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# Added Sugars Consumption Decreased Iron and Zinc Intake among Children Aged 24-59 Months in Central Java

## *Konsumsi Gula Tambahan Menurunkan Asupan Zat Besi dan Seng pada Anak Usia 24-59 Bulan di Jawa Tengah*

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**ABSTRACT**

**Background:** High sugar consumption was found among children in Indonesia. Excessive intake of added sugars was predicted to cause micronutrient dilution, a negative potential effect compromising micronutrient intake such as iron and zinc.
**Objectives:** This study examined the association between added sugar consumption and iron and zinc intake among children aged 24-59 months.
**Methods:** This study was a secondary data analysis of the 2014 Total Diet Study in Central Java Province. The subjects were 394 children aged 24-59 months. Dietary intake and sociodemographic data were assessed using the 24-hour food recall and household questionnaire. Added sugars consumption was classified into six cut-offs based on its contribution to daily energy (%E), namely: C1 (<5%E), C2 (5%E - <10%E), C3 (10%E - <15%E), C4 (15%E - <20%E), C5 (20%E - 25%E), and C6 (>25%E).
**Results:** 48% of subjects had added sugar intake exceeding the WHO recommendation. Subjects with iron and zinc intake below the Estimated Average Requirement (EAR) were 15.2% and 24.1%, respectively. As the added sugar consumption increased, iron and zinc intake decreased significantly (p<0.05). This study found a significant decrease in the intake of iron occurred at added sugar consumption ≥20%E (C5 and above) while decreasing the intake of zinc at added sugar consumption ≥15%E (C4 and above) (p<0,05).
**Conclusions:** Added sugar consumption had an inverse association with iron and zinc intake among children aged 24-59 months, which showed the occurrence of micronutrient dilution.

## INTRODUCTION

Malnutrition continues to be a significant nutritional issue among Indonesian children. The prevalence of malnutrition among children in Indonesia was as follows: stunting (30.8%)[1], wasting (10.2%)[1], overweight (8%)[1], anaemia (38.5%)[1], and zinc deficiency (60%)[2]. The insufficient intake of both macro and micronutrients is the immediate cause of malnutrition among children[3]. Children are especially vulnerable to malnutrition due to their increasing needs, the weaning phase, and inadequate food practices[4–7].

Iron and zinc are essential micronutrients for children's growth and development, as they play a crucial role in metabolism and cell proliferation, affecting cognitive, motor, and neurophysiological functions[8,9]. However, meeting the recommended intake for iron and zinc is challenging for children, particularly in developing countries such as Indonesia[10]. Most staple foods in Indonesian society contain low levels of these nutrients[11]. The consumption of animal-source foods rich in iron and zinc was also reported to be low, especially in rural areas and low economic status, with meat and fish average consumption of 9,4 and 2,2 kg per capita per year[12].

On the other hand, Indonesian children were among the population with high sugar consumption. Central Java province was the third province in Indonesia with the highest sugar consumption. According to the Indonesia Basic Health Research in 2018, children aged 3 to 4 had the highest percentage of sweet food and drink consumption[1]. Other studies found that 81.6% and 40% of children between 6 and 35 months old consume commercial snacks and sweetened drinks, respectively. Additionally, 29.3% of urban Indonesian children aged 3 to 5 regularly consumed sweetened condensed milk as part of their diet[13].

This dietary pattern may lead to a phenomenon called "micronutrient dilution," where the density of micronutrients at the intake level decreases as the consumption of high-energy-dense foods, such as those with high added sugar, increases[14]. World Health Organization (WHO) defines added sugar as monosaccharides and disaccharides added to food and



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beverages by manufacturers, cooks, or consumers, except for intrinsic sugar in vegetables, fruits, and milk[15]. Nutrient density at the intake level refers to the amount of essential nutrients, like vitamins and minerals, in a given amount of energy intake[16]. When more energy comes from added sugar intake, the density of certain micronutrients tends to decrease[17–20].

Studies have shown that increased added sugar intake is associated with decreased iron and zinc intake, the two micronutrients that experience the most significant decrease[17,21–23]. This decrease is also related to the food groups that decline significantly with increased added sugar intake, namely the meat and fish group[17,19,23–25].

Previous research showed that Australians experienced a decrease in micronutrient intake only when added sugar intake reached 25% of total energy intake[14]. In contrast, the United Kingdom and Japan saw a reduction in micronutrient intake at levels greater than 13% and 10% of total energy intake, respectively[17,26,27]. The added sugar intake percentage, linked to a decrease in micronutrient intake, is likely to vary among different populations and countries.

Although some studies have shown a significant negative association between added sugar and micronutrient intake, some micronutrients showed non-linear or positive association, making the "micronutrient dilution" hypothesis inconsistent[28]. Since research on the association between added sugar intake and decreased micronutrient intake in the Indonesian population has yet to be conducted, further studies are needed, mainly since high sugar consumption in food and drinks has already occurred in Indonesian children. Therefore, this study aimed to determine the association between added sugar intake and decreased iron and zinc intake in Central Java province children aged 24-59 months.

