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Dietary Iron Intake and Availability in Hill Tribe and Urban Women, Chiang Rai Province, Northern Thailand

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ABSTRACT
Data were collected as part of a cross-sectional study. The objectives were to compare dietary intakes of iron and enhancers and inhibitors of non-heme iron absorption in hill tribe and urban women of Chiang Rai province, northern Thailand, and compare iron- and vitamin C-containing foods sold in markets in both settings. Dietary data were collected using three 24-hour recalls from 128 women aged 19–50 years (hill tribe: n = 65; urban n = 63), and proportions of low-, medium- and high-iron/vitamin C containing foods were surveyed in local markets. Hill tribe women consumed less iron, animal protein, vitamin C and calcium, but market availability of iron/vitamin C foods was similar. Future interventions should focus on food choice modification, to improve intakes of iron and foods that enhance its absorption, especially among hill tribe women.

KEYWORDS
Iron intake and availability; dietary survey; market survey; hill tribe and urban women

Introduction
One quarter of women living in northern Thailand are anemic, according to data published in the most recent Thai National Health Examination Survey (NHES) (Aekplakorn et al. 2014). It was recently suggested that 26.1% of anemia cases in south east Asian women of reproductive-age (15–49 years) are attributable to iron deficiency (Petry et al. 2016), whereas the World Health Organization reported that 45.0% of anemic non-pregnant women in this region respond to iron supplementation (World Health Organization 2015). In a study conducted in Chiang Mai, northern Thailand, 35.0% of adults with microcytic hypochromic anemia were iron deficient (Pornprasert, Thongsat, and Panyachadporn 2017), while iron deficiency was the predominant cause of anemia among female university students in Bangkok (Brimson, Suwanwong, and Brimson 2019). Fewer data are available for hill tribe women in Thailand. The average hematocrit concentration of Karen hill tribe women was in the normal range, but the proportion of women with low...
Hematocrit was not presented (Silalai 2003). More recently, low hematocrit was found to be more prevalent in hill tribe women aged 30–45 years than in younger hill tribe women (Kwanbunjan et al. 2008). Suboptimal iron status has an adverse impact on educational achievement, work capacity and overall quality of life. Crucially, the negative consequences of inadequate iron are transferred from one generation to the next. Anemia remains a public health concern for a proportion of reproductive-aged women in Thailand, and suboptimal iron status is an important cause of anemia in women of this age group.

Women in the northern region of Thailand consumed 64.0% of the recommended dietary allowance (RDA) for iron, while women from rural and urban areas across all regions of Thailand consumed 54.5% and 57.6% of the RDA, respectively (Satheannoppakao et al. 2011). However, information about the nutrient intakes of hill tribe groups in Thailand is scarce and dated. Silalai (2003) noted that hill tribe women living in a peri-urban setting consumed more animal protein and heme iron than their peers living in a mountainous area. In other research, hill tribe women in a northern Thai province consumed inadequate amounts of folate (Kwanbunjan et al. 2008), which shares some of the same dietary sources as iron.

The Thai RDA for iron is currently set at 24.7 mg/d for women aged 19–50 years (Bureau of Nutrition 2003), which takes into account the lower bioavailability of dietary iron in a traditional Thai diet. A traditional Thai diet typically includes fibrous vegetables and herbs which contain polyphenols and phytates that bind dietary non-heme iron, forming insoluble complexes and reducing its absorption (Hallberg, Rossander, and Skånberg 1987; Hurrell, Reddy, and Cook 1999). Plenty of fruits provide organic acids such as ascorbic acid. Ascorbic acid enhances non-heme iron absorption via its reducing and chelating properties, and overcomes the effects of some inhibitors of non-heme iron absorption (Hurrell and Egli 2010). Nevertheless, evidence suggests that consumption of both fruit and vegetables is below the recommended number of servings, especially among Thai adults who live in rural areas, have less formal education, and lower income (Satheannoppakao, Aekplakorn, and Pradipasen 2009). Calcium has been shown to negatively affect both non-heme and heme iron absorption, although its overall impact on iron absorption from a mixed diet may be limited (Hurrell and Egli 2010).

Both heme and non-heme forms of iron are present in meat tissues. Meat intakes have reportedly increased over the past three decades (Department of Health 1995; Satheannoppakao et al. 2011). Approximately 15.0–35.0% of dietary heme iron is absorbed, in contrast with smaller and more variable proportions of dietary non-heme iron (Hurrell and Egli 2010). Moreover, the inclusion of meat in a meal enhances the absorption of non-heme iron contained in the same meal, most likely via cysteine-containing peptides that chelate non-heme iron, improve its solubility, and thereby enhance its absorption (Glahn and Van...
Greater meat consumption would therefore be anticipated to exert a positive effect on dietary iron bioavailability. However, there are notable gaps in wealth between rural and urban communities in Thailand (UNESCO 2018; World Bank 2019), and these could give rise to differences in dietary behaviors. For instance, rural Cambodian women consumed relatively small amounts of iron-rich foods and they considered foods containing highly bioavailable iron, namely beef and pork offal, to be expensive (Wallace et al. 2014). As there are particularly wide disparities between the income and educational achievement of hill tribe women and ethnic Thai women, a comparative analysis of the dietary intakes of these two groups can indicate whether discrepancies in dietary iron intake and availability also exist.

