique (Gardner et al., 2014). L'éducation et la sensibilisation aux problématiques de santé restent donc des leviers mobilisables pour amener les femmes égyptiennes à suivre le jeu de conseils modélisé, mais devront être adaptées aux facteurs influençant la motivation.

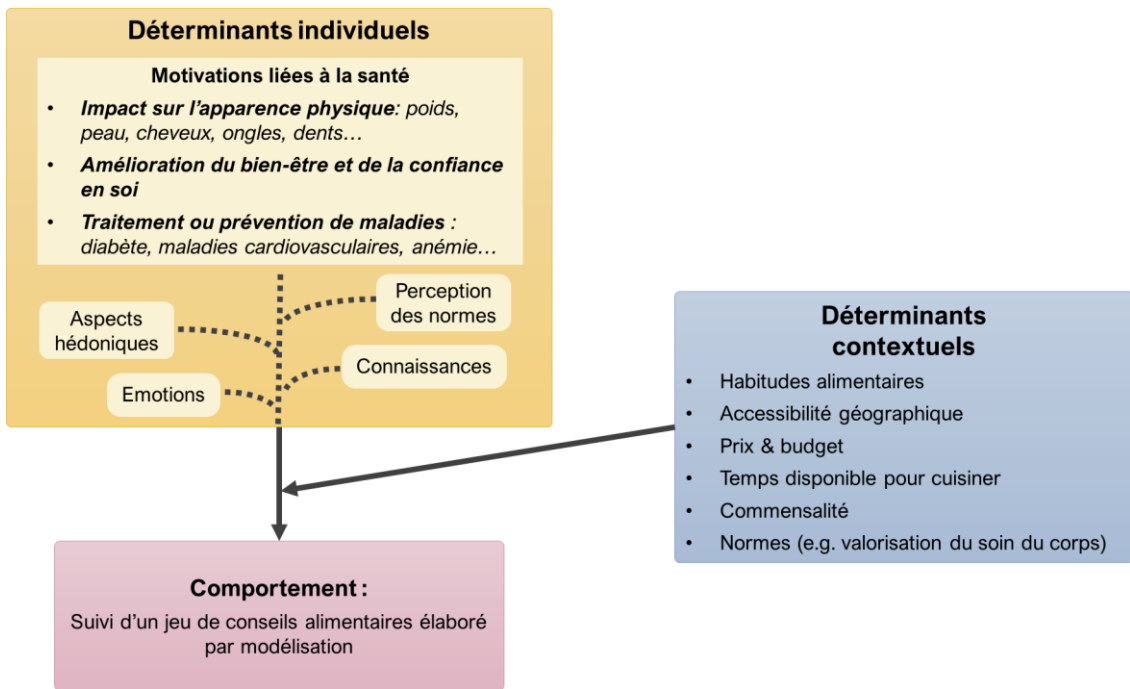


Figure 19. Déterminants individuels et contextuels du suivi d'un jeu de conseils alimentaires élaboré par modélisation par les femmes égyptiennes résidant en milieu urbain.

4.2. Perspectives

Les résultats de ces travaux de thèse ouvrent des perspectives pour appréhender les problématiques de santé des femmes égyptiennes liées aux déséquilibres nutritionnels et imaginer les interventions susceptibles de faire évoluer leurs pratiques alimentaires. Parmi les voies à explorer en complément, il faut citer (1) l'étude des causes de l'anémie, (2) la recherche de moyens pour améliorer de l'acceptabilité du jeu de conseils modélisé, et (3) la mise en place d'approches de terrain permettant de mesurer le suivi du jeu de conseils alimentaires.

4.2.1. Exploration des causes de l'anémie chez les femmes égyptiennes

Les causes de l'anémie (très prévalente (47%) chez les femmes égyptiennes (Tawfik et al., 2015)) peuvent être multiples et restent encore en partie méconnues. Les apports trop bas en fer et sa faible biodisponibilité dans les régimes contribuent au développement de l'anémie. Mais l'anémie peut être aggravée par d'autres facteurs comme des apports insuffisants en folates et vitamine D, le surpoids et la présence de parasites intestinaux. En effet, dans la partie introductive (paragraphe « L'inadéquation en fer et le risque associé d'anémie »), nous avons vu que les carences en folates (*via* leur rôle dans la synthèse de l'ADN, la division cellulaire et l'érythropoïèse (World Health Organization, 2017)) et en vitamine D (de par son rôle dans l'expression de l'hepcidine et pour l'érythropoïèse (Smith and Tangpricha, 2015)) peuvent contribuer à l'anémie. Par ailleurs, le surpoids observé chez les participantes contribue à étayer l'hypothèse d'une biodisponibilité réduite du fer du fait de l'inflammation induite par l'obésité (confirmée par les niveaux élevés de protéine C réactive) (Yanoff et al., 2007, Tawfik et al., 2015). Enfin, la consommation de légumes à feuilles vertes crus (laitue, cresson, persil, oignons verts) et de produits animaux insuffisamment cuits sont des sources classiques de parasites intestinaux en Égypte (Eraky et al., 2014, Youssef and Uga, 2014), qui peuvent aussi participer à perturber l'absorption et le métabolisme du fer (World Health Organization, 2017). Ainsi, l'étude des régimes alimentaires et de la biodisponibilité du fer réalisée dans ces travaux renseigne sur une des causes possibles de l'anémie, mais mériterait d'être complétée par des bilans sanguins et une analyse microbiologique des boissons et aliments consommés afin d'étudier cette problématique de façon plus précise (Erhardt et al., 2004, World Health Organization, 2017).

4.2.2. Amélioration de l'acceptabilité des résultats des modélisations

L'acceptabilité du jeu de conseils alimentaires et des produits enrichis modélisés pourrait être améliorée *via* une meilleure évaluation et prise en compte des habitudes de consommation et des préférences alimentaires. Les conseils alimentaires modélisés

pourraient par ailleurs être rendus plus pratiques. La conception de produits enrichis doit aussi être adaptée aux besoins et contraintes des femmes afin d'améliorer leur acceptabilité.

Forces et limites de la méthodologie employée pour modéliser des stratégies d'amélioration nutritionnelle

Une des forces de l'approche utilisée dans ces travaux est d'être basée sur des données individuelles de consommation, quantifiées et locales, pour définir la liste d'aliments et paramétrer les contraintes minimales, maximales ainsi que les portions à partir desquelles ont été générés les conseils alimentaires. Partir de données quantifiées permet de représenter précisément les pratiques alimentaires de la population étudiée et évite de se baser sur des *a priori* pour paramétrer les modèles (Gazan et al., 2018). Une autre force de ces travaux réside dans la complémentarité des analyses réalisées avec Optifood (maximisation de l'adéquation nutritionnelle pour un régime au plus proche des pratiques alimentaires observées, puis minimisation de la teneur en nutriments pour vérifier la robustesse des jeux de conseils alimentaires testés), qui permet de s'assurer d'un certain réalisme face aux choix alimentaires observés et de la robustesse des conseils générés¹⁹. Cette approche, très spécifique à Optifood, constitue une richesse puisqu'elle garantit un niveau optimal adéquation nutritionnelle pour un maximum de nutriments possible, et ce en dépit de la variabilité nutritionnelle des aliments qui composent un même groupe alimentaire. Cependant, l'utilisation d'Optifood nous a limité dans le nombre de micronutriments modélisables simultanément (12 au total). La vitamine A pouvant être exprimée en deux unités différentes dans Optifood, nous avons tiré profit de cette redondance pour modéliser la vitamine D. Cependant, il aurait été intéressant de prendre en compte, en plus de la vitamine D, d'autres macro- et micronutriments non modélisés par Optifood et consommés en quantités inadéquates par les femmes égyptiennes comme les AGS, les sucres totaux, le sodium et le potassium. Optifood a jusqu'ici plutôt été utilisé dans des contextes de sous-nutrition et d'insécurité alimentaire et ces nutriments ne sont donc pas modélisables dans l'interface. Pour pallier cette limite inhérente au logiciel, des analyses complémentaires ont été réalisées afin d'estimer les teneurs moyennes en AGS, sucres totaux, sodium et potassium (notamment) des régimes modélisés. Ces analyses complémentaires n'avaient jusqu'ici jamais été réalisées dans les autres études utilisant Optifood, et constituent un moyen simple et

¹⁹ Le module II d'Optifood génère, à partir des aliments consommés localement, un régime alimentaire qui se rapproche le plus possible des recommandations nutritionnelles tout en restant proche des fréquences de consommation moyenne des groupes alimentaires (*via* la programmation multi-objectifs), comme expliqué au paragraphe «

Présentation d'Optifood ». Il permet donc l'identification d'un régime proche des pratiques alimentaires locales et optimal nutritionnellement, qui sert de base à la formulation de conseils alimentaires. Le module III est conçu pour tester la robustesse de conseils alimentaires inspirés du régime optimal généré lors du module II, en générant une multitude d'analyses qui minimisent la teneur en un nutriment tout en appliquant les conseils alimentaires comme des contraintes. Ces approches sont donc complémentaires, puisqu'on utilise des analyses de maximisation et de minimisation des teneurs en nutriments pour identifier un jeu de conseils alimentaires à la fois proches des pratiques alimentaires et robuste sur le plan nutritionnel.

efficace de s'assurer de l'adéquation en nutriments non modélisés du jeu de conseils retenu. En effet, ces analyses ont permis d'identifier un jeu de conseils qui corresponde à un compromis maximisant l'adéquation en fer et en autres nutriments, mais qui n'excède pas les recommandations nutritionnelles en énergie, AGS et sodium notamment, limitant ainsi les quantités de viande dans les conseils alimentaires modélisés. Les groupes alimentaires qui contiennent le plus de fer par portion sont les viandes et abats, qui peuvent être riches en énergie, AGS et sodium, en particulier lorsqu'ils sont cuisinés frits. D'autres logiciels prenant en compte un plus grand nombre de nutriments simultanément pourraient être utilisés pour confirmer les résultats obtenus avec Optifood, comme par exemple l'interface « Optimeal ® » (Blonk Consultants, 2019, Van Dooren et al., 2015) ou des logiciels intégralement paramétrables comme « R » ou « SAS/STAT ® ».

Améliorations méthodologiques envisageables

D'autres critères d'acceptabilité que ceux considérés dans l'Article 2 pourraient être envisagés afin de mieux paramétrer et/ou prédire l'acceptabilité des conseils modélisés. En effet, les indicateurs d'acceptabilité portaient simplement sur la fréquence moyenne de consommation des aliments recommandés, le pourcentage de consommatrices, le prix des aliments recommandés par portion, et le fait que le conseil porte sur un aliment spécifique, un sous-groupe ou un groupe alimentaire. Certaines études ont utilisé des « scores de pénalité » pour estimer l'acceptabilité des régimes modélisés en reflétant la popularité des aliments composant le régime modélisé. Ces scores de pénalité peuvent aussi être minimisés dans les modélisations, de manière à ce que les régimes modélisés restent au plus proche des régimes observés (Tyszler et al., 2014, Kramer et al., 2017) Il serait intéressant de créer et de valider un indice d'acceptabilité incluant ces différents indicateurs afin d'améliorer la prise en compte de l'acceptabilité dans les modèles. Par ailleurs, l'analyse d'autres caractéristiques des aliments, au-delà du prisme des groupes et sous-groupes alimentaires (par exemple « sucré / salé », « chaud / froid », « consommable avec / sans couverts ») pourrait améliorer la compréhension des pratiques alimentaires et permettre une comparaison entre les conseils modélisés et les pratiques. Les analyses par clusters ou par composantes principales (Akkoyunlu et al., 2018, Lee and Seung, 1999, Luo et al., 2014, Reedy et al., 2010, Thorpe et al., 2016) visent à identifier des comportements comparables, ou des facteurs déterminants des comportements, et renseigneraient donc sur les types de comportements existants au sein d'une même population ainsi que sur l'acceptabilité des conseils alimentaires identifiés dans les différents groupes de consommateurs.

Le jeu de conseils alimentaires identifié suppose des changements dans les pratiques alimentaires des femmes. Cependant les substitutions précises qui devraient être effectuées n'ont pas été identifiées dans ces travaux. L'intelligence artificielle ouvre des pistes intéressantes pour identifier des substitutions acceptables et des conseils pratiques pour appliquer le jeu de conseils alimentaires (Schölkopf et al., 2002). En effet, les bases de données de consommation permettent de repérer des substitutions alimentaires déjà réalisées par les consommateurs, donc *a priori* acceptables. Des algorithmes permettent d'établir des scores de substituabilité en fonction du contexte environnemental (moment et

lieu de consommation, entourage) et alimentaire (aliments consommés lors de la même occasion alimentaire) de la consommation d'un aliment (Akkoyunlu et al., 2017). L'application de ces algorithmes aux données de consommation des femmes égyptiennes permettrait d'identifier des recommandations pratiques et adaptées aux pratiques alimentaires de la population.

Enfin, la personnalisation des conseils alimentaires est une voie prometteuse pour améliorer l'efficacité des conseils alimentaires (Bianchi et al., 2019). Dans ces travaux, les conseils ont été modélisés pour une population restreinte, au sein de laquelle les goûts et spécificités des individus peuvent varier. Le jeu de conseils alimentaires modélisé pourrait donc être adapté aux préférences individuelles. La modélisation à l'échelle de l'individu offre la possibilité de modéliser, pour chaque individu, un régime optimal à partir de son répertoire alimentaire (Maillot et al., 2010, Gazan, 2018) et représente donc une autre piste d'amélioration méthodologique pour mieux prendre en considération les variations des répertoires alimentaires individuels.

Adaptation des conseils alimentaires modélisés

Avant que les enquêtes qualitatives ne soient réalisées, les indicateurs quantitatifs d'acceptabilité du jeu de conseils alimentaires²⁰ laissaient penser que son adoption pouvait être compromise. En effet, le jeu de conseils inclut des aliments très spécifiques (tahini, poisson de type *Tilapia*), relativement chers (poisson *Tilapia* et viande rouge) ou peu fréquemment consommés (le yaourt, le poisson *Tilapia*, le tahini et le foie étaient par exemple consommés par moins de la moitié des femmes dans l'enquête alimentaire). Les entretiens individuels et les groupes de discussion ont permis d'explorer plus en détail les perceptions négatives des femmes vis-à-vis de chaque aliment (ou sous-groupe et groupe alimentaire) du jeu de conseils. La viande rouge est l'aliment du jeu de conseils alimentaires qui est associé aux plus de perceptions négatives. En effet, les femmes exprimaient leur réticence à consommer de la viande rouge du fait de son prix élevé, du manque de confiance dans l'origine et la sécurité alimentaire des produits animaux vendus en Égypte et des difficultés ressenties à digérer les protéines animales. La volaille était le sous-groupe alimentaire le plus consommé du groupe « viande, poissons et œufs » dans l'enquête alimentaire (64 ± 67 grammes par jour de volaille en moyenne, contre 35 ± 62 grammes par jour de viande rouge). Les réticences exprimées par les femmes à consommer de la viande rouge dans les études qualitatives ainsi que les quantités consommées de volaille dans l'enquête alimentaire laissent penser qu'il serait préférable de remplacer *a minima* une (voire deux) des deux

²⁰ Les indicateurs quantitatifs d'acceptabilité du jeu de conseils alimentaires incluaient la fréquence moyenne de consommation des aliments recommandés, le pourcentage de consommatrices de l'aliment, le coût par portion, et le fait que le conseil alimentaire porte sur un aliment spécifique ou un groupe alimentaire, comme décrit dans l'article présenté au paragraphe «

portions de viande rouge par de la volaille dans le jeu de conseils. Ce remplacement a été testé mais ne permettait pas d'apporter autant de fer que la viande rouge, et n'a donc pas été retenu. Les femmes ont également exprimé leur hésitation à consommer des légumineuses compte tenu de leurs difficultés présumées à les digérer. Des conseils sur le mode de préparation et de cuisson des légumineuses (trempage, temps de cuisson, aromates à utiliser en association...) pourraient aider les femmes à envisager la consommation de légumineuses avec moins d'*a priori* négatifs sur leur digestibilité. On voit ainsi que les perceptions des femmes sur les groupes alimentaires sont utiles pour affiner et ajuster le jeu de conseils modélisé. Une enquête qualitative synchrone aux modélisations aurait permis d'aboutir à un jeu de conseils alimentaires plus acceptable (puisque tenant compte des perceptions négatives et positives des femmes sur chacun des aliments), mais avec une moins bonne adéquation nutritionnelle (la volaille apporte par exemple moins de fer que la viande rouge (Lombardi-Boccia et al., 2002)).

Notons que le jeu de conseils modélisé repose essentiellement sur une consommation plus importante d'aliments traditionnels égyptiens tels que les légumineuses, les légumes, le foie, le poisson ou le tahini, qui ont déjà été décrits comme des aliments ayant un fort intérêt nutritionnel pour l'Égypte (Hassan-Wassef, 2004, Hassan-Wassef, 2007). Il paraît donc important de trouver des stratégies pour valoriser la cuisine traditionnelle égyptienne.

Concevoir des produits enrichis denses nutritionnellement, faciles d'utilisation et abordables économiquement.

Les résultats des modélisations ont mis en évidence que l'enrichissement en fer d'aliments de base tels que le riz ou le pain peut constituer une stratégie efficace pour réduire les risques d'inadéquations en fer. Les produits théoriques ou prototypes testés (eau en bouteille, yaourt ou lait enrichis en fer) sont également des solutions permettant d'améliorer l'adéquation nutritionnelle. Le choix des vecteurs d'enrichissement est critique. La mise à disposition d'aliments enrichis pour la population générale représente d'abord un défi technique et économique. A titre d'exemple, l'enrichissement de l'huile de cuisson en vitamine A (West et al., 2008) et du pain *baladi* en fer et folates (Elhakim et al., 2012) ont été envisagées par le passé par le gouvernement égyptien, mais ces deux programmes ont été abandonnés pour des raisons techniques et économiques (Lailou et al., 2012, Abdalla and Al-Shawarby, 2017).