## METHODS

### Study Design

This study was a secondary data analysis from the Total Diet Study (TDS) conducted in Central Java Province in 2014[29]. TDS was a community-based study that included individual samples representing the province and the nation. This study employed observational research methods, specifically descriptive analytic methods with a cross-sectional design. Researchers conducted additional analysis in this study from January to February 2022 in Semarang. This study has obtained ethical approval letter No.75/III/2022 from the Bioethics Commission of Universitas Islam Sultan Agung Semarang.

The subjects were children aged 24-59 months selected from the TDS of Central Java Province in 2014 based on specific inclusion and exclusion criteria. The TDS 2014 sample was a subset of the Indonesia Basic Health Research 2013 estimate at the provincial level, which used a two-stage stratified sampling method and was a subset of the district/city estimate. The TDS household samples were randomly selected from some representative Census Blocks in the province, and the TDS individual samples were selected randomly from households in the Central Java Province's Census Blocks that were visited by The Indonesia Basic Health Research 2013.

This study's minimum sample size was calculated using the Slovin Formula with a population size of 16,683 toddlers and a tolerance limit 0.05. Based on this calculation, the minimum sample size was 391 subjects. The inclusion criteria were that the subjects needed to be healthy during the intake data collection and no longer breastfeeding. Subjects with incomplete data (individual, household, and individual food consumption data) or included in missing data due to extreme values were excluded from the study. Subjects who met the inclusion criteria were 417 children, but there were 23 dropouts, with 10 subjects having incomplete data and 13 subjects having extreme data; thus, data from 394 subjects was analyzed.

### Measurement of Added Sugar, Iron, and Zinc Intake

The independent variable in this study was the energy from added sugar intake, and the dependent variables included iron and zinc intake, both in absolute value and density. Data on food intake was obtained from the raw data of the Total Diet Study. In the Total Diet Study, the subjects' food intake was collected through direct interviews using the 1x24-hour food recall, with the 5-step multiple-pass method recall technique[29]. This study analyzed the food intake data using Nutrisurvey 2007 software to obtain total energy, added sugar, iron, and zinc intake data. The food composition database used in this study were from the Indonesian food database in 2005, the United States Department of Agriculture National Nutrient Database for Standard Reference, Release 25 (USDA SR25) in 2012, the Indonesian Food Composition Table (IFCT) 2017, and nutritional information on packaged products. The micronutrient content in milligrams (mg) in packaged foods was calculated according to the guidelines of the Head of the Indonesian Food and Drug Monitoring Agency Regulation No. 9 in 2016 on nutritional label references. The contribution of micronutrients from food supplements was not included in the Nutrisurvey analysis as the study's primary purpose was to assess the intake of food and beverages.

The energy from added sugar intake was calculated as a percentage of total energy intake using the following formula: $\frac{Added\ sugar\ intake\ x\ 4\ kcal}{Total\ energy\ intake}$ x 100%. Added sugar refers to monosaccharides and disaccharides added to food or drinks as sweeteners by manufacturers, cooks, or consumers. It also included sugar naturally found in honey, syrup, and fruit concentrate but excluded intrinsic sugar in vegetables, fruit (fructose), and milk (lactose)[15]. Added sugar data was obtained from estimation method[30], followed by some modifications due to limitations in the availability of food ingredient and nutrient databases in Indonesia. Food groups with 0 grams of added sugar content, such as pure fruit or vegetable juices, spices, oils and fats, seeds and cereals, fresh fruits and vegetables, legumes, fish, poultry, meat, pure cow's milk, and unsweetened or artificially sweetened food and drinks were eliminated. Foods with good added sugar content, 100% and partially, such as confectionery, bakery and pastry products, cereals, sweetened beverages, and packaged products with sugar sweeteners, honey, syrup, and



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others, were kept. The added sugar content was then calculated based on these food groups' total sucrose listed on Nutrisurvey. If sucrose was unavailable, added sugar was assigned as 50% of total sugar. Products that had a composition of 100% added sugar, such as candy, syrup, and sugary products, were assigned as 100% total sugar. The energy from added sugar intake for each subject was grouped based on the cut-off (C) recommendation from the World Health Organization (WHO) and Institute of Medicines (IOM)[15,31]. There were six C groups based on the percentage of energy (%E) of added sugar intake, namely C1 (<5%E), C2 (5%E - <10%E), C3 (10%E - <15%E), C4 (15%E - <20%E), C5 (20%E - 25%E), and C6 (>25%E)[14]. Subjects included in C1 have added sugar intake below 5% of their total energy intake, while those in C6 have added sugar intake above 25%.

