Dietary Risk Factors for Non-Communicable Diseases among Omani adults by Latent Class Analysis and Structural Equation Modelling

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**Abstract**

*Background:* Risk factor surveillance is vital for public health interventions in non-communicable diseases (NCD) control due to a noticeable nutrition transition among the population affecting dietary patterns. The objective was to investigate the dietary risk factors and its associations based on a first-of-its-kind analysis employing both Latent Class Analysis (LCA) and Structural equation modelling (SEM) to explore the hidden heterogeneity and subgroups with shared dietary pattern and to demonstrate the complex interaction of dietary factors with other risk factors in the development of NCDs.

*Methods:* A cross-sectional survey was used. Secondary analysis of the 2017 Oman NCD Risk Factors Survey data was performed to investigate three major dietary risk factors (fruits and vegetables intake, eating out, and the type of oil used in cooking) of Omanis using LCA and SEM.

*Results:* Dietary risk factors are prevalent in Omanis with 55.8% reporting intake of less than five fruit and vegetable servings per day, 45.3% ate outside the home 1-3 times per week, and 87.3% used vegetable oil for cooking. LCA showed two distinct classes of Omani population with majority belonging to the class mainly eating out 1-3 times per week, eating less than the recommended servings of fruits and vegetables, vegetable oil users, educated, and married young adults. SEM showed the intricate interplay of dietary factors with 8 direct paths and several indirect paths with NCD indicators.

*Conclusions:* These findings may have important implications for targeting health promotion strategies among the high-risk group of Omanis identified in this analysis and inform decision makers for the reduction of NCDs.

**Keywords:** Dietary Risk Factors, Latent Class Analysis, Structural Equation Modelling, Oman, Non-Communicable Disease.

**Introduction**

Globally, there is a nutrition transition characterized by a rise in the consumption of dense, processed, and convenience foods with a reduction in the intake of healthy food including fibre rich food. Dietary patterns and nutrient intake are affected by this nutrition transition, which in turn affects the risk of developing non-communicable diseases (NCDs)(1). Based on global burden of diseases (GBD) reports, in 2019 dietary risk factors were attributed with 7.9 million deaths which is the cause of 30% of all NCDs-related deaths and 187.7 million DALYs globally (2).

The reduction of NCDs burden can be set in motion by targeting their predisposing risk factors including metabolic, behavioural, and environmental risk factors and by encouraging the increase of favourable behaviours, including consuming more fruit and vegetables and less salt. The reduction in NCDs is now a United Nations global health priority, advocated by the World Health Organization (WHO) Action Plan, targeting main risk factors like unhealthy diet, harmful alcohol consumption, tobacco use, and physical inactivity. A selection of cost-effective policyoptions (‘best buys’) has been identified of which promoting healthy consumption of food is one of them (3), since there is substantial evidence of a causal association between dietary habits and patterns, nutrient consumption and NCDs (4).

Healthy food includes a high intake of fibre rich food, not less than 5 servings of vegetables and fruits, low intake of saturated fat replaced by unsaturated fat, low salt intake, and low consumption of energy dense and processed food (5). In addition to minerals, vitamins and antioxidants, fresh fruits and vegetables are considered to be rich sources of dietary fibre (6).

There is reliable evidence that dietary intakes of fruit and vegetables, in excess of 5 servings (or 600g) daily promote the prevention of several chronic diseases such as obesity, hypertension, cardiovascular diseases (CVD) and certain types of cancer (7). A good indication of the occurrence of these diseases could be the trend in consumption of such healthy food.

Studies have shown that fruits and vegetables are not adequately consumed by most of the population residing in the Arab Gulf countries (5,8). In addition, it is known that some dishes traditionally consumed within the Arab Gulf region have a substantially high fat content (5% -20%) (5). Fat is essential for energy, development, and vitamin absorption. However, it is advisable to maintain a moderate intake of fat. Based on its association to heart disease and its consequent impact on elevated blood cholesterol levels, dietary fats can be categorised into two types. Fat from animal sources, which can potentially raise blood cholesterol levels, is generally found in meat, whole milk, butter, cheese, chicken skin, and liver. On the other hand, it is believed that fats from vegetable sources do not raise blood cholesterol levels compared to animal fat – however, use of coconut oil and palm oil has conflicting evidence for its role in cardiovascular disease as compared to olive, sunflower, and canola oils. However, fats do contain a lot of energy, so a disproportionate intake of food rich in fat such as fast food may be a significant factor for mounting obesity prevalence in the region. As a consequence, food of plant origin like legumes, grains, seeds and nuts are recommended to meet energy requirements. Although Oman’s Ministry of Health has supported the global overall vision of halting and reducing the threat posed by NCDs and adopted the Oman National Strategy for the Prevention and Control of NCD to oversee the implementation of definitive actions aimed at reducing the burden (9), the importance of food-based dietary guidelines (FBDG) continues to be emphasised by FAO/WHO. Hence, FBDG for the Arab Gulf countries was set up by the Arab Center for Nutrition for timely prevention and appropriate control of diet-related diseases, with a specific focus on chronic disease (5). A recent modelling study suggests that the environmental sustainability of these national and global FBDG could be enhanced by reducing red and processed meat with balanced energy intake whilst increasing consumption of whole grains, fruits and vegetables, legumes, and nuts and seeds (10). Realistic objectives for national programmes need to be set along with increased preventive measures and behavioural modification for adolescents and youth through changes in their physical, social, and economic ecosystem.

