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Fish availability mapping and food-based recommendations to promote an adequate vitamin D intake among pregnant women in East Lombok, Indonesia

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Abstract

Pregnant women are at higher risk of vitamin D deficiency due to increased nutritional requirements and limited dietary sources. Fish is the major source of vitamin D, but its availability varies by region. This study aims to assess the availability of vitamin D-rich fish and develop food-based recommendations (FBRs) for pregnant women in East Lombok, Indonesia. This comparative cross-sectional study was conducted in East Lombok, Indonesia, which is part of Action Against Stunting cohort of pregnant women. Twenty-five village markets in the area were scored based on availability of vitamin D-rich fish and number of fish sellers in each market and were categorized into high availability (HD) for the highest quartile and low availability (LD) for the lowest quartile. QGIS software was used to identify each of respondents' houses using 2.4km buffer zones to either HD or LD markets. Dietary intake data was collected from 24-hour dietary recalls and linear programming (LP) analysis using Optifood was used to identify problem nutrient and dietary inadequacy. No significant difference in vitamin D intake was found between HD and LD areas (p=0.633). While both groups' FBRs ensure adequacy of iron, zinc, vitamins A, B1, B2, B3, B6, and B12, calcium remain as dietary inadequacy in the LD group, suggesting that availability play a role in ensuring dietary adequacy. Future studies to develop nutrient-dense foods and improved fish availability mapping which consider non-static position of market (mobile vendor) are recommended.

Keywords: Geographic Information System, Food-based recommendations, Linear Programming, Pregnant women, Vitamin D

Abbreviations: FBRs, food-based recommendations; ASEAN, Association of Southeast Asian Nations; AASH, Action Against Stunting Hub; LD, Low Availability of Vitamin D Rich Fish; HD, High Availability of Vitamin D Rich Fish; QGIS, Quantum Geographic Information System; GIS, Geographic Information System; MUAC, Mid-Upper Arm-Circumference; CED, chronic energy deficiency; 24-HR, 24-hour dietary recall; FCT, Food Composition Table; SEA, Southeast Asia; RNI, Recommended Nutrient Intake; LP, Linear Programming; FP, food pattern; HWI, Household Wealth Index; ASF, animal-source food; EI/BMR, energy intake to basal metabolic rate

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Introduction

The importance of vitamin D in pregnancy is increasingly recognized. Vitamin D has a broad therapeutic impact during pregnancy for both the mother and the foetus, in addition to its usual role in the endocrine regulation of calcium and bone metabolism.[1,2] Many studies have reported that low maternal vitamin D increases the risk of adverse pregnancy outcomes such as preeclampsia, spontaneous pregnancy loss, gestational diabetes mellitus, preterm birth, low birth weight, and small for gestational age babies.[3–8]

Vitamin D can be obtained from cutaneous synthesis, diet, and supplements. The primary source of vitamin D is exposure to sunlight. Optimal sunlight exposure can facilitate the natural conversion of vitamin D in the skin. However the effect is reduced by wearing a hat, using an umbrella, wearing long-sleeved clothes, or using sunscreen.[9–11] In many Asian and Middle Eastern countries, cultural and religious practices highly influence daily exposure to sunlight.[10,12] Sun-seeking behaviour is uncommon in tropical Asian populations due to the warm climate most of the year and the cultural perception that fair skin is associated with beauty.[13,14] Furthermore, due to increasing concern about sun exposure and skin cancer,[15] people avoid it or use sun protection.

Foods rich in vitamin D become the potential source to fulfil the requirement of vitamin D. There are only a few good natural dietary sources of vitamin D. The main food groups contributing to vitamin D intake are typically fish, egg yolk, cheese, and mushrooms. Among these, fish has the highest vitamin D content and is the major natural food source of vitamin D in many populations. Compared to the other Association of Southeast Asian Nations (ASEAN) countries in 2013, the fish consumption of Indonesia's populations (31.8 kg/cap/year) is lower than Myanmar (60.7 kg/cap/year), Malaysia (54.0 kg/cap/year), Brunei (47.0 kg/cap/year), Singapore (46.9 kg/cap/year), Cambodia (41.4 kg/cap/year), and Vietnam (34.8 kg/cap/year).[16] The low fish consumption among the general Indonesian population compared with the other ASEAN countries may contribute to the inadequate vitamin D intake among most Indonesian pregnant women (64.3%).[17]

Indonesian Ministry of Maritime Affairs and Fisheries has carried out a movement called "GEMARIKAN" (Gerakan Memasyarakatkan Makan Ikan or Movement to Promote Eating Fish) to promote the health benefits and encourage fish consumption.[18] Ensuring the availability of specific food sources like fish is crucial and depends on how the market functions locally. Like other commercial commodities, fish needs to be transported from landing sites to places where it can be sold or utilized by consumers. Previous studies in Tanzania examined the consumption of animal source foods by comparing the two regions, Morogoro and Dodoma. The Morogoro region, which is closer to the ocean and has better market access, reported higher fish consumption and was nearly twice as likely to consume fish compared to Dodoma region.[19]

East Lombok District is one of the districts in Lombok Island, West Nusa Tenggara Province, Indonesia. The geographical location of East Lombok District, which is adjacent to the Java Sea, Alas Strait, and Hindia Ocean, provides a remarkable abundance of fishery resources. Apart from being surrounded by a large sea area, East Lombok District also has some areas that are geographically close to Mount Rinjani, introducing a challenge in the distribution of fish products. Fish is one of the most perishable foods and can easily be spoiled if not properly preserved.[20] In rural mountainous areas where infrastructure is poor, some nutritious foods that are perishable are unlikely to be traded in markets and might be unavailable in its fresh form. One study examined the geographical factors influencing route choice of fish distribution, reported that the choice of destination by fish traders is strongly influenced by route distance and transport costs, with shorter distances minimizing costs and allowing for efficient operations.[21] Previous studies in mountainous and coastal area in Indonesia found that average amount of fish consumption among toddlers in coastal areas is significantly higher compared to those in mountainous areas.[22]

Linear Programming has been widely used to develop FBRs targeting pregnant women. WHO Optifood software allows users to identify population-specific dietary nutrient gaps and develop food-based recommendations based on locally available foods, which were in line with existing dietary patterns and economic accessibility.[23] Previous study using LP approach found out that the typical problem nutrients among pregnant women in 10 high-stunting districts in Indonesia were iron, folate, and calcium.[24] However, most previous studies did not include vitamin D in the analysis.[24–27] Sunlight has been the primary source of vitamin D, as it enables natural synthesis in the skin.[28] However, factors such as cultural and religious practices, clothing choices, and sun-avoidance behaviours in many Asian and Middle Eastern countries have significantly reduced sun exposure.[9–11] As a result, dietary sources of vitamin D have become increasingly important in meeting vitamin D requirements.

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Therefore, this study aims to map the availability of vitamin D-rich fish, identify the dietary patterns, and develop food-based recommendations (FBRs) to promote an adequate vitamin D intake among pregnant women in East Lombok, Indonesia.

Methods

Setting

This comparative cross-sectional study is part of an observational cohort study entitled "UKRI–GCRF Action Against Stunting Hub (AASH)" study. The AASH study aims to explore the causes and typologies of stunting through a whole-child approach, considering various aspects such as epigenetics, genetics, gastrointestinal health, childcare, nutrition, and education from pregnancy until the child is aged 2-years. This study is expected to enrich the AASH study, especially on knowledge and practices to improve diet during pregnancy.

The study was conducted among pregnant women in the East Lombok District of West Nusa Tenggara Province, Indonesia. East Lombok was chosen as it is among the districts with the high stunting rates in the country. Despite West Nusa Tenggara being a province with high fish production, fish consumption remains low. In 2022, the fish supply was 216.9 kg per capita per year, while consumption was only 40.9 kg per capita per year.[29–31] This discrepancy highlights the need to study fish availability and its preferences in the community.

The recruitment of the subject was started in February 2021 and completed by the end of September 2021. Data collection for pregnant women in third trimester was conducted between June 2021 to January 2022. The mapping of vitamin D-rich fish was conducted in December 2023.

Study Participants

The study population was pregnant women in four subdistricts of East Lombok, Indonesia: Aikmel, Lenek, Sikur, and Sakra. The list of pregnant women was obtained from the Polindes (village health post). Based on this list enumerators, accompanied by the village health cadres, visited each household, invited pregnant mothers to participate in the study, and obtained their written informed consent. Eligible participants were pregnant women that met all the inclusion criteria, which were 18-40 years old, gestational age 32-36 weeks, singleton pregnancy, from the Sasak ethnic group (origin of Lombok Island), and stated their willingness to participate by signing the written informed consent. Subjects of this study were excluded if they have chronic diseases or participate in another community-based intervention, including those receiving egg intervention in the main AASH study. A total of 435 pregnant women were included in the study.

