

# Safety and Quality of Locally Processed Dark and White Chocolate Bars from Small-Scale Industries in West Java, Indonesia

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## Research Article

**Keywords:** Chocolate safety, Microbiological quality, Artisanal chocolate, ICP-MS, West Java, BPOM, Indonesian

**Posted Date:** April 24th, 2026

**DOI:** <https://doi.org/10.21203/rs.3.rs-9304149/v1>

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**Additional Declarations:** No competing interests reported.

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# Abstract

**Background:** Indonesia is experiencing a swift expansion in the production of artisanal chocolates, yet peer-reviewed safety data are scarce for these small-scale products. As one of the leading global cocoa producers, Indonesia has implemented a downstream cocoa-processing policy that has spurred the growth of artisanal chocolate production in West Java. This development has created an urgent need for a systematic baseline safety assessment.

**Methods:** Twelve chocolate bars (six dark and six white) from six small-scale brands in three districts of West Java (Cianjur, Bandung, Sukabumi) were analyzed in triplicate. ISO 4833-1:2013, ISO 21527-2:2008, and ISO 6579-1:2017 were used to determine the Total Viable Count (TVC), Total Yeast and Mould Count (TYMC), and *Salmonella* spp., respectively. The amount of lead (Pb) and cadmium (Cd) was determined using ICP-MS according to AOAC Official Method 2013.06. Adherence was evaluated against BPOM, Codex Alimentarius, and EU regulatory limits.

**Results:** All samples met BPOM microbiological standards: TVC ranged from  $2.3 \times 10^3$  to  $4.0 \times 10^3$  CFU/g (limit  $\leq 1.0 \times 10^4$  CFU/g) and TYMC from  $1.2 \times 10^2$  to  $8.5 \times 10^2$  CFU/g (limit  $\leq 5.0 \times 10^3$  CFU/g). All 25-g test portions were negative for *Salmonella* spp. Lead was within BPOM limits across all samples (dark chocolate mean:  $0.098 \pm 0.041$  mg/kg; white:  $0.038 \pm 0.012$  mg/kg). Nonetheless, six dark chocolate brands and a white chocolate sample (Brand C) had higher BPOM cadmium levels than 0.10 mg/kg ( $0.168 \pm 0.034$  mg/kg), with a strong correlation with cocoa solids content ( $r = 0.92$ ,  $p < 0.05$ ).

**Conclusion:** All brands demonstrated effective microbiological control and lead management. Cadmium contamination poses a systemic risk within the supply chain, stemming from the volcanic geochemistry of West Java's soil. To ensure artisanal dark chocolate complies fully with regulations, it is crucial to implement specific actions, including managing soil pH, using cocoa genotypes with low cadmium levels, mandating cadmium testing on farms, and modifying formulations.

## 1 Introduction

Chocolate is one of the most common confectionery items in the world, produced through a multi-step manufacturing process from *Theobroma cacao* beans [1, 2]. Indonesia is also a leading producer of cocoa worldwide, with West Java the top producer, along with other regions in Indonesia, ranking among the three largest producers [3, 4]. The downstream cocoa-processing policy has stimulated a boom in artisanal and small-scale chocolate production, especially in West Java [5, 6].

Meanwhile, consumer demand worldwide is also shifting towards high-end, single-origin dark chocolate items that are rich in cocoa, have a unique regional flavor profile, and are claimed to offer antioxidant health benefits [7]. The combination of supply-side policies and demand-side trends has created significant commercial opportunities for small-scale producers in equatorial cocoa-producing areas. The processing of cocoa beans into chocolate involves a series of unit operations: fermentation, drying,

roasting, conching, and tempering, which affect the sensory, nutritional, and food-safety properties of the final product [8, 9].

In international trade, chocolate must comply with minimum composition standards prescribed by the Codex Alimentarius Commission under Codex Stan 87-1981: dark chocolate should contain at least 35% cocoa solids, and white chocolate should contain at least 20% cocoa butter [10, 11]. All six brands surveyed in this paper, with dark chocolate cocoa contents of 55–85% and white chocolate cocoa butter contents of 20–32%, satisfied these minimum standards but exhibited significant formulation variability that directly relates to heavy metal accumulation, as discussed in this paper. Small-scale artisanal chocolate producers often lack access to certified laboratory testing, HACCP systems, and systematic contamination-management systems. In contrast, large-scale industrial chocolate manufacturers are subject to strict regulatory control. [12, 13].

The microbiological risks here are bacteria, yeasts, and molds introduced during post-roasting handling, packaging, and storage. The *Salmonella* spp. is the priority bacterium hazard in chocolate: the low water activity ( $a_{ww} = 0.40.5$ ) and high fat content of the product provide a protective hydrophobic microenvironment in which *Salmonella* can survive months under conditions that would not promote its growth. [14, 15]. High-fat matrices have a low infective dose of 1–10 CFU/g. In a review of the literature on the topic, at least 12 large chocolate-related *Salmonella* outbreaks between 1970 and 2022 were reported, with more than 3,266 cases confirmed, and the 2022 *Salmonella* Typhimurium outbreak in the European Union led to massive product recalls [16, 17]. Yeasts and molds are other biological risks: the higher residual moisture of dark chocolate, due to the cocoa solids, creates slightly more favorable conditions for fungal growth, and some species of *Aspergillus* and *Penicillium* can also produce ochratoxin A and aflatoxins under favorable humidity conditions[18]. The long-term cumulative health hazards associated with chemical contamination of chocolate with heavy metals (mainly lead (Pb) and cadmium (Cd)) have been of global regulatory interest. The environmental sources of lead contamination in cocoa are mainly post-harvest: open sun-drying of cocoa beans on the ground exposes them to soil particles, atmospheric lead dust, and vehicle emissions, and increases in Pb content (2 to 10-fold) during fermentation and drying have been documented.[19].

Cadmium, in its turn, is largely geogenic: cocoa tree roots take up Cd-enriched volcanic soils and accumulate it in the cotyledon (nib) fraction, so that, upon harvesting, no amount of handling can decontaminate it. The disproportionate heavy metal load falls on dark chocolate, since the two metals are concentrated in the cocoa solids rather than in the cocoa butter. [21, 22].