In this study, we perform a secondary in-depth analysis on the data available from the STEPS survey, the largest representative survey on a national scale to identify the magnitude of NCD risk factors among the Omani population. In order to enable countries to gather core information on the main risk factors that contribute to disease burden, the WHO conceived the STEPwise approach to risk factor surveillance (STEPS), with a flexible structure allowing countries to adapt it according to their specific needs (11). It consists of three main steps: a questionnaire to assess socio-demographic, nutritional, and behavioural information; physical measurements; and biochemical measurements of blood glucose and lipid profile, including cholesterol. Nested within are further questions to identify levels of dietary intake, in particular on intake of fruits, vegetables and salt along with the consumption of food outside home and oils used in cooking.

The main objective of this study was to investigate the dietary risk factors of the Omani population using Latent Class Analysis (LCA) to explore the hidden heterogeneity and subgroups with shared dietary pattern to enlighten and inform decision makers with more reliable information that can guide them to build targeted action plans to reduce the burden of NCDs.

**Methods**

*Sampling*

Data was derived from the dataset of a large cross-sectional nationally-representative community-based Oman NCD Risk Factors Survey adopting WHO STEPwise methodology, and employing a multi-level stratified, geographically clustered sampling approach across all governorates (regions) of the Sultanate of Oman. Adjustments were done to the sample weights by primary and secondary sampling units as well as for household non-response level. Further details of the survey methodology are available on the main NCD survey article (12). The analysis presented here included all eligible adult Omani citizens, men and women, aged 18 years and above taken from the total survey population (4,320 participants).

*Questionnaire*

Based on the WHO STEPS instrument, a questionnaire for obtaining demographic and behavioural data in addition to the physical and biochemical measurements were used. A section on dietary history related to salt, fat, and fruit and vegetable intake was included in the questionnaire. The dietary questionnaire (Template in Text S1) was based on stated consumption. Respondents were provided with examples of foods high in salt content.

*Variables*

These included reported low consumption of fruits and vegetables by participants, eating outside to represent fast food consumption and the type of oil used for cooking. Inadequate intake of fruits and vegetables was defined as intake of less than five portions (or 400g) of fruits and vegetables per day, as recommended minimal intake by the WHO (11). In the course of the survey, the questionnaire included frequency in terms of days and servings to assess the consumption of fruits and vegetables. All the outcome variables were evaluated with the several independent variables employed in this study, including age, sex, education level, marital status, and work status.

*Statistical analysis*

Statistical analysis was carried out with STATA (version 2016). Complex samples analysis was used to generate estimates with adjustment for the complex, multi-level sampling design, incorporating stratified sampling by governorates and enumerator areas. Descriptive analysis was calculated using proportions and testing relationships between categorical variables using chi square variance analysis at 95% confidence level. regression analysis then was performed to assess the significance of dietary behaviours on some unhealthy bio-physical and biochemical variables controlling for sociodemographic variables.

In addition, there is a strong emphasis by many researchers on the signs and statistical significance of effects, but very little emphasis is often placed on the substantive and practical significance of the results. Using predicted or expected values to model hypothetical or prototypical cases can often result in more tangible results (13). Thus, marginal effect analysis was conducted to extract more meaningful results. Moreover, although conventional variable-level studies (such as regression) include important information, important aspects of relationships that are often rooted in sample heterogeneity are not captured. Thus, LCA (14) was done which is one of several person-centred techniques that can be used to capture sample heterogeneity within and between various groups.

By using STATA, LCA was performed on a weighted sample. The fact that a model is estimated and a case has been selected by random selection to fit into one specific class provides some information as to what response pattern the case will have.

**Results**

*Participant characteristics*

Table 1 presents the demographic attributes of the study participants. 4320 Omani citizens were included in the secondary data analysis, of which the majority of participants were young in the age group of 18-44 years (59.39%), women (56.13%), had secondary education or above (68.44%), married (63.98%), and not currently working (62.72%).

*Prevalence of Dietary Risk Factors*

More than half of the surveyed respondents reported taking less than five fruits and vegetable servings per day (Table 2) while 45.3 % ate meals outside the home 1-3 times per week. It was also found that 87.3% used vegetable oil for cooking in comparison to butter (4.3%, 95% CI: 3.4%-5.6%) (Table 2). The prevalence of high dietary salt consumption was observed in 60.8% of the participants (Table 2).