Fish Availability Mapping

This procedure referred to the systematic process of quantifying and categorizing the presence of fish naturally rich in vitamin D within a specific geographic region. The process aimed to identify various fish that contributed to vitamin D intake. The operational steps included: (1) **Food Source Identification**: identification of fish that were considered rich sources of vitamin D. Fish were classified as rich in vitamin D if the content was ≥4µg/100 gr weight (Supplement 1). Out of thirty-five fish identified in the 25 village markets in the study area, thirty fish were identified to have vitamin D of at least 1µg /100 gr weight. These vitamin D rich fish were given a weight based on the vitamin D contents, i.e., scores of 3, 2 and 1 were assigned for fish with vitamin D content of ≥10µg/100 gr weight ≥5µg and <10µg /100 gr weight, 1-5µg /100 gr weight, respectively. (2) **Market Identification**: Twenty-five village markets in the study area (Sakra, Sikur, Aikmel, and Lenek Subdistrict) were identified through the list from Trade Office of West Nusa Tenggara Province. The 24-hr dietary recall data collection was spread over the period of six months from June 2021 until January 2022, which covers seasonal changes in both wet and dry seasons. The market survey was conducted in December 2023, and based on information from fish sellers, fish catch was stable throughout the year, with monthly fluctuation between tidal variations. (3) **Market Categorization**: categorized the markets based on the types of fish and the number of fish sellers in the markets. The score of each type of fish was multiplied by the number of fish sellers in the market. The total score was divided into four quartiles, and subsequently the market was categorized into two: first quartile as low (LD) and fourth quartile as high (HD) availability of vitamin D rich fish markets. The markets in the second and third quartile were excluded to ensure distinct comparison of LD and HD markets; nevertheless 73% of the subjects were within 2.4km buffer zone to either LD or HD markets. Quartiles were used to classify availability zones because it provides a simple, data-driven approach that ensures balanced group sizes, especially when sample sizes are limited. Alternative methods using regression based on proximity to the markets location was also tested and resulted in similar results with the quartile-based classification. (4) **Geospatial Data Collection**: recording the geographic coordinates of local markets in the four subdistricts of the study area. The geographic coordinates of respondents' residential areas were obtained from the AASH study.

(5) **Geospatial Analysis**: This step involved using Quantum Geographic Information System (QGIS) software to create buffer zones within 2.4 km of the market and identify each of the respondents' homes that fell into this buffer area. The cut-off of the buffer zones was adopted from other study conducted in North Carolina since this study also measure the food store environment (food availability and accessibility) among low-income women.[32] Respondents who fell into one or more buffer zones of "high availability of vitamin D-rich fish markets" were categorized as residing in "high availability vitamin D-rich fish areas". Respondents who fell into one or more buffer zones of "low availability of vitamin D-rich fish markets" were categorized as residing in "low availability vitamin D-rich fish areas". Respondents who fell into buffer zones of "low availability of vitamin D-rich fish markets" and "high availability of vitamin D-rich fish markets" were categorized as residing in "high availability vitamin D-rich fish areas". Respondents who did not fall into any buffer zone of any market were categorized as residing in "low availability vitamin D-rich fish areas". Spearman correlation analysis showed a weak but statistically significant positive correlation between respondents' proximity to markets and fish availability area based on the quartile's classification ($r=0.121$, $p=0.012$).

Structured questionnaire

The study's background characteristics questionnaires (i.e., age, education level, employment status, and household wealth index) were standard questionnaires used in national surveys in Indonesia, including the Indonesian Basic Health Survey (RISKESDAS), the National Socioeconomic Survey (SUSENAS), and an earlier cohort study conducted in East Java, Indonesia.[33] The food taboo questionnaire was modified from Tela et al.[34] A list of food taboos unique to pregnancy in the Lombok setting was included after this version was piloted in the local community for additional improvement. Enumerators who collected data were Lombok natives who spoke both Indonesian and Sasak and were familiar with the research population's cultural background. This ensured clear communication and proper delivery of questionnaire items.

Wealth index calculation

The household wealth index was calculated utilizing a variety of characteristics, including dwelling amenities, household assets, and mode of transportation. Each household item or asset was assigned a value of "1" if it was owned and "0" otherwise. These values were then multiplied by dataset-derived component score coefficients. The resulting scores for each variable were added together to calculate the overall household wealth index score, which was then divided into three equal groups (terciles): low, middle, and rich. The computation was performed using the principal component analysis (PCA) approach, as specified in the 2017 Indonesia Demographic and Health Survey (DHS) Program guidelines.[35]

Anthropometric Assessment

Mid-Upper Arm-Circumference (MUAC) was used to determine the nutritional status of pregnant women. The measurements were performed in accordance with standard procedures on the left upper arm of participants (if they were right-handed or vice versa), at a point halfway between the acromion and olecranon processes, to the nearest 0.1 cm using flexible and non-stretchable measuring tapes. Pregnant women were considering undernourished/chronic energy deficiency (CED) if their MUAC value was lower than 23.5 cm. The village health post was informed if pregnant women had chronic energy deficiency (CED), and they received basic antenatal care according to the health system guidelines for women with CED.

Dietary Assessment

The enumerators conducting anthropometric and dietary assessments were nutrition graduates. Training was provided before data collection, including a pilot study with evaluation and key takeaways to improve data collection techniques.

The dietary assessment was conducted via an electronic questionnaire using a four-pass 24-hour dietary recall (24-HR) to minimize bias.[36] On the first pass, each pregnant woman is asked to mention all the foods and drinks they consumed the day before. Regarding the fish consumption, respondents were asked to specify the type of fish consumed, including species known to be rich in vitamin D (e.g., sardines, mackerel, anchovy, tuna). This differentiation allowed for a more precise estimation of dietary vitamin D intake. The second pass captures data on consumption time, food and drink details (ingredients, cooking method, and brand name), and additional items or condiments for each food and drink listed (for instance, sugar added to beverages). In the third pass, portion sizes were estimated by weighing a certain amount of real food (Tanita digital scale for kitchen use, model KD-160, precision ± 1 g; Tanita Corporation), using water or kinetic sand conversion, utilizing food models or photographs, or counting the standard units consumed. On the fourth pass, the interviewer assessed the completeness of the dietary data and inquired whether the previous day’s diet was typical and, if not, how it deviated from the usual. To ensure that all interviewers follow the same approach for determining dietary portion size, a standardized guidebook has been established.

Food Composition Table

Food nutrient values were obtained from the Indonesian Food Composition Table (FCT) (www.panganku.org).[37] Folate, vitamin B6, vitamin B12, and vitamin D contents, that were not available in the Indonesian FCT, were borrowed from neighbour countries, i.e. (in priority order

1). Other Southeast Asia (SEA) FCTs e.g. Vietnam or Thailand

2). Other Asian countries e.g. Japan or Korea[38]

3). United States Department of Agriculture Food Composition Table (https://fdc.nal.usda.gov/)[39]

Borrowed values from other country FCTs were adjusted using water adjustment, yield factor, and retention factors, as appropriate following INFOODS guideline.[40,41]

Data Analysis

Socioeconomic characteristics and dietary data were analysed in IBM SPSS version 20. Prior data analysis, the dietary data underwent a cleaning process to ensure accuracy and consistency. Outlier detection was performed for portion sizes of food items. Unusually large portions that resulted in very high energy intake were revised after comparing them with dietary records in hard copy. After that, energy under- and over-reporting were checked by evaluating the ratio of reported energy intake to basal metabolic rate (EI/BMR). Participants with extreme total energy intake values (e.g., below 500 kcal/day or above 4000 kcal/day) were reviewed and excluded if considered implausible.

The energy requirements were derived from the Recommended Nutrient Intake (RNI) values for Indonesian women aged 19–29 years (body weight: 55 kg), which was 2,250 kcal. For women in their third trimester of pregnancy, the energy requirement increased by 300 kcal, resulting in a total of 2,550 kcal. The mean body weight of pregnant women in this study was similar, during recruitment and in their third trimester, the weight was 54.5±10.2 kg and 61.6±10.0 kg, with light to sedentary physical activity.

The normality test using Kolmogorov-Smirnov was performed for all continuous variables. Median and quartile (Q1-Q3) were used to display the descriptive statistic. The cleaned dietary data were then used in subsequent statistical analyses to compare the median values of

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the two groups with significance value $p<0.050$ using Whitney test. Categorical variables were compared between high- and low-availability vitamin D-rich fish areas using the Chi-square test/Fisher Exact test.