A multi-year examination of 72 United States cocoa products found that 43 percent of the products contained excessive amounts of Pb and 35 percent contained excessive amounts of Cd. [23, 24]. European and Latin American statistics indicate the same patterns in volcanic-soil production areas [25, 26]. In countries with EU regulations that set tiered Cd limits (0.10–0.80 mg/kg based on cocoa content), the Indonesian BPOM now has a single, more conservative limit of 0.10 mg/kg across all chocolate types, placing Indonesian standards among the most protective in the world [27, 28].

Although the locally produced chocolate bars in West Java are growing at an exceptionally high rate, no peer-reviewed article has yet described the microbiological or chemical safety of these bars, leaving an evidence vacuum that manufacturers, consumers, and regulatory bodies urgently need to close. The present study fills this gap by means of four tasks: (i) to identify TVC as a general processing hygiene indicator; (ii) to estimate TYMC; (iii) to measure *Salmonella* spp. prevalence as a microbiological safety indicator; and (iv) to quantify the levels of Pb and Cd and determine adherence to BPOM and international standards in six small-scale brands within three districts of

## 2 Materials and Methods

### 2.1 Study *Design and Sample Collection*

The research employed a cross-sectional survey design. Six small-scale producers, identified through purposive sampling, were chosen from three districts in West Java Province: Cianjur (Brands A and B), Bandung (Brands C and D), and Sukabumi (Brands E and F). These producers were selected based on BPOM registration and the presence of both dark and white chocolate lines. Samples were ordered online from the producers' official stores between January 2 and February 2025. They were transported in insulated boxes and stored in sterile polyethylene bags at 25–27°C, in accordance with SNI 2891:2023 guidelines. A total of 12 samples, consisting of one dark chocolate bar and one white chocolate bar from each brand, were collected and analyzed in triplicate. The cocoa content was determined using the ingredient list on the product label, in accordance with BPOM Regulation No. 31 of 2018.

A summary of the sampled brands is provided in Table 1.

Table 1  
Characteristics of chocolate samples from six small-scale brands in West Java, Indonesia

| Brand | District | Dark Chocolate Cocoa Content (%) | White Chocolate Cocoa Butter Content (%) |
|-------|----------|----------------------------------|------------------------------------------|
| A     | Cianjur  | 70                               | 28                                       |
| B     | Cianjur  | 65                               | 25                                       |
| C     | Bandung  | 85                               | 32                                       |
| D     | Bandung  | 60                               | 22                                       |
| E     | Sukabumi | 75                               | 30                                       |
| F     | Sukabumi | 55                               | 20                                       |

### 2.2 Total Viable Count (ISO 4833-1:2013)

The total viable count was assessed using the pour-plate technique as outlined in ISO 4833-1:2013, with modifications to accommodate the low-moisture, high-fat chocolate matrix. The primary dilution (10 – 1) involved homogenizing 1.0g of the sample in 9 mL of sterile 0.1% (w/v) peptone water. Subsequent

serial dilutions ( $10^{-2}$  to  $10^{-6}$ ) were created by transferring 1 mL into fresh 9 mL peptone water blanks. Each corresponding dilution (1 mL) was inoculated twice onto pre-cooled Plate Count Agar (PCA; Oxoid, UK) maintained at  $45 \pm 1^\circ\text{C}$ , and the plates were incubated at  $30 \pm 1^\circ\text{C}$  for  $72 \pm 1$  hours. A digital colony counter was employed to count the colonies, with only plates containing 30–300 colonies considered valid. The results were expressed as CFU/g.

## 2.3 Yeast and Mould Count (ISO 21527-2:2008)

The listing of yeasts and molds in ISO 21527-2:2008 was used when the product's aw was below 0.95. A  $10^{-1}$  dilution was made by stomaching (60 s) 10 g of the sample in 90 mL of sterile 0.1% (w/v) water containing peptone. The duplicate surface spread (0.1 mL on each plate) was done on Dichloran Rose Bengal Chloramphenicol Agar (DRBC; Oxoid, UK). Plates were incubated for 5 days at  $25 \pm 1^\circ\text{C}$  in the dark to avoid light-induced effects on the Bengal rose dye. A total of 10 to 150 colonies were counted on yeast and mould plates, respectively, with the yeast colonies being cream-white, smooth, and glistening. The results were reported in CFU/g; the limit of detection was 10 CFU/g.

## 2.4 Salmonella spp. Detection (ISO 6579-1:2017)

Detection of *Salmonella* spp. was conducted in accordance with ISO 6579-1:2017 guidelines, with modifications tailored to the low-moisture, high-fat chocolate matrix. The process involved four stages: (i) pre-enrichment 25 g of homogenized chocolate was mixed with 225 mL of Buffered Peptone Water (BPW; Oxoid, UK) and incubated at  $37 \pm 1^\circ\text{C}$  for  $18 \pm 2$  hours; (ii) selective enrichment surface inoculation was performed on Modified Semi-solid Rappaport-Vassiliadis (MSRV; Oxoid, UK) agar, incubated at  $41.5 \pm 1^\circ\text{C}$  for 24 to 48 hours; (iii) selective plating the edge of the migration halo was streaked onto Xylose Lysine Deoxycholate (XLD; Oxoid, UK) agar at  $37 \pm 1^\circ\text{C}$  for  $24 \pm 3$  hours; and (iv) biochemical and serological confirmation suspected colonies were verified on Triple Sugar Iron (TSI) agar and Lysine Iron Agar (LIA; Oxoid, UK) at  $37 \pm 1^\circ\text{C}$  for 24 hours, followed by serological confirmation using polyvalent O and H *Salmonella* antisera (Denka Seiken, Japan). Results were recorded as either detected or not detected per 25 g.