Table 1. Socio-demographic attributes of the respondents, Oman STEPS survey, 2017.

|  |  |  |
| --- | --- | --- |
| **Variable (n)** | **Proportion (%)** | **95% Confidence Interval** |
| **Age group, years**  18-29 (1,102)  30-44 (1,337)  40-49 (856)  50-59 (484)  60+ (542) | 33.7  25.7  19.0  10.7  10.9 | 31.3 – 36.2  23.8 – 27.8  17.0 – 21.1  9.2 – 12.5  9.5 – 12.5 |
| **Sex**  Men (1,665)  Women (2,655) | 43.9  56.1 | 41.4 – 46.4  53.6 – 58.6 |
| **Education attainment**  None (1,274)  Preparatory or less (487)  Secondary (1,648)  University or more (908) | 21.8  9.7  42.7  25.7 | 20.1 – 23.7  8.5 – 11.1  40.2 – 45.3  23.6 – 28.0 |
| **Marital status**  Not married (742)  Married (3,161)  Separated/Divorced (114)  Widowed (303) | 28.2  64.0  2.7  5.1 | 25.8 – 30.8  61.4 – 66.5  1.9 – 3.8  4.1 – 6.3 |
| **Work status**  Public sector (1,042)  Private sector (465)  Not working (2,810) | 23.9  13.4  62.7 | 21.9 – 26.0  11.6 – 15.5  60.2 – 65.1 |

Table 2. Prevalence of Dietary Risk Factors

|  |  |  |
| --- | --- | --- |
| **Dietary Variable** | **Proportion (%)** | **95% Confidence Interval** |
| **High dietary salt** | 60.8 | 44.6 – 74.9 |
| **Fruit and/or vegetable intake**  >5 servings/day  <5 servings/day | 44.2  55.8 | 41.7 – 46.7  53.3 – 58.3 |
| **Eating meals outside the home**  Never  1-3 times per week  4 or more times per week | 38.6  45.3  16.2 | 36.2 – 40.9  42.7 – 47.9  14.2 – 18.3 |
| **Type of cooking oil used**  Vegetable oil  Butter  Other | 87.3  4.3  8.4 | 85.7 – 88.8  3.4 – 5.6  7.2 – 9.6 |

*Dietary Risk Factor Associations*

Fruits and vegetables intake varied significantly within the different age groups, education level groups, and marital status groups (all p<0.001) (Table S1). The majority of respondents who had an intake of less than 5 servings of fruits and vegetables were young (18-29 years old) (37.4%), completed secondary school (42.2%) and were married (57.9%)).

Similarly, eating outside the home was associated with age, sex, education level, marital status and working status (all p<0.001). Most respondents eating more than 4 times/week were 18-29 years (56.4%), men (64.9%), and completed secondary school (48.8%), never married (30.1%), and not currently working (47.4%). Most of the women ate at home while most of the men eat 1-3 times/week outside the home. In general, as the education level increased, there was a higher tendency for eating outside the home. Most of those who were working were eating from outside but those who were not working ate mostly at home (Table S2).

We found that the type of oil used for cooking varied significantly among sex, educational level, and working status groups (all p<0.001). Most respondents who used vegetable oils were mostly women (56.2%), completed secondary school (42.3%) and not working (61.9%). Among all subcategories of the above which showed significant correlation with the type of cooking oil used, vegetable oil was the main oil used for cooking (Table S3).

Those having high blood pressure were mostly eating outside the home (55%). However, most of those who were eating more than 4 times outside had normal systolic blood pressure. They mostly used vegetable oil for cooking (88.2%). Fruits and vegetables did not vary significantly between blood pressure groups.

Most of those who are eating outside more than 4 times/week and those using vegetable oil for cooking are having normal weight but abnormal waist-to-hip ratio. Higher total cholesterol is seen more with those who are eating at home and eating less than five servings of fruits and vegetables but it is not correlated significantly with type of oil used for cooking. Interestingly, Low HDL was seen mostly among those who ate more than 4 times/week outside compared to those who ate a home. We found that high blood glucose is found more in vegetable oil users and those who are eating at home. Regressing total cholesterol on the dietary risk factors and controlling for sociodemographic (age, sex, work status, marital status, education level, family history of hypercholesteremia), and biophysical factors (obesity, waist-to-hip ratio) we found that dietary risk factors are significant indicators for total cholesterol level (Table 3). Further analysis on margins, we found that higher total cholesterol level is associated with eating less fruits and vegetables, using vegetable oil for cooking, and eating at home (Figure 1-A, B, C).

Table 3. Output of regression model of Total cholesterol on dietary risk factors controlling for sociodemographic and biophysical factors

|  |  |  |  |
| --- | --- | --- | --- |
| **Covariates** | **Coefficient (x10-3)** | **95% Confidence Intervals (x10-3)** | **p-value** |
| Age (years) | 7.9 | 4.6 - 11.1 | <0.001 |
| Sex (mnf) | 130.6 | 48.4 - 212.8 | 0.002 |
| Marital status\* | 35.7 | -21.5 - 93.0 | 0.221 |
| Educational levels\* | -56.1 | -97.6 - 14.6 | 0.008 |
| Working status\* | -131.2 | -180.0 - 82.4 | <0.001 |
| Smoking | 105.7 | -41.6 - 253.0 | 0.16 |
| Eating meal out\*\* | -223.9 | -275.8 - 172.1 | <0.001 |
| Oil used for cooking\*\* | -100.8 | -157.4 - 44.3 | <0.001 |
| Family history of high cholesterol (y/n) | 120.5 | 47.1 - 193.8 | 0.001 |
| Fruit and vegetable intake\*\* | 125.8 | 59.1 - 192.5 | <0.001 |
| Waist-to-hip ratio | 89.9 | 18.4 - 161.5 | 0.014 |
| Obesity | 87.9 | 19.2 - 156.6 | 0.012 |
| Sedentary life-style | 12.7 | -52.9 - 78.3 | 0.704 |
| \*Units in Table 1; \*\*Units in Table 2 |  |  |  |

Figure 1. Predictive Margins of Total Cholesterol by group of main dietary risk factors (a) by having meals out; (b) by type of cooking oil; (c) by fruit and vegetable consumption.