Preparation of Linear Programming Model Parameters

The LP model parameters were prepared in Microsoft Excel 365. These parameters included a list of foods consumed by the subjects, an average serving size of each food, and the weekly frequency of food consumption. The weekly frequency was estimated from the percentage of consumers for each food item, food group, and food subgroup (from a one-day 24-hour dietary recall).[42]

The 24-HR data collection was spread over the period of six months from June 2021 until January 2022, which covers seasonal changes in both wet and dry seasons. The visit was conducted across all days of the week, incorporating weekdays and weekends (the distribution was 75% data captured on weekdays and 25% on weekends.) The LP analysis used estimates from the 1-day dietary data to determine the weekly consumption frequency based on the percentage of consumers for each food item, food group, and food sub-group.[42] Foods that were commonly consumed, such as rice, which was consumed by 100% of respondents (falling into the category of 68–100% of subjects who consumed the food), had a maximum estimated weekly intake frequency of 7 days per week. In contrast, mackerel tuna was consumed by 12% of respondents, placing it in the 6–12% category, and its maximum estimated weekly intake frequency was 2 days per week. These estimates help utilize the 1-day data to capture the weekly patterns of the population.

These LP parameters were used to set up the LP models for the analysis in the WHO Optifood software V4.0.14.0. Food items were categorized into the food groups and subgroups used in Optifood. Fourteen nutrients were analysed in Optifood: protein, fat, calcium, iron, zinc, vitamin C, thiamine, riboflavin, niacin, vitamin B6, folate, vitamin B12, vitamin A, and vitamin D.

Development of Food-based Recommendations

The analysis was performed in three iterative modules to generate FBRs for pregnant women. The first module (Check diet) aimed to verify whether the solution is feasible to develop realistic diet models within the actual dietary patterns. The target group's dietary data (portion and frequency) could only be modified in this module and will be locked in the next module.[42]

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Module II (Draft recommendation) identified the two best diets for achieving nutrient goals. The two best diets consist of one best diet within the population's average food pattern (FP) and one best diet with a more extensive range of food patterns, which may deviate from average intake but still within the upper and lower range which has been inputted in Optifood, called no food pattern (No FP). Both diets come as close as possible to meeting recommended nutrient intakes.[(43)] Problem nutrients and nutrient-dense food items, food subgroups, and food groups were identified through this module to help design alternative sets of FBRs.[(42)]

In Module III (Test recommendation), the diets that had the lowest (nutrient content minimised to identify the worst-case scenario) and the highest (nutrient content maximised to identify the best-case scenario) %RNI were generated without any recommendation to provide baseline levels for comparison. The nutrients that did not achieve 100%RNI in the 2-best diets (FP and No FP) were defined as ‘problem nutrients’, and those that did not achieve 100%RNI in the best-case scenario (module III without any recommendation) were defined as absolute problem nutrient. While partial problem nutrient is a nutrient that can achieve 100%RNI in the base-case scenario.

Alternative sets of FBRs were compared in terms of the accomplishment of a nutritionally adequate diet. A set of FBRs that have the highest %RNI worst-case scenario for protein, fat, calcium, iron, zinc, vitamin C, thiamin, riboflavin, niacin, vitamin B6, folate, vitamin B12, vitamin A RE, vitamin A RAE, and vitamin D will be selected as the final set of FBRs.

The validity of the Optifood analysis was determined by its reference data, which are the FCT and RNI for energy and 14 nutrients.[(43)] The default nutrients included in Optifood analysis are protein, fat, calcium, iron, zinc, vitamin C, thiamin, riboflavin, niacin, vitamin B6, folate, vitamin B12, vitamin A RE, and vitamin A RAE. This study includes vitamin D in the analysis to develop food-based recommendations.

Ethical Approval

Ethical clearances were obtained from Ethical Review Committee, Faculty of Medicine, Universitas Indonesia – Dr. Cipto Mangunkusumo General Hospital (FMUI-RSCM) (Reference Number: ND-914/UN2.F1/ETIK/PPM.00.02/2021) and the Ethical Review Committee, Faculty of Medicine, Universitas Mataram (Reference Number: 221/UN18.F7/ETIK/2022).

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Results

Fish availability mapping

A total of 25 markets in the AASH study area were surveyed to determine the geographic coordinates and fish availability in the markets of the study area. There are 39 villages in the study area, three villages were excluded due to the market identified in that area were in the middle category (not high or low availability of vitamin D-rich fish). Twenty villages were categorized as high-availability vitamin D-rich fish (HD) areas with the median (Q1-Q3) market score was 24 (16-37), and sixteen villages were categorized as low-availability vitamin D-rich fish (LD) areas with the median (Q1-Q3) market score was 3 (0-3). HD areas were shown in blue, and LD areas were shown in red (Figure 1).

A total of 435 pregnant women were included in the study. There were statistically significant differences regarding the median age of pregnant women, Household Wealth Index (HWI), and food taboo between the two groups. The median age of the HD and LD groups subjects were 29(23.5-34) and 27(22-32), respectively. Almost half of the pregnant women in the HD group (43.3%) were in the 'Middle' wealth index, while almost half of the pregnant women in the LD group (43.6%) were in the 'Rich' wealth index (see Table 1).

Most pregnant women (66.7%) any reported food taboos during their pregnancy, with 15.2% reported taboo for fish during pregnancy. Food taboos are cultural restrictions on consuming specific, even nutritious foods due to beliefs (often misconceptions) about how specific foods may harm their pregnancy, which is often transmitted down the generations and becomes normative in the community.[34,44] Food taboos were more commonly reported in the LD group than in the HD group (p=0.025). However, the kind of food being avoided did not differ between the two groups.

Most of the subjects were not working (74.3%) and had educational levels in high school and above (51.3%). There were no significant differences in educational level and working status between pregnant women in the HD and LD groups (p>0.05). This current study found that the prevalence of CED was 14.7%. The prevalence of CED in the LD group (15.5%) was slightly higher than in the HD group (13.9%) (p=0.643).

Energy and Nutrient Intake

The average daily energy intake among participants was 1854 ± 499 kcal/day (See Table 2). The mean ratio of reported EI/BMR was 1.26 ± 0.37. Based on EI/BMR classification, 85.51% of respondents had a plausible energy intake (EI/BMR between 0.91 and 2.49).

There were several differences in actual nutrient intake between pregnant women in the HD and LD groups. Compared with pregnant women in HD group, pregnant women in LD group have significantly higher median intake of energy, carbohydrate, calcium, iron, zinc, thiamine, riboflavin, niacin, folate, and vitamin A ($p<0.05$).

Regression analysis revealed that there was no significant association between the respondent's proximity to the market and their vitamin D intakes ($\beta=0.000$, $p=0.389$). These results indicate that fish availability alone may not fully explain vitamin D intake patterns, and other factors, such as dietary preferences and alternative food choices, may contribute.

Food Patterns

Including nutrient-dense food and food consumed by ≥5% of the population, 138 and 140 food items were identified among pregnant women in the HD and LD groups, respectively. Combining food items from the two groups resulted in 163 food items, which consist of 16 food groups and 45 food subgroups. Table 3 shows the weekly frequency of food groups and subgroups consumption patterns.

On average, grains and grain products, vegetables, and miscellaneous were the most common food groups consumed in both groups (Median: 21, 6, and 6 times per week). Detailed analysis at the level of food items, white rice, fried tempeh, and *sambal terasi* (shrimp paste chili sauce) were the most common foods consumed by subjects. This was the typical food pattern of the Indonesian population.[45]

Based on the respondents' group, there were several significant differences in the weekly frequency of food group and food subgroup consumption between pregnant women in the HD and LD groups. Pregnant women in the HD group consumed higher miscellaneous food groups (Median: 10 and 5 times per week in HD and LD groups, respectively; $p<0.001$). The food items added during cooking or at the table as a seasoning were grouped as miscellaneous food groups, consisting of condiments, herbs, spices, savory, and sweet sauces. The most common miscellaneous consumed by the subjects were *sambal terasi* and *sambal bawang* (shallot chili sauce), with a participation rate of 48% and 42%, respectively, in the HD group and 38% and 36%, respectively, in the LD group.

In terms of animal-source food (ASF) consumption, the median times consumed per week were similar (5 times per week). However, pregnant women in the HD group have a higher maximum frequency of weekly ASF consumption (95^{th} percentile: 13 and 11 times per week in the HD and LD group, respectively; p=0014). The median time consumed was the average pattern of the population. The 95th percentile represents the group's upper food pattern; it could be mentioned as a positive deviant version.