Traditional stationary markets and mobile markets remain important sources of food in both urban and rural communities in Thailand. The authors have recently published data relating to the utilization of different sources of food in the hill tribe and urban women who participated in this study (Sang-ngoen et al. 2019). One notable finding, with regards to food purchasing, was that participants from both groups primarily relied on markets rather than multinational retailers. Approximately 95.0% of all participants reported sourcing ingredients for home-cooked food from markets, and 60.0–70.0% purchased ready-to-eat food from these sources (Sang-ngoen et al. 2019). This highlights the continued significance of traditional retailers in both communities. The outcomes of a nationally-representative survey also noted the importance of markets, and demonstrated that fresh market shoppers were most abundant in the northern region of Thailand (Kelly et al. 2015). Little is known about the current situation with regards to the market availability of foods that are particularly relevant to iron status. This data would help to examine current nutrition and health gaps between rural women who belong to a minority group and urban Thai women. Furthermore, data on the consumption of iron, and enhancers and inhibitors of non-heme iron absorption, combined with knowledge of the availability of iron- and vitamin C-containing food items in local markets, could provide an important basis for interventions aimed at women of reproductive age and food outlets in both settings. Therefore, the objectives were to: 1. compare dietary intakes of iron, and enhancers and inhibitors of non-heme iron absorption, in hill tribe and urban women; and 2. compare the proportions of low, medium and high iron- and vitamin C- containing foods that were sold in markets in the hill tribe and urban settings.

Methodology

Study design and approval

Dietary and market data were collected in two districts of Chiang Rai province, northern Thailand, as part of an analytical cross-sectional study conducted
from February to early-May 2017. The researchers obtained ethical approval from the Ethical Review Committee for Human Research, Faculty of Public Health, Mahidol University (COA. No. MUPH 2016–100). Local government officials also approved the study.

**Dietary survey**

**Participants and settings**

A formula for comparing two populations (alpha 0.05 and beta 0.20) gave a sample size of 65 participants per group, after the addition of 30.0% to account for missing data (Lemeshow et al. 1990). In total, dietary data were collected from 128 women; 65 women from six hill tribe villages in Therd Thai subdistrict, Mae Fah Luang district, and 63 women from five housing estates within Phan municipality, Phan district, Chiang Rai province. Participants had either Lahu, Aka or Mhong ethnicity (hill tribe group) or were ethnic Thais (urban group), and were aged 19–50 years, healthy, not pregnant and not lactating. None of the women had dietary restrictions. The study settings were purposively selected, and participants were recruited using convenience sampling with the assistance of officials from both communities. All participants provided informed consent prior to data collection, and an interpreter facilitated communication with hill tribe women who were not fluent in Thai (n = 34). Our recent publication demonstrated that the hill tribe participants had significantly less formal education and lower incomes than urban participants. Around 78.0% of the hill tribe women had minimal (primary school level) or no formal education, while approaching 60.0% of the urban women held a university degree. Monthly income for almost 90.0% of the hill tribe participants amounted to ≤10,000 Thai Baht (≤304 USD/month) (p < .001), whereas 76.0% of the urban participants had >10,000 Thai Baht/month (p < .001) (Sang-ngoen et al. 2019). The same publication contains a comprehensive description of the participants and study settings, including the reasons for choosing the selected sampling techniques.

**Data collection**

Information including socioeconomic data was collected from the two groups using an interviewer-administered questionnaire. The 24-hour dietary recall method was used to obtain details of all foods and beverages that were consumed during three nonconsecutive days, from midnight to midnight. Participants were also asked about their use of dietary supplements. Overall, 28.0% and 25.0% of the dietary recalls covered weekend days, in the hill tribe and urban groups, respectively. Thus, the dietary data reflected weekend and week day intakes in both groups to a similar extent. The first author and her assistants obtained a complete description of food and drink intake, together with an estimate of the amount consumed. Standard household measures
(e.g. ladle, tablespoon, teaspoon, glass, cup etc.) were used to estimate the portion sizes of foods and drinks, along with a portion size booklet that was especially designed for use in this study. The booklet was modeled on the format used in the fifth NHES (Aekplakorn et al. 2014), and had food examples that were most relevant to northern Thai cuisine. Food items were first prepared and then photographed on household measures that were positioned next to a ruler, to give participants a sense of scale. Prior to the commencement of the study, data collectors had received training and guidance about conducting 24-hour recall interviews from the third author.

**Data analysis**

Dietary data were entered into INMUCAL-N version 3: NB.3 (Institute of Nutrition 2013), which is a food composition database of the nutritional value of dietary items that are commonly consumed in Thailand. The database includes locally analyzed foods, and energy and nutrient values for at least 2,000 commonly consumed dietary items, including some items fortified with micronutrients. Heme and non-heme iron intakes were obtained from INMUCAL-N version 3: NB.3, which has heme iron and non-heme iron values for dietary items, in addition to total iron content. The heme and non-heme iron values of foods in INMUCAL-N version 3: NB.3 are derived from direct chemical analysis of both forms of iron. This includes the animal, fish and seafood products commonly consumed in Thailand (Kongkachuichai, Napatthalung, and Charoensiri 2002). The food composition database was used to compute intakes of: energy, iron (total iron, non-heme iron, heme iron), enhancers of non-heme iron absorption (animal protein, ascorbic acid) and inhibitors of non-heme iron absorption (fiber, calcium) for both groups. Extreme under reporters were defined as participants with energy intakes below 500 kcal, while over reporters were those with intakes greater than 3,500 kcal/day (Willett 2013) and, if identified, they were excluded from the analyzes.

