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DETERMINATION OF THE CONCENTRATIONS OF SELECTED HEAVY METALS IN MANSHANU, KINDIRMO, AND RAW MILK SAMPLES COLLECTED FROM MAYO-BELWA, YOLA SOUTH, AND JADA IN ADAMAWA STATE, NIGERIA

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Abstract

This study assessed the concentrations of selected heavy metals in dairy products obtained from different sampling locations and examined the effects of product type and location on metal concentrations. The study focused on cadmium, cobalt, copper, nickel, and lead. Descriptive and inferential statistical methods were used to analyse the data, while analysis of variance (ANOVA) was employed to determine whether significant differences existed among dairy products, sampling locations, and their interaction. The results revealed significant differences in cadmium concentration among dairy products ($F = 19.973$, $p = 0.00003$) and sampling locations ($F = 12.636$, $p = 0.00037$), while their interaction was not significant. Cobalt concentration differed significantly across sampling locations ($F = 15.626$, $p = 0.00012$), and the interaction between product type and location was also significant ($F = 4.385$, $p = 0.0119$), whereas the overall product effect was not significant. Copper and nickel concentrations differed significantly among dairy products ($F = 47.816$ and 49.737, respectively; $p < 0.001$), while location and interaction effects were not significant. The results indicated significant differences among products;. The study concludes that heavy-metal concentrations in dairy products vary according to product type and, for some metals, sampling location. Regular monitoring, laboratory verification, improved food-safety practices, and further research are recommended to safeguard consumers from potential exposure to heavy-metal contamination.

Keywords: Dairy products; Heavy metals; Cadmium

Introduction

Milk and milk products are important components of human nutrition because they provide high-quality proteins, fats, carbohydrates, vitamins and essential minerals required for growth, tissue development and maintenance of good health (Food and

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Agriculture Organization of the United Nations [FAO], 2013). In addition to their nutritional value, milk and dairy products are widely consumed by children and adults, making their chemical safety an important public health concern (FAO, 2013; Hasanvand et al., 2024). However, milk may become contaminated with potentially toxic heavy metals and metalloids through environmental pollution, contaminated animal feed, polluted drinking water and exposure to contaminated soil, depending on the production environment and handling practices (Hasanvand et al., 2024; Zhang et al., 2022). Heavy metals are elements that may occur naturally in the environment but can become harmful when exposure exceeds safe levels or when toxic elements accumulate in biological systems (World Health Organization [WHO], 2024). Metals of particular concern in food safety investigations include lead (Pb), cadmium (Cd), mercury (Hg) and certain forms of chromium (Cr), while arsenic (As), although a metalloid, is also commonly investigated because of its toxicity and potential presence in food and water (Hasanvand et al., 2024; WHO, 2024). Some metals, such as iron (Fe), zinc (Zn) and copper (Cu), are essential for normal physiological functions, but excessive exposure may also have adverse effects; therefore, their concentrations must be evaluated in relation to nutritional requirements and applicable safety standards (FAO/WHO, 2011; Hasanvand et al., 2024).

The occurrence of heavy metals in milk is a significant food-safety concern because dairy animals may be exposed to environmental contaminants through several pathways. These include ingestion of contaminated pasture, feed and drinking water, as well as contact with polluted soil and dust (Zhang et al., 2022; Hasanvand et al., 2024). Following exposure, certain metals may be absorbed into the bloodstream and transferred to body tissues or secretions, including milk, depending on the element, the animal's physiological condition and the level and duration of exposure (Hasanvand et al., 2024). Consequently, the quality of the environment in which dairy animals are raised can influence the chemical quality of the milk they produce (Zhang et al., 2022; Hasanvand et al., 2024). Raw milk deserves particular attention because it has not undergone heat treatment designed to reduce microbial hazards and may be consumed directly or used in the preparation of traditional dairy products. Although pasteurisation is important for controlling many disease-causing microorganisms, it should not be regarded as a reliable method for eliminating heavy-metal contamination, since metals are chemical elements that are not destroyed by ordinary pasteurisation temperatures (WHO, 2024; FAO and WHO, 2011). Therefore, identifying and controlling contamination at the source, alongside appropriate hygiene and processing practices, are important measures for protecting consumers of milk and dairy products (FAO, 2013; WHO, 2024).

The traditional dairy products considered in this study, namely manshanu and kindirmo, are important in the context of local milk processing and consumption in northern Nigeria. The analysis of these products alongside raw milk is useful because processing, storage, handling and the ingredients used in traditional dairy production may influence the composition and distribution of contaminants in the final products (Muehlhoff et al., 2013; Hasanvand et al., 2024). Comparing these products can therefore help establish whether the concentrations of selected metals differ between unprocessed milk and traditionally processed dairy products. The public health implications of heavy-metal contamination depend on the particular element, its concentration, the amount of contaminated food consumed and the duration of exposure. Lead is associated with

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adverse effects on neurological development, kidney function and cardiovascular health, while cadmium is particularly concerning because of its potential to damage the kidneys and skeletal system after prolonged exposure (World Health Organization [WHO], 2026; Hasanvand et al., 2024). Children may be especially vulnerable to lead exposure because their developing nervous systems are sensitive to its toxic effects (WHO, 2026). Consequently, determining metal concentrations in milk and dairy products is important for evaluating possible dietary exposure and supporting food-safety monitoring (Hasanvand et al., 2024).

Evidence from international research confirms that heavy-metal contamination in milk is a continuing food-safety concern. In a global systematic review and meta-analysis, Hasanvand et al. (2024) examined 66 studies published between 2000 and 2021 and reported the presence of lead, cadmium, mercury and arsenic in milk samples from different countries. Their findings indicated that estimated concentrations were generally within the threshold limits used in their assessment, although lead and cadmium exceeded relevant limits in some cases, raising concerns about potential health risks. The authors also identified environmental contamination and the transfer of metals through animal feed as important pathways by which these elements can enter milk. These findings demonstrate the importance of conducting location-specific investigations rather than assuming that milk from every production area has the same chemical quality (Hasanvand et al., 2024).

Research conducted in Nigeria provides further justification for investigating heavy metals in dairy products. Tobi et al. (2023) assessed copper, lead, zinc and iron in raw cow milk collected from Gwale, Dala and Ungogo Local Government Areas of Kano State, using atomic absorption spectrometry. The authors reported variations in metal concentrations among the sampling locations and identified elevated iron and lead concentrations relative to the reference limits used in their study. Their findings highlight the need for continued monitoring of raw milk in whole Northern Nigeria and provide relevant local evidence for further investigation of dairy contamination.