The higher 95th percentile of animal food sources consumed by the pregnant women in the HD group could be due to the more specific food sources available in the HD group than in the LD group. Detailed analysis of food subgroups showed that the weekly frequency of eggs and fish without bones consumption were significantly different (95th percentile: 10 and 5 times per week in HD and LD group, respectively; $p = 0.023$ for eggs; 4 and 6 times per week in HD and LD group, respectively; $p=0.044$ for fish without bones).

Pregnant women in the LD group tend to consume higher portions of added fats, fruits, grains, and grain products, eggs, miscellaneous, savory snacks, and vegetables ($p<0.05$) (Table 4). Regarding fruit consumption, the median portion in the two groups was similar (100 grams). However, the 5th and 95th percentiles were higher in the LD group than in the HD group. Comparable to egg consumption, the median portion was similar (60 grams). However, the 5th percentile was higher in the LD group compared to the HD group (Table 4).

Problem Nutrients and Food-based Recommendations

The two best diets formulated in module II showed that problem nutrients among pregnant women in the HD group were calcium, folate, vitamin D, and iron. Those four nutrients were absolute problem nutrients as they fell below 100% RNI in the best-case scenario diet without FBRs (see Table 5). Meanwhile, vitamin C, vitamin B12, and vitamin A were characterized as dietary inadequacy, given that they cannot achieve 65% of RNI in the worst-case scenario without FBRs.

Nearly identical, the identified problem nutrients among pregnant women in the LD group were folate, vitamin D, and iron. All problem nutrients were absolute problem nutrients, except for iron, which was classified as partial problem nutrients (see Table 5). Meanwhile, calcium, vitamin C, vitamin B1, vitamin B12, and vitamin A were characterized as dietary inadequacy.

The potential nutrient-dense food subgroups that could be promoted to achieve dietary adequacy were unfortified refined grains and products, soybeans and products, organ meat, fortified special biscuits, fortified fluid or powdered milk, fish without bones, vitamin A source dark green leafy vegetables, and savoury spreads & sauces. Tempeh, moringa leaves, fortified biscuits, fortified powder milk, and fresh skipjack tuna fish were identified as potential nutrient-dense food sources. These food subgroups and food items were used either separately or combined with other foods to establish the optimized FBRs alternatives in

Module III.

In Module III, 26 sets of FBRs were produced for pregnant women in the HD group, and 41 sets of FBRs were produced for pregnant women in the LD group (Supplement 2). Among those alternative FBRs, three sets of FBRs for pregnant women in the HD group and five sets of FBRs for pregnant women in the LD group were presented in Table 5. Using the LP approach, the final FBRs could achieve the recommended intake of calcium, vitamin B1, B2, B3, B6, B12, vitamin A, iron, and zinc for pregnant women in the HD group. While for pregnant women in the LD group, the final FBRs could achieve the recommended intake of vitamin B1, B2, B3, B6, B12, folate, vitamin A, iron, and zinc. However, the optimized FBRs could not achieve ≥65% RNI of vitamin C, vitamin D, and folate in the HD group, and vitamin C, vitamin D, and calcium in the LD group.

Discussion

This study was the first to map the availability of vitamin D-rich fish and analyse the different dietary patterns among pregnant women in different areas. Despite the difference in availability, we found in both groups very low vitamin D intake. Our finding highlighted the importance of specifying the vitamin D rich fish in nutrition messages to meet vitamin D adequacy in pregnant women.

In this study, the study area was categorized as having high or low availability of vitamin D-rich fish based on market survey data rather than simple geographic proximity to coastal areas. Our market data indicated significant variation in the actual availability of marine fish species high in vitamin D. This classification is further supported by our diet modelling results, which recommend sea fish consumption in high-availability areas (nearby HD markets) and freshwater fish in low-availability areas (nearby LD markets).

A study among pregnant women in mountainous and coastal populations in southern China reported that vegetables formed the main part of the diet of pregnant women in mountain areas, whilst pregnant women in coastal areas more frequently consumed food derived from animals, especially seafood and fish.[46] These findings are similar to our population, where vegetables were the main part of the diet (median weekly consumption 5x and 6x in LD and HD groups, respectively). Despite living in an island surrounded by the sea, in our study fish was only consumed by 15% and 12% of the pregnant women in LD and HD respectively), with the maximum weekly frequency of fish consumption 6x and 4x in LD and HD groups, respectively.

In terms of vitamin D intake, in addition to the very low median intake of vitamin D (1.49 µg), there was no significant difference in vitamin D intake between pregnant women in the HD and LD groups. This result suggests that simply having greater market availability of vitamin D-rich fish does not necessarily translate into higher consumption. This result was in line with a systematic review that found that availability alone was not a key determinant of dietary intake.[(47)] One possible explanation is that fish consumption is influenced by affordability and personal dietary preferences rather than mere availability. Even in high-availability areas, socioeconomic factors may limit access to fish. A study conducted in New South Wales, Australia, explores pregnant women's perceptions of consuming fish and seafood during pregnancy. It was found that fish, particularly fresh fish, was perceived as being expensive and this was a barrier to more frequent consumption.[(48)] In our study, the food environment analysis in the same population (will be published elsewhere) examined the constraints to afford fish. According to the food environment questionnaire administered to mothers of children aged 18–24 months (n=300), the most common barriers to obtaining sea fish were availability (41% of respondents), affordability (22%), and hygiene concerns (14%).

In the study area, the potential confounding factor was the presence of mobile vendors, who helped distribute vitamin D-rich fish to respondents living far from the markets with high fish availability. This suggests that mobile vendors can contribute to increasing access to fish, making them an important potential confounding factor in the study.

Our analysis showed that consumption of fish without bones as major vitamin D food sources, was higher in the LD group. This result was contrary to the initial hypothesis that expected fish without bones consumption would be higher among pregnant women in the HD group. The result of this study was also contrary to the study among pregnant women in West Sumatra, which reported that maternal vitamin D intake was associated with place of residence. Those women who lived in areas with limited fish as a common vitamin D food source had less adequate vitamin D intake than those who lived in areas with abundant fish.[(49)] However, that study did not use any method to assess the availability of fish and only divide the place of residence based on the altitudes of the area, i.e., area with altitudes of 0-15 m above sea level was identified as area with abundant fish.

The mean energy intake in this study was 1854 ± 499 kcal/d. The ratio of reported EI/BMR was 1.26 ± 0.37 (mean ± standard deviation). Underreporting (EI/BMR < 0.9) was observed in 14.0% of respondents. The findings from our study were comparable to previous research among pregnant women in Indonesia reported by Winkvist et al in which 17.6% of pregnant women in 3rd trimester had underreported energy intake, which is a common challenge in dietary assessment studies.[50] The mean energy intake in these studies was slightly higher at 1968 ± 484 kcal/day,[51] with a higher EI/BMR ratio of 1.52 ± 0.40. Generally, the percentage of underreporting in pregnant women was about 16-45% according to the available literature, depending on the population and assessment method.[52,53]

The inadequate intake of energy and nutrients among pregnant women in this study may be influenced by cultural food restrictions, limited nutritional knowledge, and economic constraints, which are known barriers to achieving adequate dietary intake during pregnancy. This aligns with findings from a meta-analysis, which reported that the intake of energy, macronutrients, calcium, iron, vitamin C, and vitamin D among Indonesian pregnant women did not meet national recommendations.[54] The existence of food taboos among pregnant women regarding certain foods may hinder the consumption of these foods and increase the risk of inadequate nutrients intake.[55–57] It was believed that these foods caused complications and difficulties during delivery.[58]

Results showed that if optimised, modelled diets could improve the intakes of problem nutrients from about 3-5% RNI (nonoptimized diets) to 40-50% RNI, or about 10-fold increase, by including local sea fish and small fish with bones. The observed vitamin D nutrient gap was lower among pregnant women in the HD group compared to pregnant women in the LD group (12.9% RNI in the HD group and 20.5% RNI in the LD group). This could explain why, when modelled diets were optimised, the HD group could consume more vitamin D-rich foods compared to the LD group. Nevertheless, diet modelling can help to identify vitamin D-rich fish and other nutritious foods to promote in FBRs to increase vitamin D intake. The FBRs from this study provide specific messages that help clarify and enhance the balanced food guidelines issued by the Ministry of Health in Indonesia.

The developed FBRs in HD and LD group differ in recommendation of fish and other animal-source foods. In the HD group, the consumption of animal-source foods was more varied. The final FBRs for pregnant women in the HD group recommend consuming four servings/week of fish. The recommendations included two servings/week of mackerel tuna fish and one serving/week of bali sardinella fish. The final FBRs for pregnant women in the LD group recommend consuming six servings/week of fish, including two servings/per week of mackerel tuna fish and one serving/per week of tilapia fish. Bali sardinella fish is a seawater fish that is highly available in the markets in the HD group, while tilapia fish is a

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freshwater fish that is highly available in the LD group area. The vitamin D content in mackerel tuna, bali sardinella, and tilapia fish is 18.27, 7.63, and 8.43 µg per 100 weights of fish, and the addition of recommendation of fish in the FBR, increase the achievement of vitamin D RNI into 33.3% and 30.1% in HD and LD group respectively.