Participants’ intakes of iron, vitamin C and calcium were expressed as a proportion of the dietary reference intakes for these nutrients. For iron and vitamin C, recommended dietary allowance (RDA) is used to estimate adherence to dietary recommendations, while adequate intake (AI) is used for calcium. Percentage intake of RDA/AI was calculated for each participant by taking their daily iron/vitamin C/calcium intake (mg), dividing it by the RDA/AI (mg) and multiplying by 100. For example, if an individual’s daily iron intake was 8.5 mg, then they were calculated to be consuming 34.4% of the RDA for iron [individual iron intake (mg/d)/24.7 (mg iron RDA for women aged 19–50 years) x 100].

Energy-adjusted nutrient intakes were calculated by dividing daily nutrient intake by energy intake, and then multiplying by 1,000. For example, a participant whose daily energy and iron intakes amounted to 1,590 kcal and 12.6 mg, respectively, was calculated to consume 7.9 mg iron per 1,000 kcal/day.
**Market survey**

**Settings**
A market survey was carried out in the same settings as the dietary survey. The survey covered the traditional (stationary) market in Therd Thai sub-district, Mae Fah Luang district (hill tribe setting) and the three traditional markets in Phan municipality, Phan District (urban setting). The market survey also covered all four mobile markets that served the hill tribe setting in Therd Thai subdistrict and the mobile market that served the urban setting in Phan municipality. Mobile markets were pick-up trucks and motorcycles that sold a selection of food items and visited the areas several times a week.

**Data collection**
The first author identified raw and cooked food items which were sold in the markets of the hill tribe and urban neighborhoods, on one occasion. These food items comprised of: 1. animal products (meat including viscera, eggs, insects) and fish (finned fish, shellfish), 2. vegetables, and 3. fruit. The amounts of total iron (mg/100 g) contained in the identified animal/fish items and vegetable items were ascertained from INMUCAL-N version 3: NB.3 (Institute of Nutrition, Mahidol University 2013). The same database was used to determine the vitamin C content (mg/100 g) of different fruits that were identified. This database shows the energy and nutrient content of food items in the forms in which they are commonly consumed in the Thai diet. Cooked and raw items were examined separately, because their iron content can differ (Florek et al. 2016). Different cooked forms of the same item found in the markets were also considered separately, as different cooking methods affect iron content to a variable extent (Pereira et al. 2014). So, for example, total iron data for boiled long green beans, shallow-fried long green beans and deep-fried long green beans were extracted from the food composition database.

**Data analysis**
Box plots were then used to categorize the market food items according to their iron or vitamin C content. Food items with an iron/vitamin C content (mg/100 g) that was within the lowest percentile for that particular food group (≤25th data percentile) were labeled ‘low’. Items that contained a moderate amount of iron/vitamin C (26–74th data percentile) were labeled ‘medium’, and items with a high iron/vitamin C content (≥75th data percentile) were labeled ‘high’. Low, medium and high iron animal/fish items (raw) contained ≤1.00 mg, 1.01–4.89 mg, and ≥4.90 mg iron/100 g, respectively. Low, medium and high iron animal/fish items (cooked) contained ≤1.33 mg, 1.34–6.04 mg, and ≥6.05 mg iron/100 g, respectively. The iron contents of low, medium and high iron vegetables (raw) were: ≤0.60 mg,
0.61–2.22 mg, and ≥2.23 mg iron/100 g, respectively. The amounts of iron contained in low, medium and high iron vegetables (cooked) were: ≤0.61 mg, 0.62–1.74 mg, and ≥1.75 mg iron/100 g, respectively. Fruit designated as low vitamin C had ≤7.42 mg vitamin C/100 g, while fruit assigned medium and high contained 7.43–35.49 mg and ≥35.50 mg vitamin C/100 g, respectively. The percentages of animal/fish items and vegetables with low, medium and high iron contents were calculated for the hill tribe setting, and also for the urban setting. Likewise, the percentages of fruit with low, medium and high vitamin C contents were determined for each setting.

**Statistical analysis**

PASW Statistics for Windows, Version 18.0. (Chicago: SPSS Inc.) was used, and statistical significance was set at $p < .05$. Continuous data (age, energy and nutrient intakes) were tested for normality of distribution using the Kolmogorov-Smirnov test. Age data followed a normal distribution, whereas energy and nutrient intake data had asymmetrical (skewed) distributions. Therefore, averages were presented as mean (±SD) for the former and as median (25th, 75th percentile) for the latter. Comparisons between women in the two groups (hill tribe women versus urban women) were made using the unpaired Student’s $t$-test for parametric data (age), and the Mann Whitney U test for non-parametric data (energy and nutrient intakes). For exploration of the associations between nutrient intakes and indicators of socioeconomic status (categories of education level and income), nutrient intakes were then categorized into < median and ≥ median intake. The associations between nutrient intakes and indicators of socio-economic status were subsequently determined using Pearson’s Chi-Square test. The Chi-Square test was also used to examine associations between setting (hill tribe and urban) and the proportions of market foods with low, medium and high iron/vitamin C content.