Statement of the Problem

Milk and dairy products are important sources of essential nutrients, but their safety may be compromised by contamination with potentially toxic heavy metals originating from polluted soil, water, animal feed and other environmental sources (Hasanvand et al., 2024). When these contaminants enter the food chain, they may accumulate in animal tissues or be transferred into milk, creating potential exposure risks for consumers (Hasanvand et al., 2024). Lead is of particular concern because exposure can damage the nervous system, kidneys and other organs, and the World Health Organization (WHO, 2026) states that no level of lead exposure is known to be without harmful effects (Hasanvand et al., 2024; WHO, 2026).

A specific concern is that manshanu, kindirmo and raw milk differ in their processing, handling and storage. Consequently, findings obtained exclusively from raw milk cannot automatically be used to determine the concentrations of heavy metals in these traditional dairy products. Although Hasanvand et al. (2024) documented the occurrence of heavy metals in milk across different countries, their global review does not establish the concentrations of individual metals in manshanu and kindirmo collected from Kumbotso, Rimin Gado and Ungoggo. Therefore, the

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concentrations of the selected metals in these products and their possible differences across the three locations require direct laboratory investigation.

Furthermore, without reliable analytical data for the three dairy sample types, consumers, dairy handlers and relevant food-safety authorities may lack sufficient local evidence to evaluate the chemical quality of these products or identify samples that may require further investigation. Hasanvand et al. (2024) emphasized the importance of monitoring metal concentrations in milk because some studies have reported lead and cadmium levels above the reference limits used in their assessment. The Codex Alimentarius Commission (2025) also provides international guidance for evaluating contaminants in food, although the appropriate limits must be selected according to the specific metal and applicable food category

Aims and Objectives

The aim was to determine the concentrations of selected heavy metals in the indigenous milk substances, while the specific objectives were:

i. Determine the concentrations of selected heavy metals in Manshanu, Kindirmo and raw milk collected from the selected study locations
ii. Compare heavy metal concentrations among Manshanu, Kindirmo and raw milk
iii. Determine compliance with applicable maximum permissible limits

Materials and Methods

The experiment was conducted in Adamawa and its environs. The study involves an experiment in a complete randomized design. (CRD). Samples of fresh milk and indigenous dairy products were collected from three different locations in Adamawa state including: Mayo-Belwa, Yola South and Jada. A total of 27 samples including Raw Milk, *Man shanu* and *kindirmo* were collected in clean glass bottles to avoid the chances of post-harvest contamination. The samples were stored in ice box during transportation to the laboratory.

The digestion method and analysis were done in accordance with the procedure of Association of Official Analytical Chemists (AOAC, 2007). It was employed for the digestion of milk samples for which 10 ml of Nitric acid (HNO_3) was added to 1 ml of milk in a 100 ml conical flask and heated at 80˚C for 20 min. After cooling down to room temperature 5ml of per chloric acid was added to the flask and heated at 180˚C until the volume is reduced to 2-3 ml. The digested milk samples were diluted with deionized water up to 50 ml. For metal analysis the prepared samples were loaded on atomic absorption spectrophotometer by using a mixture of air and acetylene for flame production.

Chemicals of analytical grade were used for the experiments and the standard solutions of various metals were obtained from CPA chemicals (CPA chemicals Ltd., Stara Zagora, Bulgaria). Sample drying and digestion were performed using hot air oven (Memmert UNB 200, Munich, Germany) and hot plate (Lab Tech EH 35A plus, Beijing, China), respectively. Flame atomic absorption spectrophotometer (Thermo Scientific 3000 Series, Waltham, MA, USA) was used for the quantification of heavy metals in milk samples. For measuring the limit of detection (LOD) twelve blanks were digested in the same way as the milk samples and the concentrations of lead (Pb), Cadium (Cd), Cobalt (Co), Nickel (Ni) and Copper (Cu) were recorded by analyzing through flame

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atomic absorption spectrophotometer. The LOD values for each element were recorded as three times the standard deviation (SD) of twelve blanks (3.3 SD/b). The LOD values recorded for Pb, Cd, Co, Ni and Cu were 0.5, 0.1, 0.2, 0.7 and 3.2µg/kg respectively. One way analysis of variance (ANOVA) was used for treatment and replication followed by the least significant difference (LSD) test. The probability level selected for statistically significant differences was $P< 0.05$. Statistical analyses were performed using the statistical functions of statistical package for agricultural Research (SPAR 2.0).

RESULT AND DISCUSSION

Table 1. Heavy metal concentrations in Manshanu, Kindirmo and raw milk across the study locations.

Values are reported as mean ± standard deviation (mg/L),

Heavy metal	Product	Mayo-Belwa	Yola South	Jada
Cd	Manshanu	0.021 ± 0.0014	0.018 ± 0.0008	0.020 ± 0.0007
Cd	Kindirmo	0.023 ± 0.0011	0.021 ± 0.0008*	0.023 ± 0.0009
Cd	Raw milk	0.021 ± 0.0001	0.020 ± 0.0012	0.021 ± 0.0004
Co	Manshanu	0.120 ± 0.0013	0.112 ± 0.0031	0.112 ± 0.0011
Co	Kindirmo	0.120 ± 0.0013	0.112 ± 0.0031	0.122 ± 0.0044
Co	Raw milk	0.121 ± 0.0026	0.115 ± 0.0017	0.114 ± 0.0042
Cu	Manshanu	0.044 ± 0.0031	0.041 ± 0.0057	0.045 ± 0.0062
Cu	Kindirmo	0.051 ± 0.0016	0.051 ± 0.0052	0.053 ± 0.0029
Cu	Raw milk	0.066 ± 0.0068	0.059 ± 0.0034	0.066 ± 0.0008
Ni	Manshanu	0.032 ± 0.0006	0.027 ± 0.0053	0.030 ± 0.0047
Ni	Kindirmo	0.047 ± 0.0020	0.046 ± 0.0044	0.047 ± 0.0026
Ni	Raw milk	0.039 ± 0.0032	0.035 ± 0.0049	0.039 ± 0.0017
Pb	Manshanu	0.032 ± 0.0006	0.027 ± 0.0053	0.030 ± 0.0047
Pb	Kindirmo	0.047 ± 0.0020	0.046 ± 0.0044	0.047 ± 0.0026
Pb	Raw milk	0.039 ± 0.0032	0.035 ± 0.0049	0.039 ± 0.0017

Source: Laboratory Analysis, 2026.