Le prix d'achat et la densité énergétique et nutritionnelle des aliments sont aussi des critères importants lors de la sélection d'un vecteur d'enrichissement, étant donné que ces aliments peuvent avoir un impact non négligeable sur la mise en place de comportements alimentaires obésogènes. En dehors des stratégies d'enrichissement, de nombreux experts ont montré que le fait de rendre très accessibles des aliments de base à haute densité énergétique et faible densité nutritionnelle avait probablement eu un rôle dans le développement de l'obésité et des carences en micronutriments en Égypte (Asfaw, 2006,

Asfaw, 2007a, Asfaw, 2007b, Ecker et al., 2016)²¹. Les différentes crises économiques qui ont affecté l'Égypte ont augmenté fortement le prix des aliments non subventionnés comme les fruits et légumes, ce qui a possiblement participé à ce que les foyers égyptiens orientent leurs régimes vers des aliments à bas prix et à haute teneur énergétique, et donc à l'augmentation des IMC (Asfaw, 2006, Asfaw, 2007a, Asfaw, 2007b, Ecker et al., 2016). Des produits de plus grande densité nutritionnelle et de plus faible densité énergétique sont donc à favoriser comme vecteurs d'enrichissement en fer.

Les femmes évoquaient les contraintes d'accessibilité géographique et économiques à une alimentation plus saine sur leurs lieux d'études ou de travail, et mentionnaient consommer une grande partie de leur repas hors domicile. Des produits enrichis en fer consommables hors-foyer, accessibles géographiquement et économiquement et à forte densité nutritionnelle semblent donc plus prometteurs que l'enrichissement d'aliments de base relativement énergétiques (comme le pain) ou nécessitant une préparation (comme le riz), d'autant que ces aliments sont généralement aussi consommés par d'autres membres du foyer, qui peuvent avoir des besoins plus bas en fer (enfants par exemple).

4.2.3. Interventions pour améliorer la qualité de l'alimentation des femmes égyptiennes résidant en zone urbaine

Les résultats des modélisations ont montré qu'un jeu de conseils alimentaires formulé uniquement à partir d'aliments consommés et non enrichis ne suffit pas à couvrir les besoins en fer des femmes égyptiennes résidant en milieu urbain. Il serait donc intéressant de développer et d'intégrer dans le jeu de conseils alimentaires un (ou des) produit(s) enrichi(s) en fer qui réponde(nt) aux contraintes économiques et de temps des femmes et qui garantis(ser) une meilleure adéquation en fer. Une fois ce(s) produit(s) enrichi(s) développé(s) et le jeu de conseils alimentaires adapté en conséquence, un essai d'amélioration des pratiques sur une quinzaine de jours pourrait être mis en place, afin d'anticiper les barrières et leviers rencontrés en conditions réelles pour appliquer les conseils alimentaires et consommer le (ou les) produit(s) enrichi(s) (Muehlhoff et al., 2011). Cette étape pourrait aboutir à une adaptation du nouveau jeu de conseils dont la promotion pourrait être testée au cours d'une intervention.

Il existe une multitude d'interventions possibles pour faire évoluer les comportements (Michie et al., 2011). Les stratégies les plus efficaces semblent être les stratégies adaptées aux préférences, aux pratiques et aux caractéristiques socio-économiques et démographiques des populations visées (Hawkes et al., 2015). Ainsi, une étude d'intervention portant sur le

²¹ Depuis 1941, le gouvernement égyptien subventionne des aliments de base tels que le pain, l'huile de cuisson et le sucre afin de fournir ces aliments à bas prix pour la majorité de la population. Devant la plus grande prévalence de surpoids et d'obésité observée chez des mères égyptiennes qui présentaient des carences en micronutriments, une étude interrogeait la pertinence des stratégies de subventions alimentaires et du type de produits subventionnés (ASFAW, A. 2007b. Micronutrient deficiency and the prevalence of mothers' overweight/obesity in Egypt. *Economics & Human Biology*, 5, 471-483.).

style de vie (pratique d'activité sportive et comportement alimentaire) a permis d'améliorer l'état de santé de femmes atteintes de syndrome métabolique résidant en Israël *via* la prise en compte des spécificités de la population et des normes culturelles locales : les activités sportives étaient pratiquées à l'intérieur, l'équipe d'intervention était constituée uniquement de femmes, les recommandations alimentaires incluaient des conseils spécifiques pour le Ramadan, des exemples d'adaptation des plats traditionnels étaient fournis et un maximum de flexibilité était possible dans l'implémentation du programme afin de correspondre aux contraintes familiales des participantes (Kalter-Leibovici et al., 2010). Ainsi, une intervention tout aussi adaptée aux contraintes et motivations des jeunes femmes résidant en milieu urbain en Egypte pourrait être envisagée pour promouvoir le jeu de conseils alimentaires modélisé. Nous avons vu que les préoccupations esthétiques (le poids et l'amélioration de l'apparence des cheveux, ongles, dents et peau) et psychologiques (la volonté de retrouver un bien-être et une confiance en soi) interviennent dans la motivation des femmes à adopter de meilleures pratiques alimentaires, mais la prise en compte de ces paramètres reste délicate et potentiellement à risque, et doit donc être testée avec soin au préalable à toute intervention. L'inaccessibilité géographique ou économique, ainsi que les contraintes de temps doivent être surmontées, en particulier pour les étudiantes et les femmes actives, qui disposent de peu d'options pour mieux s'alimenter en dehors de leur domicile. Des interventions sur les lieux d'étude et de travail, adaptées aux spécificités et aux contraintes des étudiantes et travailleuses pourraient donc avoir un intérêt.

4.3. Conclusion

Ces travaux de thèse ont permis de quantifier les apports alimentaires d'une population de femmes âgées de 19 à 30 ans résidant en Égypte urbaine, et de montrer que leurs apports étaient caractéristiques de populations traversant une transition nutritionnelle, avec des apports élevés en énergie, en sodium, et insuffisants en fer, folates et vitamine D. Les analyses par modélisation ont montré que les aliments consommés par les femmes pouvaient en théorie suffire à assurer l'adéquation nutritionnelle, sauf pour le fer. Un jeu de conseils alimentaires a été modélisé pour améliorer l'adéquation nutritionnelle, et le potentiel de produits enrichis en fer a été testé pour améliorer spécifiquement l'adéquation en fer. Les enquêtes qualitatives ont permis d'identifier des pistes pour communiquer autour du jeu de conseils alimentaires. L'alimentation de ces femmes semble associée à des enjeux psychologiques et esthétiques importants, bien que soumise à des contraintes liées au mode de vie de ces jeunes urbaines et à des aspects économiques. L'approche transdisciplinaire associant la nutrition, des modélisations mathématiques et les sciences de la consommation semble une voie prometteuse pour identifier des changements alimentaires plus acceptables et répondre à des enjeux de santé publique locaux. Des stratégies pour promouvoir des conseils alimentaires acceptables et mettre à disposition des produits enrichis en fer attractifs doivent à présent être envisagées pour améliorer l'alimentation des jeunes femmes égyptiennes résidant en milieu urbain.

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ANNEXE – Article 4

Mathematical optimisation to explore tomorrow's sustainable diets: a narrative review

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ABSTRACT:

A sustainable diet is by definition nutritionally adequate, economically affordable, culturally acceptable, and environmentally respectful. Designing such a diet has to integrate different dimensions of diet sustainability that may not be compatible with each other. Among multi-criteria assessment methods, diet optimisation is a whole-diet approach that simultaneously combines several metrics for dimensions of diet sustainability. This narrative review based on 67 published studies shows how mathematical diet optimisation can help understand the relationships between the different dimensions of diet sustainability and how it can be properly used to identify sustainable diets. Diet optimisation aims to find the optimal combination of foods for a population, a subpopulation or an individual that fulfils a set of constraints while minimising/maximising an objective function. In the studies reviewed, diet optimisation was used to examine the links between dimensions of diet sustainability, identify the minimum cost or environmental impact of a nutritionally adequate diet, or identify food combinations able to combine two or more sustainability dimensions. If some constraints prove difficult to fulfil, it signals either an incompatibility between nutrient recommendations, over-monotonous food consumption patterns, inadequate supply in nutrient-rich foods, or incompatibility with other dimensions. If diet optimisation proves successful, it can serve to design nutritionally-adequate and/or culturally-acceptable and/or economically-affordable and/or

environmentally-friendly diet. Diet optimisation results can help define dietary recommendations, tackle food security issues and/or promote sustainable dietary patterns. This review emphasizes the importance of carefully choosing the model parameters (variables, objective function, constraints) and input data, and the need for appropriate expertise to correctly interpret and communicate the results. Future research should make improvements in the choice of metrics used to assess each aspect of a sustainable diet, especially the cultural dimension, to improve the practicability of the results.

Keywords (5-10): nutrition, food, epidemiology, cost, greenhouse gas emissions, linear programming, recommendations, multicriteria assessment, diet optimisation, sustainability

Introduction

Obesity and noncommunicable diseases are increasingly prevalent high-income countries (1), while undernutrition and obesity coexist in low-income populations (2). The current food production system in more economically-developed countries carries a significant burden of environmental impacts that is further accentuated by intensification of industrial and agricultural production in fast-developing countries like China and India (3). Given this context, the concept of sustainable diets, i.e. diets that are “protective and respectful of biodiversity and ecosystems, culturally acceptable, accessible, economically fair and affordable; nutritionally adequate, safe and healthy; while optimising natural and human resources”, is gaining attention in both high-income and low-income countries (4).

Assessing diet sustainability entails simultaneously exploring their health/nutrition, economic, cultural and environmental dimensions. Research investigating the relationship between the health and economic dimensions, both in observational or modelling studies, has found that nutritionally adequate diets (i.e. diets covering a set of nutrient recommendations) are often more expensive than unhealthy diets (5). Research tackling the challenge of climate change has explored the relationship between the nutritional quality and environmental impact of self-selected diets, and the results showed that nutritionally adequate diets are not necessarily associated with low dietary greenhouse gas emissions (GHGE) (6,7). Different dimensions of diet sustainability may not be compatible with each other, so no aspect of sustainable diet should be left out (6). It is now necessary to imagine tomorrow’s diets by establishing the best balance between the different dimensions of a sustainable diet, using multi-criteria assessment methods.

Operational research (OR) encompasses several advanced analytical methods that help to identify optimal or near -optimal solutions to solve complex problems (8). OR methods offer suitable tools for integrating the multi-dimensional complexity of sustainable diets. Among many other OR methods, substitution and mathematical optimisation are common problem-solving techniques used for designing healthier diets. Substitution approaches can test an “*a priori* hypothesis” by replacing one or several foods with others, based on *a priori* reasoning. Food substitution methods have been used to assess nutritional (9–11) and economic (12–14) or environmental (15,16) impacts of dietary changes. An alternative substitution method used an iterative process to identify, without *a priori* reasoning, the best food and beverage substitutions required within a diet to improve a nutritional quality score (17). However, these heuristic approaches require multiple steps to finally identify a diet that is not always the optimal one. In order to find the very best way to simultaneously fulfil a given set of constraints, researchers have used mathematical optimisation to model theoretical diets (18). Mathematical diet optimisation (‘diet

optimisation') tackles the challenge of identifying the optimal combination of foods to answer a given question under a set of predefined constraints (e.g. imposed nutrient recommendations, a total diet cost, an environmental target, etc.). Diet optimisation has, for instance, been used to answer questions such as: Is it feasible to achieve all the nutritional recommendations (i.e. nutritional adequacy) with the current food supply (19)? What is the minimum cost of a nutritionally adequate diet (20–22)? Which optimal food combinations would be required to reach nutritional adequacy while staying as close as possible to the current diet (23,24)? What is the optimal combination of foods to reduce environmental impact, while fulfilling nutrient recommendations and departing the least from an existing diet (25,26)? Diet optimisation is increasingly used in the field of public health nutrition. There is a need to establish a general picture of the numerous ways to mathematically optimise diets, especially in the context of sustainable diets.

The aim of this narrative review, based on 67 relevant original publications, is to show how mathematical diet optimisation can help understand the links between the different dimensions of diet sustainability, and how it can be properly used to identify sustainable diets.

1. Introduction to diet optimisation

Mathematical diet optimisation, also called diet modelling or diet optimisation, started in the 1940s with Georges Stigler, who chose diet as an example to translate a complex problem into a mathematical model called the "Diet problem". The goal of the diet problem was to find the set of foods that satisfied daily nutritional requirements at minimum cost (27). The technical solution for solving this problem was developed by Dantzig through the Simplex algorithm, which is the backbone of linear programming (18). The optimal solution of the "Diet problem" was finally reached by Laderman, who demonstrated the solving capacity of the Simplex algorithm (18). Today, optimisation problems can take other forms than linear functions, such as quadratic programming (28), mixed-integer programming when using integer variables (29), or goal-programming to solve problems with multiple objectives (30,31). All these different approaches are covered in this paper.

The parameters of a mathematical optimisation problem are the decision variables, the constraints, and the objective function. Mathematically, an optimisation model aims to find the unique combination of values for decision variables that generates the optimal value for one objective function, while fulfilling a set of equalities or inequalities, called constraints. Applied in nutrition, a diet optimisation model aims to find the unique combination of foods that minimises or maximises an objective (e.g. total diet cost, energy content or the content of a given nutrient, total deviation from the observed diet), while fulfilling nutritional recommendations and/or maximal amount of foods, food groups and/or other constraints. An illustration of a diet optimisation with its parameters is presented in **Figure 1**. The model has a feasible solution when at least one combination of decision variables can simultaneously meet all the constraints. When there are multiple combinations that fulfil the set of constraints, the unique solution of the model is selected as the one that best answers the objective function. However, it may happen that a model has no feasible solution, meaning that at least two constraints are not compatible using the decision variables. Special attention must be given to each parameter of the model, in particular to avoid getting unrealistic and extreme solutions. For instance, in 1959, after obtaining, for a British family, a nutritionally adequate and affordable diet that contained only six foods out of 73, Smith had the idea of introducing food-habit constraints in

order to obtain a more realistic diet—dubbed “palatable human diet”—which could be more acceptable (32).

Throughout this paper, “observed” diet refers to the current diet of a given population, a subpopulation or an individual, while “optimised” diet refers to one theoretical diet obtained after running one diet optimisation model. A diet optimisation model is usually designed for a daily (or weekly) diet or a food basket. Here we consider diet optimisation as “population-based optimisation” when applied for a given population or subpopulation, and as “individual-based optimisation” when applied for each individual of a population. In population-based optimisation, only one diet is modelled for the whole population. The decision variables are the foods (food items or food groups which are aggregations of similar foods) mostly consumed—or potentially available—in the population of interest. With this approach, it is assumed that all foods are potentially acceptable for all individuals from the population of interest. In individual-based optimisation, one diet is modelled for each individual of the population. For each model, the decision variables are the foods consumed by the individual, completed if necessary by “new” foods, i.e. foods not currently consumed by the individual but consumed in the wider population. When the aim of the model is to stay closer to the current diet, the objective function in population-based optimisation aims to stay as close as possible to the average observed diet, whereas in individual-based optimisation the model for each individual aims to deviate the least from each individual observed diet, thus better taking individual food habits into account. When dealing with public health and nutrition issues, applying diet optimisation at individual level creates a diverse range of optimised diets, which can be statistically analysed, thus providing robustness in the conclusion.

The literature strategy used to compile the 67 relevant original publications using mathematical diet optimisation is presented in **Supplemental Material 1**. Studies using mathematical optimisation without a whole-diet approach were excluded from this review. A description of each of the 67 studies reviewed can be found in the **Supplemental Tables 1a, 1b, 1c**, which detail the population studied, type of modelling (individual or population-based), objective function, constraints for each dimension of diet sustainability (health/nutrition, culture, economy, environment) and software used.

2. Dimensions and metrics of diet sustainability

Appropriate metrics need to be chosen to assess each dimension of diet sustainability, namely health/nutrition, culture, economy, and environment. All 67 studies of this review considered the nutrition and cultural dimensions, and some papers also included the economic and/or environmental dimensions (**Supplemental Tables 1a; 1b; 1c**). The cultural dimension, also called “cultural acceptability”, was taken into account in various ways that will be described and discussed in what follows. Foods habits of the population studied was considered a proxy for cultural acceptability, based on the list of foods available and/or consumed in the food survey and/or food consumption pattern. The nutrition dimension was studied through nutritional quality or adequacy of diets. As diet optimisation rarely considers the health aspect, it is only addressed in the discussion. The economic dimension was depicted via economic affordability using diet cost. The environmental dimension was assessed through one or more diet-related environmental metrics (e.g. GHGE, indirect land use, water use).

3. Nutritionally adequate diets

A nutritionally adequate diet is compliant with nutritional recommendations, meaning that it fulfils a set of reference values (RVs). RVs are quantitative reference values of nutrient intakes for healthy individuals, given for different population groups and derived from health-related criteria (35). Diet optimisation, which can translate nutrient recommendations into an optimal combination of foods, has been used to answer several questions:

- Is reaching nutritional adequacy feasible, and what are the implications for food choices?
- Which nutrient recommendations are the most difficult to fulfil or, in the case of infeasibility, what are the “problem nutrients”?

3.1 Identifying the food combinations required to reach a nutritionally adequate diet

When nutritional recommendations are reachable with available foods, diet optimisation can translate the full set of nutrient-based recommendations into food combinations (type and amount), which can potentially serve as a basis for developing food-based recommendations (FBRs). Working on specific subpopulations and/or at individual level may then help to improve the acceptability of the optimal food combinations identified.

Models optimising a given nutritional characteristic (e.g. minimising total energy content) have been used to identify food combinations that reach nutritional adequacy starting from a simple list of foods. For example, from the list of locally-available foods in Malawi, linear programming was applied for each season (harvest and nonharvest) to select foods satisfying nutritional and food-habit constraints at a minimal amount of energy (24). Food-habit constraints were introduced to avoid departing too much from current food habits. Results showed that the minimum energy intake required to meet all constraints was realistic (i.e. below the average energy intake observed in the population) in the harvest season but consistently higher than the average energy intake in the nonharvest season unless the energy from vegetables or meat, fish and eggs was above the 75th percentile observed in the population. In France, the minimum energy needed to fulfil French recommended nutrient intakes and food-habit constraints was estimated at 1500 kcal for women and 1700 kcal for men (19).