**Results**

**Dietary survey**

Among women who met the study criteria, motivation to take part in the survey was high; 100.0 and 95.0% of approached eligible women in the hill tribe and urban settings, respectively, agreed to participate. Data from all 65 hill tribe women and 63 urban women were included in the dietary analyzes, as no extreme under- or over-reporters were identified based on the definition provided by Willett (2013). Mean (± SD) age was 35.0 ± 9.8 years in the hill tribe group, and 37.7 ± 9.3 years in the urban group ($p = .417$). None of the participants reported taking dietary supplements.
Hill tribe women consumed less total iron, non-heme iron and heme iron, both before and after adjustment for energy intake (all \( p < .001 \), Tables 1 and 2). The hill tribe group consumed a smaller proportion of the Thai RDA for iron, in contrast with the urban group (approximately 26.3 and 41.6%, respectively, \( p < .001 \), Table 1). Hill tribe women also ate smaller amounts of animal protein and vitamin C (enhancers of non-heme iron absorption) compared with their urban peers, prior to and following adjustment for energy intake (\( p < .001 \) and \( p < .05 \), Tables 1 and 2). In addition, unadjusted and energy-adjusted intakes of calcium, an inhibitor of non-heme iron absorption, were lower in the hill tribe group (both \( p < .001 \)), but the two groups consumed similar amounts of dietary fiber (Tables 1 and 2).

Intakes of total iron, heme iron, animal protein and calcium were associated with education level and income (all \( p < .05 \); Tables 3 and 4). At least two thirds of participants who had below median intakes of total iron, heme iron, animal protein and calcium had minimal (primary school level) or no formal education and incomes ≤10,000 Thai Baht. Intakes of non-heme iron and vitamin C were not associated with education level or income.

Table 1. Daily energy and nutrient intakes in hill tribe and urban women.

<table>
<thead>
<tr>
<th>Nutrient</th>
<th>Hill tribe ((n = 65))</th>
<th>Urban ((n = 63))</th>
<th>(p)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy (kcal)</td>
<td>1248.04 (984.14, 1495.79)</td>
<td>1303.03 (1070.87, 1594.04)</td>
<td>.398</td>
</tr>
<tr>
<td>Total iron (mg)</td>
<td>6.50 (4.41, 8.79)</td>
<td>10.27 (7.37, 12.80)</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>% RDA for iron</td>
<td>26.3 (17.9, 35.6)</td>
<td>41.6 (29.8, 51.8)</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Heme iron (mg)</td>
<td>1.79 (0.99, 2.53)</td>
<td>3.42 (2.26, 5.42)</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Non-heme iron (mg)</td>
<td>3.82 (2.79, 5.60)</td>
<td>5.15 (4.06, 6.96)</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Animal protein (g)</td>
<td>20.45 (11.74, 28.22)</td>
<td>32.54 (24.65, 44.51)</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Vitamin C (mg)</td>
<td>44.38 (22.80, 73.98)</td>
<td>57.38 (38.10, 101.24)</td>
<td>.007</td>
</tr>
<tr>
<td>% RDA for vit C</td>
<td>59.2 (30.4, 98.6)</td>
<td>76.5 (50.8, 135.0)</td>
<td>.007</td>
</tr>
<tr>
<td>Dietary fiber (g)</td>
<td>9.00 (5.97, 11.13)</td>
<td>10.16 (6.73, 13.92)</td>
<td>.172</td>
</tr>
<tr>
<td>Calcium (mg)</td>
<td>177.98 (96.12, 270.19)</td>
<td>269.02 (195.87, 409.41)</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>% AI for calcium</td>
<td>22.3 (12.0, 33.8)</td>
<td>33.6 (24.5, 51.2)</td>
<td>&lt;.001</td>
</tr>
</tbody>
</table>

Median (25th, 75th percentiles). Mann-Whitney \( U \) test was used for between-group comparison of daily energy and nutrient intakes. % RDA/AI is the median nutrient intake expressed as a percentage of the Thai RDA/AI. *Recommended dietary fiber intake for this age group is 25 g/day.

Table 2. Energy-adjusted daily nutrient intakes in hill tribe and urban women.

<table>
<thead>
<tr>
<th>Nutrient</th>
<th>Hill tribe ((n = 65))</th>
<th>Urban ((n = 63))</th>
<th>(p)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total iron (mg/1,000 kcal)</td>
<td>5.25 (4.49, 6.40)</td>
<td>7.35 (6.46, 9.35)</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Heme iron (mg/1,000 kcal)</td>
<td>1.32 (0.93, 1.98)</td>
<td>2.70 (1.73, 3.81)</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Non-heme iron (mg/1,000 kcal)</td>
<td>3.33 (2.24, 4.30)</td>
<td>4.13 (3.66, 4.76)</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Animal protein (g/1,000 kcal)</td>
<td>16.31 (10.32, 21.86)</td>
<td>25.02 (19.45, 32.97)</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Vitamin C (mg/1,000 kcal)</td>
<td>32.62 (18.32, 58.85)</td>
<td>49.42 (27.95, 79.77)</td>
<td>.010</td>
</tr>
<tr>
<td>Dietary fiber (g/1,000 kcal)</td>
<td>6.93 (5.31, 8.48)</td>
<td>7.32 (5.70, 8.87)</td>
<td>.210</td>
</tr>
<tr>
<td>Calcium (mg/1,000 kcal)</td>
<td>139.82 (88.55, 202.35)</td>
<td>200.05 (169.94, 294.70)</td>
<td>&lt;.001</td>
</tr>
</tbody>
</table>