(a) (b) (c)



*Latent Class Analysis*

We compared two models for identifying possible population subgroups using LCA analysis and we selected the two-class model as it had a lower Akaike’s Information Criterion (AIC) and Bayesian Information Criterion (BIC) (Table S4). Using LCA we found that there are two distinct subgroups of dietary habits (Table 4), where most Omanis (90%) are more likely to be in class 2. In other words, each Omani is having 90% probability of being in class 2. Table 5 presents Class 2 which are those who are eating less than the recommended servings of fruits and vegetables, following sedentary lifestyle, using vegetable oil for cooking, and mostly eating at home. Putting the dietary habits as indicators for waist-to-hip ratio in the LCA, we found that those in class 2 were with higher probability of having abnormal waist-to-hip ratio (64%) (Table S5, S6).

Table 4. Latent class marginal probabilities for dietary subgroups (x10-2)

|  |  |  |  |
| --- | --- | --- | --- |
| **Class** | **Margin** | **Standard Error** | **95% Confidence Intervals** |
| 1 | 9.95 | 3.57 | 4.82 -19.43 |
| 2 | 90.04 | 3.57 | 80.56 - 95.18 |

Table 5. Latent class marginal means for dietary habits (x10-2)

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | **Class 1** | | **Class 2** | |
|  | Margin | 95% Confidence  Intervals | Margin | 95% Confidence  Intervals |
| **Eating outside the home (times per week)** | | | | |
| Never  1-3 times  4 or more times | 0.00013  79.6  20.4 | 68.4 – 87.5  12.5 – 31.6 | 58.1  32.1  9.7 | 53.3 – 62.8  28.2 – 36.3  8.3 – 11.4 |
| **Number of serving of fruit and/or vegetables per day** | | | | |
| > 5  < 5 | 20.6  79.4 | 12.6 – 31.9  68.1 – 87.4 | 39.2  60.8 | 37.3 – 41.2  58.8 – 62.7 |
| **Fat used for cooking** | | | | |
| Vegetable oil  Butter  Other | 62.6  0.49  37.0 | 41.3 – 79.8  0 – 98.9  18.6 – 60.1 | 90.6  4.0  5.4 | 89.4 – 91.7  3.3 – 4.8  4.5 -6.4 |
| **Physical activity** | | | | |
| Insufficient  Sufficient | 70.7  29.3 | 60.3 – 79.3  20.7 – 39.7 | 59.8  40.2 | 57.9 – 61.6  38.4 – 42.1 |

When the LCA was extended to include sociodemographic factors with the dietary factors, we found 2 distinct classes with each Omani having a 67% probability of being in Class 1 which were those in the 18-39 age group, completed secondary school, married, not working, eating less than the recommended servings of fruits and vegetables, having sedentary lifestyle, eating outside for 1-3 times/week, and using vegetable oil for cooking (Tables S7, S8). Regressing blood glucose on the above classes’ variables using LCA, we found that on condition of categorised in Class 1, an individual would have a 21% and 6% probability of developing pre-diabetes and diabetes, respectively (Tables S9, S10). However, being in Class 2 (being married, above 50 years of age, not having formal education, not working, having sedentary lifestyle, eating outside the home, and eating less serving of fruits and vegetables, and using vegetable oil for cooking), an individual would have a 32% probability of developing diabetes. As a result, we can see that increasing age is a strong indicator for diabetes as it raises the probability of developing diabetes from 6% to 32% despite the individual having almost the same dietary habits. Thus, most Omani citizens in Class 1 would have a higher probability of developing diabetes if they keep the same lifestyle habits as they are aging.

*Direct effects of dietary risk factors*

Using Structural equation modelling, we proposed the model in Figure 2 which showed the standardized coefficients to control for measurement differences. The model showed good fit (Table S11). It was found that dietary risk factors have a direct effect through 8 paths on main biophysical (Waist-to-hip ratio, Systolic blood pressure) and main biochemical (blood glucose, total cholesterol, and HDL) risk indicators of NCDs along with several indirect effects (Table 6).