Comparatively, the study of FBR development for the general population in the Netherlands generated four scenarios to optimize vitamin D intake. The linear modelling program Optimeal® 2.0 (Blonk Consultants, Gouda, the Netherlands) was used to model scenarios of dietary shifts in that study. The modelling relied on vitamin D-fortified bread, milk, and oil, along with increases in fish consumption. Its baseline diet consists of 3 µg/d of vitamin D per 2000 kcal or 21% of RNI. With the actual dietary pattern, achieving 13.4 µg/d of vitamin D was not possible unless the calorie consumption was increased two-fold. The author stated that it is impossible to obtain adequate vitamin D unless more vitamin D-fortified foods are a necessary part of the diet. The modelling shows that the addition of fish increased vitamin D by 22-fold from baseline, whereas inclusion of fortified bread and breakfast cereals increased vitamin D by 170-fold.[59] This was similar to our findings, with the baseline median vitamin D intake of 1.49 µg/d or 10% of RNI, the diet modelling with fish can only meet half of the RNI, which are 52.1% and 44.5%RNI in HD and LD groups, respectively.

While our mapping categorized markets based on availability of vitamin D rich fish, it is also important to note that fish especially small fish with bone is rich in calcium. Our LP analysis suggest that HD group had better improvement in meeting dietary adequacy as compared to LD group. Calcium was initially a problem nutrient in HD group but became dietary adequate in the optimized FBR (minimised %RNI was above 65% i.e. 70.4%). On the other hand, calcium was dietary inadequacy in LD group and remained inadequate in the optimized FBR (minimised %RNI was still below 65% i.e. 62.5%). By promoting more consumption of fish in the optimized FBRs, %RNI in the minimised scenario increased i.e. from 46.3% to 70.4% in HD; and from 44.3% to 62.5% in LD. Previous study (Knight, et al., 2023) used WHO Optifood to assess whether local foods including small fish could meet calcium intake among nonpregnant and non-breastfeeding women of reproductive age in Uganda, Bangladesh, and Guatemala. The final sets of FBRs can achieve 47.7%-143.5% of calcium population reference intakes in the Module III minimized calcium diets.[60]

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Small fish with bones tend to be more frequently consumed in HD group but with a smaller portion than LD group. This was due to varied animal-source foods being available in the HD area compared to the LD area. While the area of this study is not in extreme mountainous and coastal areas, the high availability of fish also indicates a good distribution of other protein food sources. Dried anchovy is one of the food items in the small, whole fish, with bones food subgroup that was identified as calcium-dense food in this population. Dried anchovy was highly available in the two-group areas; however, the median portion size of this food was higher among pregnant women in the LD group. Based on the results of Trials of Improved Practices, which was conducted as part of this study to assess food preferences, dried anchovy was perceived as an 'inferior' animal-source food compared to fresh fish, chicken, beef, and eggs. This perception was primarily influenced by food preference, where dried anchovy was a less desirable option despite its affordability and nutritional value. Our findings suggest that high fish availability doesn't always lead to high consumption.

Despite improvement of vitamin D intakes in the optimized FBRs, the gaps in problem nutrients remain i.e., 12.9% in HD, 20.5% in LD. Development of nutrient-dense food, such as chili sauce mixed with fish, fish balls, or fish crackers, could be an option to improve vitamin D intake in the population. These nutrient gaps for vitamin D correspond to intakes of multiple micronutrient supplements (containing 33.3% RNI for vitamin D) of 3 days/week and 5 days/week for HD and LD groups, respectively. Policymakers should consider these strategies in combination with food-based approaches to ensure adequate nutrient coverage.

To the best of our knowledge, this is the first study to develop fish availability mapping using geospatial analysis and develop FBRs to promote adequate vitamin D intake among pregnant women. The development of fish availability mapping ensures that the developed FBRs are in line with food availability and would not require drastic changes to acquire the food items.

Some limitations were identified in this study. First, the Geographic Information System (GIS) mapping, while assessing the distance between respondents' houses to the markets, did not take into account the geographic features which may affect access to markets.

Second, the socioeconomic differences between the two groups, could introduce potential bias or confounding. Households with higher socioeconomic status may have greater access to diverse and nutrient-rich foods. Studies found that energy and protein intakes among pregnant women decreased along with decreasing economic quintiles.[61]

This study focuses on food availability and food intake but does not account for economic access to food. As a result, factors such as food affordability and financial constraints that may influence food choices and consumption patterns were not considered. This limitation may affect the comprehensiveness of the findings, as economic access plays a crucial role in determining dietary intake.

The absence of mobile vendors in the analysis of this study also becomes one of its limitations. Mobile vendors were identified as one of the ways to acquire food among populations. However, due to the logistical challenges of tracking mobile vendors, their influence on food availability was not included in the initial design. Their exclusion may have led to an underestimation of vitamin D-rich fish availability, particularly in more remote areas. Moreover, nonmarket-based food sources were also found to be important in some settings in low-middle-income countries, which is not analysed in this current study.

In conclusion, in both high- and low-availability fish area vitamin D was inadequate in the diet of pregnant women and was identified as problem nutrient. While both groups' FBRs ensure adequacy of iron, zinc, vitamins A, B1, B2, B3, B6, and B12, calcium remain as dietary inadequacy in the LD group, suggesting that availability play a role in ensuring dietary adequacy. Future studies to develop nutrient-dense recipes, explore the best-practice of vitamin D supplementation among pregnant women, as well as explore new methods for fish availability mapping, which consider non-static position of market (mobile vendor), are recommended. Future studies can also incorporate economic factors to provide a more holistic understanding of the relationship between food availability, accessibility and consumption.

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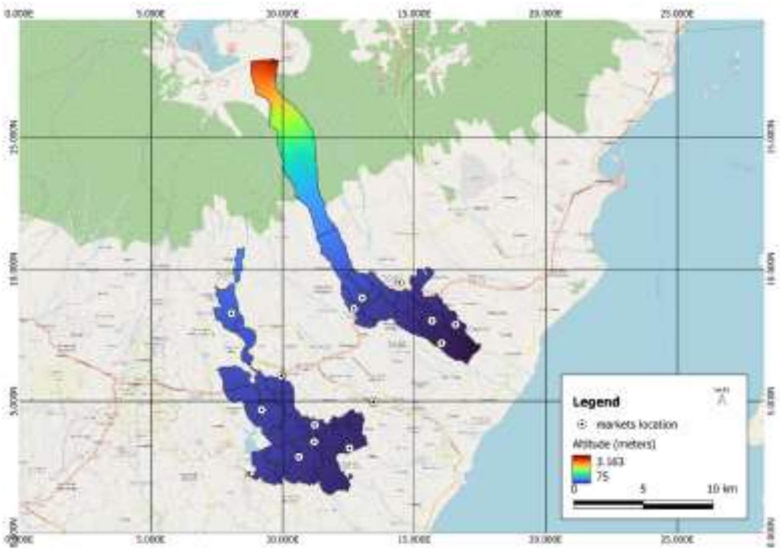

Figure 1. Geographic map of study area

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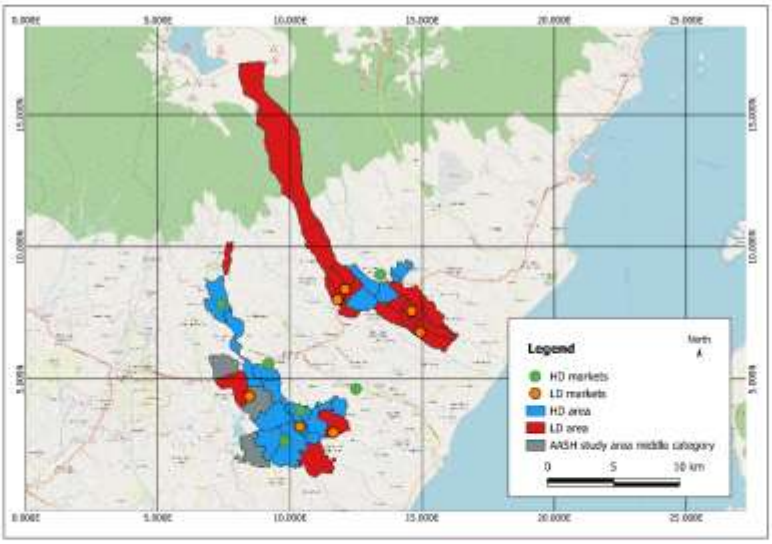