Models minimising dietary changes from an average observed diet were developed to better take into account cultural acceptability when designing nutritionally adequate diet. For example, in 1993, an acceptable nutritionally adequate diet was designed to stay closer to the average diet of US women (23). Results helped to gain insight for promoting nutrition education messages by identifying the food changes required to reach nutritional adequacy (namely more fruit and vegetables and milk, and less cheese and composite dishes). In Japan, nutritionally-adequate optimised diets were built for different age and gender groups deviating as little as possible from the average observed diet of each subpopulation (36). Among Japanese adults, food changes were smaller for older (women especially) than younger groups who had to strongly increase their fruit and vegetables amount. Two pioneering studies, one using data from Malawi (37) and the other using data from Australia (38), applied diet optimisation to help design practical FBRs, which are usually burdensome and time-consuming to develop (39). The FBRs were created in several steps: i) using diet optimisation to design a nutritionally optimal diet respecting population food-habit constraints and then using this optimised diet as a basis to create draft FBRs, re-expressed as frequency of consumption of typical serving sizes; ii) testing whether fulfilling the draft FBRs ensures nutritional adequacy; iii) adjusting the FBRs based on expert feedback (30,38). Based on this approach, a pre-set

software called 'Optifood' was created specifically for designing FBRs taking into account subpopulation specificities (e.g. age, sex, food habits and food supply) in low-income countries (40). Optifood's modules are further detailed in **Supplemental Material 2**. Optifood's software has been extensively used for developing FBRs for under-2-year-old children (e.g. in Kenya (41,42), Guatemala (43), Indonesia (30,44), Cambodia (45) and in five Southeast Asian countries (46)), older children (in specific regions of Malawi (37) or Kenya (47)), and women in Guatemala (43). Diet optimisation also contributed to the development of a food guide in Benin for several adult age-gender subpopulations (48). Diet optimisation can also be used to test the coherence and efficacy of FBRs, which are usually developed via collective expertise based on scientific evidence linking diet to health and diseases. For example, the compatibility between nutritional requirements and meeting the 2005 US Food Guide Pyramids (49), the 2007 US cancer prevention recommendations (50), or a specific US recommendation on solid fats and added sugars (51), were all checked using diet optimisation. Diet optimisation was also used in the UK to assess the nutritional efficacy and cost implications of new updated UK dietary guidelines on sugar and fibre (52). In 2010, the European Food Safety Authority (EFSA) advocated the use of modelling techniques to test whether FBRs meet nutrient recommendations and adapt them as appropriate (53). Diet optimisation can greatly improve the FBRs development process, but the results still warrant careful expert examination to potentially re-adjust them in order to craft concise, realistic and readily-understandable food guidance messages specific to the population of interest.

Individual-based diet optimisation reflects individual variability in food consumption, which is a way to improve cultural acceptability. In 1990, diet optimisation was applied for the first time at individual level in a clinical study to demonstrate the potential value of diet optimisation for paediatric dietitians. Tailored and nutritionally adequate optimised diets were designed by maximising a preferential score for the diet (after assigning a preference score to each food) (54). Individual-based optimisation was then applied to minimise the deviations from each individual's observed diet in clinical and interventional studies on small samples of individuals (55,56). More recently, individual-based optimisation was developed in the field of nutritional epidemiology for public health and research purposes, and was first applied to 1171 individuals from a representative sample of the French population (57). Through this approach, average dietary changes required to reach nutritional adequacy were identified and quantified in the whole population or by subpopulation, while accounting for the inter-individual variability of food consumption (57–59). On average, in the population, the dietary changes required to fulfil nutritional constraints using individual-based optimisation were consistent with usual dietary advice (more fruit and vegetables, fish and unsalted nuts, less sweet products, meat and animal fat) (57). There are actually multiple ways to reach nutritional adequacy from the same set of nutrient constraints, food-habit constraints and foods available depending on the observed diets. Individual food changes can be assessed per-subpopulation. For example, specific food changes to reach nutritional adequacy were obtained by comparing average dietary changes among French individuals with or without excessive intakes of free sugars ($\leq 10\%$ or $>10\%$ dietary energy according to the WHO recommendation, respectively) (60). An increase in vegetables and decreases in sugar-sweetened beverages, sweet products and fruit juices were specifically required to reach nutritional adequacy for individuals with excessive free sugar intakes. Another study used individual-based optimisation to design nutritionally adequate diets among 12-18-month-old UK children and compared average optimised diets between subpopulations based on their current consumption of young child formula (YCF) and/or supplements. Food changes were bigger for children

who did not initially consume YCF nor supplements than children who did, with a switch from cow's milk to YCF (61).

3.2 Identifying binding constraints and problem nutrients to reach nutritional adequacy

A RV can be difficult to reach or even unattainable, either due to insufficient amount of nutrients in the food supply or incompatibility with another constraint applied in the model. Higher-income countries enjoy a diverse and nutrient-rich food supply that makes it easier to attain nutritionally adequate diet than in low-income countries, but the fulfilment of some nutrient constraints may still be a concern. When all RVs cannot be met simultaneously with the current food supply, specific models can be run to obtain the best near-optimal solution. Another possibility for solving an unfeasible model is to allow new food variables in the model.

When a nutritionally adequate diet is feasible, some RVs can have a higher influence on food selection than others, in which case they are identified as the most difficult RVs to fulfil. A nutrient constraint is called "binding constraint" (or "active constraint") when the amount of the nutrient in the optimised diet is just equal to the imposed value (i.e. RV), meaning that fulfilment of its RV strongly influences the food content in the optimised diet. Binding constraints can be identified and ranked by assessing the dual values, also known as shadow costs, which give the impact on the objective function when the constraint is relaxed by one unit. Zinc, vitamin B2, vitamin B6 and iron were identified as binding nutrient constraints when modelling a nutritionally adequate diet while minimising the total diet cost for 1–3-year-old French children (62). When designing nutritionally adequate diets departing the least from the average observed diet in adults, the upper limit on sodium and saturated fatty acids, and the minimal content of fibre were binding in France and Japan (26,36), and the minimal content of iron and vitamin A were binding in the US and Japan (36,51,63). In France, controversial macronutrient recommendations (i.e. total fat, total carbohydrates, MUFAs (MonoUnsaturated Fatty Acids), and cholesterol) were investigated by imposing various combinations of macronutrient constraints in an individual-based optimisation (58). The constraint applied on MUFAs ($\geq 15\%$ of total energy) was shown to be very difficult to satisfy, and MUFAs content in optimised diets without this constraint was consistently reduced.

A too high (or too low) nutrient level imposed as a constraint is problematic, since it can lead to unrealistic optimised diets or may even make the model infeasible (meaning that this nutrient constraint is incompatible with at least one other constraint of the model). To test the compatibility between one specific nutrient recommendation and the others, one can either assess whether the recommendation is reached when maximising the value of the nutrient while fulfilling the other nutrient constraints, or assess the impact of varying or removing the value of this nutrient constraint on the model's feasibility of. The US RV for vitamin E, which was criticised as unattainable, was compared to the highest vitamin E level achievable while meeting different sets of RVs and food-habit constraints for different age-gender groups (64). Although meeting the US RV for vitamin E was achievable for all age-gender strata, it was only feasible with dramatic dietary changes including a strong increase in rarely-consumed foods like nuts and seeds. Two US studies explored the compatibility between the maximal recommended sodium intake and the nutritionally-adequate potassium intake. The sodium and potassium goals (≤ 2300 mg/d and ≥ 4700 mg/d, respectively) were theoretically compatible with other RVs for all age-gender subpopulations but required strong deviations from average observed diets (65,66). The more restrictive recommended amount of

sodium (<1500 mg/d) was not compatible with the potassium goal and other RVs for several US subpopulations except men older than 51 years old (65,66). Sometimes, it can be impossible to reach nutritional adequacy, either because of incompatibility between RVs imposed in constraints or a problem with food availability, especially when background poverty limits physical and/or financial access to nutrient-rich foods. Nevertheless, one way to improve nutritional quality is to seek the “nutritionally best diet” by maximising nutrient coverage itself while respecting food-habit constraints (30,41). Nutrients for which RVs are not fulfilled in the “nutritionally best diets” are defined as “problem nutrients” (41). For example, this approach integrated in the Optifood software (**Supplemental Material 2**) helped to highlight iron as a “problem nutrient” since the nutritionally best diets only reached 21%–66% of the iron RV depending on age-district subgroup in Bogota (Colombia) (41). Iron, zinc and calcium were common problem nutrients in 6–23-month-old children living in Indonesia (67), in 5 southeast Asia countries (46), and in Kenya (41,42), whereas vitamin A and zinc were problematic for 4–6-year-old Kenyan children (47). Thiamin was identified as the only “problem nutrient” for a population of 12-month-old children from Bogota (Colombia) (68). When nutrient gaps remain with locally-available food sources, there is evidence for advocacy to modify the food supply in order to reach nutritional adequacy. In the context of severe malnutrition, it was shown that no combination of local foods was able to achieve a nutrient density as high as diets promoted by the World Health Organization (WHO), thus demonstrating the need for fortified foods in this specific health condition (69). Several others studies have found that nutritional adequacy was only attainable via the inclusion of fortified products (46,47,68). For example, in Kenya, with no zinc-fortified water, only 76% of the zinc RVs could be covered in the nutritionally best diet for young children, which was improved to 101% with the fortified product (47). Individual-based optimisation can test whether the foods consumed by an individual are sufficient to build nutritionally adequate diets or if he/she needs to expand his/her habitual food repertoire. To achieve nutritional adequacy, the introduction of new foods was necessary for 78% and 92.5% of individuals in France (70) and the UK (71), respectively. Among UK children, nutritional adequacy was almost impossible to reach without introducing YCFs and/or supplements, especially for children whose observed diets lacked YCFs and supplements (61).

4. Affordable diets

A positive association between diet cost and nutritional quality is a consistent finding worldwide (5). As price could be a strong barrier to healthier food choices, the relationship between diet cost and nutritional adequacy has been a focus of interest in several diet optimisation applications to answer the following questions:

- What would be the influence of a cost constraint on the nutritional adequacy and cultural acceptability of diets?
- What is the minimum cost of a nutritionally adequate diet?
- How to design a low-cost diet that would also be culturally acceptable and nutritionally adequate?

4.1 Impact of a cost constraint on nutritional quality and cultural acceptability of diet

Healthy diets generally cost more than unhealthy diets (5). However, with transversal and observational data, causality (i.e. whether healthy diets are more costly due to their high dietary quality)

cannot be addressed. Even longitudinal studies cannot demonstrate a causal link between diet cost and dietary quality, because any reduction in food budget (for instance due to job loss) will induce a number of changes in everyday life outside other than just dietary behaviour. In that respect, mathematical diet optimisation is a tool of interest for simulating the impact of varying one isolated factor on the outcomes of the model. Several isoenergetic diets were designed to be as close as possible to the French average observed diet (72,73). Then, to assess the relationship between diet cost and nutritional adequacy, a cost constraint alone (i.e. without any nutritional constraints) was imposed and strengthened (by steps of €0.50) until no solution was feasible (72,73). Strengthening a cost constraint had a negative influence on food selection, since it impaired nutritional adequacy and diet quality, mainly through a decrease in most micronutrients and an increase in amount in fat and carbohydrates (including sugars) at the expense of proteins (72), and an increase in energy density (73). In the US, food selection obtained from diet modelling with a cost constraint alone did not fulfil most of the nutrient RVs and did not provide recommended quantity for each MyPyramid food group (63). In both the French and the US studies, forcing the cost to decrease also expanded the distance from the average observed diet, thus compromising cultural acceptability (63,72).

4.2 Minimum cost of a nutritionally adequate diet

Given that food prices influence food choices, studies have compared the price of nutritious food baskets (74,75) or diets (76) designed by experts against the budget of poor people in different populations. Results consistently showed that poor people cannot afford a nutritious food basket or diet. However, the cost of these nutritious baskets or diets was not necessarily minimal. This is where diet optimisation can be used to identify the minimum cost of a nutritionally adequate diet and assess whether the lowest-cost nutritionally adequate diet would be affordable for poor people and under which conditions it would be culturally acceptable.

Studies have shown that it is possible to achieve nutritional adequacy at a very low cost, but the realism of the optimised diet was highly dependent on food-habit constraints (22,77–79). For instance, in the UK, nutritional adequacy was reachable from just four or five foods for around £2 per week (which was 5 times less than the average household food expenditure in 1987) in subpopulations with different physical activity levels (78); however, the minimal cost increased between 4-fold and 9-fold as soon as food-habit constraints were included in the models to improve acceptability (78). In France, the theoretical minimal cost for a nutritionally adequate diet considering food-habit constraints was estimated at €3.20/day for women and €3.40/d for men, i.e. close to the food budget of poor people in this country (22). Without food-habit constraints, theoretical cost was as low as €1.50/day for men and women (22). Likewise, in Denmark, the minimal cost for a culturally acceptable food basket for a theoretical household rose almost linearly with an increase in food variety within each food group, so that minimal cost was at least three times cheaper without than with cultural acceptability considered (79).

A diet optimisation software tool called “Cost of the Diet (CoD)” was specifically developed to identify the “Minimum Cost Nutritious Diet” (MCND) from a list of foods for a typical household by minimising cost while covering energy and/or nutrient requirements and/or food-habit constraints (20,21,80–83). The methodology applied in CoD can be seen as a population-based optimisation, considering the household as a subgroup counting a specific number of individuals, more often representing a typical household in the studied country. When a comparison with household incomes

shows that families/households cannot afford the MCND, the introduction of fortified products can be considered and evaluated through the impact on household's budget (80). In Mozambique, iron, riboflavin and pantothenic acid were identified as binding nutrients, meaning that fulfilling their RVs had a big impact on total diet cost (80). The study thus went on to assess the cost-effectiveness of four fortification vehicles (vegetable oil, sugar, wheat flour and maize flour) and showed that the minimal cost obtained in the model without fortified products could be reduced up to 18% by introducing maize flour fortified with vitamin B12, iron, zinc and folic acid could. Indeed, the cheapest fortified foods replaced some nutrient-dense but expensive foods such as small dried fish or beef liver, which were required when minimising cost with local foods only (80). In Indonesia, the CoD tool was used to highlight regional differences in meeting nutritional requirements and propose relevant food fortification interventions (21). The CoD tool has been used in several countries for advocacy purposes, for example to stress a situation of nutritional emergency in a Syrian refugee camp in Jordan (82) or to suggest interventions to improve access, availability and demand for nutritious foods in 10 regions of Madagascar (83).

4.3 Designing low-cost and culturally-acceptable nutritionally adequate diets

The previous sections support the evidence that it is necessary to simultaneously consider both diet cost and cultural acceptability when defining nutritionally adequate diets. Several diet optimisation studies have attempted to find a trade-off in the model parameters in order to design nutritionally-adequate, culturally-acceptable and economically-affordable diets.

The United States Department of Agriculture (USDA) has developed four food plans, which have been revised at regular intervals since 1971, for different food budgets and 15 age-gender groups (84). In the 2006 version (28,85), each optimised food plan was a nutritionally-adequate combination of 29 food groups (i.e. respecting the 1997–2005 RVs, 2005 Dietary Guidelines for Americans, and 2005 MyPyramid), respecting an upper bound on diet cost (no more than the previous version adjusted for inflation). Cultural acceptability was ensured by food-habit constraints and by minimising the deviation of food groups from the average observed diet in the US population. Based on the optimised food plans obtained in the 2006–2007 revision, the total cost of each food plan is updated monthly and used to define the amount of institutional food aid (i.e. food allowances) in the United States. In low-income countries, FBRs for 9–11-month-old Indonesian children costing less than 2500 Indonesian rupiahs (corresponding to the mean daily food expenses for infants) were developed using Optifood (44) with an upper-bound constraint on diet cost and imposing food-habit constraints. Affordable and district-specific FBRs included recommendations on breastfeeding frequency as well as on the minimum number of servings per week of several foods, including fortified foods. Similarly, the cost and nutrient content of several sets of FBRs were compared among 9–10-month-old rural children from Malawi (86) as well as 6–23-month-old children from rural Kenya (41) to finally select the simplest set of FBRs for each population that best ensured nutritional quality at low cost.

Nevertheless, designing a diet that is nutritionally adequate, culturally acceptable and economically affordable is no easy task, often requiring trade-offs between decreasing diet cost, reaching nutritional adequacy, and staying close to current food habits. To study these trade-offs, various scenarios can be run to investigate the impact of progressively varying the set of constraints (i.e. progressively increasing the stringency of nutrient constraints introduced in the model, or imposing food-habit constraints with

progressively less tolerance for any deviation from the observed diet) on dietary changes (22). Lowest-cost diets meeting three levels of nutritional requirements and seven levels of food-habit constraints were developed for French adults (22), and results showed that both types of constraints increased the minimal cost when they were more stringent (for instance, all RVs were obtained for as little as €1.50/day when consumption constraints were ignored, but the minimal cost doubled when the most stringent consumption constraints were imposed) (22). In another study, the total cost of diets for French women was gradually decreased by steps of €0.50 using population-based optimisation until no solution was feasible (87). Nutritionally-adequate optimised diets unconstrained by cost were €0.58/day/person more expensive than the average observed diet (€4.41/day/person) and required modest dietary changes. However, reaching nutritional adequacy at the lowest achievable cost (i.e. €3.18/day/person) required large deviations from the current food habits, relying on foods with good nutritional quality for their price but which could be rarely consumed by the population (88). Likewise, a study in the US found that both nutrition and culture are costly demands (63). A recent study using individual-based optimisation among French adults showed that even if reaching nutritional adequacy increased the diet cost by €0.22€/day/person on average, the diet cost decreased for some individuals (89), which somewhat tones down the conclusions of the previous population-based optimisation studies (22,63,87). In addition, modelling a nutritionally adequate and culturally acceptable diet at no extra cost was possible for all individuals in the study sample, even those who had the lowest observed diet cost (89).

5. Environmentally-friendly diets

Research tackling the challenge of climate change has increasingly focused on the environmental impact of diets, which has mainly been assessed using dietary GHGE (6,7). However, a diet with reduced GHGE is not necessarily a healthy diet (7,90). A healthy and environmentally-friendly diet may not be easy to attain, and not necessarily affordable nor acceptable. Diet optimisation has been used to specifically address the following questions:

- What would be the influence of reducing diet-related environmental impact on diet costs and nutritional quality?
- What is the minimum diet-related environmental impact reduction achievable while achieving nutritional adequacy?
- How to find the best trade-off between reducing environmental impact, reaching nutritional adequacy and staying close to current food habits, ideally at no extra cost?