Energy-adjusted nutrient intakes were calculated by dividing daily nutrient intake by energy intake, and then multiplying by 1,000. Median (25th, 75th percentiles). Mann-Whitney \( U \) test was used for between-group comparison of daily energy and nutrient intakes.
Table 3. Association between participant characteristics and daily iron intakes (n = 128).

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Total iron intake</th>
<th>Heme iron intake</th>
<th>Non-heme iron intake</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>&lt;Median</td>
<td>≥Median</td>
<td>P</td>
</tr>
<tr>
<td>Education</td>
<td></td>
<td></td>
<td>.017</td>
</tr>
<tr>
<td>No formal education</td>
<td>24 (37.5)</td>
<td>12 (18.8)</td>
<td>27 (42.2)</td>
</tr>
<tr>
<td>Primary school</td>
<td>16 (25.0)</td>
<td>14 (21.8)</td>
<td>14 (21.9)</td>
</tr>
<tr>
<td>High school or vocational diploma</td>
<td>13 (20.3)</td>
<td>12 (18.8)</td>
<td>15 (23.4)</td>
</tr>
<tr>
<td>Bachelor degree or higher</td>
<td>11 (17.2)</td>
<td>26 (40.6)</td>
<td>8 (12.5)</td>
</tr>
<tr>
<td>Income (Thai Baht§/mo)</td>
<td></td>
<td></td>
<td>.009</td>
</tr>
<tr>
<td>≤5,000</td>
<td>28 (43.8)</td>
<td>11 (17.2)</td>
<td>32 (50.0)</td>
</tr>
<tr>
<td>5,001–10,000</td>
<td>16 (25.0)</td>
<td>17 (26.6)</td>
<td>17 (26.5)</td>
</tr>
<tr>
<td>10,001–15,000</td>
<td>3 (4.7)</td>
<td>10 (15.6)</td>
<td>4 (6.3)</td>
</tr>
<tr>
<td>15,001–20,000</td>
<td>7 (10.9)</td>
<td>8 (12.5)</td>
<td>4 (6.3)</td>
</tr>
<tr>
<td>≥20,001</td>
<td>10 (15.6)</td>
<td>18 (28.1)</td>
<td>7 (10.9)</td>
</tr>
</tbody>
</table>

Pearson’s chi-square test was used to analyze associations between characteristics and nutrient intakes. §1 Thai Baht = 0.031 USD.
Table 4. Association between participant characteristics and daily intakes of nutrients that affect non-heme iron absorption (n = 128).

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Animal protein intake</th>
<th>Vitamin C intake</th>
<th>Calcium intake</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>&lt;Median</td>
<td>≥Median</td>
<td>P</td>
</tr>
<tr>
<td>Education</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No formal education</td>
<td>24 (38.1)</td>
<td>12 (18.5)</td>
<td>.003</td>
</tr>
<tr>
<td>Primary school</td>
<td>17 (27.0)</td>
<td>13 (20.0)</td>
<td></td>
</tr>
<tr>
<td>High school or vocational diploma</td>
<td>13 (20.6)</td>
<td>12 (18.5)</td>
<td></td>
</tr>
<tr>
<td>Bachelor degree or higher</td>
<td>9 (14.3)</td>
<td>28 (43.0)</td>
<td></td>
</tr>
<tr>
<td>Income (Thai Baht§/mo)</td>
<td></td>
<td>&lt;.001</td>
<td>.624</td>
</tr>
<tr>
<td>≤5,000</td>
<td>30 (47.6)</td>
<td>9 (13.9)</td>
<td></td>
</tr>
<tr>
<td>5,001–10,000</td>
<td>17 (26.9)</td>
<td>16 (24.6)</td>
<td></td>
</tr>
<tr>
<td>10,001–15,000</td>
<td>4 (6.4)</td>
<td>9 (13.9)</td>
<td></td>
</tr>
<tr>
<td>15,001–20,000</td>
<td>4 (6.4)</td>
<td>11 (16.9)</td>
<td></td>
</tr>
<tr>
<td>≥20,001</td>
<td>8 (12.7)</td>
<td>20 (30.7)</td>
<td></td>
</tr>
</tbody>
</table>

Pearson’s chi-square test was used to analyze associations between characteristics and nutrient intakes. §1 Thai Baht = 0.031 USD
**Market survey**

Hill tribe and urban markets sold similar proportions of low, medium and high iron animal/fish items (raw: \( p = .556 \), Figure 1a; cooked: \( p = .611 \), Figure 1b). Around one fifth of the raw and cooked animal/fish items found in the hill tribe markets had a high iron content, versus one quarter in the urban markets.