Figure 2. Fish availability mapping of high and low availability vitamin D-rich fish

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Table 1. Socio-demographic characteristics and nutritional status of pregnant women in high and low availability vitamin D-rich fish areas

Variables	HD Group (n=233)	LD Group (n=202)	Total (n=435)	p-value[a]
	Median (Q1-Q3)			
Age	29 (23.5-34)	27 (22-32)	28(23-33)	0.013[c]
Educational level				
Junior high and below	112(48.1)	100(49.5)	212(48.7)	0.765
High school and above	121(51.9)	102(50.5)	223(51.3)	
Mothers' working status				
Working	64(27.5)	48(23.8)	112(25.7)	0.378
Not working	169(72.5)	154(76.2)	323(74.3)	
Household Wealth Index[b]				
Poor	72(30.9)	71(35.1)	143(32.9)	<0.001[d]
Middle	101(43.3)	43(21.3)	144(33.1)	
Rich	60(25.8)	88(43.6)	148(34.0)	
Food taboos[f]				
Any taboo	143(61.3)	147(72.7)	290(66.7)	0.025[d]
Fruits taboo	105(45.1)	109(53.9)	214(49.2)	0.100[d]
Seafood taboo	94(40.3)	96(47.5)	190(43.7)	0.187[d]
Meat & poultry taboo	3(1.3)	4(1.9)	7(1.6)	0.711[e]
Nutritional status[g]				
Chronic energy deficiency	32(13.9)	31(15.5)	63(14.7)	0.643[d]

Abbreviation: HD, High Availability of Vitamin D Rich Fish Area; LD, Low Availability of Vitamin D Rich Fish Area

[a]Significance was tested for median rank differences between respondents in high and low availability vitamin D rich fish area

[b]Household Wealth Index was divided into tertile, Poor is the lowest income, Middle is the middle income, and Rich is the highest income

[c]Significance was tested by the Mann Whitney U test

[d]Significance was tested by the Chi-Square test

[e]Significance was tested by the Fisher's Exact test

[f]n=428

[g]Nutritional status was determined by Mid-Upper Arm Circumference (MUAC), which MUAC less than 23.5 cm was categorized as Chronic energy deficiency, n=430

Table 2. Actual energy and nutrient intakes among pregnant women in high and low availability Vitamin D-rich fish area

Nutrients	Unit	RNI	HD Group (n=233)		LD Group (n=202)		Total (n=435)		p-value[a]
			Median	Q1-Q3	Median	Q1-Q3	Median	Q1-Q3	
Energy	(kcal)	2550	1811.96	1605.86-2120.91	2115.06	1886.69-2355.89	1974.62	1688.67-2252.56	<0.001
Protein	(g)	90	58.74	44.96-77.01	59.12	46.52-77.34	59.09	45.77-76.86	0.611
Fat	(g)	67.3	63.87	59.06-68.35	63.99	57.70-68.87	63.90	58.53-68.46	0.471
Carbohydrate	(g)	400	254.87	211.31-307.67	316.71	278.78-364.91	289.61	232.51-341.23	<0.001
Calcium	(mg)	1200	528.67	370.39-761.19	581.41	434.50-906.44	559.35	382.70-828.85	0.019
Iron	(mg)	27	12.22	9.59-15.92	13.77	9.71-18.91	13.05	9.68-17.63	0.033
Zinc	(mg)	12	7.27	5.74-9.25	8.19	6.32-10.04	7.77	5.98-9.61	0.007
Vitamin C	(mg)	85	38.39	15.71-72.33	42.74	19.83-91.61	39.96	18.20-80.25	0.072
Thiamin	(mg)	1.4	0.91	0.62-1.23	0.96	0.72-1.36	0.92	0.67-1.29	0.016
Riboflavin	(mg)	1.4	0.98	0.76-1.28	1.13	0.89-1.53	1.05	0.84-1.42	<0.001
Niacin	(mg)	18	19.38	16.15-24.18	23.23	19.60-28.14	21.34	17.24-26.56	<0.001
Vitamin B6	(mg)	1.9	1.46	1.08-1.94	1.53	1.09-2.42	1.49	1.09-2.09	0.079
Folate	(mcg)	600	154.20	115.45-206.77	172.01	118.18-271.78	161.83	116.18-235.32	0.011
Vitamin B12	(mcg)	4.5	1.62	0.64-6.49	1.43	0.51-7.74	1.53	0.56-6.65	0.508
Vitamin A	(RE)	900	617.62	317.81-1027.87	807.03	305.99-1450.51	672.54	314.55-1184.28	0.021
Vitamin D	(mcg)	15	1.51	0.46-6.55	1.44	0.32-8.46	1.49	0.39-7.22	0.633

Abbreviations: RNI, Recommended Nutrients Intake; HD, High Availability of Vitamin D Rich Fish Area; LD, Low Availability of Vitamin D Rich Fish Area

[a]Significance was tested using Mann-Whitney U test

Table 3. Weekly food frequency among pregnant women in high and low availability Vitamin D-rich fish area

Food Groups Food Subgroups	**Time consumed per week** **HD Group (n=233)**		**LD Group (n=202)**		**Total (n=435)**		**p-value**[a]
	Median	**P_5-P_{95}**	**Median**	**P_5-P_{95}**	**Median**	**P_5-P_{95}**	
Added fats	**1**	**0-2**	**0.5**	**0-1**	**1**	**0-2**	**0.539**
Other added fats	0	0-0	0.5	0-1	0	0-0	0.213
Vegetable oil	0.5	0-1	0	0-0	0	0-0	0.024[b]
Added sugars	**1**	**0-2**	**0**	**0-0**	**1**	**0-1**	**0.038**[b]
Bakery & breakfast cereals	**1**	**0-3**	**1**	**0-3**	**1**	**0-3**	**0.057**
Sweetened bakery, fortified	0	0-0	0.5	0-1	0	0-0	0.014 [b]
Sweetened bakery, unfortified	1	0-3	1	0-2	1	0-3	0.109
Beverages	**0.5**	**0-1**	**1**	**0-2**	**0.5**	**0-1**	**0.044**[b]
Brewed coffee	0	0-0	0	0-0	0	0-0	0.010[b]
Chocolate beverage	0	0-0	0	0-0	0	0-0	0.886
Other beverages	0	0-0	0	0-0	0	0-0	0.882
Sugar sweetened beverages	0.5	0-1	1	0-2	0.5	0-1	0.237
Composites (mixed food groups)	**1**	**0-2**	**1**	**0-4**	**1**	**0-3**	**0.138**
Broths	0	0-0	0	0-0	0	0-0	0.187
Grain products with fillings	1	0-2	1	0-3	1	0-2	0.081
Main meal recipes	0.5	0-1	0	0-0	0.5	0-1	0.115
Other composites	0	0-0	0	0-0	0	0-0	0.234
Soups	0	0-0	1	0-1	0	0-0	0.006[b]
Dairy products	**1**	**0-3**	**1**	**0-2**	**1**	**0-3**	**0.725**
Cheese	0	0-0	0	0-0	0	0-0	0.004[b]
Fluid or powdered milk, fortified	1	0-3	1	0-2	1	0-3	0.734
Sweetened dairy products	0	0-0	0	0-0	0	0-0	0.352
Fruits	**1**	**0-3**	**1**	**0-4**	**1**	**0-4**	**0.487**
Other fruit	1	0-2	1	0-2	1	0-2	0.393
Vitamin A source fruit	0	0-0	0	0-0	0	0-0	0.666
Vitamin C-rich fruit	1	0-2	1	0-2	1	0-2	0.650
Grains & grain products	**21**	**14-23**	**21**	**14-25**	**21**	**14-23**	**0.057**
Fortified grains and products	1	0-2	1	0-3	1	0-3	0.402
Refined grains and products, unfortified	21	14-21	21	14-21	21	14-21	0.092
Legumes, nuts &seeds	**5**	**0-15**	**4**	**0-16**	**5**	**0-15**	**0.801**
Nuts, seeds, and unsweetened products	1	0-2	1	0-2	1	0-2	0.827
Soybeans and products	5	0-15	4	0-15	5	0-15	0.805
Sweetened legume, nut, seed products	0	0-0	0	0-0	0	0-0	0.848
Meat, fish & eggs	**5**	**0-13**	**5**	**0-11**	**5**	**0-12**	**0.014**[b]
Eggs	1	0-10	1	0-5	1	0-10	0.023[b]
Fish without bones	1	0-4	1	0-6	1	0-4	0.044[b]
Organ meat	0	0-0	0	0-0	0	0-0	0.319
Other animal parts	0	0-0	0	0-0	0	0-0	0.480
Poultry, rabbit	1	0-8	1	0-6	1	0-8	0.174