## 2.5 Heavy Metal Analysis (ICP-MS)

The ICP-MS at the Saraswanti Indo Genetech (SIG) Laboratory, Bogor, Indonesia, was used to determine the concentrations of lead (Pb) and cadmium (Cd) using the AOAC Official Method 2013.06. About 0.5 g of the homogenized sample was microwave-assisted digested (CEM MARS 6, CEM Corporation, USA) with 8 mL of concentrated  $\text{HNO}_3$  (TraceSELECT 2000, Merck) and 2 mL of  $\text{H}_2\text{O}_2$  (30 percent, Merck, Germany), followed by a dilution to 50 mL using ultrapure water. Agilent 7900 ICP-MS (Agilent Technologies, USA) was used to quantify the samples using bismuth ( $^{209}\text{Bi}$ ) as the internal standard to eliminate signal drift and matrix effects. Pb and Cd were quantified at m/z 208 and 111, respectively [29, 30]

## 2.6 Statistical Analysis

All experiments were conducted in triplicate. The results are shown as mean  $\pm$  95% SD and were analyzed using one-way ANOVA (IBM SPSS Statistics v26.0) followed by Tukey HSD post-hoc test at an alpha level of 0.05. The Pearson correlation coefficient (r) was employed to assess the association between cocoa solids content and heavy metal levels. The findings were compared with BPOM Regulation No. 13/2019, Codex Alimentarius Commission standards, and EU Regulation 2023/915.

## 3 Results and Discussion

### 3.1 Cocoa Content Profile

The dark chocolate contained a minimum of 55% (Brand F) and a maximum of 85% (Brand C) of cocoa content, which was determined based on the ingredient declarations in product labels in compliance with the BPOM Regulation No. 31 of 2018, with a mean of  $68.3 \pm 10.8\%$  (Table 1). The content of the white chocolate cocoa butter was 20–32 (Brand F), 26.2  $\pm$  4.6 (Brand C) on average. All dark chocolate samples had at least 35 percent cocoa solids as required by Codex Stan 87-1981, and all white chocolate samples had at least 20 percent cocoa butter as required by Codex Stan 87-1981. The significant inter-brand difference is due to the difference in product formulation and market positioning: Brand C has a premium artisanal positioning with 85% of dark and 32% of white (Brand C), whereas Brand F is a low-end formulation with 55% of dark and 20% of white (Brand C). Such a difference in the cocoa content is of crucial analytical significance as cocoa solids and cocoa butter are the major matrices in which the heavy metals are concentrated in chocolate products, which shall be investigated in some detail in Sections 3.4 and 3.5 below.

### 3.2 Total Viable Count (TVC)

The 12 samples met the BPOM regulatory limit of  $\leq 1.0 \times 10^4$  CFU/g (Table 2). Dark chocolate TVC ranged from  $2.5 \pm 0.4 \times 10^3$  (Brand F) to  $4.0 \pm 0.7 \times 10^3$  CFU/g (Brand E); overall mean  $3.2 \pm 0.6 \times 10^3$  CFU/g. White chocolate TVC ranged from  $2.3 \pm 0.3 \times 10^3$  (Brand F) to  $3.8 \pm 0.6 \times 10^3$  CFU/g (Brand E); mean  $3.0 \pm 0.5 \times 10^3$  CFU/g. There was no significant difference in chocolate types ( $p = 0.05$ ); however, there was a significant difference between brands ( $p = 0.05$ ). The values of all TVC were within 2340 percent of the BPOM maximum, suggesting proper implementation of GMP across the sector. The natural physicochemical characteristics of chocolate, as a rule, are not favorable to the growth of microorganisms: low  $a_w$  (0.4–0.5), high sugar concentration, and polyphenolic activity that is bacteriostatic. [31, 32]. Roasting cocoa at 120/150 °C yields a 46-log reduction in vegetative bacteria, which is sufficient to destroy most of the original microflora [32]. The values of West Java TVC were favorable compared with Italian retail chocolate ( $2.5 \times 10^3$  –  $8.5 \times 10^4$  CFU/g; 15–25% of samples exceeded the regulatory limits) [24] and Bangladeshi commercial chocolate ( $2.2$ – $3.1 \times 10^3$  CFU/g) [33]. Brand E's elevated TVC ( $4.0 \pm 0.7 \times 10^3$  CFU/g dark;  $3.8 \pm 0.6 \times 10^3$  CFU/g white) may reflect suboptimal post-roasting hygiene or storage conditions, whereas Brand F's consistently low counts ( $2.5 \pm 0.4 \times 10^3$ ;  $2.4 \pm 0.3 \times 10^3$  CFU/g) represent best practice. The difference between the inter-brand television

commercials (Brand F or Brand E) (1.6-fold) is in line with reported differences in post-roasting handling hygiene and facility ventilation between small-scale producers [35, 36].

Table 2  
Total Viable Count (TVC) in dark and white chocolate bars by brand (CFU/g; mean  $\pm$  SD, n = 3)

| Brand | Dark Chocolate (Mean $\pm$ SD)        | White Chocolate (Mean $\pm$ SD)                | BPOM Limit (CFU/g)     | Compliance |
|-------|---------------------------------------|------------------------------------------------|------------------------|------------|
| A     | $3.4 \pm 0.5 \times 10^3$ $\boxtimes$ | $3.1 \pm 0.4 \times 10^3$ $\boxtimes$          | $\leq 1.0 \times 10^4$ | ✓          |
| B     | $2.8 \pm 0.4 \times 10^3$ $\boxtimes$ | $2.3 \pm 0.3 \times 10^3$ $\boxtimes$          | $\leq 1.0 \times 10^4$ | ✓          |
| C     | $3.5 \pm 0.6 \times 10^3$ $\boxtimes$ | $3.2 \pm 0.5 \times 10^3$ $\boxtimes$          | $\leq 1.0 \times 10^4$ | ✓          |
| D     | $2.9 \pm 0.5 \times 10^3$ $\boxtimes$ | $2.7 \pm 0.4 \times 10^3$ $\boxtimes\boxtimes$ | $\leq 1.0 \times 10^4$ | ✓          |
| E     | $4.0 \pm 0.7 \times 10^3$ $\boxtimes$ | $3.8 \pm 0.6 \times 10^3$ $\boxtimes$          | $\leq 1.0 \times 10^4$ | ✓          |
| F     | $2.5 \pm 0.4 \times 10^3$ $\boxtimes$ | $2.4 \pm 0.3 \times 10^3$ $\boxtimes$          | $\leq 1.0 \times 10^4$ | ✓          |
| Mean  | $3.2 \pm 0.6 \times 10^3$             | $3.0 \pm 0.5 \times 10^3$                      | $\leq 1.0 \times 10^4$ | 100%       |

Table 2. Microbiological safety of 6 West Java artisanal chocolate brands: all TVC counts (CFU/g) met BPOM limits; Brand E was the highest, Brand F the lowest.