Figure 2. Structural Equation Modelling (SEM) of dietary risk factor associations

**A close up of a map

Description automatically generated**

Table 6.Direct and indirect effect of dietary risk factors on the main biophysical and biochemical parameters (x10-2)

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  | **Waist-to-Hip Ratio** | **Total**  **Cholesterol** | **Blood Glucose** | **High-Density Lipoprotein** | **Systolic Blood Pressure** |
| **Eating outside the home (times per week)** | | | | | |
| Total  Direct  Indirect | 3.73  12.70  3.73 | 10.61  12.15  -1.54 | -3.71  -3.90  0.20 | -2.63  7.32  84.10 | 0.33  0.09  0.25 |
| **Number of serving of fruit and/or vegetables per day** | | | | | |
| Total  Direct  Indirect | 1.51  7.30  1.51 | 4.53  5.15  -0.62 | 0.08  35.00  0.08 | -2.91  -2.91  9.20 | 0.19  7.10  0.19 |
| **Fat used for cooking** | | | | | |
| Total  Direct  Indirect | 7.95  7.17  0.78 | 2.15  5.42  -3.27 | 0.67  26.00  0.67 | 15.00  7.00  9.30 | 4.91  4.28  0.63 |

**Discussion**

Few published studies have assessed the context of a broad range of dietary risk behaviours among Omanis and its interaction with other biophysical and biochemical risk factors in the development of NCDs. This study showed that diet-related risk factors for NCDs are prevalent in Oman, similar to the other parts of the world, and are discriminated by age, sex, and work status. Consumption of fruit and vegetables varies substantially among and within countries, to a significant extent being influenced by the existing economic, cultural, and agricultural environments, however consumption remains low in several parts of the world (15). More than half of the population of Omanis were consuming less than the minimum daily recommended five portions of fruits and vegetables, while a large proportion of Omanis ate outside the home 1-3 times per week. Strikingly, we also found that three out of five Omanis were consuming more than the recommended minimum salt intake. This was supported by findings from a 24-hour analysis of urine samples which also found that less than 10% fulfilled WHO targets for potassium excretion (16).

Consumption of fruit and vegetables may mitigate the risk of NCDs through the enhanced availability of an assortment of nutrients and their ability to regulate associated risk factors. It has been shown that nutrients provided by fruits and vegetables lower blood pressure and cholesterol which are considered risk factors for cardiovascular disease and stroke (17). We found that a low intake of fruits and vegetables was strongly associated with raised cholesterol level in Omanis, however it showed no significant effect on blood pressure. The non-significance of the effect on blood pressure might be due to the lack of time series data which are more capable to pick this effect than cross-sectional data used in this study.

Dietary fibre can also help to control insulin levels which could have an effect on the risk of developing type 2 diabetes (18). Our study observed that a low intake of fruit and vegetables was not directly associated with raised blood glucose, though by LCA we found that among other dietary risk factors and sociodemographic features (but not in isolation), it increases the probability of having high blood glucose. Increased fibre intake, in addition to high water content of fruit and vegetables, can help reduce the risk of obesity by supporting satiety and reducing hunger thereby limiting overall energy consumption (19). Supporting this, we found that a low intake of fruits and vegetables was strongly associated with an abnormal waist-to-hip ratio (abdominal obesity) although with no significant correlation with general obesity.

Diets which include energy-dense, highly-refined foods and processed starches contribute to overweight and obesity, which in turn is associated with increased all-cause mortality and elevated risk of disease or death from cardiovascular disease, diabetes, and various types of cancer (20). It does so by raising blood pressure, insulin resistance, and blood cholesterol as well as hormone levels (20). Several determinants with regard to fruits and vegetable consumption in various populations worldwide have been indicated, including preferences, ethnicity, availability, affordability and cultural variations. Most of those who have low intake of fruits and vegetables in the population of Omanis are young and educated (at least completed secondary school). This might alarm health promotion programmes offered to this group which are often challenging to educate and often in need for modern, updated, and innovative channels for health education outreach. Availability and affordability might not be an issue in a country like Oman, but a comparably low affordability and high availability of energy dense food might reduce the intake of fruits and vegetables (21).

Consumption of fast food frequently is largely unhealthy and leads to weight gain, obesity, type 2 diabetes, and heart disease (22-23). Fast food typically has a high-energy density, which, coupled with bigger portions, prompts overconsumption of calories (24). The Cardia study done on American population suggests that regular consumption of fast-food is positively correlated with increased weight gain and extended risk of insulin resistance over a 15 years’ duration. Individuals who consumed fast food for more than two times per week gained 4.5 kg in weight and had an insulin resistance increase of 104% when compared to individuals eating less than one fast food meal per week (25). We assume that a majority of those eating outside the home are consuming fast food due to its higher availability and affordability. Our study revealed that most Omanis are eating 1-3 times/week outside the home, and are largely young and educated males. Further analysis discovered that among those who with prevailing high blood pressure and high waist-to-hip ratio, most of them ate outside the home. However, on the contrary, we found that raised total cholesterol and raised blood glucose was associated more with those who ate at home. This can be explained by the availability and affordability of ready-to-make high calorie, processed food easily prepared at home which is similar to fast food prepared at restaurants. Other studies have also found associations with unhealthy diets in men and younger people (26-27). This could possibly be owed to the migration among the youth to the main cities for career opportunities as well as the growing popularity of diets high in processed foods from restaurants and fast food. Falling short of the recommended minimum intake of fruits and vegetables was the most prevalent factor related to unhealthy diet. Further studies are warranted to assess knowledge and attitude on their intake which could contribute to establishing strategies to improve the trend of healthy diet consumption.