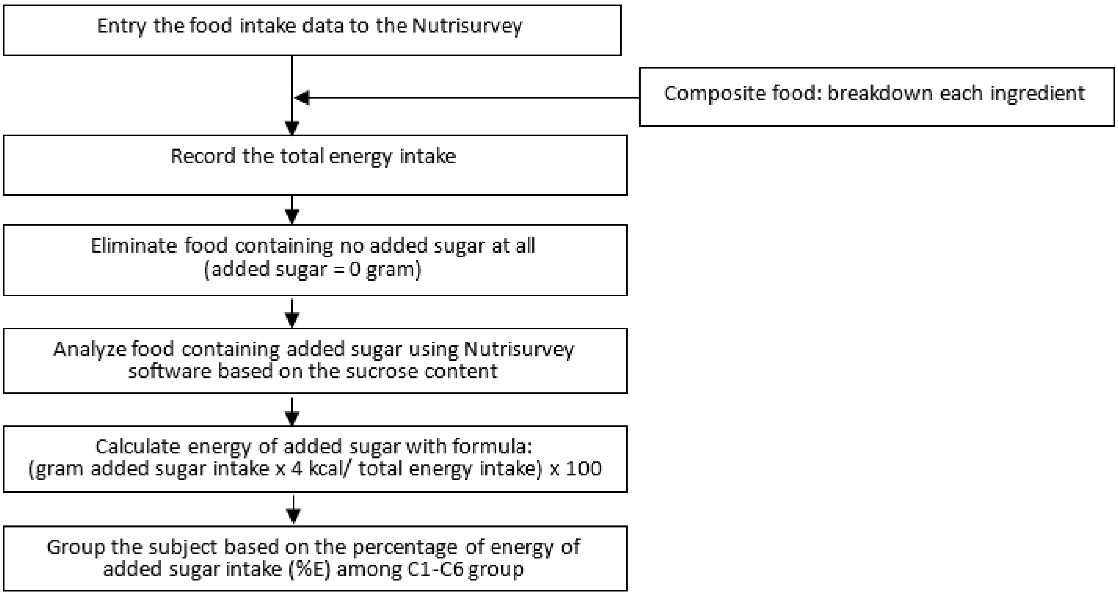


**Figure 1.** Chart of How to Obtain the Added Sugar Variable

Iron and zinc intake variables were presented as absolute values and densities. Absolute values were displayed in mg/day units, while nutrient density was the ratio of nutrients per 1000 kcal. Nutrient density was calculated using the following formula: $\frac{Nutrient\ intake}{Total\ energy\ intake}$ x 1000[32]. Iron and zinc intake was compared to the Estimated Average Requirement (EAR) to estimate the adequacy[33]. The EAR for iron for children aged 1-3 and 4-6 years was 3 and 4.1 mg/day, while the EAR for zinc for children aged 1-3 and 4-6 years was 2.5 and 4 mg/day[34].

**Measurement of Demographic and Socioeconomic Data**

The covariate variables included area of residence, parents' working status, parents' education level, and economic status. Demographic and socioeconomic data were collected through direct household interviews using a questionnaire. Based on TDS, the area of residence variable was classified as either urban or rural. Parent's working status referred to the employment status of the head of household and was categorized as not working, working, or student. The parent's education level represented the highest level of education attained by the head of household, including never going to school, not graduating from Elementary School, graduating from Elementary School, graduating from Junior High School, graduating from Senior High School, graduating at D1/D2/D3, and graduated at university. The quintile index of ownership of durable goods determines economic status. It is divided into five categories: lowest quintile, lower-middle quintile, middle quintile, upper-middle quintile, and highest quintile. Education level was categorized as "low" if graduation at high school had not been attained and "high" if graduated from high school or higher education. Economic status was divided into three groups: low, middle, and high. The low category included subjects with the lowest and lower-middle quintiles of ownership, the middle category included subjects with middle and upper-middle quintiles of ownership, and the high category included subjects with the highest quintile of ownership[35].

**Statistical Analysis**

The data analysis used SPSS version 25 software with a 95% confidence level ($\alpha = 0.05$). Univariate analysis was presented with median and minimum-maximum values for numerical data, while frequency and percentage for categorical data. The normality test used the Kolmogorov-Smirnov test because the sample size exceeded 30 subjects. Since the research data was not normally distributed, the Mann-Whitney test was used to determine the difference in added sugar intake, iron, and zinc based on place of residence and education level. Meanwhile, the Kruskall-Wallis test was used to determine the difference based on economic status. The association between added sugar consumption and iron and zinc intake was also tested using Kruskall-Wallis. The results showed a significant difference, so a Dunn-Bonferroni post-hoc test was performed to determine the difference between groups. Multivariate analysis used multiple logistic regression to determine the association between groups from added sugar intake and the incidence of micronutrient inadequacy after



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controlling variables such as parental education level and economic status.

## RESULTS AND DISCUSSION

### Subject Characteristics

The subjects were 394 children aged 24-59 months in Central Java Province. Based on Table 1, almost half of the subjects (48.9%) had added sugar intake exceeding WHO recommendations (≥10% E), and 24 subjects (6.1%) had added sugar intake > 25% E, which exceeded the upper limit of IOM recommendations. Subjects with iron and zinc intake below EAR were 15.2% and 24.1% respectively. As many as 75% of subjects with inadequate iron intake and 63.2% with inadequate zinc intake were subjects with added sugar intake that exceeded the recommendations.

Over half of subjects aged three years or above had added sugar intake that exceeded recommendations. These characteristics are consistent with the developmental stage of these children, which involves increasing autonomy and the desire to build social relationships outside of the family[10]. As a result, children may reject or choose specific foods according to their preferences, including sugary foods. Additionally, external factors may influence sugar intake, such as the higher amount of added sugar in dairy products marketed to children over two years old than those marketed to younger children.