### 3.3 Total Yeast and Mould Count (TYMC)

Table 3 shows the TYMC results. All samples were within the BPOM limit of  $\leq 5.0 \times 10^3$  CFU/g. Dark chocolate TYMC ranged from  $1.5 \pm 0.5 \times 10^2$  (Brand F) to  $8.5 \pm 2.8 \times 10^2$  CFU/g (Brand E); white chocolate from  $1.2 \pm 0.4 \times 10^2$  to  $6.2 \pm 2.2 \times 10^2$  CFU/g. Compared to white chocolate, dark chocolate always exhibited a much higher TYMC ( $p < 0.05$ ), which is due to the higher residual moisture and organic nutrient level in cocoa solids, which marginally favored the growth of fungi [37, 38]. A considerable difference between brands was identified ( $p < 0.05$ ); Brand E has higher counts than the other brands, and Brand F has lower counts, which align with the TVC trends of the two brands, indicating a shared hygiene infrastructure determinant. Even though all TYMC values were still very low (maximum of  $8.5 \times 10^2$  CFU/g versus limit of  $5.0 \times 10^3$  CFU/g; i.e., 17% of the limit), the consistent presence of fungal propagules should be actively monitored since *Aspergillus* and *Penicillium* species are under the influence of high post-packaging conditions. It has been revealed by Gachara et al. [38] that the mycotoxin-producing molds, especially ochratoxin A-elaborating strains of *Aspergillus ochraceus* and aflatoxin-producing *Aspergillus flavus*, can survive in low-moisture food matrices and recover mycotoxigenicity if the relative humidity increases beyond Manufacturers are thus recommended to package the product in a container with water-vapor transmission rates  $\leq 0.5\text{g/m}^2/\text{day}$ , and store them at temperatures below 20°C. West Java TYMC values were found at the lower end of the international range: Ecuadorian artisanal cocoa products had TYMC of  $1.0 \times 10^2$ – $2.0 \times 10^2$ . The TYMC found in the current study is relatively low, which is attributed to the control of the roasting temperature and the

high antifungal polyphenol content of the dark cocoa solids, which prevent the germination of the spores under the influence of oxidative stress [38, 40]

Table 3  
Total Yeast and Mould Count (TYMC) in dark and white chocolate bars by brand (CFU/g; mean ± SD, n = 3)

| Brand | Dark Chocolate (Mean ± SD)    | White Chocolate (Mean ± SD)    | BPOM Limit (CFU/g)      | Compliance |
|-------|-------------------------------|--------------------------------|-------------------------|------------|
| A     | 5.2 ± 1.8 × 10 <sup>2</sup> ☒ | 3.8 ± 1.5 × 10 <sup>2</sup> ☒☒ | ≤ 5.0 × 10 <sup>3</sup> | ✓          |
| B     | 3.5 ± 1.2 × 10 <sup>2</sup> ☒ | 2.8 ± 1.0 × 10 <sup>2</sup> ☒  | ≤ 5.0 × 10 <sup>3</sup> | ✓          |
| C     | 6.8 ± 2.5 × 10 <sup>2</sup> ☒ | 4.5 ± 1.8 × 10 <sup>2</sup> ☒  | ≤ 5.0 × 10 <sup>3</sup> | ✓          |
| D     | 3.2 ± 1.0 × 10 <sup>2</sup> ☒ | 2.5 ± 0.8 × 10 <sup>2</sup> ☒  | ≤ 5.0 × 10 <sup>3</sup> | ✓          |
| E     | 8.5 ± 2.8 × 10 <sup>2</sup> ☒ | 6.2 ± 2.2 × 10 <sup>2</sup> ☒  | ≤ 5.0 × 10 <sup>3</sup> | ✓          |
| F     | 1.5 ± 0.5 × 10 <sup>2</sup> ☒ | 1.2 ± 0.4 × 10 <sup>2</sup> ☒  | ≤ 5.0 × 10 <sup>3</sup> | ✓          |
| Mean  | 4.8 ± 2.1 × 10 <sup>2</sup>   | 3.6 ± 1.8 × 10 <sup>2</sup>    | ≤ 5.0 × 10 <sup>3</sup> | 100%       |

Table 3. Yeast & mould counts (CFU/g) across 6 West Java chocolate brands are all 100% compliant with BPOM limit; dark chocolate is higher than white; Brand E is the highest, Brand F is the lowest.

### 3.4 Detection of Salmonella spp.

Salmonella spp. was not identified in all 12 samples (Table 4), with 100% agreement with the BPOM requirement of none in 25 g. This is an important finding, considering that chocolate presents a particularly challenging food-safety environment: low aw and high fat form a hydrophobic microenvironment that shields Salmonella against thermal inactivation and environmental stress, allowing it to survive long periods under conditions that would otherwise be unfavorable to growth [14, 41]. High-fat foods have one of the lowest infective doses of 1–10 CFU/g [42, 43]. The lack of Salmonella in all brands could be explained by two control factors: (1) effective thermal inactivation of the pathogen during cocoa roasting: temperatures 120 °C and above in over 5 min are sufficient to achieve a log 6 reduction in cocoa products [9, 44], more than sufficient to affect the pathogen; and (2) the low aw of the final product, which does not support the growth of These results are consistent with the work of Bangladesh and Ghana, which proved that the small-scale manufacturers can manage the pathogens with basic hygiene controls in the first place, the appropriate roasting temperature confirmation, and post-roasting prevention of the cross-contamination [45, 46]. Nevertheless, given that Campagnollo et al. [46] reported a Salmonella prevalence of 28% among raw cocoa beans entering the supply chain, regular supplier inspection and frequent testing of the final product remain necessary steps in risk management nonetheless, Campagnollo et al. [46] found 2–8% Salmonella prevalence in raw cocoa beans, and Latek et al. [47] described 12 major outbreaks around the world between 1970 and