Although dietary fats and fatty acids are vital nutrients, the type of fat along with the amount consumed have contrasting effects on overall health as well as substantial implications for prevention and treatment of chronic disease, including type 2 diabetes, cancer, respiratory diseases, and multiple sclerosis (28). Furthermore, research indicates that dietary fats have distinct implications (29). The latest dietary recommendations suggest replacing saturated fats with unsaturated fats (30). Saturated fats, such as butter, raises the cholesterol level, which consequently increases the risk of heart disease. As per the recommendation of the American Heart Association, substituting saturated fats with vegetable oils (which contain linoleic acid, a polyunsaturated fat) is presumed to contribute in reducing cholesterol levels, improving overall heart health. Higher levels of linoleic acid are found in certain vegetable oils, such as sunflower and corn, whereas others like canola and olive have lower levels (31). The healthier oil choice to be used for cooking is still debatable. A couple of recent reports have also obfuscated the relationship between saturated fat and cardiovascular disease. A meta-analysis of 72 studies with over 103,052 people revealed that there was insufficient evidence that saturated fats increased the risk of heart disease, although replacing them with polyunsaturated fat might actually reduce this risk (32-34). The finding was also corroborated by other major studies which concluded that substituting saturated fat with polyunsaturated fats such as vegetable oils or high-fibre carbohydrates is the best approach for heart disease risk reduction, though notably substituting saturated fat with highly processed carbohydrates could possibly be counterproductive (35-37). Our study found that most Omanis use vegetable oil for cooking and it is significantly correlated with raised cholesterol and abnormal waist-to-hip ratio. Moreover, there is a 90% probability for any Omani to be in a class of population who are mostly users of vegetable oil.

To realistically reflect the complex interplay of dietary risk factors with other risk factors that could possibly contribute to NCD development, we used Structural Equation Modelling (SEM) to give a more holistic overview of the consolidation of socio-demographic, behavioural, and metabolic attributes that more accurately depict the multitude of factors that contribute to the development of NCDs. It showed that dietary risk factors significantly play an important role in the development of NCDs through direct and indirect effects on the main biophysical and biochemical indicators. Overall, fruit and vegetable intake largely had an indirect effect except for a direct effect on cholesterol. Similarly, eating meals outside the home had a direct effect on blood glucose and total cholesterol; whilst type of cooking oil had a direct effect on waist-to-hip ratio, total cholesterol, and blood pressure.

The strength of this study is that it is the first of its kind employing both LCA and SEM to discover the heterogeneity and the complex interaction of dietary risk factors with other indicators in the development of NCDs. The possibility of recall bias was one of the limitations of the study, since the questionnaire was based on food recall and only utilised reported dietary intake.

**Conclusions**

The harmful outcomes of behavioural and dietary risk factors on NCDs, and the metabolic and physiological aspects that mediate their effects, have been well established in prospective cohort studies and randomized controlled trials.

However, it will also be necessary to establish the burden of disease attributable to dietary risk factors in Oman with a thorough analysis at country level on the basis of data from this study which has shown that such risk factors are widespread among adult Omanis together (38). Our analysis revealed that the WHO dietary intake recommendations had not been met in most of the assessed variables. Moreover, the findings from this analysis also demonstrate the value of tailored strategies for health promotion programmes with innovative process and techniques among the Omani population.

**List of abbreviations**

AIC: Akaike’s Information Criterion

BIC: Bayesian Information Criterion

CVD: cardiovascular diseases

DALY: Disability-adjusted life years

FAO: Food and Agricultural Organization

FBDG: Food-based dietary guidelines

GBD: Global burden of diseases

HDL: High-density Lipoprotein

LCA: Latent Class Analysis

NCD: Non-communicable diseases

SEM: Structural equation modelling

STEPS: STEPwise approach to risk factor surveillance

WHO: World Health Organization

**Declarations**

**Ethics approval and consent to participate:** The study was conducted according to the guidelines laid down in the Declaration of Helsinki and was approved by the Central Research and Ethical Review & Approval Committee of the Ministry of Health, Sultanate of Oman. (Approval No: 26/2015). Written informed consent was obtained separately from all individuals during health history collection and measurement of biophysiological parameters. The confidentiality of the data gathered was maintained.

**Consent for publication:** Not applicable.

**Availability of data and materials:** The datasets generated and/or analysed during the current study are not publicly available due to data sharing policies of Oman and the Ministry of Health but are available from the corresponding author on reasonable request.

**Competing Interests:** FPC: Past-President, British & Irish Hypertension Society (2017-9) (unpaid); Member, Action on Salt and World Action on Salt, Sugar and Health (unpaid); Head, World Health Organization (WHO) Collaborating Centre for Nutrition (unpaid); Senior Advisor, WHO (received travel, accommodation, per-diem, refund of expenses); OMRON Academy (received speaker fees, travel, accommodation, expenses); Annual Royalties from Oxford University Press (OUP) for 2 books on topics unrelated to salt. There are no other competing interests to declare.