**Table 1.** Subject Characteristics Based on Added Sugar Intake Group

| Variable | Percent of Energy from Added Sugar Intake# | | | | | | Total |
|---|---|---|---|---|---|---|---|
| | C1 n=83 | C2 n=118 | C3 n=88 | C4 n=56 | C5 n=25 | C6 n=24 | |
| **Age** | | | | | | | |
| 24-36 month | 32 (24.2%) | 42 (31.8%) | 23 (17.4%) | 16 (12.1%) | 10 (7.6%) | 9 (6.8%) | 132 (33.5%) |
| 37-59 month | 51 (19.5%) | 76 (29.0%) | 65 (24.8%) | 40 (15.3%) | 15 (5.7%) | 15 (5.7%) | 262 (66.5%) |
| **Gender** | | | | | | | |
| Male | 41 (21.5%) | 58 (30.4%) | 48 (25.1%) | 21 (11.0%) | 13 (6.8%) | 10 (5.2%) | 191 (48.5%) |
| Female | 42 (20.7%) | 60 (29.6%) | 40 (19.7%) | 35 (17.2%) | 12 (5.9%) | 14 (6.9%) | 203 (51.5%) |
| **Area of Residence** | | | | | | | |
| Urban | 35 (17.9%) | 63 (32.1%) | 43 (21.9%) | 29 (14.8%) | 12 (6.1%) | 14 (7.1%) | 196 (49.7%) |
| Rural | 48 (24.2%) | 55 (27.8%) | 45 (22.7%) | 27 (13.6%) | 13 (6.6%) | 10 (5.1%) | 198 (50.3%) |
| **Parent's Working Status** | | | | | | | |
| Unemployed | 7 (21.9%) | 10 (31.3%) | 10 (31.3%) | 2 (6.3%) | 2 (6.3%) | 1 (3.1%) | 32 (8.1%) |
| Employed | 76 (21.1%) | 108 (29.9%) | 77 (21.3%) | 54 (15.0%) | 23 (6.4%) | 23 (6.4%) | 361 (91.6%) |
| Student | 0 | 0 | 1 (100%) | 0 | 0 | 0 | 1 (0.3%) |
| **Parent's Education Level** | | | | | | | |
| Low | 57 (19.9%) | 87 (30.4%) | 70 (24.5%) | 38 (13.3%) | 16 (5.6%) | 18 (6.3%) | 286 (72.6%) |
| High | 26 (24.1%) | 31 (28.7%) | 18 (16.7%) | 18 (16.7%) | 9 (8.3%) | 6 (5.6%) | 108 (27.4%) |
| **Economic Status** | | | | | | | |
| Low | 24 (17.1%) | 41 (29.3%) | 37 (26.4%) | 20 (14.3%) | 11 (7.9%) | 7 (5.0%) | 140 (35.5%) |
| Medium | 34 (20.5%) | 51 (30.7%) | 34 (20.5%) | 27 (16.3%) | 8 (4.8%) | 12 (7.2%) | 166 (42.1%) |
| High | 25 (28.4%) | 26 (29.5%) | 17 (19.3%) | 9 (10.2%) | 6 (6.8%) | 5 (5.7%) | 88 (22.3%) |
| **Iron Intake** | | | | | | | |
| Below EAR | 5 (8.3%) | 10 (16.7%) | 12 (20.0%) | 10 (16.7%) | 10 (16.7%) | 13 (21.7%) | 60 (15.2%) |
| Adequate | 78 (23.4%) | 108 (32.3%) | 76 (22.8%) | 46 (13.8%) | 15 (4.5%) | 11 (3.3%) | 334 (84.8%) |
| **Zinc Intake** | | | | | | | |
| Below EAR | 9 (9.5%) | 26 (27.4%) | 22 (23.2%) | 20 (21.1%) | 11 (11.6%) | 7 (7.4%) | 95 (24.1%) |
| Adequate | 74 (24.7%) | 92 (30.8%) | 66 (22.1%) | 36 (12.0%) | 14 (4.7%) | 17 (5.7%) | 299 (75.9%) |

#C1 (<5%E), C2 (5%E - <10%E), C3 (10%E - <15%E), C4 (15%E - <20%E), C5 (20%E - 25%E), C6 (>25%E)

### Added Sugar, Iron, and Zinc Intake

Table 2 shows that the median value of added sugar intake in children aged 24-59 months in Central Java Province was 32.85 grams/day, which was higher compared to the recommended added sugar intake for children based on the American Heart Association (AHA) that should be less than 25 grams/day. The subjects' median energy intake from added sugar was 9.72% E, below the maximum recommended limit of <10% E. The subjects' median absolute iron and zinc intakes were 5.95 and 4.2 mg/day, respectively. The median densities of iron and zinc were 4.66 and 3.25 mg for every 1000 kcal, respectively.