2022—one of which is the 2022 EU Salmonella Typhimurium outbreak (369 confirmed cases) - highlighting that

| Table 4<br>Detection of Salmonella spp. in dark and white chocolate bars by brand (ISO 6579-1:2017; n = 3) |                         |                          |                  |            |
|------------------------------------------------------------------------------------------------------------|-------------------------|--------------------------|------------------|------------|
| Brand                                                                                                      | Dark Chocolate (Result) | White Chocolate (Result) | BPOM Requirement | Compliance |
| A                                                                                                          | Not Detected            | Not Detected             | Negative / 25 g  | ✓          |
| B                                                                                                          | Not Detected            | Not Detected             | Negative / 25 g  | ✓          |
| C                                                                                                          | Not Detected            | Not Detected             | Negative / 25 g  | ✓          |
| D                                                                                                          | Not Detected            | Not Detected             | Negative / 25 g  | ✓          |
| E                                                                                                          | Not Detected            | Not Detected             | Negative / 25 g  | ✓          |
| F                                                                                                          | Not Detected            | Not Detected             | Negative / 25 g  | ✓          |

Table 4 results from the author show that no Salmonella was detected in all samples

### 3.5 Heavy Metal Contamination – Lead (Pb)

Lead concentrations are presented in Table 5 and Fig. 3. In dark chocolate, lead levels varied from  $0.052 \pm 0.008$  mg/kg in Brand F (55% cocoa) to  $0.176 \pm 0.024$  mg/kg in Brand C (85% cocoa), with an average of  $0.098 \pm 0.041$  mg/kg, which is 19.6% of the BPOM dark chocolate limit of 0.50 mg/kg. For white chocolate, lead levels ranged from  $0.022 \pm 0.004$  mg/kg in Brand F to  $0.055 \pm 0.010$  mg/kg in Brand C, with an average of  $0.038 \pm 0.012$  mg/kg, equating to 12.7% of the 0.30 mg/kg limit. All samples complied with BPOM limits. A strong positive Pearson correlation was found between cocoa content and lead ( $r = 0.87$ ,  $p = 0.05$ ), consistent with the understanding that lead, as a hydrophilic contaminant, tends to accumulate in the aqueous components of cocoa solids rather than in cocoa butter [22, 49]. The low lead levels observed (maximum brand mean: 0.176 mg/kg; 35.2% of the 0.50 mg/kg BPOM dark chocolate limit) are favorable compared to US data, where 43% of dark chocolate products exceed California Proposition 65 limits[49, 50] and Nigerian commercial chocolate, which ranges from 0.15 to 0.89 mg/kg. Vanderschueren et al[51]. showed that fermentation and drying of cocoa beans through atmospheric deposition and soil-contact contamination could increase lead levels by a factor of 210.

A study in Ghana demonstrated that high-temperature drying of bamboo mats reduced soil lead contamination by 60% compared to ground-drying[51]. The low lead levels in West Java suggest that local cocoa suppliers have largely adopted high-drying platforms and similar post-harvest practices that limit environmental lead deposition. This represents a significant step towards supply-chain GAP compliance. However, further monitoring is warranted given the potential for atmospheric lead deposition during fermentation to increase contamination by 2–10 times above farm-level baseline levels [52]

### 3.6 Heavy Metal Contamination – Cadmium (Cd)

The most essential food safety outcome of the study was cadmium contamination, a systemic agronomic issue that cannot be addressed solely by implementing manufacturing hygiene solutions. All the dark chocolate brands were above the limit of 0.10 mg/kg BPOM [53](Table 5; Fig. 4) and the concentration of cocoa butter was  $0.168 \pm 0.034$  mg/kg (mean); with a range of 0.1 A positive Pearson correlation between cocoa solids content and dark chocolate Cd was very strong and significant ( $r = 0.92$ ,  $p = 0.05$ ): cocoa butter was found to contain only 5–15 percent of total Cd based on the extraction method[54, 55]. The analysis of the cocoa content of the various brands in Table 6 and Fig. 2 confirms the dose-response relationship: Brand C (85% total cocoa; 62% cocoa nibs, 23% cocoa butter) had the highest Cd ( $0.192 \pm 0.032$  mg/kg), and Brand F (55% total cocoa; 38% coco It was confirmed that a significant nibs–Cd dose-response exists ( $r = 0.89$ ,  $p < 0.05$ ). The implications of this finding are direct: decreasing the fraction of cocoa nibs is among the limited approaches manufacturers can use to operate within the current supply chain. Cadmium in cocoa is largely geogenic: unlike lead, which is a post-harvest contaminant that can be mitigated by better handling practices, Cd in cocoa is actively taken up by the cocoa root system through the uptake of naturally Cd-enriched volcanic soils and then concentrated in the cotyledon. The soil geochemical processes of Cd accumulation in cacao systems were documented by Wiersma[56], who confirmed that the volcanic soils found mainly in the cocoa-growing regions of West Java naturally have higher Cd levels that are not readily reduced by standard post-harvesting methods. This tendency has been reported in cocoa-producing areas of volcanic-soil Latin America, especially Ecuador and Colombia, where similar Cd exceedances are also reported. The Indonesian BPOM now uses a single, constant limit of 0.10 mg/kg for all forms of chocolate, whereas EU Reg. 2023/915 uses tiers of 0.10–0.80 mg/kg based on the cocoa content [57]. The fact that dark chocolate in Indonesia is already above the limit, with 100 percent exceedance, underscores the systemic nature of this problem and the need to intervene at the supply chain level. As a public health issue, cadmium is a Group 1 human carcinogen according to IARC [57, 58], and the proximal renal tubule is its main target organ. Cd accumulation is irreversible over decades of dietary exposure[59, 60]. Regular high-cocoa dark chocolate consumers can easily surpass the WHO provisional tolerable weekly intake (PTWI) of 7 -1g/kg body weight: a 60 -kg adult who eats 40 -1g/day of Brand C dark chocolate high in cocoa (Cd:  $0.192$  -1g/kg) would ingest 7.68 -1g C Kids are at an increased risk due to the increased efficiency of gastrointestinal Cd absorption (3040 per cent vs. 5 per cent in adults) and reduced body weight [61, 62]. The clinical endpoints of concern in chronic disease are itai-itai-type bone demineralization and tubular proteinuria. Such statistics support the need for supply-chain Cd mitigation measures rather than consumer advisories.