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**Authors’ Contributions:** MM and AAH retrieved the data and performed analysis. AAM, ADP, FPC and AAH drafted the manuscript. FPC and AB substantively revised the manuscript. All authors reviewed and commented on subsequent drafts of the manuscript and approved the final submission.

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**References**

1. PPA\_NCD\_Alliance\_Nutrition. Available from: https://www.wcrf.org/sites/default/files/PPA\_NCD\_Alliance\_Nutrition.pdf

2. Qiao J, Lin X, Wu Y, Huang X, Pan X, Xu J, et al. Global burden of non-communicable diseases attributable to dietary risks in 1990–2019. *Journal of Human Nutrition and Dietetics*. **2022;**35(1):202–13.

3. Action Plan for the Prevention and Control of Noncommunicable Diseases in the WHO European Region. :39.

4. Ruel G, Shi Z, Zhen S, Zuo H, Kröger E, Sirois C, et al. Association between nutrition and the evolution of multimorbidity: the importance of fruits and vegetables and whole grain products. *Clinical Nutrition*. **2014**;33(3):513–20.

5. Musaiger AO, Takruri HR, Hassan AS, Abu-Tarboush H. Food-Based Dietary Guidelines for the Arab Gulf Countries [Internet]. Vol. 2012, *Journal of Nutrition and Metabolism.* Hindawi; 2012 [cited 2020 Aug 31]. p. e905303. Available from: https://www.hindawi.com/journals/jnme/2012/905303/

6. Slavin JL, Lloyd B. Health benefits of fruits and vegetables. *Advances in nutrition*. **2012**;3(4):506-16.

7. Aune D, Giovannucci E, Boffetta P, Fadnes LT, Keum N, Norat T, et al. Fruit and vegetable intake and the risk of cardiovascular disease, total cancer and all-cause mortality—a systematic review and dose-response meta-analysis of prospective studies. *International journal of epidemiology.* **2017**;46(3):1029–56.

8. Musaiger AO, Hassan AS, Obeid O. The Paradox of Nutrition-Related Diseases in the Arab Countries: The Need for Action. *Int J Environ Res Public Health*. **2011**;8(9):3637–71.

9. MOH Launches National Policy & Multisectoral Plan on NCDs - Media Center Display Page - Ministry of Health [Internet]. [cited 2020 Aug 31]. Available from: https://www.moh.gov.om/en/-/---669

10. Springmann M, Spajic L, Clark MA, Poore J, Herforth A, Webb P, et al. The healthiness and sustainability of national and global food based dietary guidelines: modelling study. *BMJ*. **2020**;370:m2322.

11. steps\_framework\_dec03.pdf [Internet]. [cited 2020 Aug 31]. Available from: https://www.who.int/ncd\_surveillance/en/steps\_framework\_dec03.pdf

12. Al-Mawali A, Jayapal SK, Morsi M, Al-Shekaili W, Pinto AD, Al-Kharusi H, et al. Prevalence of Risk Factors of Non-Communicable Diseases in the Sultanate of Oman: STEPS Survey 2017. 2020;

13. Williams R. Using the Margins Command to Estimate and Interpret Adjusted Predictions and Marginal Effects. *The Stata Journal*. **2012** ;12(2):308–31.

14. Weller BE, Bowen NK, Faubert SJ. Latent class analysis: a guide to best practice. *Journal of Black Psychology*. **2020**;46(4):287–311.

15. (PDF) Global Variability in Fruit and Vegetable Consumption [Internet]. ResearchGate. [cited 2020 Aug 30]. Available from: https://www.researchgate.net/publication/24274085\_Global\_Variability\_in\_Fruit\_and\_Vegetable\_Consumption

16. Al-Mawali A, D’Elia L, Jayapal SK, Morsi M, Al-Shekaili WN, Pinto AD, et al. National survey to estimate sodium and potassium intake and knowledge attitudes and behaviours towards salt consumption of adults in the Sultanate of Oman. *BMJ Open*. **2020**;10(10):e037012.

17. WHO | Increasing fruit and vegetable consumption to reduce the risk of noncommunicable diseases [Internet]. WHO. World Health Organization; [cited 2020 Aug 30]. Available from: http://www.who.int/elena/titles/bbc/fruit\_vegetables\_ncds/en/

18. Weickert MO, Pfeiffer AFH. Metabolic effects of dietary fiber consumption and prevention of diabetes. *J Nutr.* **2008**;138(3):439–42.

19. PRIME PubMed | Dietary fiber and weight regulation [Internet]. [cited 2020 Aug 30]. Available from: https://www.unboundmedicine.com/medline/citation/11396693/Dietary\_fiber\_and\_weight\_regulation\_

20. PPA\_NCD\_Alliance\_Nutrition.pdf [Internet]. [cited 2020 Aug 30]. Available from: https://www.wcrf.org/sites/default/files/PPA\_NCD\_Alliance\_Nutrition.pdf

21. Miller V, Yusuf S, Chow CK, Dehghan M, Corsi DJ, Lock K, et al. Availability, affordability, and consumption of fruits and vegetables in 18 countries across income levels: findings from the Prospective Urban Rural Epidemiology (PURE) study. *The lancet global health*. **2016**;4(10):e695–703.