Similar proportions of vegetable items with a low, medium and high iron content were found in both markets (raw: \( p = .850 \), Figure 2a; cooked: \( p = .164 \), Figure 2b). In both the hill tribe and urban settings, around one fifth of the surveyed raw vegetables had a high iron content. Just below one fifth of the surveyed cooked vegetables in the hill tribe markets and one quarter in the urban markets had a high iron content.

The proportions of low, medium, and high vitamin C fruits that were sold in markets in the hill tribe and urban settings did not differ (\( p = .513 \); Figure 3). Just over one fifth of the fruits surveyed in the hill tribe markets were high in vitamin C, versus almost one third of fruits in the urban markets.

**Discussion**

Hill tribe women consumed less heme iron and animal protein. Similarly, data collected over 15 years ago showed that hill tribe women living in a more remote...
setting had lower intakes of iron and protein derived from animal tissues, compared with their peers who lived in a peri-urban area (Silalai 2003). The absorption of heme iron ranges from 15.0 to 35.0% (Hurrell and Egli 2010), and it is considered to be the most bioavailable form of dietary iron. Intakes of non-heme iron and vitamin C were also lower in the hill tribe group. Both vitamin C and meat factors enhance the absorption of dietary non-heme iron. Non-heme iron is absorbed to a lesser extent from meals that contain a lower ratio of enhancers (e.g. vitamin C) to inhibitors (e.g. phytates found in fiber-containing foods) of non-heme iron absorption (Conway et al. 2006). Therefore, iron in the diet of the hill tribe women may be less bioavailable, which increases the risk of iron deficiency anemia. Nevertheless, intakes of calcium were low, and both groups consumed less than half the recommended daily amount of dietary fiber. In addition, the timing of the consumption of foods containing modifiers of non-heme absorption and non-heme iron is an important determinant of their enhancing/inhibiting effect. Iron bioavailability is also a function of physiological factors. The absorption of sufficient amounts of iron to meet physiological iron demands and cover iron losses is critical to maintaining body iron balance and an iron replete state.

Figure 2. Percentages of (a.) raw and (b.) cooked vegetables with low, medium and high iron content in hill tribe and urban markets. (a.) Raw vegetables. Iron content categories: low \( \leq 0.60 \text{ mg Fe/100 g} \); medium \( 0.61 \text{–} 2.22 \text{ mg Fe/100 g} \); high \( \geq 2.23 \text{ mg Fe/100 g} \). Number of low, medium and high iron items in markets in each setting: hill tribe ‘low’ \( n = 24 \), ‘medium’ \( n = 30 \), ‘high’ \( n = 12 \); urban ‘low’ \( n = 25 \), ‘medium’ \( n = 37 \), ‘high’ \( n = 16 \). (b.) Cooked vegetables. Iron content categories: low \( \leq 0.61 \text{ mg Fe/100 g} \); medium \( 0.62 \text{–} 1.74 \text{ mg Fe/100 g} \); high \( \geq 1.75 \text{ mg Fe/100 g} \). Number of low, medium and high iron items in markets in each setting: hill tribe ‘low’ \( n = 6 \), ‘medium’ \( n = 24 \), ‘high’ \( n = 7 \); urban ‘low’ \( n = 24 \), ‘medium’ \( n = 40 \), ‘high’ \( n = 22 \). † Pearson’s Chi Square test was used to analyze the association between proportions of vegetables with low-, medium- and high-iron and setting.
Our findings reaffirm the existence of differences in dietary intakes between rural and urban communities, as has been previously reported (Satheannoppakao et al. 2011; Satheannoppakao, Aekplakorn, and Pradipasen 2009). Fruit is an important source of vitamin C, while many vegetables that are part of the Thai diet contain inhibitors of non-heme iron absorption as well as containing non-heme iron. Research has shown that intakes of fruit and vegetables are lower in rural areas of Thailand and among those with lower indicators of socio-economic status (Satheannoppakao, Aekplakorn, and Pradipasen 2009). Although vitamin C intakes were lower in the rural hill tribe group in the present study, vitamin C intakes were not associated with education level or income. Nevertheless, lower socio-economic status is frequently associated with poorer dietary quality alongside other signs of unfavorable health, and inadequate micronutrient intake persists in some population sub-groups, such as women of reproductive age. Animal products are generally associated with higher cost (Wallace et al. 2014) and this factor may compromise the intake of nutrients derived from animal sources among low-income groups. In the hill tribe group, consumption of less animal protein (an enhancer of non-heme iron absorption) and lower intakes of total of iron, in particular the heme iron fraction, may have been partly attributable to their poorer socioeconomic circumstances. Indeed,

**Figure 3. Percentages of fruit with low, medium and high vitamin C content in hill tribe and urban markets.** Vitamin C content categories: low ≤7.42 mg vitamin C/100 g; medium 7.43–35.49 mg vitamin C/100 g; high ≥35.50 mg vitamin C/100 g. Number of low, medium and high vitamin C fruits in markets in each setting: hill tribe ‘low’ n = 5, ‘medium’ n = 13, ‘high’ n = 5; urban ‘low’ n = 7, ‘medium’ n = 10, ‘high’ n = 8. † Pearson’s Chi Square test was used to analyze the association between proportions of fruit with low-, medium- and high-vitamin C and setting.
education level and income in the hill tribe participants were notably lower than in the urban group (Sang-ngoen et al. 2019) and, in the present analysis, minimal or no formal education and low income were associated with below-average intakes of animal protein, total iron and heme iron.