Table 1 presents the mean concentrations and standard deviations of cadmium (Cd), cobalt (Co), copper (Cu), nickel (Ni) and lead (Pb) in manshanu, kindirmo and raw milk collected from Myo-Belwa, Yola South and Jada Local Government Areas of Adamawa State. The results show variations in the measured concentrations across dairy products and sampling locations. Such variations may be associated with differences in environmental exposure, animal feed, water quality, processing methods and handling practices, although these potential explanations cannot be confirmed from the concentration data alone (Hasanvand et al., 2024). A global systematic review by Hasanvand et al. (2024) similarly identified environmental contamination and the

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transfer of metals through animal feed as important pathways through which metals can enter milk

Cadmium (Cd) Concentration in Dairy Products

The cadmium concentrations in manshanu ranged from 0.018 ± 0.0008 mg/L in Yola South to 0.021 ± 0.0014 mg/L in Myo-Belwa, while the concentration in Jada was 0.020 ± 0.0007 mg/L. For kindirmo, the concentrations were 0.023 ± 0.0011 mg/L in Mayo-Belwa, 0.021 ± 0.0008 mg/L in Yola South and 0.023 ± 0.0009 mg/L in Jada. Raw milk recorded concentrations of 0.021 ± 0.0001, 0.020 ± 0.0012 and 0.021 ± 0.0004 mg/L in Mayo-Belwa, Yola South and Jadda, respectively. Overall, kindirmo showed the highest reported cadmium concentrations, while the lowest value occurred in manshanu from Yola South.

The relatively higher cadmium concentrations in kindirmo may reflect differences in the raw milk used, processing conditions or contamination introduced during handling and storage. However, further investigation would be required to establish the actual source of these differences. Hasanvand et al. (2024), in their global systematic review and meta-analysis, found that cadmium occurs in milk samples from different countries and reported that some studies recorded concentrations exceeding the reference limits used in their assessment. Their findings support the importance of determining cadmium concentrations in different milk products rather than assuming that all dairy products have similar contamination profiles.

The results can also be considered alongside the work of Nasiru et al. (2022), who investigated heavy metals in cow milk collected from Bichi, Rano and Nassarawa Local Government Areas of Kano State. Their study reported that cadmium concentrations were below the permissible limits applied in their assessment. This provides a useful comparison with the present investigation, although a direct conclusion that the two studies agree or disagree requires the exact numerical results, the analytical methods and the same comparison standard. The current results therefore provide additional information about cadmium in manshanu, kindirmo and raw milk from the three locations investigated in this study.

Cobalt (Co) Concentration in Dairy Products

The cobalt concentrations in manshanu were 0.120 ± 0.0013 mg/L in Mayo-Belwa, 0.112 ± 0.0031 mg/L in Yola South and 0.112 ± 0.0011 mg/L in Jada. In kindirmo, the concentrations were 0.120 ± 0.0013, 0.112 ± 0.0031 and 0.122 ± 0.0044 mg/L, respectively. Raw milk recorded 0.121 ± 0.0026 mg/L in Mayo-Belwa, 0.115 ± 0.0017 mg/L in Yola South and 0.114 ± 0.0042 mg/L in Jada. The highest reported cobalt concentration was observed in kindirmo from Jada (0.122 mg/L), while the lowest concentrations (0.112 mg/L) occurred in manshanu and kindirmo from Yola South.

These findings indicate that cobalt concentrations varied relatively little across the products and locations, although the observed differences have not been established as statistically significant. The findings can be compared with those of Bilandžić et al. (2022), who investigated cobalt, silver and vanadium in raw cow's milk in Croatia and assessed potential consumer exposure. Their study demonstrates the relevance of monitoring cobalt in milk, but a direct quantitative comparison requires the numerical results and compatible reporting units from both studies.

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Similarly, the 2024 study by researchers assessing essential and potentially toxic metals in raw cow's milk from Mukaturi, Ethiopia, detected cobalt among the elements investigated and reported that some measured essential metals exceeded the reference levels applied in their assessment. This supports the need to examine cobalt concentrations in dairy products from different geographical settings (Assessment of essential and potentially toxic metals in raw cow milk from Mukaturi town, Oromia Regional State, Ethiopia, 2024).

Copper (Cu) Concentration in Dairy Products

Copper concentrations in manshanu ranged from 0.041 ± 0.0057 mg/L in Yola South to 0.045 ± 0.0062 mg/L in Jada, with Mayo-Belwa recording 0.044 ± 0.0031 mg/L. For kindirmo, the values were 0.051 ± 0.0016 mg/L in Mayo-Belwa, 0.051 ± 0.0052 mg/L in Yola South and 0.053 ± 0.0029 mg/L in Jada. Raw milk recorded higher copper concentrations of 0.066 ± 0.0068 mg/L in Myo-Belwa, 0.059 ± 0.0034 mg/L in Yola South and 0.066 ± 0.0008 mg/L in Jada. Thus, raw milk had the highest reported copper concentration in each of the three locations, whereas manshanu generally had the lowest.

This pattern suggests that copper concentrations differed among the dairy products. Possible explanations include differences in the source milk, processing and handling, or contact with equipment and containers. However, the results do not establish which of these factors was responsible. Copper is an essential trace element required for normal physiological functions, but excessive intake can cause adverse health effects; its concentration should therefore be interpreted in relation to dietary exposure and relevant safety guidance.

The results can be compared with Tobi et al. (2023), who investigated copper in raw cow milk collected from Gwale, Dala and Ungoggo in Kano State. They reported copper concentrations of 0.0584, 0.0714 and 0.2604 mg/L, respectively. The values recorded in the present study for raw milk (0.059–0.066 mg/L) are close to the values reported for Gwale and Dala, but lower than the concentration reported for Ungoggo by Tobi et al. (2023). Dibie and Asuelimen (2022) also investigated selected mineral elements, including copper, cobalt, cadmium and lead, in raw cow and goat milk from animal markets in Benin City, Nigeria. Their study provides additional Nigerian evidence that copper and other trace elements are relevant parameters in dairy-quality assessment.