5.1 Impact of an environmental impact constraint on nutritional quality, diet cost and cultural acceptability

There is still no consensus on the relationship between the environmental impact and nutritional adequacy of diets. A systematic review, including both epidemiological and modelling studies, on the association between GHGE and diet nutritional quality (and other health indicators such as cancer prevalence) found that low-GHGE diets have a lower content in sodium and saturated fats but negative nutritional outcomes, such as a decrease in several key micronutrients and increase in sugar content (7). In the UK, minimising GHGE without nutritional constraints except on energy led to a diet high in sugared foods and sweetened beverages and low in meat, fruits and vegetables (91). Only one study has analysed

the impact of a progressive GHGE reduction on nutritional quality, diet cost and cultural acceptability (26). Isoenergetic diets were modelled by minimising departure from the average French diet under the impact of stepwise GHGE reductions (10% steps), but without nutritional constraints or with constraints on macronutrients only (26). Reducing GHGE by 30% (or less than 30%) induced only minor food deviations (mainly a moderate decrease in meat) and therefore had only minor impacts on nutritional quality and diet cost. In contrast, forcing GHGE to reduce by more than 30% significantly decreased nutritional quality (even with constraints on macronutrients), tended to decrease diet cost, and involved more food changes from the average observed diet. These results showed that although environment and cost can be made easily compatible, it is not necessarily the case between environment and nutrition and between environment and cultural acceptability.

5.2 Food combinations for a nutritionally adequate diet at minimum environmental impact

With increasing recognition of our food system's environmental impact, there has been a surge in efforts to identify how far the environmental impact could be reduced while ensuring nutritional adequacy. Diet optimisation identified the lowest-environmental-impact diets by minimising one or more environmental metrics (26,92–96), but this led to large deviations from current food habits.

In the UK, a maximal reduction of 90% of GHGE (from the observed baseline in 1990) was reachable while meeting constraints on 12 nutrients without food-habit constraints, but only 7 food groups from a list of 82 were included in the modelled diet (93). Introducing constraints to account for food habits led to a healthy and environmentally-friendly diet with 52 food groups achieving a 36% GHGE reduction from the baseline while diet cost decreased by 12% from the UK's average 2009 household spending on food (93,95). In France, the minimal GHGE reduction achievable while attaining nutritional adequacy (i.e. more than 30 nutritional constraints) was 70% and 74% for women and men, respectively, but induced substantial changes from the average observed diet (e.g. big reduction in the meat, fish and eggs group, and substantial reduction of the fruit and vegetables group) with a diet cost reduction (26). In Italy, working up from foods declared by students in a dietary record, optimised diets were designed by simultaneously minimising diet cost and three environmental metrics (GHGE, water use, land use), while fulfilling constraints on 9 nutrients as well as a large set of food-habit constraints (e.g. maximal values on portion sizes, food consumption frequencies, food association constraints between complementary foods) (92). The optimised diet involved large changes liable to impair cultural acceptability, such as a complete removal of meat replaced by a high increase in fruit and vegetables, legumes, bread and dairy. A modelling study on 5 European countries recently showed that achieving nutritional adequacy with maximal GHGE reductions from 62% to 78% (depending on country and gender) was theoretically possible but would require large departures from observed diets entailing changes in the quantity of at least 99% of food variables (96).

5.3 Designing sustainable diets

The previous sections have outlined the challenge of combining dimensions of sustainability for a nutritionally-adequate, culturally-acceptable, economically-affordable and environmentally-friendly diet. Among self-selected diets in a nationally representative survey in France, the positive deviance approach (i.e. the identification of uncommon but beneficial behaviours in a given population) was used to identify

diets more sustainable than others (i.e. diets with both a lower GHGE and a higher nutritional quality) (97). Results showed that “more sustainable diets” were consumed by approximately 20% of adults, and their GHGE values were approximately 20% lower than the average value at no additional cost, but nutritional adequacy was not fully ensured. With observational data, it was not possible to establish whether greater GHGE reduction would be achievable while ensuring the other dimensions. As a multi-criteria approach, diet optimisation can combine several dimensions of diet sustainability, without impairing any of them, provided they are included in the models.

A few studies have identified sustainable diets by imposing environmental, nutritional and food-habit constraints while minimising the departure from observed diets (25,71,98,99). The environmental constraint is generally based on institutional goals for environmental impact reduction or on reduction from actual baseline environmental impact levels. For instance, among Dutch adults, a 50% reduction was imposed to hit the European goal of keeping global warming below 2°C, along with a cost reduction of 50% from the average observed diet (99). In France, Spain and Sweden, ‘LiveWell’ diets were identified by reducing GHGE by 25% from baseline while remaining acceptable for the population with no increase in cost (25). In another study in Dutch adults, the goal for the environmental impact reduction was derived from a first optimisation that aimed to design a vegan diet complying with nutritional and food-habit constraints but no environmental constraints, and the resulting environmental impact level of this optimised vegan diet was taken as a goal to be reached in the next set of diets modelled (98). Regardless of diet optimisation model applied and local-country specificities (i.e. food habits and nutritional recommendations), a more sustainable diet required an increase in fruit and vegetables, legumes and a decrease in meat products. Note that a sustainable diet is not necessarily exclusively plant-based (25). For instance, in an individual-based optimisation in UK, meat intake had to increase for a small number of individuals to reduce GHGE by 30% while attaining nutritional adequacy (71).

The environmental target imposed in the studies described above may not be the best trade-off between all diet sustainability dimensions. The best threshold of environmental impact reduction compatible with other diet sustainability dimensions has been identified in models imposing stepwise reductions (until infeasibility) of diet environmental impact while staying as close as possible to the average observed diet and meeting nutrients recommendations (26,96,100–102). This approach is able to pinpoint the level of environmental impact reduction for which the optimised diet deviates too far from the observed diet. In France, GHGE could be reduced by 30% at no extra cost while still fulfilling food-habit and nutritional constraints and without major departure from the average observed diet (26). A similar threshold of environmental impact reduction (30%) was identified among Dutch adults by imposing a stepwise reduction of a global environmental metric taking into account GHGE, fossil-energy use and land occupation (100). However, diet cost was not considered (100). In the UK, GHGE could be reduced progressively by up 40% without any major changes to average observed diet among both men and women. For example, at this threshold, the optimisation mainly relied on “within-food-group” substitutions (e.g. replacing red meat by the less impacting pork and chicken meats or replacing cheese by milk) (101). In this study, the expenditure share and price elasticity of each food group were considered in the objective function as a proxy for acceptable changes. The health impact of adopting the optimised UK diets with a progressive GHGE reduction was explored using an epidemiological model (IOMLIFET, (103)) by assessing the changes in theoretical years of life loss between the observed and optimised diets (102). The more GHGE was reduced, the more it would be beneficial for health (decrease in coronary heart disease, stroke,

cancer and type-2 diabetes). According to these simulations, it was estimated that dietary changes necessary at the threshold of 40% GHGE reduction would save almost 7 million years of life over 30 years and increase life expectancy at birth by around 8 months (102).

Hence, with the current food production system (i.e. assuming no changes in the environmental impact and price of foods), nutritional, cultural, economic and environmental dimensions seem compatible until a 30–40% reduction in the environmental impact of diets.

DISCUSSION

Diet optimisation has proven a unique and powerful tool for studying sustainable diets. This narrative review based on 67 publications shows how mathematical diet optimisation has been used to examine the links between different dimensions of diet sustainability and to design tomorrow's nutritionally-adequate, culturally-acceptable, economically-affordable and environmentally-friendly diets (**Supplemental Tables 1b; 1c**). This review highlights the strengths of diet optimisation as an approach to investigate the impact of varying one factor (e.g. diet cost, environmental impact) on outcomes of interest (e.g. food combinations, nutritional adequacy) and to qualify and quantify the dietary changes needed to achieve the best trade-off between diet sustainability dimensions. Mathematical diet optimisation has been applied in the field of public health nutrition in the past few decades, and the number of publications has increased since 2008 (**Figure 2**). Papers in the last few years have focused more specifically on the environmental dimension, as the nutritional and economic aspects of diet were explored earlier (**Figure 2** and **Supplemental Table 1a; 1b; 1c**). This review shows how diet optimisation can be applied for different subpopulations, based on age-gender criteria or on specific consumption patterns, or even at individual level to account for individual food habits. Nevertheless, the difficulty when designing a sustainable diet revolves around the relevance of the model parameters (variables, objective function, constraints) and the quality of the input data.

The health dimension was almost always considered through nutritional constraints (**Supplemental Table 1b**). However, careful analysis of published studies shows that using too few nutritional constraints can lead to deceptive conclusions or meaningless results. For example, certain studies, without clear justification, elected to omit some key nutrients (in particular minerals and vitamins) essential to maintain good health (92,101,104), which may unintentionally deteriorate the content of those nutrients not taken into account in the models. Indeed, the failure to account for certain nutrients impairs nutritional adequacy, as shown in studies testing various sets of nutritional constraints (26,58). Because fulfilling some RVs could be difficult and lead to infeasibility or unexpected results, some studies chose, with appropriate justification, to relax the constraints for some nutrients. For instance, vitamin D level was imposed to be not lower than its observed intakes (105) or even removed (106) as vitamin D can be provided by supplements. In the several versions of USDA food plans (28,85), no solution could be obtained with the dietary standards for vitamin E, potassium and sodium. Therefore, for each age-gender group, these constraints were relaxed. However, when reaching a RV proves difficult, the issue may be the relevance of the recommended levels set for those difficult-to-fulfil constraints (64–66). When the RV for a beneficial nutrient is abnormally high, some foods containing traces of that nutrient may be introduced or increased by the model even though they are not the naturally abundant sources of this nutrient, leading to weird food combinations. When fulfilling the set of RVs is too difficult, a goal programming approach

can be used to find the best achievable (or “near-optimal”) diet, accepting that it is not fully nutritionally adequate (30). Indeed, when the food supply lacks nutrient-rich foods, it is preferable to maximise nutritional quality rather than trying to obtain diets respecting a set of hard nutritional constraints at the price of impracticability or even infeasibility. This is the method applied in Optifood software as described in **Supplemental Material 2** (40).

Further advances have been made to more accurately estimate the health dimension. Some studies have improved the assessment of nutritional adequacy by accounting for nutrient bioavailability (37,81,105) or exposure to food contaminants (106,107). Accounting for nutrient bioavailability (i.e. efficiency of nutrient absorption and utilisation or retention by the body) is relevant because of its impact on the quality of nutrient intakes. Some nutrients (e.g. iron, zinc) have better bioavailability when derived from animal-based foods (108). Therefore, a shift towards more plant-based diets, as advocated to meet sustainability goals, may prove nutritionally *inadequate* due to the reduced bioavailability of some nutrients when provided by plant- instead of animal-based foods. For instance, among French adults, accounting for iron, zinc, protein and provitamin A nutrient bioavailability induced changes in the foods selected by the optimisation process, in particular within the meat category (105).

The cultural dimension needs to be considered to avoid unrealistic results. In all the studies reviewed, the assumption for diet optimisation models was that the closer the model is to the observed diet, the more acceptable the optimised diet would be. Staying closer to food habits has been done in more or less refined ways, by imposing food-habit constraints and/or by minimising the deviation from an observed diet, working at either population, sub-population or individual levels.

Cultural acceptability has traditionally been taken into account by introducing food-habit constraints, imposing minimum and maximum quantities on foods and/or food groups, and/or setting complementarity relationships between raw foods or ingredients (e.g. relationship between bread and jam) (32). In the papers reviewed, food-habit constraints were mostly based on the distribution of food or food-group intakes in dietary surveys (24,30,44,57), but could also be based on expertise and *a priori* choices (28,94) (**Supplemental Table 1b**). When one single metric is optimised (e.g. diet cost or GHGE) (22,77,78,92,94,109), the model very often leads to puzzling results. For instance, in Mozambique, nutritionally-adequate diets at minimum cost were designed without food-habit constraints, leading to non-diversified low-cost diets mostly based on high amounts of very few nutrient-rich foods (110). Even food-habit constraints are not sufficient to ensure cultural acceptability of the modelled diets when cost or environmental impact is directly minimised. In a New Zealand study, arbitrary constraints were imposed on several foods to improve acceptability, but the lowest GHGE diets were not very diversified and seemed to be mainly driven by the food-habit constraints (94). It is therefore key to avoid arbitrary constraints on food habits when modelling diets, and optimising just one single diet characteristic is not recommended.

Deviating as little as possible from observed diets is assumed as the best way to model acceptable diets, even though no one knows whether the minimum deviation achieved would be realistic and effective in terms of behaviour change. Because there is no formal definition of minimal deviation from an existing diet, the objective function can be chosen in such a way as to favour specific types of behaviour. Minimising quadratic deviation from the observed intake would foster minimal variations on all foods and penalize large variations (28,85), whereas expressing the deviation in percentage of the observed diet (37,57,72) would induce larger variations on fewer foods. Because no form is better than the others, the choice must

be done based on a hypothesis of what the population of interest would find most acceptable. In an innovative individual-based optimisation, cultural acceptability was considered using a stepwise approach making it increasingly difficult to depart from the observed diet (71). The authors assumed that an individual would prefer to increase the amount of any food currently eaten before adding a new food or removing a food from the diet (71). Finally, to foster the communication of the results, the model and results should be adapted to the objectives. For instance, for public health purposes, it may be more appropriate to run diet optimisation with a limited number of variables (i.e. food groups as decision variables) or to communicate the results at food-group level only in order to develop more practical FBRs. Conversely, running diet optimisation with individual foods as decision variables, or building FBRs based on specific food items (and not food groups), allows more flexibility in the model, but could lead to over-specific messages based on nutrient-rich foods identified as “key foods” but that may not widely consumed and not realistically promotable.

In all published studies, cultural acceptability remained difficult to evaluate as there are still no objective criteria to determine what is acceptable and what amount is considered a “small” or “large” dietary changes. Another unresolved issue is whether it is acceptable to promote variation of many foods in small quantities, or large variations for a few foods. Therefore, to respect the cultural dimension of a sustainable diet, properly characterizing the population, sub-population or individual food habits is key, and all model parameters need to be carefully justified and adapted to the study objectives, when designing the model and when interpreting the results.

Designing an affordable diet has long been a concern in diet optimisation studies, whereas the environmental impact has been integrated in diet optimisation models for less than ten years. Both the economic and environmental dimensions have been taken into account either by imposing a minimal or maximal constraint, by running *a posteriori* evaluation, or by being directly minimised. Only one study accounted for the economic dimension by adding the expenditure share and price elasticity of each food as weighting factors on each decision variable to favour certain foods over others, as it considered the price as a major driver of food choices (101). The difficulty when imposing a constraint on the metric studied (e.g. diet cost or GHGE) was to objectively define the target value, which was usually set as not lower than in the observed diet (25) or based on expert opinion (28,44,71,95,98,99). Nevertheless, the best way to find the best trade-offs between decreasing the environmental impact of diet, decreasing diet cost, reaching nutritional adequacy and staying close to current food habits is to apply diet optimisation with a stepwise approach (26,96,100–102).

Among the 16 studies that aimed to identify a sustainable diet, only 9 included the economic dimension (25,26,92–95,99,101,102) (**Supplemental Table 1c**), but further research is needed to design a “fully” sustainable diet. Regarding the environmental dimension, its impact has mostly been assessed using GHGE, yet there are many other important impacts, such as fossil energy, land occupation or water use. The integration of co-production relationships would also be beneficial to ensure coherence with the current food production system (105). For instance, it is questionable policy to encourage the consumption of low-fat milk while promoting a reduction in consumption of cream, which is a by-product of the current dairy production system (91).

Whatever the dimensions of sustainability considered in a diet optimisation model, input data must be carefully selected to accurately represent the population considered and the foods consumed and/or

available in a given food system. Quantified food intakes are a prerequisite in any attempt to ensure cultural acceptability, whether by identifying the list of foods usually consumed in the population, taking into account food consumption distribution in the constraints, or deriving the average observed diet if the aim is to stay as close as possible to current food habits. Complete and accurate nutrient composition data, environmental food data or cost data are crucial in all models to avoid boosting or deleting certain foods in the optimised diets due to possible over- or underestimated values. The main challenge for modelling sustainable diets now is probably to combine several databases containing metrics of each dimension of diet sustainability. A methodology was recently published that describes how to combine different data sources on food consumption habits, nutrient composition, food prices and environmental impact of foods (111).

Finally, the applicability of the results of a diet optimisation study, which stay very theoretical, can also be improved, either upstream by adapting the parameters of the model (variables, objective function, constraints) or downstream by refining the expression of the results or adjusting them after testing their practicability in real life. For instance, food contents of the optimised diet are generally expressed in real numbers, in grams per day or per week, which are probably not meaningful for individuals when food changes amount to only a few grams. More pragmatic dietary changes could be obtained by running optimisation with integer numbers (number of portion sizes), called 'integer linear programming' (29), but the process is computationally intensive. In the Optifood software, the decision-variable values, which are the number of portions for each food (expressed in real numbers), are expressed *a posteriori* in integer numbers of portions per week or per day, by rounding the optimised values (40). To improve practicability, further research could be done to run diet optimisation by moments of consumption, to avoid, for instance, removing all foods consumed during breakfast without replacing them with other foods habitually consumed at this time of the day. Certain studies have imposed "association" constraints between foods, such as between bread and jam, but they remain limited and arbitrarily chosen (55,78,92). To take a step further, the outputs of the optimisation should be tested in real life among the population studied, with the objective of assessing the realism and feasibility of the dietary changes, to adjust them or to review the model parameters. A few studies have checked *a posteriori* the acceptability, feasibility or effectiveness of FBRs designed using diet optimisation (67,112–114), via qualitative techniques such as the "Trial of Improved Practices", which consists in a series of visits with an interviewer to analyse participants practices, discuss the challenges for applying new practices, and to readjust and test the guidelines in a trial experience (115,116). This technique was applied in Myanmar (112) and Indonesia (67) to test the acceptability and feasibility of FBRs developed using Optifood. In Kenya, results of diet optimisation were combined with a qualitative study (a focus ethnographic study) to identify the perception of cost, convenience, accessibility and appropriateness of the foods included in the FBRs (113). These qualitative studies underline the added value of going beyond the theoretical solutions to identify barriers (e.g. financial, cultural, accessibility-constraint) and opportunities, such as providing advice on how to cook the promoted foods, informing on health benefits of consuming specific nutrient-dense foods, or developing the accessibility of promoted foods through agronomic interventions.