Reasonably high proportions of high-iron containing foods (one quarter to one fifth of animal/fish and vegetables items) were available in the markets of both settings. Likewise, just over one fifth of the fruit present in the hill tribe markets was high in vitamin C, versus almost one third of the fruit in the urban markets. The markets surveyed in the current study were those that served the communities who partook in the dietary survey. It is possible that foods from these markets were not utilized in favor of foods from other sources. However, other commercial sources, such as supermarkets, sell seasonally-available fruit and vegetables and cooked foods that resemble those available from the traditional and mobile markets.

Although markets in the two settings were similar in terms of the iron/vitamin C food items that were on sale, the hill tribe women had lower iron and vitamin C intakes, as discussed above. Unfortunately, food prices were not recorded in each area during the market surveys. Based on published research, in spite of their physical availability, the relatively high price of certain food items is often given as a reason for not consuming more of these items, and this factor is most pronounced in those who earn less (Chapman et al. 2017). Wallace et al. (2014) reported that rural Cambodian women considered meats and offal that contained highly bioavailable iron to be expensive. All of the respondents had suboptimal iron intakes, and low levels of education and income were important circumstances behind their inferior dietary intakes (Wallace et al. 2014). Similarly, rural hill tribe women in the current study formed the greatest proportion of participants with less formal education and lower income, and intakes of nutrients including animal protein and heme iron were poorest among these individuals. However, Wallace et al. (2014) also noted that rural Cambodian women infrequently consumed iron-containing vegetables such as water morning glory, even though they categorized them as easy-to-find, inexpensive and healthy. This was also the case for vitamin C containing fruits such as mango and papaya. Thus, the determinants of nutrient intake are complex, especially in rural communities where traditional food taboos and other cultural factors often influence dietary behavior, alongside socioeconomic factors. Theory-based frameworks often underpin programs that aim to initiate and maintain positive changes in food choice, but a combination of improved access to affordable healthy food and behavioral intervention has had mixed success in low income communities (Kang et al. 2017; Leone et al. 2018; Reinbott et al. 2016).
Other factors could partially account for lower intakes of iron and most other nutrients in the hill tribe women compared with their urban peers. Ghosh-Jerath et al. (2016) recently highlighted seasonal variation in iron intake among the Oraon tribe of India, although dietary iron intakes were inadequate across all three seasons. Some hill tribe women consumed foraged plant items that were not found in the Thai food composition database (Sang-ngoen et al. 2019). Food items with similar characteristics were subsequently chosen from the database. In doing this, the dietary assessment of the hill tribe women may have produced a less accurate picture of their nutrient intakes, in contrast with the results obtained for their urban peers. Nevertheless, this factor probably made a minimal contribution to the differences in nutrient intakes between the two groups, as the number of unidentifiable dietary items was small.

The energy and nutrient intakes of the hill tribe and urban groups were below the recommended levels. The hill tribe and urban women consumed around 6.5 and 10.3 mg of iron daily, respectively. Both figures are considerably lower than the Thai RDA of 24.7 mg iron/day for women aged 19–50 years (Bureau of Nutrition, Department of Health, Ministry of Public Health 2003). Similarly, calcium intakes in the hill tribe and urban groups were around one fifth and one third of the Thai AI, respectively. Nationally representative surveys also report iron and calcium intakes far below the recommended amounts for women aged ≥19 years. NHES data indicated that Thai women in both rural and urban areas consumed approximately 28.0% of the Thai AI for calcium (Satheannoppakao et al. 2011). The same survey showed that rural women consumed 54.5% of the Thai RDA for iron, and urban women consumed 57.6% of the recommended amount. The Thai RDAs for iron were set higher than those used by many western countries, because a traditional Thai diet typically contains less meat and has more food items that reduce the bioavailability of dietary non-heme iron. As data from national surveys suggest that meat intakes have increased over the past three decades, it is possible that the iron bioavailability of a typical present-day Thai diet may be underestimated. Nevertheless, this might not be the case for some rural diets, and it is worth noting that the daily iron intake of the hill tribe women in the present study (26.3% of the Thai RDA for iron) was around half the daily iron intake of the rural Thai participants in a past NHES (54.5% of the Thai RDA for iron, Satheannoppakao et al. 2011).

Limitations and strengths

Underreporting was likely to be partly responsible for the relatively low energy and nutrient intakes, as it is a pitfall encountered in all dietary surveys. Daily energy intakes were 1,248 and 1,303 kcal in the hill tribe and
urban groups, respectively, which were lower than the recommended amount of 1,800 kcal/day for women aged 19–50 years (Bureau of Nutrition, Department of Health, Ministry of Public Health 2003). However, comparable median energy intakes of 1,162 kcal/day (women aged 19–30 years) and 1,238 kcal/day (women aged 31–50 years) were obtained from the fourth Thai NHES (Satheannoppakao et al. 2011). Moreover, there is no reason to believe that there was a difference in the degree of underreporting between the two groups, and the energy intakes of the two groups were similar.

Missing dietary items is one weakness of the Thai food composition database, and the researchers were unable to identify the scientific names and common Thai names of two plant items that were consumed by a small number of hill tribe women. Consequently, foods which most closely resembled these items were instead included in the dietary analysis. Although this may have introduced a greater degree of error in to the analysis of the hill tribe dietary data, the authors expect it was minor as it only concerned a small number of plant items.