**Table 2.** Added Sugar, Iron, and Zinc Intake in Subjects

| Variable | Median (Min-Max) |
|---|---|
| **Added Sugar (gram/day)** | 32.85 (0.00 – 139.5) |
| **Energy of Added Sugar Intake (%)** | 9.72 (0.00 – 55.84) |
| **Percentage of Energy from Added Sugar Intake (%)** | |
| C1 | 2.89 (0.00 – 4.92) |
| C2 | 7.56 (5.04 – 9.86) |



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| Variable | Median (Min-Max) |
|---|---|
| C3 | 12.62 (10.05 – 14.97) |
| C4 | 17.06 (15.07 – 19.86) |
| C5 | 22.12 (20.03 – 24.67) |
| C6 | 29.02 (25.12 – 55.84) |
| **Iron** | |
| Absolute (mg/day) | 5.95 (0.80 – 22.40) |
| Density (per 1000 kcal) | 4.66 (0.55 – 15.72) |
| **Zinc** | |
| Absolute (mg/day) | 4.20 (0.60 – 14.40) |
| Density (per 1000 kcal) | 3.25 (0.48 – 9.66) |

**Differences in Added Sugar, Iron, and Zinc Intake Based on Demographic and Economic Status**

Table 3 shows a significant difference in intake of iron and zinc, both absolute and nutrient density, based on parents' educational level and economic status (p<0.05). Subjects with higher parental education levels and economic status had higher iron and zinc intakes. There was no significant difference in added sugar intake based on place of residence, parents' educational level, and economic status (p>0.05).

**Table 3.** Differences in Added Sugar, Iron and Zinc Intake Based on Demographic and Economic Status

| Variable | Added Sugar median (min-max) | | Iron Intake median (min-max) | | Zinc Intake median (min-max) | |
|---|---|---|---|---|---|---|
| | Added sugar (g/day) | Added Sugar (%E) | Absolute (mg/day) | Density (per 1000 kcal) | Absolute (mg/day) | Density (per 1000 kcal) |
| **Area of Residence** | | | | | | |
| Urban | 33.7 (0.0-139.5) | 9.9 (0.0-40.1) | 6.3 (0.8 – 23.0) | 4.7 (0.8-13.6) | 4.3 (0.7-14.4) | 3.3 (0.6-9.7) |
| Rural | 30.6 (0.0-123.0) | 8.0 (0.0-55.8) | 5.7 (0.8 – 24.0) | 4.6 (0.6-16.1) | 4.0 (0.6-3.0) | 3.2 (0.5-8.3) |
| *p-value*[a] | 0.092 | 0.259 | 0.585 | 0.878 | 0.099 | 0.294 |
| **Parent's Education Level** | | | | | | |
| Low | 33.3 (0.0-137.9) | 9.8 (0.0-55.8) | 5.5 (0.8-24.0) | 4.4 (0.6-16.1) | 4.0 (0.6-13.2) | 3.1 (0.5-9.7) |
| High | 31.5 (0.0-139.5) | 7.5 (0.0-35.2) | 7.8 (0.8-23.5) | 5.5 (1.2-15.7) | 4.9 (1.0-14.4) | 3.7 (0.7-9.0) |
| *p-value*[a] | 0.758 | 0.876 | <0.001* | 0.001* | <0.001* | <0.001* |
| **Economic Status** | | | | | | |
| Low | 33.8 (0.0-136.0) | 10.7 (0.0-40.7) | 5.0 (0.8-20.1) | 4.1 (0.8-16.1) | 3.8 (0.6-13.2) | 3.1 (0.5-7.5) |
| Medium | 31.7 (0.0-139.5) | 9.7 (0.0-55.8) | 6.0 (0.8-23.5) | 4.7 (0.6-14.9) | 4.5 (0.7-13.0) | 3.3 (0.6-9.7) |
| High | 31.3 (0.0-110.9) | 9.0 (0.0- 40.1) | 7.7 (1.6-24.0) | 5.2 (1.5-15.7) | 4.8 (1.7-14.4) | 3.4 (1.3-9.0) |
| *p-value*[b] | 0.701 | 0.266 | <0.001* | 0.003* | <0.001* | 0.003* |

*Significance at p-value <0,05; Mann-Whitney Test[a] and Kruskal-Wallis[b].

Demographic factors, such as place of residence, education level, and economic status, did not show significant differences in added sugar intake. These findings are consistent with those of the National Socioeconomic Survey (SUSENAS) conducted by the Central Statistics Agency (BPS) in 2014[36]. Children from rural and urban areas, whose parents have varying levels of education or economic status, consume similar amounts of added sugar. There are several potential reasons for these results. First, the study only covered one province within Java Island, so physical access and food availability were similar. Second, sugary foods are available at different price points, ranging from inexpensive to expensive, which means anyone can access them.

In contrast to added sugar intake, parental education level and economic status significantly affect iron and zinc intake in children. Individuals with higher economic status tend to have a diet with less carbohydrate consumption and replace it with protein and fat sources such as meats[37]. Most iron and zinc sources come from protein sources such as meat, fish, seafood, and poultry, which have a relatively higher price. Individuals with higher economic status have greater access to these types of foods. Higher education is also related to higher income, so greater economic access exists[38].

**Association of Added Sugar Consumption with Iron and Zinc Intake**

The results of the bivariate test in Table 4 show that the intake of the added sugar group had a significant association with the absolute value and density of iron and zinc intake (p<0.05). There was an inverse association between added sugar intake and micronutrients. As the intake of the added sugar group increased, there was a significant decrease in iron and zinc intake both in absolute and density (Figure 2).