CONCLUSION

This review provides evidence that diet optimisation is a powerful tool for identifying the best balance to combine all dimensions of diet sustainability and promote the food choices needed to make

the transition towards more sustainable diets. Mathematical diet optimisation is increasingly used in the literature, but its great flexibility and power can actually become weaknesses if the models aren't well designed and if there are too many arbitrary decisions on the model parameters (variables, constraints, objective function). Solid expertise is necessary at all stages, from model construction to correct interpretation and communication of results. Care should be taken to clearly and transparently describe the models, and give justification of all choices. It would be beneficial, for designing tomorrow's sustainable diets, to integrate more relevant metrics assessing each aspect of a sustainable diet, and to improve the real-world practicability of theoretical results.

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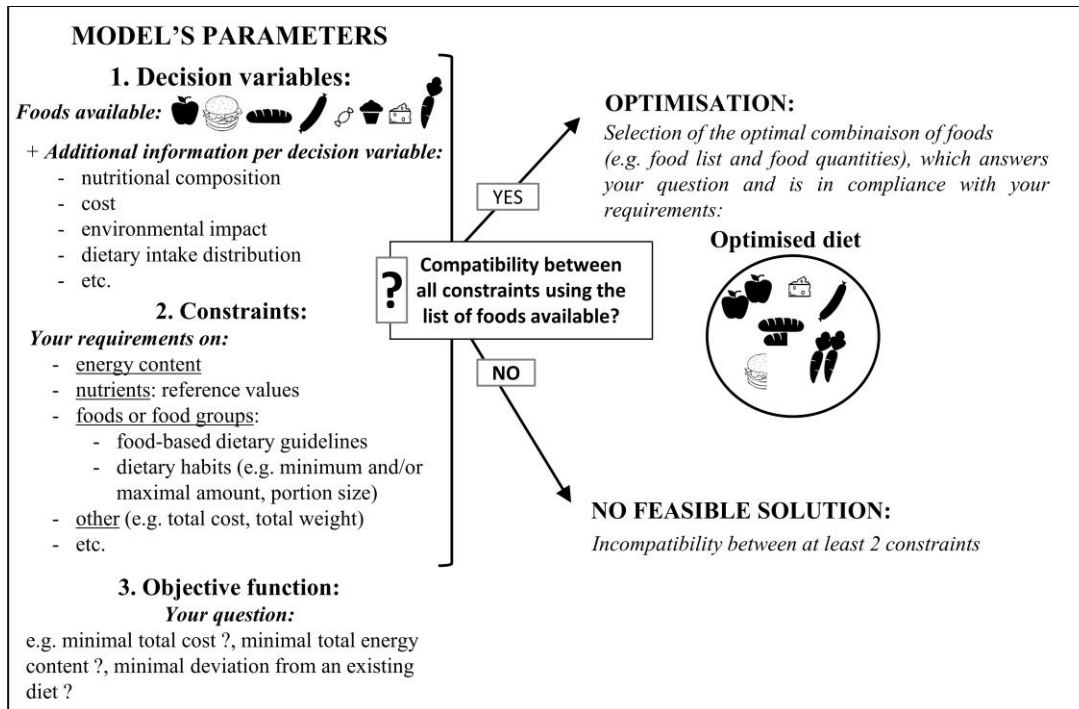
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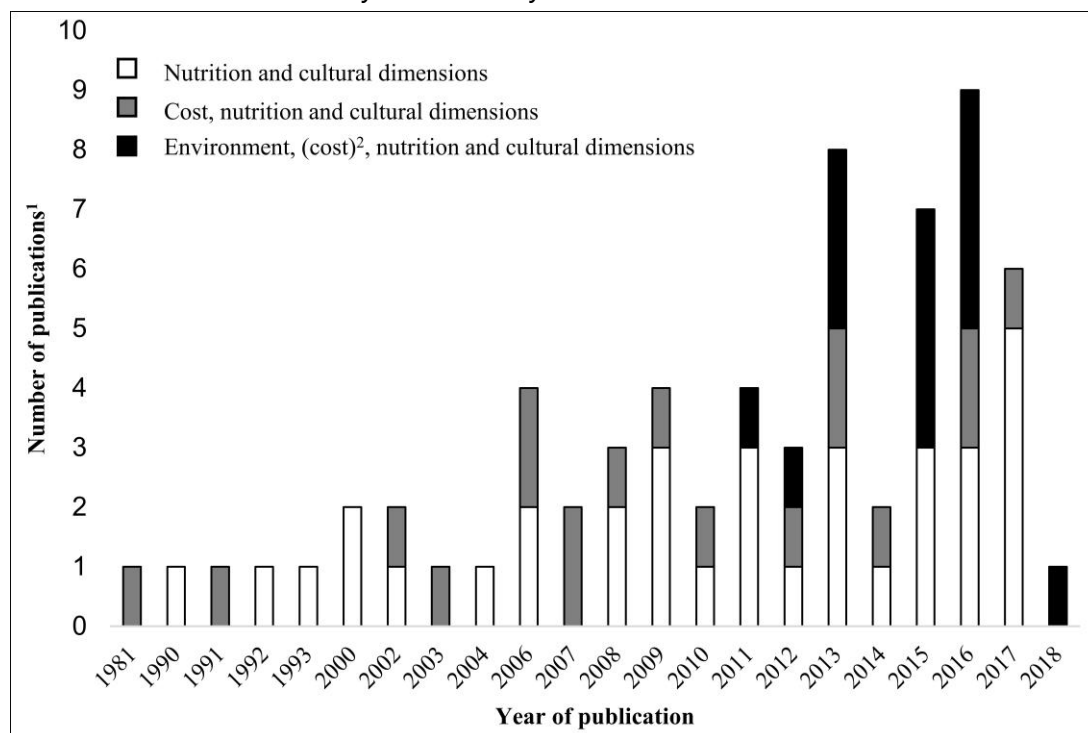
FIGURES

Figure 1: Schematic representation of mathematical diet optimisation¹



¹ Adapted from Darmon et al. (2008) (33); food images are under Creative Commons CC0 licence (34)

Figure 2. Number of selected publications using diet modelling in the field of nutrition, public health and sustainable diets, stratified by sustainability dimensions taken into account.



¹The figure includes in total the 67 papers reviewed in this paper from sections 3.1 to 5.3. Studies that present tools or methodological concepts are not included.

²The cost was not always taken into account in studies considering the environmental impact.

Mathematical Optimization to Explore Tomorrow's Sustainable Diets: A Narrative Review

SUPPLEMENTARY MATERIAL

SUPPLEMENTAL MATERIAL 1. Literature strategy

A scientific literature search was conducted on PubMed in September 2016 and updated in January 2018. The aim was to identify relevant articles concerning the use of mathematical optimisation to study diet sustainability, using a combination of the following terms: 'diet intake', 'dietary intake', 'food intake', 'food consumption', 'food choice', 'nutrient intake', 'dietary guideline', 'nutritional requirement', 'food-based recommendation', 'linear programming', 'nonlinear programming', 'goal programming', 'quadratic programming', 'mathematical optimisation', 'diet optimisation', 'diet modelling'. The terms 'modeling' and 'optimization' were also tested instead of 'modelling' and 'optimisation'. This electronic search updated in 2018 resulted in 94 articles, which were manually screened. Studies were selected if they met the following inclusion criteria: a) used mathematical optimisation techniques; b) assessed two or more dimensions of diet sustainability, i.e. nutritional adequacy, cultural acceptability, food affordability, and/or environmental profile; c) used a whole-diet approach; d) were applied for humans; e) were run at population/subpopulation or individual level. Historical or methodological studies describing the diet optimisation approach were also retained. Studies that were based on food substitutions or ran mathematical optimisation for animals, to formulate foods, to validate nutrient profiling systems, or for clinical purposes were excluded, leading to a final sample of 51 studies. The list was completed by any other publication matching the inclusion criteria of which the authors were aware, and on the basis of consultations with experts. This process yielded 75 studies on mathematical optimisation of diets, including 9 studies describing the principles underpinning the diet optimisation approach or its tools, and 67 studies that applied mathematical optimisation to study the dimensions of diet sustainability. These 67 studies form the basis of the present review.

SUPPLEMENTAL MATERIAL 2. Description of Optifood's software modules

Optifood is a user-friendly software based on goal programming and co-developed by the London School of Hygiene and Tropical Medicine, the World Health Organization (WHO), and FANTA III. Optifood runs four modules to help the user answer public health questions. The mathematical details of Optifood have been described in full elsewhere (1, 2), as well as the modules of the current-version software (2). Module I allows to check models parameters. Module II allows to create draft Food Based Recommendations (FBRs) and to identify "problem nutrients". Module II generates two best possible diets, both of which respect food-habit constraints while maximising nutritional quality: the "food-pattern diet" which comes as close as possible to meeting reference values (RVs) and observed food habits, and the "no food pattern diet" which comes as close as possible to meeting RVs only (i.e. allows to deviate from current food habits). The outcomes of Module II help identify problem nutrients, which are nutrients that cannot reach 65% or 70% of the RV in the "no food pattern" diet. Module II can also be used to draft FBRs that can be tested in Module III. Module III combines and compares FBRs in order to select the best combination. It runs for each nutrient and cost "worse case scenario" by individually minimising each nutrient content and cost while respecting the set of food recommendations tested. The combination of FBRs selected for the target population is the one that best ensures nutritional quality at the lowest cost, with as few recommendations as possible. The last module, Module IV (optional), generates the lowest-cost nutritionally-best diet (i.e. minimising the cost and the deviation from recommended nutrient values).

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SUPPLEMENTAL TABLE 1a. Population studied, type of modelling (at individual or population level) and interface used in the 67 studies reviewed.

Reference		1st author, year of publication, journal	Title	Population studied, country	Modelling		Interface
Reference number	Sections of the review				Individual level	Population level	
19	3.1	Martin et al., 2000, book	Equilibre alimentaire et couverture des besoins (<i>Balance food intakes and respect for nutritional needs</i>)	Adult man and woman, child between 1-3 yo, France (theoretical example)		X	1
20	4.2	Chastre et al, 2009, Save The Children	The minimum cost of a healthy diet. Findings from piloting a new methodology in four study locations	Theoretical households from Bangladesh, Ethiopia, Myanmar, Tanzania (data^ collected in 2006-07, n=5 persons per household)		X	2
21	4.2	Baldi et al., 2013, Food Nutr Bull	Cost of the Diet (CoD) tool: first results from Indonesia and applications for policy discussion on food and nutrition security.	Theoretical household, Indonesia (data^ collected in 2012, n= 4)		X	2
22	4.2 4.3	Maillot et al., 2010, Public Health Nutr	Are the lowest-cost healthful food plans culturally and socially acceptable?	Adults, France (INCA1, 1999, n=1332)		X	3
23	3.1	Cleveland et al., 1993, J Am Diet Assoc	Method for identifying differences between existing food intake patterns and patterns that meet nutrition recommendations	19-50 yo women, US (national USDA survey in 1985, n= 915)		X	4
24	3.1	Darmon et al., 2002, Am J Clin Nutr	Linear and nonlinear programming to optimize the nutrient density of a population's diet: an example based on diets of preschool children in rural Malawi	Preschool (3-6yo) children, Malawi (data^ collected in 1986, n=65)		X	1
25	5.3	Thompson et al., 2013, LiveWell report	LiveWell for Life. A balance of healthy and sustainable food choices for France, Spain and Sweden.	Adults : - Women, France (INCA2, 2006-07, N=1141) - Men and women, Sweden (Riksmaten, NA, n=NA), - Men and women, Spain (ENIDE, NA, N=NA)		X	1 5A
26	5.1 5.2 5.3	Perignon et al., 2016, Public Health Nutr	How low can dietary greenhouse gas emissions be reduced without impairing nutritional adequacy, affordability and acceptability of the diet? A modelling study to guide sustainable food choices.	Adults, France (INCA2, 2006-07, n=1899)		X	3
28	4.3	Carlson, 2006, Thrifty Food Plan	Thrifty Food Plan	Low income general population (≥1yo), US (NHANES 2001-02, n=3527)		X	4
30	3.1 3.2	Ferguson et al., 2006, J Nutr	Design of Optimal Food-Based Complementary Feeding Recommendations and Identification of Key "Problem Nutrients" Using Goal Programming	Rural breast-fed 9 to 11-mo infants, Indonesia (theoretical example)		X	1

Table 1a - *Continued*

Reference				Population studied, country	Modelling		Interface
Reference number	Sections of the review	1st author, year of publication, journal	Title		Individual level	Population level	
36	3.1 3.2	Okubo et al., 2015, Nutr J	Designing optimal food intake patterns to achieve nutritional goals for Japanese adults through the use of linear programming optimization models	Adults, Japan (data [^] collected in 2002-2003, n=174, split in 4 age & sex groups)		X	1
37	3.1	Ferguson et al., 2004, J Nutr	Food-Based Dietary Guidelines Can Be Developed and Tested Using Linear Programming Analysis	3-6 yo children, rural Malawi (data [^] collected in 1986, n= 60)		X	1
38	3.1	National Health and Medical Research Council, 2011, [report].	A modelling system to inform the revision of the Australian Guide to Healthy Eating	General population (from 6-12mo infants to >70yo adults), Australia (NCNPAS07, 2007, 24 age-sex groups).		X	1
41	3.2 4.3	Ferguson et al., 2015, Matern Child Nutr	Zinc, iron and calcium are major limiting nutrients in the complementary diets of rural Kenyan children.	6-23 mo children, rural Kenya (data [^] collected in 2012, n=401)		X	6
42	3.1 3.2	Vossenaar et al., 2016, Public Health Nutr	Context- complementary feeding recommendations developed using 6 could improve the diets of breast-fed infants and young children from diverse livelihood groups in northern Kenya	Infants and young children, 3 counties from Northern Kenya (data [^] collected in 2013, n=882)		X	6
43	3.1	FANTA, 2013, Report	Summary report: Development of Evidence-Based Dietary Recommendations for Children, Pregnant Women, and Lactating Women Living in the Western Highlands of Guatemala	Children, pregnant and lactating women, Western highlands of Guatemala (data [^] collected in 2012, n=547)		X	6
44	3.1 4.3	Santika et al., 2009, J Nutr	Development of Food-Based Complementary Feeding Recommendations for 9- to 11-Month-Old Peri-Urban Indonesian Infants Using Linear Programming	9-11 months old children, Indonesia (data [^] collected in 2005-06, n=100)		X	6
45	3.1	Skau et al., 2014, Am J Clin Nutr	The use of linear programming to determine whether a formulated complementary food product can ensure adequate nutrients for 6- to 11-month-old Cambodian infants	6-11mo infants, Cambodia (data [^] collected in 2010, n=78)		X	6
46	3.1 3.2	Ferguson et al., submitted in 2017, Matern Child Nutr. [under review]	A realistic food-based approach alone may not ensure dietary adequacy for populations of women and young children in South-east Asia without fortification; an analyses based on linear programming analyses.	Women of reproductive age and 6-23mo children, South East Asia (Data from national surveys for Thailand (2008-9), Indonesia (2012), Vietnam (2009-10) and Cambodia (2009-15), and specific data [^] collection for Cambodia (for age groups) and Lao (2012), n=unclear)		X	6

Table 1a - *Continued*

Reference				Population studied, country	Modelling		Interface
Reference number	Sections of the review	1rst author, year of publication, journal	Title		Individual level	Population level	
47	3.1 3.2	Kujinga et al., 2017, Matern Child Nutr	Combining food-based dietary recommendations using 6 with zinc-fortified water potentially improves nutrient adequacy among 4- to 6-year-old children in Kisumu West district, Kenya	4-6-yo children, Kisumu West district, Kenya (data^ collected in 2014, n=62)		X	6
48	3.1	Levesque et al., 2014, Public Health Nutr	Contribution to the development of a food guide in Benin: linear programming for the optimization of local diets.	General population (>2yo) including pregnant and lactating women, Southern Benin (data^ collected in 2005-06, n=541)		X	1
49	3.1	Gao et al, 2006, J Nutr (1)	The 2005 USDA Food Guide Pyramid is associated with more adequate nutrient intakes within energy constraints than the 1992 Pyramid.	Adults, UK (NHANES 2001-02, n=4271, divided by sex)		X	1
50	3.1	Masset et al., 2009, J Nutr	Diet optimization methods can help translate dietary guidelines into a cancer prevention food plan.	Adults, Pacific Northwest, US (unclear date of collection , n=161)		X	3
51	3.1 3.2	Maillot et al., 2011, J Nutr	Energy allowances for solid fats and added sugars in nutritionally adequate U.S. diets estimated at 17-33% by a linear programming model.	Adults (>20yo), US (NHANES 2001-02, n=4295, split in 6 gender-age groups)		X	3
52	3.1	Scarborough et al., 2016, BMJ Open	Eatwell Guide: modelling the dietary and cost implications of incorporating new sugar and fibre guidelines.	Adults aged 19 and above, UK (NDNS, 2008-11, n=1491)		X	1
54	3.1	Colavita et al. 1990, Br J Nutr	Linear programming and pediatric dietetics.	Clinical case study on a 10 yo girl (Food list from European tables in the litterature)	X		unclear
55	3.1	Soden et al., 1992, Br J Nutr	Modifying diets to satisfy nutritional requirements using linear programming.	50 yo overweight female subject, UK (Food list from Microdiet software, n=1)	X		7
56	3.1	Maes L., et al., 2008, Int J Obes	A feasibility study of using a diet optimization approach in a web-based computer-tailoring intervention for adolescents.	14-17 yo adolescents, Belgium (data^ collected in Helena study, NA, n=48)	X		8