Nickel (Ni) Concentration in Dairy Products

The nickel concentrations in manshanu were 0.032 ± 0.0006 mg/L in Mayo-Belwa, 0.027 ± 0.0053 mg/L in Rimin Gado and 0.030 ± 0.0047 mg/L in Jada. In kindirmo, the concentrations were 0.047 ± 0.0020, 0.046 ± 0.0044 and 0.047 ± 0.0026 mg/L, respectively. Raw milk recorded 0.039 ± 0.0032 mg/L in Mayo-Belwa, 0.035 ± 0.0049 mg/L in Rimin Gado and 0.039 ± 0.0017 mg/L in Jada. The highest reported nickel concentration was 0.047 mg/L in kindirmo from Mayo-Belwa and Jada, while the lowest was 0.027 mg/L in manshanu from Rimin Gado. Across all three locations, kindirmo had higher nickel concentrations than either manshanu or raw milk. This may indicate differences in the composition of the source milk, processing practices or environmental exposure. The consistency of this product-level pattern across the three locations makes nickel an important parameter for further investigation.

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These findings can be compared with the 2024 investigation of raw cow milk from Mukaturi, Ethiopia, which included nickel among its measured elements and reported that some essential metals, including nickel, exceeded the permissible levels used by the researchers. This reinforces the importance of interpreting nickel concentrations using appropriate toxicological guidance rather than assuming that detection alone demonstrates a health hazard (Assessment of essential and potentially toxic metals in raw cow milk from Mukaturi town, Oromia Regional State, Ethiopia, 2024).

Lead (Pb) Concentration in Dairy Products

The reported lead concentrations and standard deviations in all nine product-location combinations are exactly identical to the corresponding nickel values. For example, manshanu from Mayo-Belwa is reported as 0.032 ± 0.0006 mg/L for both Ni and Pb, while kindirmo from Mayo-Belwa is reported as 0.047 ± 0.0020 mg/L for both elements. Lead is a toxic metal of particular public health concern. The World Health Organization (WHO, 2026) states that no level of lead exposure is known to be without harmful effects and identifies the nervous system, kidneys and cardiovascular system among the systems affected by exposure. Therefore, verifying the lead results is particularly important before assessing potential consumer exposure or drawing conclusions about the safety of the sampled dairy products. For comparison, Tobi et al. (2023) reported lead concentrations of 0.0350, 0.0390 and 0.4100 mg/L in raw cow milk from Gwale, Dala and Ungoggo, respectively.

Overall Comparison Across Products and Sampling Locations

Overall, the results show that the relative concentrations of the measured elements differed by product and location. Kindirmo generally recorded the highest cadmium and nickel concentrations, while raw milk had the highest copper concentrations in all three locations. Cobalt concentrations were comparatively similar across the products, although small differences were observed. These descriptive patterns suggest that the type of dairy product may be relevant when investigating metal concentrations, but the data alone cannot establish whether processing caused the differences.

The results contribute to the evidence on dairy contamination in Kano State. Tobi et al. (2023) demonstrated variation in copper, zinc, iron and lead concentrations among raw cow milk samples collected from selected local government areas of Kano State. Hasanvand et al. (2024) likewise showed, through a global systematic review and meta-analysis, that metal concentrations in milk vary among studies and geographical settings. The present findings extend this line of investigation by including manshanu and kindirmo alongside raw milk, although direct comparisons with earlier studies are limited by differences in the metals measured and the products sampled.

Table 2. Descriptive comparison of mean heavy metal concentrations among dairy products

Heavy metal	Manshanu (mg/L)	Kindirmo (mg/L)	Raw milk (mg/L)	Highest average
Cadmium (Cd)	0.0197	0.0223	0.0207	Kindirmo
Cobalt (Co)	0.1147	0.0467	0.1167	Kindirmo

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Heavy metal	Manshanu (mg/L)	Kindirmo (mg/L)	Raw milk (mg/L)	Highest average
Copper (Cu)	0.0433	0.0517	0.0637	Raw milk
Nickel (Ni)	0.0297	0.0467	0.0377	Kindirmo
Lead (Pb)	0.0433	0.0517	0.0637	Raw milk

Source: Source: Laboratory Analysis, 2026.

Table 2 presents a descriptive comparison of the average concentrations of cadmium (Cd), cobalt (Co), copper (Cu), nickel (Ni) and lead (Pb) in manshanu, kindirmo and raw milk collected from Mayo-Belwa, Yola South and Jada Local Government Areas of Adamawa State. The results suggest differences in the distribution of some metals among the dairy products. Such differences are relevant because heavy-metal concentrations in milk can be influenced by environmental contamination, animal feed, water quality and other factors along the dairy production chain (Hasanvand et al., 2024). However, the results should be interpreted cautiously because the table contains apparent inconsistencies in the cobalt and lead entries that need to be corrected before drawing final conclusions.

Cadmium (Cd)

The mean cadmium concentration was highest in kindirmo (0.0223 mg/L), followed by raw milk (0.0207 mg/L), while manshanu recorded the lowest mean concentration (0.0197 mg/L). The difference between the highest and lowest product means was 0.0026 mg/L. This descriptive pattern suggests that cadmium concentrations were somewhat higher in kindirmo than in the other two products. The finding is consistent with the broader concern raised by Hasanvand et al. (2024), whose systematic review and meta-analysis documented cadmium occurrence in milk samples from different countries. The authors found that cadmium concentrations exceeded the reference limits used in their assessment in some studies, demonstrating the importance of measuring this metal in dairy products rather than assuming that all milk products have similar contaminant profiles. In Kano State, Nasiru et al. (2022) investigated cadmium and other metals in cow milk from Bichi, Rano and Nassarawa Local Government Areas. Their study reported cadmium concentrations below the permissible limits applied in their assessment. This provides relevant local context, although it does not establish whether the current values are higher or lower without comparing the exact concentrations, analytical methods and applicable reference standards.

Cobalt (Co)

According to the numerical values presented in Table 2, manshanu recorded a mean cobalt concentration of 0.1147 mg/L, while raw milk recorded 0.1167 mg/L. The reported mean for kindirmo was 0.0467 mg/L. If these values are correct, raw milk had the highest cobalt concentration, followed by manshanu, with kindirmo recording the lowest. However, the cobalt values in Table 2 require verification. Table 1 reports cobalt concentrations for kindirmo of 0.120, 0.112 and 0.122 mg/L across the three locations. Their arithmetic mean is approximately 0.1180 mg/L, not 0.0467 mg/L. The value of 0.0467 mg/L appears to have been copied from the nickel results. Therefore, the highest-average entry for cobalt should also be reconsidered: using the location-

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specific values in Table 1, kindirmo has the highest average cobalt concentration. The importance of investigating cobalt in milk is supported by Bilandžić et al. (2022), who examined cobalt and other trace elements in raw cow's milk in Croatia and assessed potential consumer exposure. Their study provides a relevant example of cobalt monitoring in dairy products, although the numerical results must be checked before making a direct comparison with the present findings. Hasanvand et al. (2024) also emphasised the importance of assessing metals in milk in relation to their occurrence and potential exposure implications.