Based on further tests by using post hoc analysis presented in Table 4, there were no significant differences in iron intake in absolute nor density in subjects with added sugar intake <5%E (C1) to 15-20%E (C4). Significant differences were shown in subjects with added sugar intake ≥20% E (C5 and above). Furthermore, there were no significant differences in zinc intake in absolute value nor density in subjects with the added intake of sugar <5%E (C1) to 10-15%E (C3). Significant differences in zinc density were shown only between



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subjects by added sugar intake <10%E (C1 and C2) and 15-20%E (C4) only. Overall, subjects with the most optimal intake of iron and zinc, both in absolute value and density, were found in the first three groups (C1-C3), with intake of added sugar <15%E.

**Table 4.** Association between Added Sugar and Micronutrients Intake

| Micronutrient | Percent of Energy from Added Sugar Intake# (median (min-max)) | | | | | | p-value |
|---|---|---|---|---|---|---|---|
| | C1 | C2 | C3 | C4 | C5 | C6 | |
| **Iron** | | | | | | | |
| Absolute (mg/day) | 7.1 (2.5-24.0)$^{a}$ | 7 (1.2-22.3)$^{a}$ | 5.2 (1.5-23.5)$^{a.b}$ | 5.5 (1.0-17.1)$^{a.c}$ | 3.7 (0.8-11.5)$^{b.c}$ | 3.2 (1.2-19.8)$^{c}$ | <0.001* |
| Density (per 1000 kcal) | 5.2 (2.0-16.1)$^{a}$ | 5.1 (0.8-13.6)$^{a}$ | 4.4 (1.4-15.7)$^{a.b}$ | 4.6 (0.6-9.1)$^{a.c}$ | 3.5 (0.9-10.8)$^{b.c}$ | 2.7 (1.1-0.5)$^{c}$ | <0.001* |
| **Zinc** | | | | | | | |
| Absolute (mg/day) | 4.8 (0.6-13.1)$^{a}$ | 4.6 (0.7-14.4)$^{a}$ | 4.1 (0.7-10.8)$^{a.b}$ | 3.5 (0.7-13.2)$^{b}$ | 2.9 (0.8-9.0)$^{b}$ | 3.5 (1.2-7.8)$^{a.b}$ | <0.001* |
| Density (per 1000 kcal) | 3.5 (0.5-9.0)$^{a}$ | 3.3 (0.7-9.7)$^{a}$ | 3.1 (0.6-8.2)$^{a.b}$ | 2.7 (0.6-5.9)$^{b}$ | 2.8 (0.9-8.4)$^{a.b}$ | 2.8 (1.1-7.6)$^{a.b}$ | 0,001* |

#C1 (<5%E), C2 (5%E - <10%E), C3 (10%E - <15%E), C4 (15%E - <20%E), C5 (20%E - 25%E), C6 (>25%E)
*Significance at p-value <0.05; Kruskall-Wallis test.
Post hoc analysis using Dunn-Bonferroni post hoc. Different *superscripts* $^{a, b,}$ and $^{c}$ showed a significantly different group.