Table 1a - *Continued*

Reference		1rst author, year of publication, journal	Title	Population studied, country	Modelling		Interface
Reference number	Sections of the review				Individual level	Population level	
57	3.1	Maillot et al., 2010, Am J Clin Nutr	Individual diet modeling translates nutrient recommendations into realistic and individual- food choices.	Adults, France (INCA1, 1999, n=1171)	X		3
58	3.2	Maillot et al., 2011, Am J Clin Nutr	The shortest way to reach nutritional goals is to adopt Mediterranean food choices: evidence from computer-generated personalized diets.	Adults, France (INCA1, 1999, n=1171)	X		3
59	3.1	Clerfeuille et al., 2013, J Acad Nutr Diet	Dairy Products: How They Fit in Nutritionally Adequate Diets.	Adults, France (INCA1, 1999, n=1171)	X		3
60	3.1	Lluch et al., 2017, Nutrients	Individual Diet Modeling Shows How to Balance the Diet of French Adults with or without Excessive Free Sugar Intakes.	Adults with excessive or adequate intakes of free sugars, France (INCA2, 2006-07, n=1719)	X		3
61	3.1 3.2	Vieux et al., 2016, Nutrients	Role of Young Child Formulae and Supplements to Ensure Nutritional Adequacy in U.K. Young Children.	12-18mo children, UK (DNSIYC, 2011, n=1174)	X		3
62	3.2	Briend et al. 2000, Pediatrics	Determining Limiting Nutrients by Linear Programming: A New Approach to Predict Insufficient Intakes From Complementary Foods.	1-3yo children of low income families, France (Food list from Val de Marne survey in 1991)		X	1
63	3.2 4.1 4.3	Wilde et al, 2009, J Consum Aff	Using the Thrifty Food Plan to Assess the Cost of a Nutritious Diet.	Low-income American adults, US (NHANES 2001-02, 15 age-sex groups, n=3527)		X	3
64	3.2	Gao et al, 2006, J Nutr (2)	The maximal amount of dietary alpha-tocopherol intake in U.S. adults (NHANES 2001-2002).	Adults, US (NHANES, 2001-02, n=4351)		X	1
65	3.2	Maillot et al, 2013, Nutr Res	Food pattern modeling shows that the 2010 Dietary Guidelines for sodium and potassium cannot be met simultaneously.	Adults, US (NHANES, 2001-02, n=4295)		X	3
66	3.2	Maillot et al, 2012, Am J Prev Med	A conflict between nutritionally adequate diets and meeting the 2010 dietary guidelines for sodium.	Adults (≥ 20 yo), US (NHANES, 2001-02, n= 4295, 6 age-sex groups)		X	3
67	3.2	Fahmida et al, 2015, Am J Clin Nutr	Effectiveness on improving knowledge, practices, and intakes of "key problem nutrients" of a complementary feeding intervention developed by using linear programming: experience in Lombok, Indonesia.	9-16mo children, Lombok, Indonesia (Food list from data^ collected in 2010-11, n=215)		X	6

Table 1a - *Continued*

Reference		1rst author, year of publication, journal	Title	Population studied, country	Modelling		Interface
Reference number	Sections of the review				Individual level	Population level	
68	3.2	Tharrey et al., 2017, J Pediatr Gastroenterol Nutr	Adaptation of New Colombian Food-based Complementary Feeding Recommendations using Linear Programming.	12-23mo children, Bogota, Colombia (data [^] collected in 2010-2011, n=72)		X	6
69	3.2	Ferguson et al., 2008, J Pediatr Gastroenterol Nutr	Can optimal combinations of local foods achieve the nutrient density of the F100 catch-up diet for severe malnutrition?	6-15 mo severely malnourished children, Ghana, Bangladesh and Latin America (food list from a study published in 2004, n=NA)		X	1
70	3.2	Maillot et al., 2009, J Nutr	To meet nutrient recommendations, most French adults need to expand their habitual food repertoire.	Adults, France (INCA1, 1999, n= 1171)	X		3
71	3.2 5.3	Horgan et al., 2016, Int J Behav Nutr Phys Act.	Achieving dietary recommendations and reducing greenhouse gas emissions: modelling diets to minimise the change from current intakes.	Adults, UK (NDNS 2008-11, n = 1491)	X		5B
72	4.1	Darmon et al., 2002, J Nutr	A cost constraint alone has adverse effects on food selection and nutrient density: an analysis of human diets by linear programming.	Adults (≥18yo), Paris area, France (Val de Marne survey in 1991, n=837)		X	1
73	4.1	Darmon et al., 2003, Appetite	Do economic constraints encourage the selection of energy dense diets?	Adults (≥18yo), Paris area, France (Val de Marne survey in 1991, n=837)		X	1
77	4.2	Foytik, 1981, J Nutr Educ	Very low-cost nutritious diet plans designed by linear programming.	Low-income household (composed of 1 man, 1 woman and 2 children), US (food list from USDA publications, NA, n=NA)		X	unclear
78	4.2	Henson, 1991, J Agric Econ	Linear programming analysis of constraints upon human diets.	General population (from 3 to >75yo), UK (National Food Survey, 1987 and other database, n=NA, 24 age, sex and physical activity level groups)		X	unclear
79	4.2	Parlesak, 2016, PlosOne	Use of Linear Programming to Develop Cost-Minimized Nutritionally Adequate Health Promoting Food Baskets	Theoretical household (composed of 1 man, 1 woman and 2 children), Denmark (food list collected in 2014)		X	1
80	4.2	Frega et al., 2012, Food Nutr Bull	What linear programming contributes: world food programme experience with the "cost of the diet" tool.	Theoretical household, Mozambique (unclear, n=NA)		X	2

Table 1a - *Continued*

Reference		1rst author, year of publication, journal review	Title	Population studied, country	Modelling		Interface
Reference number	Sections of the review				Individual level	Population level	
82	4.2	Busquet, 2016 [report]	Cost of the Diet Analysis in Azraq Refugee Camp, Jordan. 2016.	Standard family of 5 refugees (2 parents, 3 children aged 12-23 mo, 4-5y and 9-10y), Azraq Camp, Jordan (data^ collected in 2016, n=NA)		X	2
83	4.2	Save the Children et al., 2016, [report]	A Cost of the Diet analysis in the Sava region of Madagascar	6-23mo children, pregnant and lactating women, adolescents girls (10-19yo), Sava region, Madagascar (data^ collected in 2014-15, n=NA)		X	2
85	4.3	Carlson, 2007, The Low-Cost, Moderate-Cost and Liberal Food plans	The Low-Cost, Moderate-Cost and Liberal Food plans,	Low income general population (≥ 1 yo), US (NHANES, 2001-02, n=3527)		X	4
86	4.3	Hemsworth, 2014, PhD manuscript	Development of Food-Based Dietary Guidelines and Analysis of the Theoretical Effects of Various Doses of LNS on Dietary Adequacy of 9-10 month old infants in rural Malawi: A Linear-Programming Analysis.	9-10mo infants, rural Malawi (data^ collected in 2010-11, n=568)		X	6
87	4.3	Darmon et al., 2006, J Nutr Educ Behav	Impact of a cost constraint on nutritionally adequate food choices for French women: an analysis by linear programming.	Women (≥ 18 yo), Paris Area, France (Val de Marne survey in 1991, n=476).		X	1
88	4.2	Maillot et al., 2008, J Nutr	Nutrient Profiling Can Help Identify Foods of Good Nutritional Quality for Their Price : a Validation Study with Linear Programming	General population (15-92yo), France (INCA1, 1999, n=1332)		X	3
89	4.3	Maillot et al., 2017, PLoS One	Dietary changes needed to reach nutritional adequacy without increasing diet cost according to income: An analysis among French adults.	Adults (≥ 20 yo), France (INCA2, 2006-07, n=1719)	X		3
91	5.1	MacDiarmid et al., 2013, Proc Nutr Soc	Is a healthy diet an environmentally sustainable diet?	19-50yo woman, UK (food list from NDNS, n=1)		X	5A
92	5.2	Donati et al., 2016, Appetite	Towards a sustainable diet combining economic, environmental and nutritional objectives.	Young adults (18-20 yo), Parma, Italy (NA, n=104)		X	unclear
93	5.2	MacDiarmid et al., 2012, Am J Clin Nutr	Sustainable diets for the future: Can we contribute to reducing greenhouse gas emissions by eating a healthy diet?	19-50yo woman, UK (food list from NDNS, n=1)		X	5A

Table 1a - *Continued*

Reference number	Sections of the review	1rst author, year of publication, journal	Title	Population studied, country	Modelling		Interface
					Individual level	Population level	
95	5.2	MacDiarmid et al., 2011, LiveWell report	Livewell: a balance of healthy and sustainable food choices.	19-50yo woman, UK (NDNS, 2000-01, n=1)		X	5A
96	5.1	Vieux et al., 2018, EJCN	Dietary changes needed to improve diet sustainability: are they similar across Europe?	Adults, Finland (FINDIET, 2012, n=1248), Sweden (Riksmaten, 2010, n=1352), UK (NDNS, 2008-2012, n=1378), Italy (INRAN-SCAI, 2005, n=2072), France (INCA2 2006-2007, n=2253), by sex for each country		X	3
98	5.3	Tyszler et al., 2015, Int J Life Cycle Assess	Just eating healthier is not enough: studying the environmental impact of different diet scenarios for Dutch women (31–50 years old) by linear programming.	Women (31–50 years old), Netherlands (DNFCS, 2007-10, n=unclear)		X	9
99	5.3	van Dooren et al., 2015, Sustainability	Combining Low Price, Low Climate Impact and High Nutritional Value in One Shopping Basket through Diet Optimization by Linear Programming.	Adults (31–50 yo), Netherlands (DNFCS, 2007-10, n=699)		X	9
100	5.3	Kramer et al., 2016, Public Health Nutr	Decreasing the overall environmental impact of the Dutch diet: how to find healthy and sustainable diets with limited changes.	Adults (31–50 years old), Netherlands (DNFCS, 2007-10, n=3819, 4 age-sex groups)		X	9
101	5.3	Green et al., 2015, Clim Change	The potential to reduce greenhouse gas emissions in the UK through healthy and realistic dietary change.	Adults, UK (NDNS, 2008-11, n=1571)		X	5C
102	5.3	Milner et al., 2015, BMJ Open	Health effects of adopting low greenhouse gas emission diets in the UK.	Adults, UK (NDNS, 2008-11, n=1571)		X	5C

Footnote: ^ Data can refer to cross-sectional surveys and/or interviews and/or literature researches. **Softwares** : 1 Microsoft Excel Solver (Frontline Systems) ; 2 Cost of the Diet tool ; 3 Operational Research, Package of SAS software ; 4 General Algebraic Modeling System (GAMS) ; 5A Rglpk package of the R statistical software environment ; 5B IpSolveAPI package of the R statistical software environment ; 5C Alabama package of the R statistical software environment ; 6 Optifood ; 7 Microdiet System (Salford University) ; 8 LINGO Hyper Systems ; 9 Optimeal® software (Blonk Consultants and the Netherlands Nutrition Centre).

SUPPLEMENTAL TABLE 1b. Description of the model parameters used to take into account nutrition and cultural acceptability in the 67 studies reviewed.

Reference number	1st author, year of publication, journal	Objective function	NUTRITION		CULTURAL ACCEPTABILITY +	
				Constraint	Objective function	Constraint
19	Martin et al., 2000, book	Minimise total energy content		8 macronutrients, 21 micronutrients		Maximum on each food quantity (50th, 75th, 90th centiles of average observed diet)
20	Chastre et al, 2009, Save The Children			Fixed energy (equal to energy requirement) 2 macronutrients, 12 micronutrients		Maximum on energy from food groups (percentages of energy requirements per household members)
21	Baldi et al., 2013, Food Nutr Bull			Fixed energy (equal to the energy requirement) 2 macronutrients, 13 micronutrients		Minimum on each food and food group quantity ; Maximum on each food and food group quantity (based on focus groups results)
22	Maillot et al., 2010, Public Health Nutr			Progressively stringent constraints: Level A: Fixed energy (equal to average observed energy intake), 3 macronutrients. Level B: Fixed energy, EAR for 10 macronutrients, 22 micronutrients. Level C: Fixed energy, RDA for 10 macronutrients, 22 micronutrients.		7 levels of consumption constraints progressively stringent, based on observed distribution of food intakes
23	Cleveland et al., 1993, J Am Diet Assoc			Fixed energy (equal to energy requirement) 9 macronutrients, 16 micronutrients + sodium	Minimise the sum of the square relative deviation of 37 food categories from average observed diets	Minimum on each food group quantity (0.5% of the quantity in the average observed diet); Maximum on sugars/sweets, sugar-based beverages, and low-calorie beverages quantity (based on the average observed diet)
24	Darmon et al., 2002, Am J Clin Nutr	Minimise total energy content		1 macronutrient, 11 micronutrients A posteriori evaluation of absorbable iron and zinc		Minimum on energy from all food groups (25th percentile in the observed diet); Maximum on energy from all food groups (75th percentile in the observed diet); on each food quantity (from 75th to 90th percentile in the observed diet)
25	Thompson et al., 2013, LiveWell report			Minimum and maximum on energy content Nutritional requirements according to the country FBDGs for France	Only for France: Minimise the sum of the absolute relative deviation from an average observed diet	Minimum on each food quantity for France and on foods for Spain and UK to achieve 25% reduction GHGE Maximum on each food quantity for France and on foods for Spain and UK to achieve 25% reduction GHGE Spain and UK: ensure that most of 30% of popular foods remained

Table 1b - *Continued*

Reference number	1st author, year of publication, journal	Objective function	NUTRITION		CULTURAL ACCEPTABILITY +	
			Constraint	Objective function	Constraint	
26	Perignon et al., 2016, Public Health Nutr		Fixed energy (equal to average energy in the observed diet) 3 scenarios : 1/ no nutritional constraints 2/ constraints on 3 macronutrients 3/ constraints on 12 macronutrients & 21 micronutrients A posteriori calculation of MAR and MER	Minimise the sum of the absolute relative deviations for 402 food items and 8 food groups from average observed diets	Minimum on total food quantity (80% from the average total quantity in the observed diet); Maximum on total food quantity (120% from the average total quantity in the observed diet); on each food, subgroup and food group quantity (90th percentile in the observed diet)	
28	Carlson, 2006, Thrifty Food Plan		Fixed energy (equal to the energy requirement, $\pm 5\%$) 8 macronutrients, 17 micronutrients	Minimise the sum of the square deviation of 58 categories expressed in logarithm form, from average observed diets	Minimum on each food group quantity (slightly above 0); Maximum on each food group quantity (from 3 to 10 times the observed consumption); Food groups constraints based on MyPyramid	
30	Ferguson et al., 2006, J Nutr	All phases include nutrients in the objective functions: Phase 1: minimise negative deviation from nutrient goals (2 macronutrients, 11 micronutrients), positive deviation from cost goal and positive and negative deviation from food pattern goals to identify draft FBRs. Phase 2: test robustness of draft FBRs by minimising each nutrient content individually and cost, defining the "worst-case scenario nutrient levels" Phase 3: identify foods to improve the first draft FBRs by minimizing the number of foods that could together provide the desired amount of problem nutrients.	Fixed energy (equal to the energy requirement) Phase 4: Compare a posteriori the cost and the "worst-case scenario" nutrient levels of alternative FBRs to select the final set of FBRs.	Phase 1: minimise negative deviation from nutrient goals (X macronutrients, X micronutrients), positive deviation from cost goal and positive and negative deviation from food pattern goals to identify draft FBRs.	Minimum on number of servings/week for each food group; Maximum on number of servings/week for each food group and each food quantity.	
36	Okubo et al., 2015, Nutr J		Fixed energy (equal to the energy requirement) 7 macronutrients, 22 micronutrients	Minimise the sum of the absolute relative deviation of 19 food categories from average observed diet	Minimum on each food subgroup and group quantity (5th centiles in the observed diet) Maximum on each food subgroup and group quantity (95th centiles in the observed diet); maximum for whole grains and reduced fat dairy product	

Table 1b - *Continued*

Reference number	1st author, year of publication, journal	NUTRITION		CULTURAL ACCEPTABILITY +	
		Objective function	Constraint	Objective function	Constraint
37	Ferguson et al., 2004, J Nutr	Phase III-IV: minimise quantity of a selected nutrient in order to evaluate the robustness of the draft FBDGs	All phases: Energy = 6.0 MJ/d Phase I-II: Nutrients \geq FAO/WHO RNIs	Phase I-II: Minimise the sum of the absolute relative deviation from observed diet, to select optimal diets and draft FBDGs	All phases: Minimum on energy from food groups (25th percentile of the observed diet) Maximum on energy from food groups (75th percentile of observed diets); on each food quantity (90th percentile of the observed diet) Phase III-IV Minimum on number of portions included as FBDGs Serving size by food group based on scientific knowledge, taking into account cultural habits and food availability based on experts' knowledge.
38	National Health and Medical Research Council, 2011, [report].	Minimise energy (food group level, on a weekly basis)	1/ "Foundation diet" models: Energy, 1 macronutrient (protein), 9 micronutrients 2/ "Total diet" models: Energy, 1 macronutrient (protein), 9 micronutrients, Addition of composite foods to reach various energy levels. 13 macronutrients and 10 micronutrients assessed as outputs from modelling, a posteriori		
41	Ferguson et al., 2015, Matern Child Nutr	- Module I*: minimise and maximise energy content to test model parameters - Module II*: minimise relative deviations below the nutrient goals to create draft FBRs - Module III*: maximise or minimise nutrient content to identify problem nutrients and test FBRs 1 macronutrient, 11 micronutrients	Module II and III Fixed energy (equal to the average energy requirement) Bioavailabilities of iron and zinc were assumed to be low (5% and 15%, respectively).		In all modules: Minimum on food, subgroup and food group consumption frequency; Maximum on food, subgroup and food group consumption frequency; Fixed food portion sizes (median observed portions)
42	Vossenaar et al., 2016, Public Health Nutr	- Module II*: minimise relative deviations below the nutrient goals to create draft FBRs - Module III*: maximise or minimise nutrient content to identify problem nutrients and test FBRs 2 macronutrients, 11 micronutrients	Module II and III Fixed energy (equal to the average energy requirement) Low bioavailability was assumed for iron and zinc.		In all modules: Minimum on food, subgroup and food group consumption frequency; Maximum on food, subgroup and food group consumption frequency; Fixed food portion sizes (median observed portions)
43	FANTA, 2013, Report	- Module II*: minimise relative deviations below the nutrient goals to create draft FBRs- Module III*: maximise or minimise nutrient content to identify problem nutrients and test FBRs 2 macronutrients, 11 micronutrients	Module II and III Fixed energy (equal to the average energy requirement)		In all modules: Minimum on food, subgroup and food group consumption frequency; Maximum on food, subgroup and food group consumption frequency; Fixed food portion sizes (median observed portions)