Table 5

Heavy metal concentrations (mg/kg) in dark and white chocolate bars by brand (mean  $\pm$  SD, n = 3). Cells marked with an asterisk (\*) indicate values exceeding BPOM regulatory limits

| Brand             | Cocoa % | Pb Dark (mg/kg)                 | Pb White (mg/kg)                | Cd Dark (mg/kg)                   | Cd White (mg/kg)                  | Pb | Cd Status                |
|-------------------|---------|---------------------------------|---------------------------------|-----------------------------------|-----------------------------------|----|--------------------------|
| <b>BPOM Limit</b> | —       | $\leq 0.50$                     | $\leq 0.30$                     | $\leq 0.10$                       | $\leq 0.10$                       | —  | —                        |
| <b>A</b>          | 70      | $0.112 \pm 0.018$ <sup>ab</sup> | $0.038 \pm 0.008$ <sup>ab</sup> | $0.185 \pm 0.028$ <sup>ab</sup> * | $0.095 \pm 0.012$ <sup>ab</sup>   | ✓  | <sup>ab</sup> Dark only  |
| <b>B</b>          | 65      | $0.085 \pm 0.012$ <sup>ab</sup> | $0.032 \pm 0.006$ <sup>ab</sup> | $0.142 \pm 0.022$ <sup>ab</sup> * | $0.078 \pm 0.010$ <sup>ab</sup>   | ✓  | <sup>ab</sup> Dark only  |
| <b>C</b>          | 85      | $0.176 \pm 0.024$ <sup>ab</sup> | $0.055 \pm 0.010$ <sup>ab</sup> | $0.192 \pm 0.032$ <sup>ab</sup> * | $0.105 \pm 0.015$ <sup>ab</sup> * | ✓  | <sup>ab</sup> Both types |
| <b>D</b>          | 60      | $0.068 \pm 0.010$ <sup>ab</sup> | $0.028 \pm 0.005$ <sup>ab</sup> | $0.125 \pm 0.018$ <sup>ab</sup> * | $0.072 \pm 0.009$ <sup>ab</sup>   | ✓  | <sup>ab</sup> Dark only  |
| <b>E</b>          | 75      | $0.145 \pm 0.020$ <sup>ab</sup> | $0.048 \pm 0.009$ <sup>ab</sup> | $0.178 \pm 0.025$ <sup>ab</sup> * | $0.098 \pm 0.013$ <sup>ab</sup>   | ✓  | <sup>ab</sup> Dark only  |
| <b>F</b>          | 55      | $0.052 \pm 0.008$ <sup>ab</sup> | $0.022 \pm 0.004$ <sup>ab</sup> | $0.108 \pm 0.015$ <sup>ab</sup> * | $0.065 \pm 0.008$ <sup>ab</sup>   | ✓  | <sup>ab</sup> Dark only  |
| <b>Mean</b>       | —       | $0.098 \pm 0.041$               | $0.038 \pm 0.012$               | $0.168 \pm 0.034$                 | $0.091 \pm 0.019$                 | —  | —                        |

Note: \* indicates values exceeding the BPOM Cd limit of 0.10 mg/kg. Superscript letters denote statistically homogeneous groups (Tukey HSD,  $\alpha = 0.05$ ). ND = Not determined. — = Not applicable.

Figure 3. Lead (Pb) concentrations in dark and white chocolate bars by brand (mean  $\pm$  SD, n = 3). Horizontal dashed lines indicate BPOM maximum limits: red = 0.50 mg/kg (dark); orange = 0.30 mg/kg (white). All brands comply with both limits.

Table 6

Cocoa-derived component composition and cadmium concentrations by brand, illustrating the dose–response relationship between cocoa nib content and cadmium load

| Brand | Total Cocoa (%) | Cocoa Nibs (%) | Cocoa Butter (%) | Cd Dark (mg/kg) | Cd White (mg/kg) | Regulatory Status            |
|-------|-----------------|----------------|------------------|-----------------|------------------|------------------------------|
| A     | 70              | 50             | 20               | 0.185 ± 0.028 * | 0.095 ± 0.012    | Dark exceeds the limit.      |
| B     | 65              | 47             | 18               | 0.142 ± 0.022 * | 0.078 ± 0.010    | Dark exceeds the limit.      |
| C     | 85              | 62             | 23               | 0.192 ± 0.032 * | 0.105 ± 0.015 *  | Both types exceed the limit. |
| D     | 60              | 43             | 17               | 0.125 ± 0.018 * | 0.072 ± 0.009    | Dark exceeds the limit.      |
| E     | 75              | 54             | 21               | 0.178 ± 0.025 * | 0.098 ± 0.013    | Dark exceeds the limit.      |
| F     | 55              | 38             | 17               | 0.108 ± 0.015 * | 0.065 ± 0.008    | Dark exceeds the limit.      |

## 4 Conclusions

This research examines the microbiological and chemical safety of artisanal dark and white chocolate bars produced by small-scale manufacturers in West Java, Indonesia, filling a void in the country's bean-to-bar sector. The main findings include: (i) all twelve samples complied with BPOM microbiological standards for TVC, TYMC, and Salmonella, suggesting effective hygienic practices such as proper cocoa roasting; (ii) lead concentrations were within BPOM and international limits, ranging from only 12–20% of the thresholds; (iii) cadmium contamination poses a significant risk, with 100% of dark chocolate and one white chocolate sample surpassing the BPOM limit of 0.10 mg/kg, showing a strong correlation between cadmium levels and cocoa solids content ( $r = 0.92$ ,  $p < 0.05$ ), indicating a geogenic soil source. Brand F demonstrated excellent microbiological control and low heavy metal levels, whereas Brand E exhibited the highest microbial count, reflecting varying degrees of GMP implementation. The excess of cadmium poses serious health risks, as Cd is irreversible in the environment, and volcanic soil geochemistry cannot be mitigated by hygiene alone. Recommendations include: (1) systematic cadmium soil mapping in West Java to prioritize interventions; (2) proven soil management strategies such as liming to increase soil pH, phosphate application, and evaluating low-Cd-accumulating cocoa genotypes [68]; (3) selective sourcing of raw materials by blending beans from high-Cd with low-Cd origins; (4) formulation adjustments, reducing cocoa nib fractions in products for children and frequent consumers; (5) mandatory Cd monitoring with full traceability; and (6) consumer advisories on high-cocoa dark chocolate for vulnerable groups. Future research should examine seasonal and annual Cd variation, evaluate the effectiveness of soil amendments in Indonesia, and quantify Cd exposure from all food sources in Indonesia.