Copper (Cu)

The mean copper concentration was highest in raw milk (0.0637 mg/L), followed by kindirmo (0.0517 mg/L), while manshanu had the lowest mean (0.0433 mg/L). The raw milk mean was approximately 47% higher than that of manshanu, based on the reported values. This suggests a descriptive difference in copper concentration among the three dairy products. The finding can be compared with Tobi et al. (2023), who investigated copper concentrations in raw cow milk collected from Gwale, Dala and Ungoggo Local Government Areas of Kano State. They reported mean copper concentrations of 0.0584, 0.0714 and 0.2604 mg/L, respectively. The present raw milk mean of 0.0637 mg/L is higher than the value reported for Gwale but lower than those reported for Dala and Ungoggo. Therefore, the present findings are partly consistent with the earlier study in terms of the general range of concentrations.

Nickel (Ni)

The mean nickel concentration was highest in kindirmo (0.0467 mg/L), followed by raw milk (0.0377 mg/L), while manshanu had the lowest mean (0.0297 mg/L). The mean concentration in kindirmo was approximately 57% higher than that in manshanu, based on the values presented in Table 2. The same general pattern is visible in Table 1, where kindirmo recorded higher nickel concentrations than the other products in each of the three locations. This consistent descriptive pattern suggests that nickel warrants further investigation in kindirmo. However, it does not establish whether the difference resulted from fermentation, the source milk, processing equipment, or environmental exposure. These possible explanations would require further targeted sampling and laboratory analysis. Research by Hasanvand et al. (2024) provides a broader context for assessing metal contamination in milk and highlights the importance of evaluating measured concentrations rather than assuming uniform contamination across products and locations.

Lead (Pb)

Table 2 reports mean lead concentrations of 0.0433 mg/L in manshanu, 0.0517 mg/L in kindirmo and 0.0637 mg/L in raw milk. If these values are correct, raw milk had the highest mean lead concentration, followed by kindirmo and manshanu. The importance of verifying lead measurements is supported by Hasanvand et al. (2024), whose systematic review found that lead and cadmium concentrations exceeded the reference limits used in their assessment in some milk studies. In Nigeria, Tobi et al. (2023) reported lead concentrations of 0.0350 mg/L in raw cow milk from Gwale, 0.0390 mg/L in milk from Dala and 0.4100 mg/L in milk from Ungoggo. These results

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provide relevant local evidence, but a direct comparison with the present table would be unreliable until the duplicated lead figures have been corrected. Lead is a toxic metal associated with adverse effects on neurological development and other body systems. The World Health Organization (WHO, 2026) states that no level of lead exposure is known to be without harmful effects.

Overall Comparison of Heavy Metal Concentrations Among Dairy Products

Based strictly on the reported values in Table 2, kindirmo had the highest mean cadmium and nickel concentrations, whereas raw milk had the highest mean copper concentration. The cobalt comparison cannot be accepted without correction because the reported kindirmo mean conflicts with the location-specific results. Similarly, the lead results cannot be interpreted confidently because they duplicate the copper means in Table 2 and the nickel values in Table 1. The findings are relevant to the wider literature on heavy metals in dairy products. Hasanvand et al. (2024) demonstrated that metal concentrations in milk vary across studies and that lead and cadmium may exceed relevant reference limits in some settings. Tobi et al. (2023) also documented differences in copper and lead concentrations among raw cow milk samples collected from selected local government areas of Kano State. These studies support continued monitoring of dairy products in the state.

Table 3. Comparison of observed heavy metal concentrations with the limits supplied in the study

Heavy metal	Stated limit (mg/L)	Manshanu range (mg/L)	Kindirmo range (mg/L)	Raw milk range (mg/L)	Preliminary interpretation
Cadmium (Cd)	0.003	0.018–0.021	0.021–0.023	0.020–0.021	All reported values exceed the stated limit
Cobalt (Co)	0.005	0.112–0.120	0.122 -0.052	0.114–0.121	All reported values exceed the stated limit
Copper (Cu)	1.000	0.041–0.045	0.051–0.053	0.059–0.066	All reported values are below the stated limit
Nickel (Ni)	0.050	0.027–0.032	0.046–0.047	0.035–0.039	All reported values are below the stated limit
Lead (Pb)	0.050	0.027–0.032	0.046–0.047	0.035–0.039	All reported values are below the stated limit

Source: Laboratory Analysis, 2026.

Comparison of heavy metal concentrations with permissible limits

Table 3 presents a comparison of cadmium (Cd), cobalt (Co), copper (Cu), nickel (Ni) and lead (Pb) concentrations in Manshanu, Kindirmo and raw milk against the permissible limits supplied for this study. The results indicate that cadmium and cobalt exceeded their respective stated limits in all three dairy products, whereas copper, nickel and lead were below their stated limits. These findings suggest that cadmium and cobalt warrant particular attention in assessing the safety of the dairy products sampled in Mayo-Belwa, Yola South and Jada. The findings are relevant to Yan et al. (2022), who conducted a systematic review of heavy metals in milk and dairy products in China. Their review identified potentially toxic metals, including cadmium and lead, in dairy samples

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and discussed environmental contamination, animal feed and packaging materials as possible sources. The authors also found that conclusions about compliance differed depending on the metal and the regulatory standard used. This supports the importance of comparing measured concentrations with appropriate limits rather than assuming that all dairy products present the same contamination risk.

Cadmium (Cd)

The results showed that cadmium concentrations ranged from 0.018 to 0.021 mg/L in Manshanu, 0.021 to 0.023 mg/L in Kindirmo and 0.020 to 0.021 mg/L in raw milk. All these values exceeded the stated permissible limit of 0.003 mg/L. Based on the supplied limit, the observed concentrations were approximately 6.0–7.0 times the limit in Manshanu, 7.0–7.7 times in Kindirmo and 6.7–7.0 times in raw milk. Kindirmo had the highest reported cadmium range, suggesting that it deserves particular attention in follow-up testing. Nevertheless, the difference between the products cannot automatically be attributed to fermentation or processing. The observed pattern may reflect differences in the milk used, environmental exposure or other production-related factors, which would require further investigation.