Food Groups Food Subgroups	**Time consumed per week**						**p-value[a]**
	HD Group (n=233)		**LD Group (n=202)**		**Total (n=435)**		
	Median	**P_5-P_{95}**	**Median**	**P_5-P_{95}**	**Median**	**P_5-P_{95}**	
Processed meat	1	0-2	1	0-2	1	0-2	0.776
Seafood	0.5	0-1	0	0-0	0	0-0	0.151
Small, whole fish, with bones	1	0-3	0	0-0	1	0-2	0.083
Miscellaneous	**10**	**0-22**	**5**	**0-20**	**6**	**0-20**	**<0.001[b]**
Condiments, herbs, spices	0	0-0	0	0-0	0	0-0	0.990
Other miscellaneous	0	0-0	0	0-0	0	0-0	0.569
Savory spreads and sauces	10	0-22	5	0-20	6	0-20	<0.001 [b]
Savory snacks	1	**0-8**	1	**0-8**	1	**0-8**	**0.758**
Special fortified products	**0**	**0-0**	**0**	**0-0**	**0**	**0-0**	**0.480**
Starchy roots & plants	**0.5**	**0-1**	**0.5**	**0-1**	0.5	**0-1**	**0.070**
Sweetened snacks & desserts	**0**	**0-0**	**0.5**	**0-1**	**0**	**0-0**	**0.207**
Vegetables	**6**	**0-16**	**5**	**0-12**	**6**	**0-14**	**0.106**
Condiment vegetables	0	0-0	0	0-0	0	0-0	0.404
Other vegetables	3	0-8	2	0-8	2	0-8	0.518
Vitamin A source dark green leafy vegetables	2	0-7	2	0-6	2	0-6	0.264
Vitamin A source other vegetables	1	0-6	1	0-6	1	0-6	0.106

Abbreviations: HD, High Availability of Vitamin D Rich Fish Area; LD, Low Availability of Vitamin D Rich Fish Area

[a]Significance was tested for mean rank difference of food frequency between pregnant women in high and low availability of vitamin D rich fish area

[b]Mann-Whitney U test with significance value $p<0.05$

Table 4. Portion size of pregnant women in high and low availability Vitamin D-rich fish area

Food Groups	Median Portion Size (gram)						
Food Subgroups	**HD Group (n=233)**	**P_5-P_{95}**	**LD Group (n=202)**	**P_5-P_{95}**	**Total (n=435)**	**P_5-P_{95}**	**P-value**
Added fats	**10**	**2-100**	**20**	**5-96**	**10**	**17-100**	**0.027[a]**
Other added fats	31	10-100	21	9-97	21	10-100	0.876
Vegetable oil	4	2-13	7	4-8	4	1-13	0.382
Added sugars	**20**	**5-30**	**20**	**15-23**	**20**	**8-30**	**0.540**
Bakery & breakfast cereals	**44**	**19-100**	**40**	**20-120**	**40**	**19-100**	**0.459**
Sweetened bakery products, fortified	24	19-38	40	11-135	32	12-130	0.390
Sweetened bakery products, unfortified	45	18-100	40	20-100	41	20-100	0.405
Beverages	**180**	**2-220**	**150**	**6-282**	**150**	**4-260**	**0.900**
Brewed coffee	4	4-4	8	5-29	7	4-28	0.120
Chocolate beverage	23	20-25	25	25-25	25	21-25	0.317
Other beverages	220	220-220	21	20-22	121	20-220	0.102
Sugar sweetened beverages	180	2-206	190	30-322	180	2-313	0.277
Composites	**62**	**30-250**	**55**	**29-223**	**60**	**30-250**	**0.148**
Broths	37	33-40	-	-	37	33-40	-
Grain products w/fillings	50	30-100	56	30-127	53	30-125	0.346
Main meal recipes	175	65-250	215	70-250	188	63-250	0.672
Other composites	58	51-158	150	150-150	60	51-170	0.480
Soups	142	23-249	34	19-212	35	19-244	0.264
Dairy products	**40**	**18-107**	**40**	**11-220**	**40**	**12-220**	**0.458**
Cheese	-	-	14	6-235	14	6-235	-
Fluid or powdered	40	18-108	40	25-220	40	20-220	0.160

Food Groups	**Median Portion Size (gram)**						
Food Subgroups	**HD Group (n=233)**	**P_5-P_{95}**	**LD Group (n=202)**	**P_5-P_{95}**	**Total (n=435)**	**P_5-P_{95}**	**P-value**
milk (fortified)							
Sweetened dairy products	90	90-90	-	-	90	90-90	-
Fruits	**100**	**25-197**	**100**	**40-228**	**100**	**29-213**	**0.019[a]**
Other fruit	80	20-200	100	40-208	100	25-200	0.012[a]
Vitamin A source fruit	97	35-262	170	50-376	112	38-302	0.329
Vitamin C-rich fruit	100	36-120	100	59-232	100	38-150	0.571
Grains & grain products	**158**	**99-236**	**185**	**112-237**	**167**	**104-237**	**<0.001[a]**
Fortified grains and products	65	23-139	56	21-168	60	21-151	0.262
Refined grains and products, unfortified	162	118-246	200	136-254	185	121-248	<0.001[a]
Legumes, nuts &seeds	**45**	**25-89**	**43**	**20-92**	**45**	**21-91**	**0.221**
Nuts, seeds, and unsweetened products	30	17-131	35	9-218	30	13-188	0.507
Soybeans and products	45	30-80	45	30-80	45	30-80	0.133
Sweetened legume, nut, seed products	53	41-94	41	37-49	45	37-88	0.289
Meat, fish & eggs	**50**	**22-82**	**50**	**25-87**	**50**	**23-84**	**0.562**
Eggs	60	26-60	60	29-60	60	26-60	0.023[a]
Fish without bones	55	30-85	53	27-97	54	30-91	0.602
Organ meat	45	32-59	35	26-78	35	26-79	0.814

Food Groups	**Median Portion Size (gram)**						
Food Subgroups	**HD Group (n=233)**	**P_5-P_{95}**	**LD Group (n=202)**	**P_5-P_{95}**	**Total (n=435)**	**P_5-P_{95}**	**P-value**
Other animal parts	42	42-42	32	28-36	36	29-41	0.221
Poultry, rabbit	50	30-80	49	26-92	50	27-85	0.326
Processed meat	40	20-195	45	27-189	40	21-199	0.872
Seafood	42	30-96	40	21-44	40	22-84	0.202
Small, whole fish, with bones	21	15-40	30	19-47	30	15-46	0.050
Miscellaneous	**12**	**4-30**	**17**	**5-35**	**15**	**4-34**	**<0.001[a]**
Condiments, herbs, spices	2	0-18	5	0-14	3	0-17	0.602
Other miscellaneous	20	11-47	13	10-19	15	10-41	0.354
Savory spreads and sauces	13	4-30	18	5-35	15	5-33	<0.001[a]
Savory snacks	**15**	**10-40**	**20**	**10-75**	**18**	**10-57**	**0.008[a]**
Special fortified products	**20**	**20-20**	**60**	**24-96**	**20**	**20-92**	**0.121**
Starchy roots & plants	**71**	**17-215**	**60**	**21-161**	**60**	**19-200**	**0.657**
Other starchy plant foods	73	17-215	60	21-161	60	19-200	0.419
Sweetened snacks & desserts	**26**	**20-100**	**22**	**4-59**	**25**	**5-100**	**0.392**
Sweet snack foods (candy and chocolate)	28	20-100	22	4-59	25	5-100	0.163
Vegetables	**37**	**18-86**	**53**	**20-114**	**43**	**19-104**	**<0.001[a]**
Condiment vegetables	70	43-114	60	38-75	60	38-105	0.487
Other vegetables	37	14-109	49	18-117	40	15-117	0.003[a]

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Food Groups Food Subgroups	Median Portion Size (gram)						
	HD Group (n=233)	**P_5-P_{95}**	**LD Group (n=202)**	**P_5-P_{95}**	**Total (n=435)**	**P_5-P_{95}**	**P-value**
Vitamin A source dark green leafy vegetables	40	18-77	55	15-145	43	15-120	0.002[a]
Vitamin A source other vegetables	15	7-44	20	8-43	18	7-43	0.405

Abbreviations: HD, High Availability of Vitamin D Rich Fish Area; LD, Low Availability of Vitamin D Rich Fish Area

[a]Significance was tested for mean rank difference of food frequency between pregnant women in high and low availability of vitamin D rich fish area