# Abbreviations

| <b>Abbreviation</b>  | <b>Full Definition</b>                                                                |
|----------------------|---------------------------------------------------------------------------------------|
| <b>ANOVA</b>         | Analysis of Variance                                                                  |
| <b>AOAC</b>          | Association of Official Analytical Chemists                                           |
| <b>a<sub>w</sub></b> | Water activity                                                                        |
| <b>BPW</b>           | Buffered Peptone Water                                                                |
| <b>BPOM</b>          | Badan Pengawas Obat dan Makanan (Indonesian National Agency of Drug and Food Control) |
| <b>Cd</b>            | Cadmium                                                                               |
| <b>CFU/g</b>         | Colony-Forming Units per gram                                                         |
| <b>Codex</b>         | Codex Alimentarius Commission                                                         |
| <b>DRBC</b>          | Dichloran Rose Bengal Chloramphenicol Agar                                            |
| <b>EU</b>            | European Union                                                                        |
| <b>GAP</b>           | Good Agricultural Practices                                                           |
| <b>GMP</b>           | Good Manufacturing Practices                                                          |
| <b>HACCP</b>         | Hazard Analysis and Critical Control Points                                           |
| <b>ICP-MS</b>        | Inductively Coupled Plasma Mass Spectrometry                                          |
| <b>ICMSF</b>         | International Commission on Microbiological Specifications of Foods                   |
| <b>ISO</b>           | International Organization for Standardization                                        |
| <b>LIA</b>           | Lysine Iron Agar                                                                      |
| <b>MKTTn</b>         | Müller-Kauffmann Tetrathionate Novobiocin Broth                                       |
| <b>MSRV</b>          | Modified Semi-solid Rappaport-Vassiliadis medium                                      |
| <b>m/z</b>           | Mass-to-charge ratio                                                                  |
| <b>Pb</b>            | Lead                                                                                  |
| <b>PCA</b>           | Plate Count Agar                                                                      |
| <b>RVS</b>           | Rappaport-Vassiliadis Soya Peptone Broth                                              |
| <b>SD</b>            | Standard Deviation                                                                    |
| <b>SNI</b>           | Standar Nasional Indonesia (Indonesian National Standard)                             |
| <b>SSA</b>           | Salmonella-Shigella Agar                                                              |
| <b>TSI</b>           | Triple Sugar Iron agar                                                                |

| Abbreviation | Full Definition                 |
|--------------|---------------------------------|
| <b>TVC</b>   | Total Viable Count              |
| <b>TYMC</b>  | Total Yeast and Mould Count     |
| <b>WHO</b>   | World Health Organization       |
| <b>XLD</b>   | Xylose Lysine Deoxycholate Agar |

## Declarations

Data availability.

All data analyzed during this study are included in this published article.

Author contributions.

**G. Fabien:** Conceptualization, Methodology, Investigation, Data Curation, Writing–Original Draft. **U. Hasanah:** Supervision (Lead), Project Administration, Writing–Review & Editing. **H.D. Kusumaningrum & H.N. Lioe:** Supervision, Writing–Review & Editing.Funding. The research does not receive any funding

## Acknowledgements:

The authors express their gratitude to the Kemitraan Negara Berkembang (KNB) Scholarship and the Ministry of Higher Education, Science, and Technology of the Republic of Indonesia for providing financial support during their studies in Indonesia. The funding source did not influence the study's design, data collection, analysis, or publication decisions.

Ethics approval and consent to participate.

In this research, food products obtained from commercial sources were examined. There was no involvement of human participants, human data, or animal subjects. According to Indonesian national guidelines, ethical approval was not necessary.

A clinical trial number: not applicable

Consent for publication: not applicable.

Competing interests: The researchers declare no conflicts of interest

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## Figures

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Figure 1

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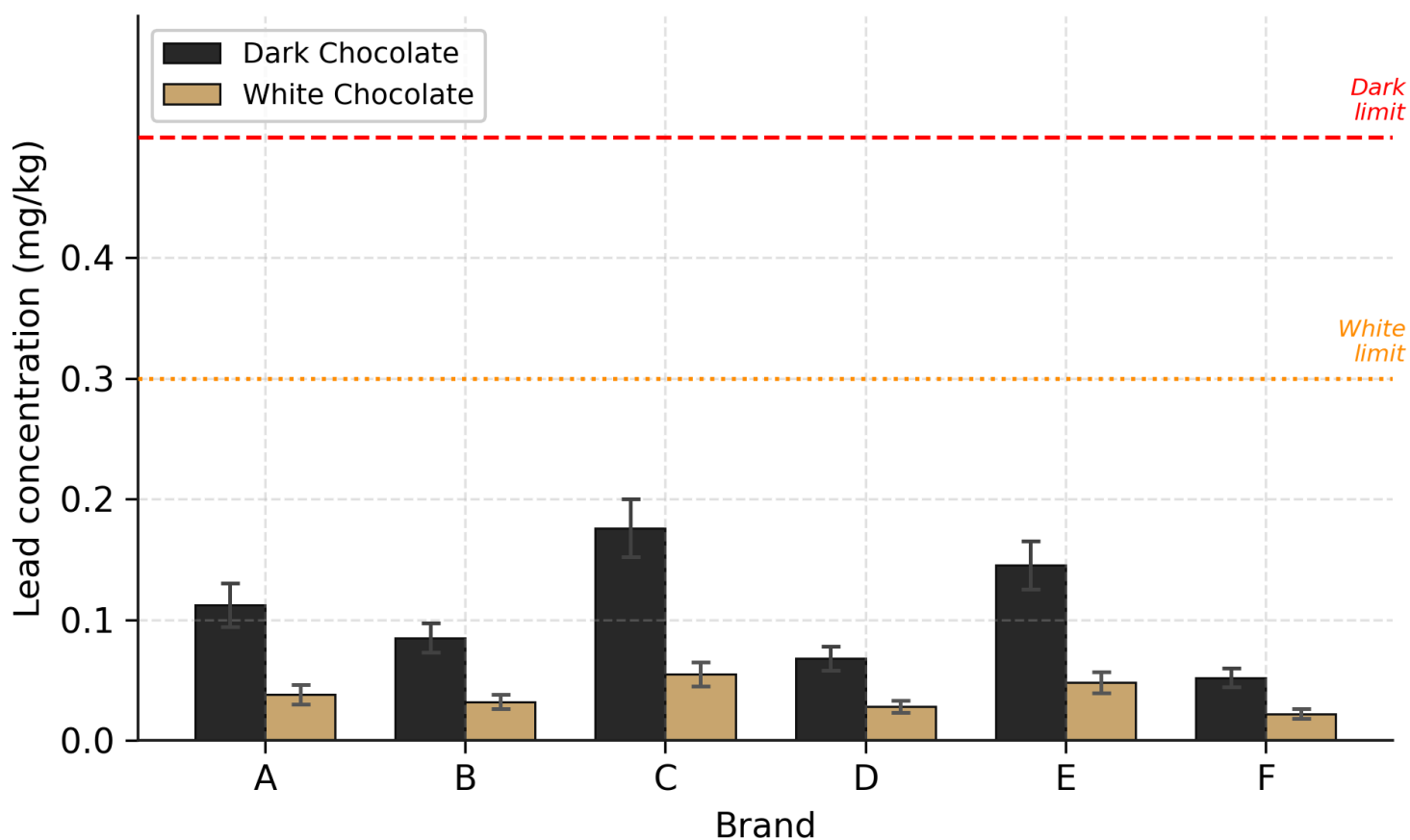