22. Alkerwi A, Crichton GE, Hébert JR. Consumption of ready-made meals and increased risk of obesity: findings from the Observation of Cardiovascular Risk Factors in Luxembourg (ORISCAV-LUX) study. *British Journal of Nutrition*. **2015**;16(2):270–7.

23. Rosenheck R. Fast food consumption and increased caloric intake: a systematic review of a trajectory towards weight gain and obesity risk. *Obesity reviews*. **2008**;9(6):535–47.

24. Stender S, Dyerberg J, Astrup A. Fast food: unfriendly and unhealthy. *International Journal of Obesity*. **2007,** 31(6):887–90.

25. Pereira MA, Kartashov AI, Ebbeling CB, Horn LV, Slattery ML, Jacobs DR, et al. Fast-food habits, weight gain, and insulin resistance (the CARDIA study): 15-year prospective analysis. *The Lancet.* **2005**;365(9453):36–42.

26. Mwenda V, Mwangi M, Nyanjau L, Gichu M, Kyobutungi C, Kibachio J. Dietary risk factors for non-communicable diseases in Kenya: findings of the STEPS survey, 2015. *BMC public health.* **2018;**18(3):1–8.

27. Martinez-Lacoba R, Pardo-Garcia I, Amo-Saus E, Escribano-Sotos F. Socioeconomic, demographic and lifestyle-related factors associated with unhealthy diet: a cross-sectional study of university students. *BMC public health*. **2018;**18(1):1–10.

28. Weisburger JH. Dietary fat and risk of chronic disease: insights from experimental studies mechanistic. *Journal of the American Dietetic Association.* **1997**;97(7):S16–23.

29. Wang DD, Li Y, Chiuve SE, Stampfer MJ, Manson JE, Rimm EB, et al. Specific Dietary Fats in Relation to Total and Cause-Specific Mortality. *JAMA Intern Med*. **2016**;176(8):1134–45.

30. Mozaffarian D, Katan MB, Ascherio A, Stampfer MJ, Willett WC. Trans fatty acids and cardiovascular disease. *N Engl J Med*. 2006;354(15):1601–13.

31. Healthy Cooking Oils [Internet]. [cited 2020 Aug 30]. Available from: https://www.heart.org/HEARTORG/HealthyLiving/HealthyEating/SimpleCookingwithHeart/Healthy-Cooking-Oils-101\_UCM\_445179\_Article.jsp#.Vw-camQrKRY

32. Souza RJ de, Mente A, Maroleanu A, Cozma AI, Ha V, Kishibe T, et al. Intake of saturated and trans unsaturated fatty acids and risk of all cause mortality, cardiovascular disease, and type 2 diabetes: systematic review and meta-analysis of observational studies. *BMJ* on-line. **2015** Aug 12 [cited 2020 Aug 30];351. Available from: https://www.bmj.com/content/351/bmj.h3978

33. Effects on Coronary Heart Disease of Increasing Polyunsaturated Fat in Place of Saturated Fat: A Systematic Review and Meta-Analysis of Randomized Controlled Trials [Internet]. [cited 2020 Aug 30]. Available from: https://journals.plos.org/plosmedicine/article?id=10.1371/journal.pmed.1000252

34. Chowdhury R, Warnakula S, Kunutsor S, Crowe F, Ward HA, Johnson L, et al. Association of dietary, circulating, and supplement fatty acids with coronary risk: a systematic review and meta-analysis. *Ann Intern Med*. **2014**;160(6):398–406.

35. Willett WC, Koplan JP, Nugent R, Dusenbury C, Puska P, Gaziano TA. Prevention of Chronic Disease by Means of Diet and Lifestyle Changes. In: Jamison DT, Breman JG, Measham AR, Alleyne G, Claeson M, Evans DB, et al., editors. Disease Control Priorities in Developing Countries [Internet]. 2nd ed. Washington (DC): World Bank; **2006** [cited 2020 Aug 30]. Available from: http://www.ncbi.nlm.nih.gov/books/NBK11795/

36. Expert Consultation on Diet, Nutrition, and the Prevention of Chronic Diseases, Weltgesundheitsorganisation, FAO, editors. Diet, nutrition, and the prevention of chronic diseases: report of a WHO-FAO Expert Consultation ; [Joint WHO-FAO Expert Consultation on Diet, Nutrition, and the Prevention of Chronic Diseases, 2002, Geneva, Switzerland]. Geneva: World Health Organization; **2003**. 149 p. (WHO technical report series).

37. Dietary fats and cardiovascular disease - Sax Institute - Sax Institute [Internet]. [cited 2020 Aug 30]. Available from: https://www.saxinstitute.org.au/publications/evidence-check-library/dietary-fats-cardiovascular-disease/

38. Ezzati M, Riboli E. Behavioral and Dietary Risk Factors for Noncommunicable Diseases. *New England Journal of Medicine*. **2013**;369(10):954–64.