These findings are broadly consistent with Yan et al. (2022), who identified cadmium as one of the potentially toxic metals reported in milk and dairy products and highlighted environmental contamination as a possible source. The review supports the need to monitor cadmium in milk, although its findings from China cannot be assumed to represent the precise contamination conditions in Kano State, Nigeria. The Joint FAO/WHO Expert Committee on Food Additives (JECFA) has also evaluated cadmium toxicity, highlighting the kidney as a particularly sensitive target of long-term exposure (World Health Organization [WHO], 2023).

Cobalt (Co)

Cobalt concentrations ranged from 0.112 to 0.120 mg/L in Manshanu and 0.114 to 0.121 mg/L in raw milk, compared with the stated limit of 0.005 mg/L. These reported values are approximately 22.4–24.0 times the stated limit in Manshanu and 22.8–24.2 times in raw milk. The Kindirmo range in Table 3 is incorrectly written as 0.122–0.052 mg/L; based on Table 1, it should be 0.112–0.122 mg/L, provided the original measurements confirm these figures. This corrected range would also exceed the supplied limit substantially. The results suggest that cobalt warrants further investigation. However, the interpretation depends on whether 0.005 mg/L is an appropriate maximum permissible limit for cobalt in these particular dairy products. The limit must be traced to an identifiable regulatory source before the exceedance can be presented as a confirmed regulatory violation. Yan et al. (2022) demonstrated that environmental conditions, animal feed and other contamination sources can influence the occurrence of metals in milk and dairy products..

Copper (Cu)

Copper concentrations ranged from 0.041 to 0.045 mg/L in Manshanu, 0.051 to 0.053 mg/L in Kindirmo and 0.059 to 0.066 mg/L in raw milk. All values were below the stated limit of 1.000 mg/L. The results therefore indicate that copper concentrations complied with the benchmark supplied in Table 3. The highest reported copper concentrations occurred in raw milk, while Manshanu had

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the lowest range. This pattern is consistent with the descriptive results in Table 2, which identified raw milk as having the highest average copper concentration. Nevertheless, being below the stated limit does not mean that copper concentrations are identical across products, nor does it establish that every possible exposure level is safe.

The present findings are broadly consistent with Tobi et al. (2023), who measured copper in raw cow's milk from three local government areas in Kano State. They reported concentrations of 0.0584, 0.0714 and 0.2604 mg/L in Gwale, Dala and Ungogo, respectively. Their first two measurements are close to the lower end of the raw-milk range in the present study, whereas their third measurement is substantially higher. This illustrates that copper concentrations in raw milk can differ between sampling locations. Yan et al. (2022) also highlighted the importance of assessing heavy metals in milk using appropriate standards and considering potential environmental sources. The present results provide preliminary evidence that copper concentrations were below the supplied limit.

Nickel (Ni)

The nickel concentrations ranged from 0.027 to 0.032 mg/L in Manshanu, 0.046 to 0.047 mg/L in Kindirmo and 0.035 to 0.039 mg/L in raw milk. All values were below the stated limit of 0.050 mg/L. Kindirmo had the highest nickel range and was closest to the stated limit, whereas Manshanu had the lowest range. These results suggest that nickel did not exceed the supplied benchmark in any of the three products. Nevertheless, Kindirmo's maximum reported concentration of 0.047 mg/L was close to the stated limit, which makes accurate measurement and continued monitoring worthwhile. The results can be discussed in the context of Yan et al. (2022), whose review examined heavy metal occurrence in milk and dairy products and highlighted the need for monitoring potentially toxic elements..

Lead (Pb)

The reported lead concentrations ranged from 0.027 to 0.032 mg/L in Manshanu, 0.046 to 0.047 mg/L in Kindirmo and 0.035 to 0.039 mg/L in raw milk. Based on the supplied limit of 0.050 mg/L, all reported values were below the stated benchmark. Kindirmo had the highest lead range and was closest to the limit. Tobi et al. (2023) reported lead concentrations of 0.0350, 0.0390 and 0.4100 mg/L in raw cow's milk collected from Gwale, Dala and Ungogo in Kano State. The first two concentrations fall within or close to the range reported for raw milk in the present study, while the third is substantially higher. Their study also reported that the highest lead concentration exceeded the limit they used. This comparison illustrates the potential for geographical variation in lead contamination and the importance of verifying results before concluding that a product complies with a safety standard.

Yan et al. (2022) similarly found that conclusions about lead contamination varied according to the samples and regulatory standards examined. Their review reported that some studies identified lead concentrations exceeding the European Commission standard even when other comparisons suggested compliance with the Chinese standard.

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Overall implications of the comparison

Overall, Table 3 suggests that cadmium and cobalt are the principal metals of concern because their reported concentrations exceeded the supplied limits in all three dairy products. Copper, nickel and lead were below their respective stated limits, although the lead conclusion remains uncertain because its reported values duplicate those for nickel. These findings broadly agree with Yan et al. (2022), who emphasised that heavy metal contamination in milk and dairy products varies by metal, sampling context and the regulatory standard applied. They also relate to Tobi et al. (2023), whose study in Kano State documented variation in copper and lead concentrations among raw milk samples collected from different locations.

Table 4. Two-way ANOVA of heavy metal concentrations by dairy product and study location

Calculation assuming 3 independent replicates per product–location combination, with the reported ± values representing sample standard deviations.

Heavy metal	Source of variation	df	F-value	p-value	Decision at 5%
Cd	Dairy product	2	19.973	0.00003	Significant
Cd	Location	2	12.636	0.00037	Significant
Cd	Product × location	4	1.019	0.4240	Not significant
Co	Dairy product	2	3.236	0.0630	Not significant
Co	Location	2	15.626	0.00012	Significant
Co	Product × location	4	4.385	0.0119	Significant
Cu	Dairy product	2	47.816	0.00000006	Significant
Cu	Location	2	2.356	0.1233	Not significant
Cu	Product × location	4	0.500	0.7361	Not significant
Ni	Dairy product	2	49.737	0.00000005	Significant
Ni	Location	2	2.139	0.1467	Not significant
Ni	Product × location	4	0.306	0.8704	Not significant
Pb*	Dairy product	2	49.737	0.00000005	Significant
Pb*	Location	2	2.139	0.1467	Not significant
Pb*	Product × location	4	0.306	0.8704	Not significant

Significance level: \(p<0.05\). df = degrees of freedom. The calculations use the reported means and standard deviations.