Figure 2

Figure 3. Lead (Pb) concentrations in dark and white chocolate bars by brand (mean  $\pm$  SD, n = 3). Horizontal dashed lines indicate BPOM maximum limits: red = 0.50 mg/kg (dark); orange = 0.30 mg/kg (white). All brands comply with both limits.

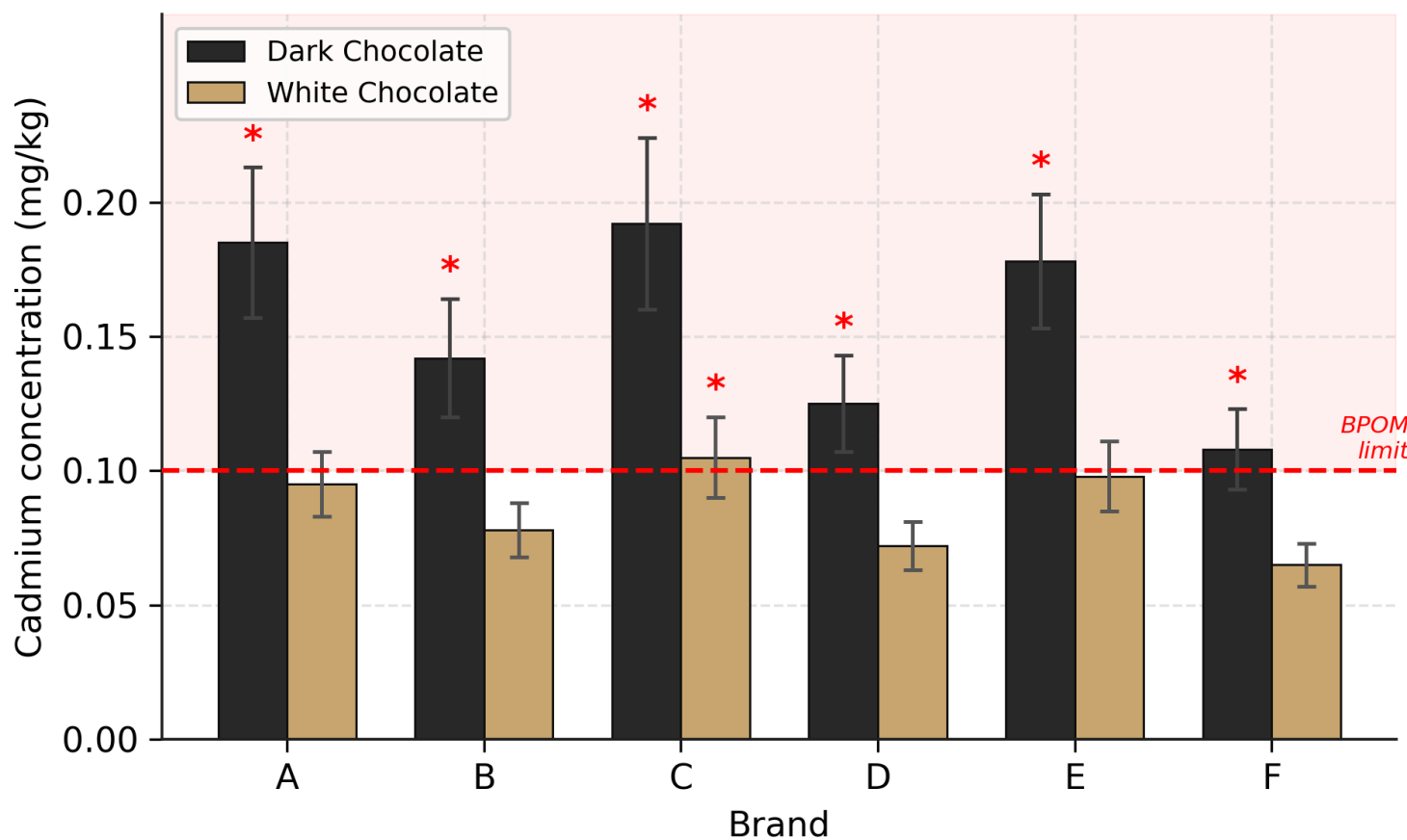


Figure 3

Figure 4. Cadmium (Cd) concentrations in dark and white chocolate bars by brand (mean ± SD, n = 3). Dashed red line = BPOM limit (0.10 mg/kg). Asterisks (\*) denote values exceeding the limit. The shaded region indicates the regulatory exceedance zone. All dark chocolate brands and Brand C white chocolate exceed the BPOM Cd limit.