Table 1b - *Continued*

Reference number	1st author, year of publication, journal	NUTRITION		CULTURAL ACCEPTABILITY +	
		Objective function	Constraint	Objective function	Constraint
44	Santika et al., 2009, J Nutr	<ul style="list-style-type: none"> - Module II*: minimise relative deviations below the nutrient goals to create draft FBRs - Module III*: maximise or minimise nutrient content to identify problem nutrients and test FBRs 	Module II and III Fixed energy (equal to the average energy requirement)		In all modules: Minimum on food, subgroup and food group consumption frequency; Maximum on food, subgroup and food group consumption frequency; Fixed food portion sizes (median observed portions)
45	Skau et al., 2014, Am J Clin Nutr	5 models were run to test the relevance of fortified foods. The models included successively: Nothing (Baseline), WinFood (WF), WinFood-Lite (WF-L), Corn-Soy-Blend Plus (CSB+), and Corn-Soy-Blend Plus Plus (CSB+++) products. <ul style="list-style-type: none"> - Module II*: minimise relative deviations below the nutrient goals to create draft FBRs - Module III*: maximise or minimise nutrient content to identify problem nutrients and test FBRs 	Bioavailability assumed: Zinc: moderate Iron: 10% absorption		In all modules: Minimum on food, subgroup and food group consumption frequency; Maximum on food, subgroup and food group consumption frequency; Fixed food portion sizes (median observed portions)
46	Ferguson et al., submitted in 2017, Matern Child Nutr [under review]	1 macronutrient, 11 micronutrients <ul style="list-style-type: none"> - Module I*: minimise and maximise energy content to test model parameters - Module II*: minimise relative deviations below the nutrient goals to create draft FBRs - Module III*: maximise or minimise nutrient content to identify problem nutrients and test FBRs 	Module II and III Fixed energy (equal to the average energy requirement)		In all modules: Minimum on food, subgroup and food group consumption frequency; Maximum on food, subgroup and food group consumption frequency; Fixed food portion sizes (median observed portions)
47	Kujinga et al., 2017, Matern Child Nutr	1 macronutrient, 11 micronutrients <ul style="list-style-type: none"> - Module I*: minimise and maximise energy content to test model parameters - Module II*: minimise relative deviations below the nutrient goals to create draft FBRs - Module III*: maximise or minimise nutrient content to identify problem nutrients and test FBRs 	Module II and III Fixed energy (equal to the average energy requirement) Iron: 5% bioavailability was assumed Zinc: 15% bioavailability was assumed		In all modules: Minimum on food, subgroup and food group consumption frequency; Maximum on food, subgroup and food group consumption frequency; Fixed food portion sizes (median observed portions)

Table 1b - *Continued*

Reference number	1st author, year of publication, journal	Objective function	NUTRITION		CULTURAL ACCEPTABILITY +	
				Constraint	Objective function	Constraint
48	Levesque et al., 2014, Public Health Nutr		Minimum on energy content 3 macronutrients, 12 micronutrients Low bioavailability assumed for iron and zinc. Calcium content multiplied by absorption efficacy (Ca is absorbed at 32.1% from milk v. 17.0% from white beans)		As close as possible to the local eating patterns (exact form of the objective function not mention)	Maximum on each food group quantity (+ 2sd of the average quantity in observed diet per 1000kcal) and food (at the average portion size)
49	Gao et al., 2006, J Nutr (1)		Fixed energy (3 energy levels) 5 scenarios for each Food Guide pyramid (1992 and 2005) adding incrementally: 4 macronutrients, 16 micronutrients		Minimise the sum of the square deviation of 61 subgroups from average observed diet	Maximum on each food quantity (90th percentile of the observed diet)
50	Masset et al., 2009, J Nutr		Fixed energy (equal to average energy from observed diet) 2 scenarios: 1/ model with American Institute of Cancer Research dietary guidelines on energy density, "Fruits and non starchy vegetables", "red meat", fiber and sodium. 2/ model with constraints on 7 macronutrients and 22 micronutrients, following DRIObserved and optimised diets' nutrient quality measured a posteriori using mean adequacy ration (MAR)		Minimise the sum of the absolute relative deviation of 152 food categories from average observed diet	Minimum on food subgroup and groups (5th percentile of observed diet); Maximum on food subgroup and groups (90th percentile of observed diet)
51	Maillot et al., 2011, J Nutr		Fixed energy (equal to energy requirement then equal to energy content in the observed diet) 9 macronutrients, 18 micronutrients Calculation a posteriori of energy density based on all foods, and based on solid foods only.		Minimise the sum of the absolute relative deviation of 39 categories from average observed diet	Minimum on food groups (10th percentile of the observed diet); Maximum on foods, food subgroups, food groups (75th percentile of the observed diet)
52	Scarborough et al., 2016, BMJ Open		Fixed energy (equal to average energy from observed diet) 6 macronutrients, 1 micronutrient (sodium)		Minimise the sum of the square absolute deviation of 125 food categories from average observed diet	Minimum on F&V, fish quantities ; Maximum on red and processed meat quantities (EatWell Guide recommendations)
54	Colavita et al. 1990, Brit J Nutr		Evaluation a posteriori of the content of modeled diet in 4 macronutrients, 5 micronutrients and of the ratio Ca:P		Maximise a preferential score of food preferences	Minimum on percentage of energy coming from breakfast, lunch, snack and dinner; Maximum on percentage of energy coming from breakfast, lunch, snack and dinner and on each food quantity

Table 1b - *Continued*

Reference number	1rst author, year of publication, journal	Objective function	NUTRITION		CULTURAL ACCEPTABILITY +	
				Constraint	Objective function	Constraint
55	Soden et al., 1992, Br J Nutr		Several scenarios 1\ maximum on energy only (energy requirement) 2\ energy and 3 macronutrient constraints Unclear		Minimise the sum of the deviation from each individual's observed diet	Minimum on each food quantity; Maximum on each food quantity; Constraint on links between 2 foods (sponge pudding and custard)
56	Maes L., et al., 2008, Int J Obes				Minimise the sum of the square deviation from each individual's observed diet	NA
57	Maillot et al., 2010, Am J Clin Nutr		Fixed energy (equal to energy from each individual's observed diet) 11 macronutrients, 21 micronutrients		Minimise the sum of the absolute relative negative deviation from each individual's observed diet and the sum of additional foods	Maximum on each food, subgroup and food group quantity (97.5th percentile of observed diet) and on total food quantity (115% of total food quantity in individual's observed diet)
58	Maillot et al., 2011, Am J Clin Nutr		8 macronutrients, 20 micronutrients + 8 scenarios: inclusion or not of constraints on total fats, total carbohydrates, total MUFAs, and cholesterol.		Minimise the sum of the absolute relative negative deviation from each individual's observed diet and the sum of additional foods	Maximum on each food, subgroup and food group quantity (97.5th percentile of the observed diet) and on total food quantity (115% of total food quantity in the individual's observed diet)
59	Clerfeuille et al., 2013, J Acad Nutr Diet		Fixed energy (equal to the energy in the observed diet) 8 macronutrients, 20 micronutrients		Minimise the sum of the absolute relative negative deviation from each individual's observed diet and the sum of additional foods	Maximum on each food, subgroup and food group quantity (97.5th percentile of the observed diet) and on total food quantity (115% of total food quantity in the individual's observed diet)
60	Lluch et al., 2017, Nutrients		Fixed energy (equal to energy from each individual's observed diet) 13 macronutrients, 20 micronutrients		Minimise the sum of the absolute relative negative deviation from each individual's observed diet and the sum of additional foods	Maximum on each food, subgroup and food group quantity (97.5th percentile of the observed diet) and on total food quantity (115% of total food quantity in the individual's observed diet)
61	Vieux et al., 2016, Nutrients		Fixed energy (equal to energy from each individual's observed diet) 7 macronutrients, 24 micronutrients		Minimise the sum of the absolute relative negative deviation from each individual's observed diet and the sum of additional foods	Maximum on each food, subgroup and food group quantity (97.5th percentile of the observed diet)
62	Briend et al. 2000, Pediatrics		Minimum energy content (1000kcal/d) 2 macronutrients, 17 micronutrients			Maximum on each food quantity (1/ 90th; 2/ 75th and 3/ 50th centiles in the observed diet)
63	Wilde et al, 2009, J Consum Aff		4 scenarios with additional constraints: (1) food energy (equal to energy requirement) (2) food energy constraints and MyPyramid food category constraints (3) food energy constraints and nutrient constraints (4) all of the above constraints together.		1/ minimise the sum of the square deviation of 58 categories, expressed in logarithm form, from average observed diets 2/ minimise the sum of the square deviation of 58 categories from average observed diets	

Table 1b - *Continued*

Reference number	1st author, year of publication, journal	Objective function	NUTRITION		CULTURAL ACCEPTABILITY +	
				Constraint	Objective function	Constraint
64	Gao et al, 2006, J Nutr (2)	Maximise dietary α -tocopherol intake		Maximum on energy content (energy requirement) 3 macronutrients, 15 micronutrients		Maximum on each foodsubgroup quantity (75th percentile of observed intakes); on each food group quantity (90th percentile of observed intakes) + Sensitivity analyses on food group constraints
65	Maillot et al, 2013, Nutr Res	Scenario 1: maximise potassium content		Scenario 1: ratio of Na-K constant at 0.49. Then starting from the amount of sodium found in the first step, the sodium amount decreased by steps of 0.1 g until the LP model became infeasible. Senario 3: Simulation of 10% reduction in sodium content of food supply	Scenario 2: Minimise the sum of the relative deviation of 128 food categories from average observed diet	Minimum on each food group quantity (10th percentile of the observed diet); Maximum on each food group quantity (90th percentile of the observed diet); on each food subgroup quantity (75th percentile of the observed diet)
66	Maillot et al, 2012, Am J Prev Med			Fixed energy (equal to energy requirement) Stepwise reduction of maximum sodium content(min = 1500 lg/day sodium) 9 macronutrients, 17 micronutrients + sodium. A posteriori : Macronutrient composition, energy density, solid fats and added sugars, and MyPyramid, servings for F&V, whole grains, refined grains, meats and fish, beans and nuts, and dairy (i.e., milk and milk products).	Minimise the sum of the relative deviation of 128 food categories from average observed diet	Minimum on each food group quantity (10th percentile of the observed diet); Maximum on each food group quantity (90th percentile of the observed diet); on each food subgroup quantity (75th percentile of the observed diet)
67	Fahmida et al, 2015, Am J Clin Nutr	- Module II*: minimise relative deviations below the nutrient goals to create draft FBRs - Module III*: maximise or minimise nutrient content to identify problem nutrients and test FBRs 2 macronutrients, 11 micronutrients		Moderate bioavailability for zinc, and 10% absorption for iron		In all modules: Minimum on food, subgroup and food group consumption frequency; Maximum on food, subgroup and food group consumption frequency; Fixed food portion sizes (median observed portions)
68	Tharrey et al., 2017, J Pediatr Gastroenterol Nutr	- Module II*: minimise relative deviations below the nutrient goals to create draft FBRs - Module III*: maximise or minimise nutrient content to identify problem nutrients and test FBRs 2 macronutrients, 11 micronutrients		Existing complementary feeding recommendations for 6-12mo infants were tested as constraints to assess their relevance for 12-23mo children. Constraints on number of weekly servings of meat, red meat, cow's liver, chicken giblets, F&V, legumes, eggs and dairy products 15% bioavailability for iron.		Optimisation without and with commercial fortified food products In all modules: Minimum on food, subgroup and food group consumption frequency; Maximum on food, subgroup and food group consumption frequency; Fixed food portion sizes (median observed portions)

Table 1b - *Continued*

Reference number	1st author, year of publication, journal	Objective function	NUTRITION		CULTURAL ACCEPTABILITY +	
				Constraint	Objective function	Constraint
69	Ferguson et al., 2008, J Pediatr Gastroenterol Nutr	Minimise total diet weight (in grams)	Fixed energy (equal to the energy requirement) Minimum energy density (≥ 100 kcal/100g in order to achieve or exceed F100 \square Nutrient density) Phytate:zinc ration ≤ 15 2 macronutrients, 16 micronutrients			Upper constraints on individual food item quantities, based on published maximum portions for infants.
70	Maillot et al., 2009, J Nutr		Fixed energy (equal to the energy content of the individual observed diet) ⁶ 6 macronutrients, 21 micronutrients	Minimise the sum of the absolute relative positive and negative deviation from each individual's observed diet		Maximum on each food, subgroup and food group quantity (97.5th percentile of the observed diet) and on total food quantity (115% of total food quantity in the individual's observed diet)
71	Horgan et al., 2016, Int J Behav Nutr Phys Act.		Fixed energy (equal to energy content in each individual's observed diet) 7 macronutrients, 16 micronutrients F&V (minimum amount g/d) White fish & dishes (minimum amount g/d) Red meat and dishes (maximum amount g/d) no increase of alcohol	Minimisation of food group (n=134) quantities for each individual 1/ up to a maximum of 50 % deviation in the amount of any food group from each individual's observed diet 2/ up to a maximum of 50 % deviation in the amount of any food group from each individual's observed diet and new foods added to the diet 3/ up to a maximum 50 % increase and/or 75 % reduction in the amount of any food group from each individual's observed diet and new foods added to the diet 4/ up to a maximum of 50 % deviation in the amount of any food group from each individual's observed diet and food items removed from the diet		
72	Darmon et al., 2002, J Nutr		Fixed energy (equal to average energy intake in the observed diet) Evaluation of nutritional quality of modeled diets a posteriori.	Minimise the sum of the absolute relative deviation of 73 food groups from average observed diet		Minimum on energy from each subgroup (5th percentile of the observed diet); on energy from each food group (10th percentile of the observed diet); Maximum on each food quantity (75th percentile of the observed diet); energy from each food subgroup (95th percentile of the observed diet); energy from each food subgroup (90th percentile of the observed diet)

Table 1b - *Continued*

Reference number	1st author, year of publication, journal	NUTRITION		CULTURAL ACCEPTABILITY +	
		Objective function	Constraint	Objective function	Constraint
73	Darmon et al., 2003, Appetite		Fixed energy (equal to average energy intake in the observed diet) 2 scenarios: 1/ No constraint on nutrients; 2/ minimal level for the energy density (in MJ/kg) of the optimised diet, increasing by 0.5kJ/g. 1st sets of models: evaluation of the impact of the diet cost constraint on energy density of the modeled diet a posteriori	Minimise the sum of the absolute relative deviation of 73 food groups from average observed diet	Minimum on energy from each subgroup (5th percentile of the observed diet); on energy from each food group (10th percentile of the observed diet); Maximum on each food quantity (75th percentile of the observed diet); energy from each food subgroup (95th percentile of the observed diet); energy from each food subgroup (90th percentile of the observed diet)
77	Foytik, 1981, J Nutr Educ		Sum of nutrient recommendations (RDA) for members of the household: Fixed energy (equal to the sum of energy requirements for the household) 1 macronutrient, 10 micronutrients A posteriori : content of the modeled diet in 6 micronutrients assessed.		(60 constraints) on - Fixed amount of foods - minimum and maximum for food according to their nutrient density and cost
78	Henson, 1991, J Agric Econ		All scenario: minimum on energy content on various nutrient (unclear) Scenarios 2 and 4: "healthy diets" constraints: fiber, total fat, saturated fat, sugar and salt		Scenario 3 and 4 : Minimum on each food groups quantity; Maximum on each food group quantity; Constraints on associated foods (eg bread and yellow fat, drinking chocolate and milk, tea and milk, coffee and milk, flour and fats)
79	Parlesak, 2016, PlosOne		Fixed energy (equal to energy recommendation) in the 5 scenarios 10 macronutrients (scenarios 3, 4 and 5) 20 micronutrients (scenarios 3, 4 and 5) FBRs (only scenario 2 and 5)		Maximum on the relative deviation for each food group; (scenario 1 and 4) Step by step decrease of the maximum on the proportion of each food within a food group (from 200% to 10%)
80	Frega et al., 2012, Food Nutr Bull		Fixed energy (equal to the energy requirement) 2 macronutrients, 13 micronutrients		Minimum on the frequency on consumption per week and by food; Maximum on the frequency on consumption per week and by food;

Table 1b - *Continued*

Reference number	1st author, year of publication, journal	Objective function	NUTRITION		CULTURAL ACCEPTABILITY +	
			Constraint	Objective function	Constraint	
82	Busquet, 2016 [report]			4 scenarios were run 1/ with constraints on energy only 2/ with constraints on energy and 2 macronutrients recommendations 3/ with constraints on energy, 2 macronutrients and 13 micronutrients recommendations 4/ with constraints on energy, 15 nutrient recommendations and food habits constraints		Scenario 4: minimum and maximum food frequency (outputs from focus group discussions and questionnaire)
83	Save the Children et al., 2016, [report]			3 scenarios were run 1/ energy requirement 2/ energy requirement, 2 macronutrients and 13 micronutrients 3/ energy requirement, 15 nutrient recommendations and food habits constraints		Scenario 3: minimum and maximum food consumption frequency (outputs from focus group discussions and questionnaire)
85	Carlson, 2007, The Low-Cost, Moderate-Cost and Liberal Food plans			Idem Carlson, 2006, Thrifty Food Plan;	Idem Carlson, 2006, Thrifty Food Plan;	Idem Carlson, 2006, Thrifty Food Plan;
86	Hemsworth, 2014, PhD manuscript	- Module I*: minimise and maximise energy content to test model parameters - Module II*: minimise relative deviations below the nutrient goals to create draft FBRs - Module III*: maximise or minimise nutrient content to identify problem nutrients and test FBRs 1 macronutrient 11 micronutrients		Fixed energy (equal to the energy requirement) Diet containing either 0, 10, 20 or 40g per day of lipid-nutrient supplements Bioavailability assumed: low for zinc and iron.		In all modules: Minimum on food, subgroup and food group consumption frequency; Maximum on food, subgroup and food group consumption frequency; Fixed food portion sizes (median observed portions)
87	Darmon et al., 2006, J Nutr Educ Behav			Fixed energy (equal to average energy intake in the observed diet) 7 macronutrients, 20 micronutrients	Minimise the sum of the absolute relative deviation of 21 food groups from average observed diet	Minimum on energy from food group (5th percentile in the observed diet); Maximum on food quantity (75th percentile in the observed diet); on energy from food group (95th percentile in the observed diet)