[b]Mann-Whitney U test with significance value $p<0.05$

Table 5. Comparison of nutrient levels of the two best diet (module ii), worst-case and best-case scenario diets without FBRs (Module III) among pregnant women in high and low availability Vitamin D rich fish area

Analysis	Achievement of nutrients (%RNI)													
	Protein	Fat	Ca	Vit C	Vit B1	Vit B2	Vit B3	Vit B6	Folate	Vit B12	Vit A RE	Vit D	Fe	Zn
Pregnant Women in High Availability of Vitamin D Rich Fish Area														
Best diet (food patterns)	106.30	118.10	70.10	51.80	94.20	110.00	152.40	120.10	34.10	105.00	100.00	25.50	81.20	100.00
Best diet (no-food pattern)	100.00	108.40	**75.30**[a]	100.00	107.60	120.40	162.50	128.60	**62.90**[a]	277.00	153.90	**56.80**[a]	**85.60**[a]	100.00
Best-case scenario without FBRs	112.80	141.80	**83.40**[b]	124.20	138.50	148.20	181.10	148.10	**73.90**[b]	331.10	247.90	**67.60**[b]	**93.30**[b]	112.60
Worst-case scenario without FBRs	80.2	100.70	46.30	**20.00**[c]	68.70	76.10	124.00	75.10	17.80	**20.20**[c]	**39.20**[c]	5.20	56.10	77.20
FBRs1a	89.3	108.1	61.4	40.2	80.6	112.4	148.6	104.5	51.9	199.3	116.4	26.2	69.8	90.9
FBRs2a	92.0	106.4	62.2	37.4	85.5	114.4	158.9	110.2	52.2	284.3	119.4	48.1	70.3	93.3
FBRs3a*	96.1	110.5	70.4	56.9	90.2	122.7	164.5	120.4	56.6	287.2	149.9	52.1	77.4	99.5
Pregnant Women in Low Availability of Vitamin D Rich Fish Area														
Best diet (food patterns)	94.60	115.80	92.90	50.40	91.70	120.30	173.20	147.10	55.90	241.80	366.30	41.00	81.10	114.40
Best diet (no-food pattern)	95.70	105.10	100.00	100.00	112.00	120.50	188.00	175.70	**83.90**[a]	392.50	429.30	**73.00**[a]	**90.30**[a]	118.80
Best-case scenario without FBRs	111.20	138.20	110.60	135.30	156.80	156.00	262.20	192.70	**91.30**[b]	437.60	494.60	**80.3**[b]	103.50	129.40
Worst-case scenario without FBRs	77.00	84.70	**44.30**[c]	**16.60**[c]	**58.20**[c]	67.10	125.50	71.70	17.00	**17.40**[c]	**24.00**[c]	3.40	54.70	75.80
FBRs1b	83.1	89.2	56.4	29.8	68.9	101.1	154.8	97.7	61	324.2	249.4	37.6	66.9	91.2
FBRs2b	83.1	89.2	58.7	31.2	71.6	103.4	155.1	97.7	61	324.5	249.4	37.6	67.4	91.3
FBRs3b	85.1	91.8	59.4	52.3	72.4	104.4	158.7	104.1	64.2	327.6	257.5	41.4	70.3	94.6
FBRs4b	85.1	91.8	61.2	52.3	74.7	106.3	158.7	104.1	64.2	327.6	257.5	41.4	70.3	94.7

Analysis	Achievement of nutrients (%RNI)													
	Protein	Fat	Ca	Vit C	Vit B1	Vit B2	Vit B3	Vit B6	Folate	Vit B12	Vit A RE	Vit D	Fe	Zn
FBRs5b*	86.3	92.2	62.5	55.1	76.4	108.2	159.8	110.7	65	327.7	262.7	44.5	71.9	97

Abbreviations: RNI, Recommended Nutrient Intake; FBRs, food-based recommendations; Vit, Vitamin

[a]Bold in Best diet (no-food pattern) refers to problem nutrient, which is model achievement could not meet 100% RNI

[b]Bold in Best-case scenario refers to absolute problem nutrient, which is maximized scenario could not meet 100% RNI

[c]Bold in Worst-case scenario refers to dietary inadequacy, which is minimized scenario could not meet 65% RNI

FBRs1a: MFP12, Egg2, Poultry3, Fish4, Smallfish2, Organ1 - Veg14, DGLV7 - Fruit3, VitCfruit2

FBRs2a: MFP12, Egg2, Poultry3, Fish4, Smallfish2, Organ1 - Veg14, DGLV7 - Fish4, Mackereltuna2, Balisardinella1

FBRs3a*: MFP12, Egg2, Poultry3, Fish4, Smallfish2, Organ1 - Veg14, DGLV7 - Fruit3, VitCfruit2 - Fish4, Mackereltuna2, Balisardinella1 - FortifMilk2 (selected FBRs)

FBRs1b: Legumes11, Soybean7 - Veg12, DGLV6 - MFP10, Fish6, Smallfish1, Liver2 - Mackereltuna2

FBRs2b: Legumes11, Soybean7 - Veg12, DGLV6 - Fortifiedmilk2 - MFP10, Fish6, Smallfish1, Liver2 - Mackereltuna2

FBRs3b: Veg12, DGLV6 - Fruit4, VitCfruit2, VitAfruit1 - MFP10, Fish6, Smallfish1, Liver2 - Mackereltuna2

FBRs4b: Veg12, DGLV6 - Fruit4, VitCfruit2, VitAfruit1 - Fortifiedmilk2 - MFP10, Fish6, Smallfish1, Liver2 - Mackereltuna2

FBRs5b*: Veg12, DGLV6 - Fruit4, VitCfruit2, VitAfruit1 - Fortifiedmilk2 - MFP10, Fish6, Smallfish1, Liver2 - Mackereltuna2 - Tilapia1 (selected FBRs)

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Table 6. Food-based recommendations formulated for pregnant women in high and low availability of Vitamin D-rich fish area

Messages	Recommended Portion Size
High availability of Vitamin D-rich fish area	
1. Consume 3 meals in a day	1 serving of cooked white rice (200 gr)
2. Consume 2 servings/day of animal-source foods, including:	1 serving of animal-source foods:
- At least 3 servings/week of chicken	1 serving of chicken (50 gr)
- At least 1 servings/week of chicken liver	1 serving of chicken liver (45 gr)
- At least 2 servings/week of egg	1 serving of egg (60 gr)
- At least 4 servings/week of fish without bones, including 2 servings/week of mackerel tuna, and 1 serving/week of bali sardinella	1 serving of mackerel tuna fish (54 gr) 1 serving of bali sardinella fish (100 gr)
- At least 2 servings/week of dried anchovy	1 serving of dried anchovies (20 gr)
3. Consume 1 serving/day of plant-based protein	1 serving of plant-based protein: 1 serving of tempeh (45 gr), or 1 serving of tofu (40 gr)
4. Consume 2 servings/day of vegetables, including:	1 serving of vegetables:
- At least 1 serving/day of dark green leafy vegetable	-1 serving of spinach (40 gr), or -1 serving of green mustard (50 gr)
5. Consume 1 serving/day of fruit, including:	1 serving of fruit:
- At least 2 servings/week of vitamin C-rich fruit	-2 medium-sized oranges (100 gr), or -1 big-sized guava (100 gr), or
Low availability of Vitamin D-rich fish area	
1. Consume 3 meals in a day	1 serving of cooked white rice (200 gr)
2. Consume 2 servings/day of animal-source foods, including:	1 serving of animal-source foods:
- At least 2 servings/week of chicken/beef liver	1 serving of chicken liver (45 gr)
- At least 6 servings/week of fish without bones, including 2 servings/week of mackerel tuna, and 1x serving/week of tilapia	1 serving of mackerel tuna fish (54 gr) 1 serving of tilapia fish (60 gr)

- At least 1 serving/week of dried anchovy	1 serving of dried anchovies (30 gr)
3. Consume 1 serving/day of plant-based protein	1 serving of plant-based protein: 1 serving of tempeh (45 gr), or 1 serving of tofu (40 gr)
4. Consume 2 servings/day of vegetables, including:	1 serving of vegetables:
- At least 1 serving/day of dark green leafy vegetable	-1 serving of spinach (40 gr), or -1 serving of green mustard (50 gr)
5. Consume 1 serving/day of fruit, including:	1 serving of fruit:
- At least 2 servings/week of vitamin C-rich fruit	-2 medium-sized oranges (100 gr), or -1 big-sized guava (100 gr), or
- At least 1 serving/week of vitamin A source fruit	-1 servings of papaya (100 gr)
6. Consume fortified powder milk for pregnant women at least 2 servings/week	1 serving of powder milk (40 gr)

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