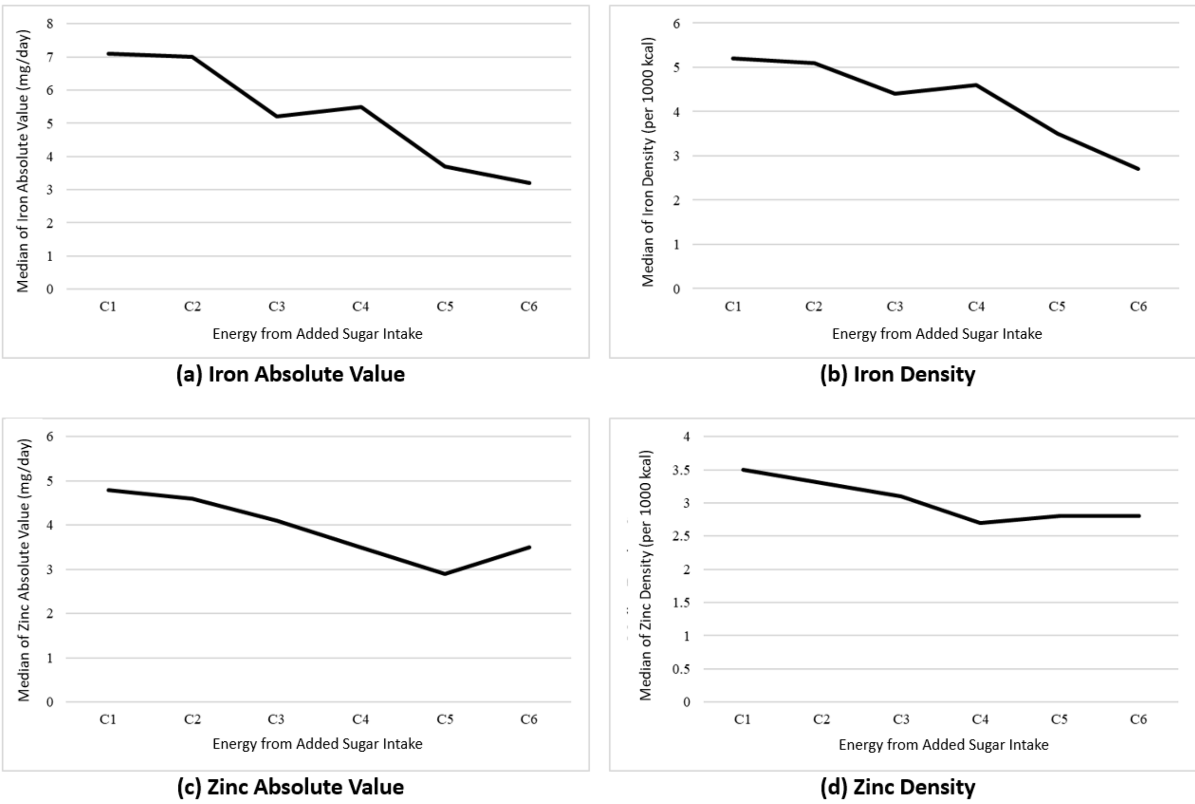


**Figure 2.** Chart of Decreasing Trend of Micronutrient Intake based on Added Sugar Intake

This study demonstrates that children aged 24-59 months experience a significant decrease in both absolute and nutrient density of iron and zinc intake, consistent with the micronutrient dilution hypothesis presented in previous studies[17,23]. The reduction in micronutrient intake due to added sugar intake can be attributed to two reasons. First, added sugar intake significantly increases total energy intake without contributing to adding essential nutrients, thereby lowering nutrient density intake[32]. Second, a systematic review has concluded that added sugar intake, beyond a certain level, affects the decrease of other nutrient intake and diet quality[19]. Some studies have highlighted that increased added sugar intake, especially in children, has been linked to a decrease in nutrient-dense food intake such as meat, fish, eggs, grains, fruits, vegetables, and milk[17,19,23–25]. Meat, fish, grains, and vegetables are the primary sources of iron and zinc. Previous studies also



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suggest that the reduced micronutrient intake associated with increased added sugar intake may be more significant and vulnerable in children than adults, as adults can consume more calories and a wider variety of food than children[20].

Substituting nutrient-dense foods with high-sugar foods can create a continuous desire for consumption. Physiologically, the brain system, oral cavity, and digestive tract have potential mechanisms for sweet taste that affect preferences and the level of acceptance of these types of food[39]. Increased sugar intake can affect changes in the nervous system. Sweetened foods and drinks have a high palatability level that can affect dopamine, opioid, and serotonergic receptors through the mesolimbic and mesocortical pathways, which are associated with the activation of the reward system in the brain[40]. These receptors have mechanisms similar to drug addiction and can trigger increased consumption to replace or reduce other food intake[39]. Furthermore, a review showed that the sweet taste signal in the oral cavity and intestine is related to hormonal and metabolic responses in the nerve that regulates the hunger-satiety cycle. It can affect food intake and appetite[41]. High-palatability foods also tend to blunt the response to satiety signals by increasing the time needed to achieve satiety. Additionally, the form of added sugar intake is related to the level of satiety produced[40].

High added sugar intake, especially in the form of drinks, has significantly reduced whole foods intake. Sweetened drinks provide calorie contributions in liquid form, also known as liquid calories. Calories in liquid form have a different response; they are digested faster than solid ones. It is related to a lower level of satiety when consumed. The characteristics of sweetened drinks, which produce low levels of satiety, combined with their tendency to cause addiction, increase the risk of excessive consumption of sweetened drinks[39,42]. In this study, we found that subjects in the highest added sugar intake group almost entirely consumed sweetened drinks such as sweet tea, packaged drinks (flavoured tea and milk), and sweetened condensed milk with a frequency of more than three times a day, which is considered frequent compared to other subjects. Studies in several other countries also show that sweetened drinks are the most significant contributor to added sugar intake[43].

A significant decrease in iron intake occurred in the group with added sugar intake ≥20%E (C5 and above), while zinc occurred in the group with added sugar intake ≥15%E (C4 and above). Compared to previous studies, the threshold for added sugar intake associated with decreased micronutrient intake in subjects in this study (≥15-20%E) is higher than that of children in Japan (≥5%E)[17]. However, it shows similar thresholds to studies on children in Australia and England (>13-20%E)[18,26]. Differences in mean added sugar intake in each population may influence this. Japanese children have a lower mean added sugar intake (6%E)[17], while Australian and English children have a mean added sugar intake of >11.5%E, almost the same as the results of this study, which is 9.72%E[18,26]. The variation in eating patterns and habits in each population makes the intake different based on availability, culture, and food preferences among populations[44]. Differences in the definition of sugar used in each study can also contribute to differences in each result[45].

The absolute and nutrient density values of zinc did not show significant differences between the C6 and C1 groups. These results differ from those obtained for iron and most other studies. Findings showed that subjects in the >25% E (C6) added sugar intake group in this study almost entirely consumed sweetened condensed milk. Food labels on the sweetened condensed milk products consumed by subjects in this study indicated the addition or fortification of vitamins and minerals, including zinc, but not iron. Fortified sugary foods may compensate for the dilution effect caused by high added sugar intake[10,46]. The infant formula consumed by subjects in this study was also fortified with micronutrients. However, it did not compensate for the dilution effect due to its lower added sugar content than sweetened condensed milk.