Some urban and hill tribe participants reported consuming dietary items that were fortified with micronutrients. These included Ovaltine chocolate malt drink and a yogurt drink; both fortified with B-vitamins and calcium. Some varieties of Ovaltine chocolate malt drink are also fortified with iron. Where participants had reported the brand name and variety of an item, these specific items were selected from the food composition database during data entry, if they were present. According to this database, Ovaltine chocolate malt drink has 0.72 mg iron per 200 ml drink serving (2.9% of the iron RDA for women aged 19–50 years). However, not all varieties of this and other fortified items are included in the food composition database, in which case the most similar product was selected. As a result, the contribution of fortified items to dietary iron and other micronutrient intakes cannot be accurately estimated. Additionally, nutrient data for some items in the food composition database are incomplete. For instance, calcium data are not available for 7.5% of items in the database, and fiber data are missing for 20.8% of items. Regardless of these drawbacks, INMUCAL-N version 3: NB.3 was the most appropriate food composition database to utilize, because it is based on the analysis of foods commonly consumed in Thailand.

Biochemical measures of iron status were not included. However, micronutrient inadequacy ascertained by using the dietary assessment technique that was applied in the current study (three 24-hour recalls) has been associated with a higher risk of IDA (Shalini et al. 2018). Furthermore, the outcomes of dietary studies contribute to the evidence base of national dietary guidelines worldwide (Hébert et al. 2014), and assist in the development of nutrition interventions.

All data were collected at the end of cool season through to hot season, with the majority of the information obtained during the latter season. As
one point of interest in the study was the availability of seasonal produce (fruit and vegetables), data collection over all three seasons would have provided a more informative picture of dietary intakes and market availability of foods/nutrients that are relevant to iron status. As anticipated, our previously published data demonstrated that traditional and mobile markets were highly significant sources of food in both study settings (Sang-ngoen et al. 2019), which justifies focusing on these types of markets. Nevertheless, each market was only surveyed on one occasion, so some daily variation in produce might have been missed. Also, food prices were not recorded during the market survey. Such information would have provided additional information that could have been useful for the analysis and discussion of the findings.

The study locations were purposively sampled based on their accessibility to the research team, therefore the findings may not be replicated if a similar study is conducted in other settings. It can be particularly challenging to obtain access to hill tribes and other under studied communities for research purposes. Consequently, these data provide a valuable insight into the nutritional status of these population groups. The authors also acknowledge that selecting participants by using convenience sampling can produce a sample that is not representative of the whole population, but this type of sampling bias affects all observational studies. Community leaders and local health officers assisted with participant recruitment and this helped to encourage women to contribute to the research. Likewise, although a non-professionally qualified local interpreter was relied on to communicate with around half of the hill tribe group, his familiarity with the community served to facilitate communication.

Several aspects of the study were robust. Participants were very motivated to contribute to this research, and the willingness of eligible women to partake in the study was comparable in each setting. Multiple 24-hour recall interviews were conducted for all participants, and the dietary data reflected weekend and week day intakes in both groups to a similar extent. The researcher used standard household measures combined with a portion size book that was especially developed for this study, to improve the accuracy of food portion size estimates. The dietary survey was conducted at the same time as the market survey, thus dietary intakes and market availability of iron- and vitamin C-containing foods were determined simultaneously. Furthermore, the market survey covered cooked foods as well as raw food items, which was important because ready-to-eat cooked foods make an important contribution to dietary intakes in these communities, and in Thai communities in general. The nutritional status of ethnic minorities, in particular hill tribe groups, is not well understood in contrast to the nutritional status of ethnic Thai communities. Here is a recent dietary analysis of hill tribe women in Mae Fah Luang district of Chiang Rai province, and the
first study to concurrently compare nutrient intakes and market availability of food items in hill tribe and urban communities. These data provide a valuable indicator of dietary iron intake and bioavailability in these groups, together with the market availability of foods relevant to iron status at the time of data collection.

**Conclusion**

Dietary intakes of bioavailable iron in the hill tribe women were lower than in urban women, although similar proportions of high-iron and high-vitamin C food items were present in local markets within each community. It was apparent that lower intakes of animal-derived nutrients were associated with lower socioeconomic status. Our findings suggest that there is a need for interventions which target women of reproductive age, particularly hill tribe women who belong to this age group. Such programs should focus on food choice modification, in order to improve intakes of dietary iron and foods that enhance iron absorption in these and other socioeconomically-disadvantaged communities. Future studies should encompass other hill tribe and urban areas, and include biochemical indicators of iron status.

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**Conflicts of Interest**

The authors declare that they have no conflicts of interest.

**Author contributions**

DS and CH formulated the research idea. DS was the primary data collector, who designed and conducted the study under the supervision of CH. Data collection tools were devised by DS with advice from CH and WS. DS developed the food portion size booklet and performed dietary data collection and analysis with guidance from WS. DS was responsible for market survey data analysis, all statistical analyses and data presentation, following advice from MT.
CH wrote the manuscript, with DS contributing some information. All authors read the manuscript, provided constructive comments, and approved it prior to submission.

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