Interpretation of the results

The ANOVA indicates the following:

1. Cadmium (Cd): Concentrations differ significantly among dairy products and study locations (\(p<0.05\)). The product-by-location interaction is not significant.
2. Cobalt (Co): The location effect and product-by-location interaction are significant, whereas the overall dairy-product effect is not significant at the 5% level.
3. Copper (Cu): Concentrations differ significantly among dairy products, but no significant location effect or interaction is detected.
4. Nickel (Ni): A significant difference among dairy products is indicated, while the location effect and interaction are not significant.

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5. Lead (Pb): The apparent pattern matches nickel exactly because the supplied lead values duplicate the nickel values. No firm conclusion about lead should be made until the data are verified.

Effect of dairy product and study location on heavy metal concentrations

The analysis of variance was used to examine differences in cadmium (Cd), cobalt (Co), copper (Cu), nickel (Ni) and lead (Pb) concentrations among Manshanu, Kindirmo and raw milk collected from Mayo-Belwa, Yola South and Jada. The results suggest that the effects of dairy product and sampling location varied according to the metal analysed. This indicates that the distribution of metals in dairy products may be influenced by differences in raw milk composition, environmental exposure, animal feed and handling or processing practices. These findings are broadly consistent with the review by Yan et al. (2022), who reported that heavy metal concentrations in milk and dairy products vary across studies and may be associated with environmental contamination, animal feed and packaging materials. Similarly, Boudalia et al. (2021), in a systematic review of raw cow's milk contamination, documented the widespread occurrence of heavy metals and discussed the influence of local environmental conditions and industrialisation on their concentrations. These studies support the importance of investigating both product type and sampling location rather than assuming that all dairy products have the same contamination profile.

Cadmium (Cd)

The ANOVA results revealed significant variations in cadmium concentration across the dairy products and sampling locations. Cadmium concentration differed significantly among the different dairy products ($F = 19.973$, $p = 0.00003$), indicating that product type had a significant effect on the observed cadmium levels. Similarly, a statistically significant difference was observed among the sampling locations ($F = 12.636$, $p = 0.00037$), suggesting that cadmium concentrations varied considerably across the locations studied. In contrast, the interaction effect between dairy product type and sampling location was not statistically significant ($F = 1.019$, $p = 0.424$). This implies that although both product type and sampling location were independently associated with variations in cadmium concentration, there was insufficient evidence to conclude that the effect of product type on cadmium concentration differed systematically across sampling locations.

The descriptive results showed that Kindirmo had the highest average cadmium concentration (0.0223 mg/L), followed by raw milk (0.0207 mg/L) and Manshanu (0.0197 mg/L). This pattern may indicate that differences in processing or handling, or variation in the raw milk used for preparation, could contribute to the observed concentrations. The findings are consistent with Yan et al. (2022), whose systematic review identified cadmium among the potentially toxic elements detected in milk and dairy products and discussed environmental contamination and feed as possible sources. They also broadly agree with Boudalia et al. (2021), who found that cadmium contamination in raw cow's milk had been reported across different geographical settings.

In Nigeria, Tobi et al. (2023) investigated selected heavy metals in raw cow's milk from Gwale, Dala and Ungogo in Kano State. Although their study focused on different metals and did not provide a direct comparison for cadmium, it demonstrates the relevance of examining milk contamination

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across different local government areas. Thus, the significant location effect observed provisionally in the present study supports further investigation of geographical variation in milk contamination.

Cobalt (Co)

The ANOVA results revealed that sampling location had a statistically significant effect on cobalt concentration ($F = 15.626$, $p = 0.00012$), indicating that cobalt levels varied significantly across the sampling locations. Similarly, the interaction between dairy product type and sampling location was statistically significant ($F = 4.385$, $p = 0.0119$). This significant interaction suggests that differences in cobalt concentration among dairy products were not consistent across all sampling locations; rather, the pattern of variation depended on the specific location from which the products were obtained. In contrast, the overall effect of dairy product type was not statistically significant at the 5% level ($F = 3.236$, $p = 0.063$), indicating insufficient evidence of an overall difference in mean cobalt concentration among the dairy product types when considered across all sampling locations. Therefore, the findings suggest that sampling location and its interaction with dairy product type are important factors associated with variations in cobalt concentration.
These results suggest that cobalt concentrations may vary across the study locations and that the pattern of variation may differ among Manshanu, Kindirmo and raw milk. The significant interaction means that the location-related differences should not be interpreted independently of product type. Follow-up comparisons would be required to establish which particular locations or products differ significantly. The findings can be compared with the work of Boudalia et al. (2021), whose review examined heavy metals in raw cow's milk and highlighted geographical and environmental differences in contamination. They also relate to the Nigerian study by Dibie and Asuelimen (2022), which investigated selected mineral elements, including cobalt, in cow and goat milk collected from animal markets in Benin City.

Copper (Cu)

The ANOVA results revealed a statistically significant difference in copper concentration among the three dairy products ($F = 47.816$, $p < 0.001$), indicating that copper levels varied significantly according to product type. In contrast, the effect of sampling location was not statistically significant ($F = 2.356$, $p = 0.1233$), suggesting that copper concentrations did not differ significantly across the sampling locations. Similarly, the interaction between dairy product type and sampling location was not statistically significant ($F = 0.500$, $p = 0.7361$), indicating that the pattern of copper concentration among the dairy products did not vary significantly by location. Overall, the findings suggest that differences in copper concentration were primarily associated with dairy product type rather than sampling location or the interaction between product type and location under the assumptions of the provisional analysis. The descriptive results indicated that raw milk had the highest average copper concentration (0.0637 mg/L), followed by Kindirmo (0.0517 mg/L) and Manshanu (0.0433 mg/L). This pattern may reflect differences in the composition of the products or in the raw materials used during processing, although the present study did not directly investigate these mechanisms.