**Association of Added Sugar Intake with Iron and Zinc Inadequacy Controlled by Parent's Education Level and Economic Status**

Table 5 shows the risk of iron and zinc intake inadequacy based on the level of added sugar intake after being controlled by the parent's education level and economic status. Subjects with higher levels of added sugar intake were at greater risk of experiencing inadequate iron intake. The added sugar intake was significantly related to the risk of iron inadequacy in the last three groups (C4-C6) or subjects with added sugar intake ≥15%E. Intake of added sugar>25%E (C6) had the greatest OR of iron inadequacy. The increased risk of zinc inadequacy also occurred as added sugar intake increased. Added sugar intake was significantly associated with the risk of zinc inadequacy in the last four groups (C3-C6) or subjects with added sugar intake ≥10%E. Subjects with added sugar intake >20%-25%E (C5) had the greatest OR in zinc inadequacy.

An increased risk of inadequate iron and zinc intake was significantly associated with increased added sugar intake. Studies in Australia and Japan also showed that the highest prevalence of inadequate intake of most micronutrients occurred in groups with the highest added sugar intake[17,18]. The findings reveal that subjects in the high added sugar group have an unbalanced food intake. There were even some subjects who only consumed dairy products and snacks in a day. The consumption of animal protein sources, plant-based sources, vegetables, and fruits in subjects could have been much higher and needed more variety. Most snacks were processed foods such as wafers, biscuits, jelly, and sweet bread or cakes with high added sugar but low micronutrient content. The selection of unbalanced food types certainly affects the fulfilment of micronutrients.

Based on this study, children with added sugar intake ≥15%E were at higher risk of inadequate iron and zinc intake. Previous studies examining the relationship between added sugar intake and obesity indicate that children with added sugar intake ≥10%E were at 2.57 times higher risk of being overweight than children with added sugar intake <10%E[47]. Although this study did not analyze the nutritional status variable, the results raised



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concerns about the high possibility that high added sugar intake is related to obesity accompanied by micronutrient deficiency. The long-term effects of inadequate micronutrient intake, especially iron and zinc, in children include an increased risk of stunting, decreased productivity, susceptibility to infections, disrupted growth, and increased mortality rates[4,48]. In addition, micronutrient deficiencies are progressive and cannot be clinically identified if they have not reached the final stage[49].

**Table 5.** Association between Added Sugar Intake with Inadequacy of Iron and Zinc Intake Controlled by Parent's Education Level and Economic Status

| Nutrient Intake | Percent of Energy from Added Sugar Intake# | | | | | | p-value |
|---|---|---|---|---|---|---|---|
| | C1 | C2 | C3 | C4 | C5 | C6 | |
| | Ref | OR (95%CI) | OR (95%CI) | OR (95%CI) | OR (95%CI) | OR (95%CI) | |
| **Below EAR** | | | | | | | |
| Iron | 1 | 1.36 (0.44 – 4.18) | 2.19 (0.73 – 6.58) | 3.33 (1.06 – 10.49) | 10.46 (3.04 – 35.92) | 19.54 (5.70 – 66.96) | <0.001* |
| Zinc | 1 | 2.24 (0.98 – 5.10) | 2.54 (1.08 – 5.93) | 4.49 (1.84 – 10.95) | 6.48 (2.23 – 18.78) | 3.3 (1.07 – 10.21) | 0.006* |

#C1 (<5%E), C2 (5%E - <10%E), C3 (10%E - <15%E), C4 (15%E - <20%E), C5 (20%E - 25%E), C6 (>25%E)
*Significance at p-value <0.05: logistic regression test after controlled with covariate variable: level of education and economic status.

This study had several limitations. The Nutrisurvey Indonesia software and IFCT 2017, used as data analysis tools for intake, do not provide detailed information on types of sugar such as total sugar, added sugar, lactose, and fructose. These limitations might affect the accuracy of estimating added sugar intake, which was the focus of this study.

The research findings demonstrate compliance with the World Health Organization's (WHO) recommendations to limit added sugar intake to less than 10% of energy intake to prevent adverse effects from excessive consumption. This study offers a new perspective on the adverse impacts of excessive added sugar intake among children, which has been proven to be associated with decreased iron and zinc intake. While this study highlights the relationship between added sugar intake and reduced micronutrient intake, it is essential to emphasize that a balanced nutrient intake is necessary to ensure optimal micronutrient and dietary quality for children. Consuming nutrient-dense foods, including three main meals and two snacks per day consisting of whole foods that provide sources of carbohydrates, animal protein, fats, vitamins, and minerals, is required.

This study found that sweetened condensed milk may help meet micronutrient intake through fortification. However, prioritizing the micronutrient intake from sugary fortified products like sweetened condensed milk is not recommended. The consumption of sweetened condensed milk should be limited to a maximum of one serving per day, while formula milk should be consumed one to two servings per day. The remaining daily energy needs should be met by prioritizing main meals and snacks with balanced nutrition principles for children aged 24-59 months.

## CONCLUSIONS

Higher levels of added sugar intake are significantly associated with decreased iron and zinc intake in children aged 24-59 months in Central Java Province, which showed the occurrence of micronutrient dilution. Further research can examine the relationship between added sugar intake and the potential emergence of obesity problems accompanied by micronutrient deficiencies.

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