Table 1b - *Continued*

Reference number	1st author, year of publication, journal	Objective function	NUTRITION		CULTURAL ACCEPTABILITY +	
				Constraint	Objective function	Constraint
88	Maillot et al., 2008, J Nutr		Fixed energy (equal to the age & gender group energy requirement) 3 increasingly stringent sets of constraints on nutrients: 1/ 6 macronutrients 2/ 6 macronutrients + EAR + upper limit on SFA, simple added sugars, and sodium 3/ 6 macronutrients + RDA + upper limit on SFA, simple added sugars, and sodium A posteriori evaluation of nutritional density of optimised diets using two scores: - NDS: positive score based on qualifying nutrients only - LIM: mean percentage of the maximal recommended values for 3 nutrients to limit in 100g of food		Minimise the sum of the absolute relative negative deviation from each individual's observed diet and the sum of additional foods	7 sets of increasingly stringent sets of constraints on specified food groups, subgroups and food items.
89	Maillot et al., 2017, PLoS One		Fixed energy (equal to energy content in each individual's observed diet) 13 macronutrients, 1 micronutrient (sodium) Observed diets: evaluation of solid energy density (SED), mean adequacy ratio (MAR) and mean excess ratio (MER)		Minimise the sum of the absolute relative negative deviation from each individual's observed diet	Maximum on each food, subgroup and food group quantity (97.5th percentile of the observed diet) and on total food quantity (115% of total food quantity in the individual's observed diet)
91	MacDiarmid et al., 2013, Proc Nutr Soc		Fixed energy (equal to requirement) Imposed only in healthy scenario (1 and 3): 6 macronutrients, 2 micronutrients			Minimal on F&V and fish quantity (only in healthy scenarios); on food and food group quantity; Maximal on red and processed meat quantity (only in healthy scenario); on food and food group quantity
92	Donati et al., 2016, Appetite		Minimum and maximum on energy content 7 macronutrients, 1 micronutrient (sodium)			Minimum on food consumption frequency ; Maximum on food consumption frequency ; Food association constraints between groups of complementary foods; Food alternative constraints to avoid the combination of certain food items in the same diet (ex: avoid to put fish and beef in the same diet)

Table 1b - *Continued*

Reference number	1st author, year of publication, journal	Objective function	NUTRITION		CULTURAL ACCEPTABILITY +	
				Constraint	Objective function	Constraint
93	MacDiarmid et al., 2012, Am J Clin Nutr		Fixed energy (equal to the energy requirement) 6 macronutrients, 6 micronutrients Requirements for adult women, with adaptation to protein requirement to take into account the lower digestibility from plant foods			Minimal on F&V and fish quantity; on each food quantity (based on foods consumed by >50% pop, with adjustment to obtain an acceptable 7-d menu plan) Maximal on red and processed mean quantity; on each food quantity (based on foods consumed by >50% pop, with adjustment to obtain an acceptable 7-d menu plan)
94	Wilson et al., 2013, PLoS One		Minimum value on energy 4 macronutrients 10 micronutrients Constraints on food groups to create a Mediterranean-style diet, or an Asian-style diet, which are both known to be healthy.			Constraints according to various scenarios: 2 scenarios with Mediterranean style, 2 scenarios with Asian style, 4 scenarios with New-Zealand style
95	MacDiarmid et al., 2011, LiveWell report		Fixed energy (equal to requirement) 6 macronutrients, 6 micronutrients			Minimal on F&V and fish quantity; on food and food group quantity; Maximal on red and processed mean quantity; on food and food group quantity
96	Vieux et al., 2018, Eur J Clin Nutr		Fixed energy (equal to average energy from observed diet) 6 macronutrients, 16 micronutrients	Minimise the sum of the absolute relative deviations for 151 food items from average observed diets		Total food weight \pm 20% to the food weight in the average observed diet Fixed ratio solid/liquid including alcohol (equal to the average proportion in the observed diet) Minimum on each food and food groups quantity (10th percentil in the observed diet); Maximum on each food and food group quantity (90th percentil in the observed diet)
98	Tyszler et al., 2015, Int J Life Cycle Assess		For all scenarios Minimum and maximum on energy content 13 macronutrients, 9 essentials amino acids, 21 micronutrients Upper and lower bounds for F&V	Minimise the sum of the absolute relative deviation of 207 foods from the average observed diet, weighted by a proxy of popularity based on the food quantity consumed 6 scenarios, adding different kinds of constraints.		4 scenarios: - Closest healthy diet (no product added, no environmental constraints) - Vegetarian M: excluded meat products - Vegetarian MF: excluded meat & fish products - Vegan: excluded meat, fish, eggs and dairy products

Table 1b - *Continued*

Reference number	1st author, year of publication, journal	Objective function	NUTRITION		CULTURAL ACCEPTABILITY +	
				Constraint	Objective function	Constraint
99	van Dooren et al., 2015, Sustainability		Scenarios 1, 2 and 3: Minimum and maximum on energy content 11 macronutrients, 19 micronutrients Upper and lower bounds for F&V		Minimise the sum of the absolute relative deviation of 206 foods from the average observed diet, weighted by a proxy of popularity based on the food quantity consumed	
100	Kramer et al., 2016, Public Health Nutr		All scenario: Minimum and maximum on energy content 9 macronutrients, 1 essential amino acid, 21 micronutrients		Minimise the sum of the absolute relative deviation of 207 foods from the average observed diet, weighted by a proxy of popularity based on the food quantity consumed	Maximum on each food quantity
101	Green et al., 2015. Clim Change		Fixed energy (equal to average energy from observed diet) 11 macronutrients, 1 micronutrient Constraints on F&V		Minimise the sum of the square relative deviation of 42 food groups from average observed diets, weighted by the ratio between share of expenditure for that food group and price elasticity	Fixed proportion from liquid and alcohol (equal to the average proportion in the observed diet)
102	Milner et al., 2015, BMJ Open		Fixed energy (equal to average energy from observed diet) 11 macronutrients, 1 micronutrient Constraints on F&V		Minimise the sum of the square relative deviation of 42 food groups from average observed diets, weighted by the ratio between share of expenditure for that food group and price elasticity	Fixed proportion from liquid and alcohol (equal to the average proportion in the observed diet)

Footnote : F&V: Fruits and vegetables ;FBRs: Food Based Recommendations; FBDGs: Food Based Dietary Guidelines ; EAR: Estimated Average Requirement ; RDA: Recommended Dietary Allowances ; RNIs: Recommended Nutrient Intakes ; DRI: Dietary Reference Intakes ; * Module I, II III and IV of 6 as described by Daelmans et al., 2013 ; † F100 is a nutrient-dense milk-based food formulated specifically to fulfill the high nutritional needs of severely malnourished children;+All papers took as variables the list of food available &/or consumed in the food survey used, which can be considered as a proxy of cultural acceptability. ; ° ReCiPe is a weighted combination of three indicators: GHGE, land use and fossil energy use.

SUPPLEMENTAL TABLE 1c. Description of the model parameters used to take into account cost and environmental impact in the 67 studies reviewed.

Reference number	1st author, year of publication, journal	Objective function	COST		ENVIRONMENT	
			Constraint	Objective function	Constraint	
19	Martin et al., 2000, book					
20	Chastre et al, 2009, Save The Children	Minimise total diet cost				
21	Baldi et al., 2013, Food Nutr Bull	Minimise total diet cost				
22	Maillot et al., 2010, Public Health Nutr	Minimise total diet cost				
23	Cleveland et al., 1993, J Am Diet Assoc					
24	Darmon et al., 2002, Am J Clin Nutr					
25	Thompson et al., 2013, LiveWell report		Total diet cost assessed a posteriori	Spain and UK: Minimise total GHGE; several scenarios to achieve 25% reduction, then 50% and 70%		France: 25% GHGE from the average observed diet, then 50% and 70%
26	Perignon et al., 2016, Public Health Nutr		Evaluation of the cost of observed and sustainable diet a posteriori	Minimize GHGE		Step by step decrease of GHGE (-10% from the observed GHGE) until unachievable.
28	Carlson, 2006, Thrifty Food Plan		Constant cost level based on inflation rate			
30	Ferguson et al., 2006, J Nutr	Phase 1: minimise negative deviation from nutrient goals (X macronutrients, X micronutrients), positive deviation from cost goal and positive and negative deviation from food pattern goals to identify draft FBRs. Phase 2: test the robustness draft FBRs by minimising each nutrient content individually and cost.	Upper limit on cost Phase 4: Compare a posteriori the cost and the "worst-case scenario nutrient levels" of alternative FBRs to select the final set of FBRs.			
36	Okubo et al., 2015, Nutr J					
37	Ferguson et al., 2004, J Nutr					
38	National Health and Medical Research Council, 2011, [report].					
41	Ferguson et al., 2015, Matern Child Nutr		Cost implications of the food based recommendations formulated, a posteriori			
42	Vossenaar et al., 2016, Public Health Nutr					
43	FANTA, 2013, Report	Module IV*: minimise total diet cost				
44	Santika et al., 2009, J Nutr		Under a treshold (2500 Indonesian rupiahs / day)			

Table 1C - *Continued*

Reference number	1rst author, year of publication, journal	Objective function	COST	Constraint	ENVIRONMENT	
					Objective function	Constraint
45	Skau et al., 2014, Am J Clin Nutr					
46	Ferguson et al., submitted in 2017, Matern Child Nutr [under review]					
47	Kujinga et al., 2017, Matern Child Nutr					
48	Levesque et al., 2014, Public Health Nutr					
49	Gao et al., 2006, J Nutr (1)					
50	Masset et al., 2009, J Nutr					
51	Maillot et al., 2011, J Nutr					
52	Scarborough et al., 2016, BMJ Open					
54	Colavita et al. 1990, Br J Nutr					
55	Soden et al., 1992, Br J Nutr					
56	Maes L., et al., 2008, Int J Obes					
57	Maillot et al., 2010, Am J Clin Nutr					
58	Maillot et al., 2011, Am J Clin Nutr					
59	Clerfeuille et al., 2013, J Acad Nutr Diet					
60	Lluch et al., 2017, Nutrients					
61	Vieux et al., 2016, Nutrients					
62	Briend et al. 2000, Pediatrics	Minimise total diet cost				
63	Wilde et al, 2009, J Consum Aff					
64	Gao et al, 2006, J Nutr (2)					
65	Maillot et al, 2013, Nutr Res					
66	Maillot et al, 2012, Am J Prev Med					

Table 1C - *Continued*

Reference number	1rst author, year of publication, journal	Objective function	COST		ENVIRONMENT	
				Constraint	Objective function	Constraint
67	Fahmida et al, 2015, Am J Clin Nutr	Module IV*: minimise total diet cost				
68	Tharrey et al., 2017, J Pediatr Gastroenterol Nutr					
69	Ferguson et al., 2008, J Pediatr Gastroenterol Nutr					
70	Maillot et al., 2009, J Nutr					
71	Horgan et al., 2016, Int J Behav Nutr Phys Act.					25% reduction compared to 1990 levels: Men: ≤3.1 kgCO ₂ e/d women: ≤2.5 kgCO ₂ e/d
72	Darmon et al., 2002, J Nutr		step by step reduction of total diet cost (-0.50€/step)			
73	Darmon et al., 2003, Appetite		1rst sets of models: maximal value for the total cost of the optimised diet, increasing gradually by 0.5€ 2nd sets of models: evaluation of the impact of the energy density constraint on diet cost, a posteriori.			
77	Foytik, 1981, J Nutr Educ	Minimise total diet cost2 scenarios with different price input data (Price input data from 1974 and 1975)		Comparison of the price of the modeled diets (assessed a posteriori) with published Thrifty Food plan menus.		
78	Henson, 1991, J Agric Econ	Scenario 1: Minimise total diet cost				
79	Parlesak, 2016, PlosOne	Minimise total diet cost (in the 5 scenarios)				
80	Frega et al., 2012, Food Nutr Bull	Minimise total diet cost				
82	Busquet, 2016 [report]	Minimise total diet cost				
83	Save the Children et al., 2016, [report]	Minimise total diet cost				
85	Carlson, 2007, The Low-Cost, Moderate-Cost and Liberal Food plans			Idem Carlson, 2006, Thrifty Food Plan;		
86	Hemsworth, 2014, PhD manuscript			Cost implications of introducing various doses of Lipid Based Nutrient Supplement on total diet cost		
87	Darmon et al., 2006, J Nutr Educ Behav			One model with no cost constraint. Then models introducing a cost constraint gradually increase by steps of 0.50€.		

Table 1C – *Continued*

Reference number	1rst author, year of publication, journal	Objective function	COST		ENVIRONMENT	
			Constraint	Objective function	Constraint	
88	Maillot et al., 2008, J Nutr	All models: Minimise total diet cost. Comparison of the minimal possible cost of the 21 diets modeled.				
89	Maillot et al., 2017, PLoS One		Total diet cost free or equal to observed			
91	MacDiarmid et al., 2013, Proc Nutr Soc		itake diet cost depending on the model used		4 scenarios: 1/ Maximise GHGE (healthy high GHGE) 2/ Maximise GHGE (unhealthy high GHGE) 3/ Minimise GHGE (healthy low GHGE) 4/ Minimise GHGE (unhealthy low GHGE)	
92	Donati et al., 2016, Appetite	Minimum Cost Diet: Minimise total diet cost Sustainable Diet (SD): multiobjective linear programming combining environmental and economic objectives			Environmentally Sustainable Diet: minimised three environmental indicators: CO2e emissions, H2O consumption and amount of land to regenerate the resources Sustainable Diet (SD): multiobjective linear programming combining environmental and economic objectives	
93	MacDiarmid et al., 2012, Am J Clin Nutr		Total diet cost assessed a posteriori, based on the cost of midrange supermarket products in the UK in 2010		Minimise GHGE	
94	Wilson et al., 2013, PLoS One	Some scenarios minimise food cost.	When objective function was to minimize GHGE, maximal cost of NZ\$5 of NZ\$9 per day.		Some scenarios minimised GHGE.	
95	MacDiarmid et al., 2011, LiveWell report		Total diet cost assessed a posteriori, based on food price from supermaket		Minimise GHGE	
96	Vieux et al., 2018, Eur J Clin Nutr				Minimize GHGE	Step by step decrease of GHGE (-10% from the observed GHGE) until unachievable.
98	Tyszler et al., 2015, Int J Life Cycle Assess					1 diet modeled with 30% less environmental impact. Environmental impact calculated using an adaptation of the ReCiPe score. (ReCiPe is a weighted combination of three indicators: GHGE, land use and fossil energy use).
99	van Dooren et al., 2015, Sustainability		Scenario 3: Cost cannot exceed €2.50 per day			Scenario 2 and 3: Upper boundary for climate impact (GHGE) set to 1.6 kg CO2eq/day A posteriori : evaluation of land use, fossil energy use and ReCiPe score°

Table 1C - *Continued*

Reference number	1rst author, year of publication, journal	Objective function	COST	Constraint	Objective function	ENVIRONMENT	
						Constraint	
100	Kramer et al., 2016, Public Health Nutr						Step by step decrease of GHGE (-10% from the observed GHGE) until unachievable (except in the first scenario)
101	Green et al., 2015. Clim Change	Minimise the sum of the square relative deviation of 42 food groups from average observed diets, weighted by the share of expenditure for that food group					Step by step reduction (-10% GHGE reduction/step)
102	Milner et al., 2015, BMJ Open	Minimise the sum of the square relative deviation of 42 food groups from average observed diets, weighted by the share of expenditure for that food group					Step by step reduction (-10% GHGE reduction /step)

Footnote : FBRs: Food Based Recommendations ; GHGE: Green House Gas Emissions; * Module I, II III and IV of 6 as described by Daelmans et al., 2013 ; ° ReCiPe is a weighted combination of three indicators: GHGE, land use and fossil energy use.

Titre : Quelles stratégies pour améliorer le régime alimentaire de jeunes femmes égyptiennes en milieu urbain ? Analyse des déséquilibres et identification de stratégies nutritionnelles par méthodes mixtes.

Mots clés : nutrition ; Égypte ; femmes ; modélisation ; acceptabilité.

Résumé : Les femmes égyptiennes constituent un exemple caractéristique mais peu étudié de population confrontée à une transition nutritionnelle, caractérisée par une forte prévalence de surpoids (88% en milieu urbain) et de déficience en fer (50%). Cette situation suggère que leurs apports alimentaires, bien que peu évalués et donc méconnus, devraient être rééquilibrés. La modélisation de l'alimentation est une approche mathématique qui permet d'identifier les changements de régimes alimentaires susceptibles d'améliorer les apports nutritionnels en prenant en compte différents paramètres du contexte alimentaire local. Cependant, l'acceptabilité des stratégies nutritionnelles modélisées est difficilement prédictible. Ces travaux de thèse ont permis de

quantifier les apports alimentaires et nutritionnels d'une population de femmes égyptiennes résidant en milieu urbain, puis de modéliser des stratégies d'amélioration nutritionnelle. L'acceptabilité des solutions « théoriquement optimales » a ensuite été évaluée par la population d'étude par des enquêtes qualitatives. L'utilisation de méthodes mixtes (approches quantitatives puis qualitatives) a permis une analyse fine de la situation ainsi que l'identification de changements envisageables au niveau des pratiques alimentaires et de l'offre de produits enrichis. Cette approche semble prometteuse pour identifier des solutions réalistes et acceptables afin de contribuer à résoudre des problématiques nutritionnelles locales.

Title: Which strategies to improve the diet of young women from urban Egypt? Analysis of unbalances and identification of nutritional strategies with mixed methods.

Keywords: nutrition; Egypt; women; modelling; acceptability.

Abstract: Egyptian women are a typical yet rarely studied example of population undergoing a nutrition transition, touched by a high prevalence of overweight (88% in urban areas) and iron deficiency (50%). This situation suggests that their dietary intakes, which are so far poorly assessed and not well known, should be rebalanced. Diet modeling is a mathematical tool which helps to identify dietary changes improving nutritional intakes, taking into consideration several parameters of the local food environment. Yet, the acceptability of the nutritional strategies modeled is hardly predictable. This research thesis enabled to

quantify the dietary intakes of young Egyptian women living in urban areas and to model strategies to improve nutritional intakes. The acceptability of the "theoretically optimal" solutions was then discussed with the population studied using qualitative surveys. The use of mixed methodologies (quantitative and then qualitative approaches) enabled to analyze in detail the local situation and to identify changes in dietary practices and in the fortified food offer. This approach seems promising to identify realistic and acceptable solutions to contribute solving local nutritional issues.