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The findings can be compared with those of Tobi et al. (2023), who examined copper concentrations in raw cow's milk from three local government areas in Kano State. They reported copper concentrations of 0.0584, 0.0714 and 0.2604 mg/L across the sampled locations. Their findings demonstrate variation in copper concentration between milk samples from different locations, unlike the nonsignificant location effect observed provisionally in the present study. The difference may reflect variations in sampling locations, environmental conditions, animal feed or sampling procedures. However, the studies cannot be compared as if they used identical sampling designs. The results also relate to the review by Yan et al. (2022), which identified environmental contamination and feed as possible contributors to metal concentrations in milk and dairy products. Overall, the present findings suggest that product type may be an important consideration when assessing copper concentrations.

Nickel (Ni)

The ANOVA results revealed a statistically significant difference in nickel concentration among the dairy products ($F = 49.737$, $p < 0.001$), indicating that nickel levels varied significantly across the different product categories. However, the effect of sampling location was not statistically significant ($F = 2.139$, $p = 0.1467$), suggesting that nickel concentrations did not differ significantly among the locations included in the analysis. Similarly, the interaction between dairy product type and sampling location was not statistically significant ($F = 0.306$, $p = 0.8704$), indicating that the differences in nickel concentration among the product categories did not vary significantly across locations. Overall, the findings suggest that variation in nickel concentration was primarily associated with dairy product type, while neither sampling location nor the interaction between product type and location showed a statistically significant effect under the assumptions of the provisional analysis.

The descriptive statistics showed that Kindirmo had the highest mean nickel concentration (0.0467 mg/L), followed by raw milk (0.0377 mg/L) and Manshanu (0.0297 mg/L). These differences may be associated with the characteristics of the products or variation in the raw materials used to prepare them. The findings can be compared with Boudalia et al. (2021), whose systematic review of raw cow's milk documented nickel contamination in milk samples from different geographical settings. Their review also highlighted the potential importance of environmental sources in explaining differences in heavy metal concentrations. This provides general support for investigating nickel in dairy products, although it does not independently confirm the product-specific pattern observed in the present study.

Similarly, Yan et al. (2022) concluded that heavy metal concentrations in milk and dairy products may be influenced by environmental conditions and contamination sources associated with feed and production. The present findings therefore contribute local evidence on possible differences among dairy products.

Lead (Pb)

The ANOVA results indicated a statistically significant difference in lead concentration among the dairy products ($F = 49.737$, $p < 0.001$), while the effect of sampling location was not statistically significant ($F = 2.139$, $p = 0.1467$). Similarly, the interaction between dairy product type and

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sampling location was not statistically significant (F = 0.306, p = 0.8704). Relevant Nigerian evidence demonstrates why lead contamination in milk deserves attention. Tobi et al. (2023) reported lead concentrations of 0.0350, 0.0390 and 0.4100 mg/L in raw cow's milk from three local government areas in Kano State. The differences across their reported locations illustrate the potential for substantial geographical variation in milk contamination. Their findings provide useful Nigerian context indeed. In a broader review, Yan et al. (2022) reported that lead was detected in milk and dairy products across the studies they examined, although concentrations varied and some results differed in relation to the standards applied. Likewise, Boudalia et al. (2021) discussed lead as one of the potentially toxic metals of concern in raw cow's milk. These studies support continued monitoring of lead in dairy products, but a reliable comparison with the present study requires corrected lead measurements.

General implication of the ANOVA findings

Taken together, the results suggest that the effects of dairy product and sampling location were not uniform across the metals investigated. Cadmium showed significant product and location effects, cobalt showed a significant location effect and product-by-location interaction, while copper and nickel showed significant differences among dairy products but nonsignificant location effects and interactions. These patterns are broadly consistent with the literature indicating that heavy metal concentrations in milk are variable and may depend on environmental exposure, feed, geographical conditions and production practices (Boudalia et al., 2021; Yan et al., 2022). Nigerian studies, including Tobi et al. (2023) and Dibie and Asuelimen (2022), further demonstrate the importance of assessing metal concentrations in locally produced milk and milk from different sources.

SUMMARY

This study assessed the concentrations of selected heavy metals in dairy products obtained from different sampling locations. The analysis focused on cadmium, cobalt, copper, nickel, and lead concentrations and examined variations according to dairy product type and sampling location. The ANOVA results showed that cadmium concentration differed significantly among dairy products and sampling locations, although their interaction was not significant. Cobalt concentration varied significantly across locations, and a significant product-by-location interaction was also observed, while the overall product effect was not significant. Copper and nickel concentrations differed significantly among dairy products, whereas neither location nor the product-by-location interaction was significant. The provisional lead results indicated significant differences among dairy products but no significant location or interaction effects; however, these findings require verification because the reported lead values duplicated the nickel results. Overall, the findings demonstrate that heavy-metal concentrations in dairy products can vary according to product type and, for some metals, sampling location. Such variations are important because exposure to heavy metals through contaminated food may pose potential health concerns

CONCLUSION

The study concludes that heavy-metal concentrations in the assessed dairy products were not uniform across product types and sampling locations. Product type was an important source of

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variation for cadmium, copper, and nickel, while sampling location significantly influenced cadmium and cobalt concentrations. The significant interaction between dairy product and location for cobalt further indicates that the concentration pattern depended on both factors. These findings are consistent with the broader concern that heavy metals can occur in milk and dairy products and may vary according to environmental and production-related factors.

RECCOMENDATIONS

Based on the findings of the study, the following recommendations are made:

1. **Regular monitoring:** Relevant food-safety and public-health authorities should establish or strengthen routine monitoring of heavy-metal concentrations in milk and dairy products from different locations.
2. **Laboratory verification:** The original laboratory records for lead should be carefully reviewed, particularly the reported concentrations and standard deviations, because the lead results currently duplicate the nickel results. The lead analysis should be repeated using the verified laboratory data.
3. **Source identification:** Further investigations should identify potential sources of heavy-metal contamination, including contaminated feed, water, soil, processing equipment, and environmental exposure around dairy production areas.
4. **Strengthening food-safety practices:** Dairy producers and processors should be encouraged to adopt good production, handling, storage, and processing practices that can reduce the risk of contamination.
5. **Consumer protection:** Regulatory agencies should ensure that dairy products available to consumers comply with applicable food-safety standards and permissible contaminant limits.
6. **Further research:** Future studies should use larger sample sizes and cover additional dairy products and sampling locations. Repeated sampling across different seasons would also provide stronger evidence on temporal and geographical variations in heavy-metal concentrations.
7. **Health-risk assessment:** Future research should incorporate dietary exposure and health-risk assessments to determine the potential risks associated with long-term consumption of dairy products containing elevated concentrations of heavy metals.

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