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Original Research Article

Residual Levels and Potential Health Risk Assessment of Heavy Metals in Varieties of Teff Using ICP-OES from Becho District, Ethiopia

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ABSTRACT

In this study, the levels of heavy metals and associated risks from frequently consumed red, mixed, and white teff grown in the Becho area of Ethiopia were determined. The sample was wet-digested and analyzed by ICP-OES. Further data acquisition and analysis, such as spike experiments, were conducted to validate the performance of the method. The levels of Fe, Mn, Zn, Cu, Cr, Co, Ni, Pb, and Cd ranged from 83.67 to 330.10, 157.02 to 299.16, 25.88 to 44.60, 2.84 to 8.03, 0.0014 to 2.50, 0.024 to 0.35, 0.0012 to 19.73, 0.0022 to 0.40, and 0.022 to 0.34 mg/kg in all teff varieties, respectively. The percentage recovery of the examined metals in the spiked tests ranged from 88.65 to 118.80%, showing the good validity of the optimized digested procedures. Non-carcinogenic health risks to exposed adults were also assessed. The THQ values of Mn and Fe in red teff and Mn and Ni in mixed teff exceeded 1, indicating that the consumption of red and mixed teff may cause possible non-carcinogenic health effects to exposed populations. The values of hazard index (HI) for white, red, and mixed teff were 3.95, 8.302, and 8.84, respectively, indicating that heavy metals exposure of the population leading to potential adverse health risks. The TCR values of Ni and Cr in mixed teff showed high cancer risk, with Cd indicating a moderate effect, and the values of Ni, Cd, Pb, and Cr in red teff; Pb in mixed teff; and Cd, Cr, and Ni in white teff showed low cancer risks in the exposed adult population in the area.

Keywords: Heavy Metals, ICP-OES, Risk Assessment, Teff.

INTRODUCTION

Teff (*Eragrostis tef*) is a cereal crop native to Ethiopia, where it has served as a fundamental component of the national diet for centuries (Adane et al., 2020). Its cultivation is most prominent in the northern and central regions of the country. Compared with other cereals such as wheat, barley, oats, and rice, teff provides a superior nutritional profile, containing higher concentrations of essential amino acids, dietary fiber, minerals, vitamins, and fatty acids (Abraha et al., 2020; Dame, 2020). In recent years, the demand for teff has expanded globally, particularly in Europe, due to its recognized health benefits and gluten-free nature.

In Ethiopia, teff is primarily used to prepare *injera*, a fermented flatbread made from teff flour, water, and a fermentation starter derived from a previously fermented batch (Callejo et al., 2016; Gebregewergis, 2021). The crop is highly resilient, thriving under a broad range of ecological conditions, including regions unsuitable for other cereals, making it a low-risk crop (Weldehawaria, 2022). Beyond its domestic importance, teff is increasingly incorporated into international food products, including fortified baby foods, through blending with chickpeas, soybeans, and other grains to improve nutritional content (Lianne et al., 2020). Regular consumption of teff has been associated with elevated hemoglobin levels and a reduced incidence of anemia, including during pregnancy, even in communities affected by hookworm infections (Habte et al., 2020).

Three major teff varieties are cultivated in Ethiopia—white, red, and mixed. Although their general composition is comparable, red teff contains relatively higher iron concentrations, making it particularly beneficial for addressing iron deficiency (Callejo et al., 2016; Gebregewergis, 2020; Habte et al., 2022). White teff typically performs best in highland regions under optimal growing conditions and is highly preferred by consumers, resulting in its higher market value. Nevertheless, red teff, known for its superior iron and calcium content, is gaining popularity among health-conscious consumers (Gebregewergis, 2020; Lianne et al., 2020). Economically, teff plays a vital role in Ethiopia's agricultural sector, ranking second only to coffee as a source of national revenue, contributing approximately $500 million annually (Alemneh et al., 2022; Gebregewergis, 2021).

Trace metal contamination poses a serious global environmental and public health issue, as these elements occur naturally in the earth's crust but have become increasingly concentrated in the environment due to human activities (Akele et al., 2017; Eghbaljoo-Gharehgheshlaghi et al., 2020). In rural settings, the primary contributors to heavy metal accumulation include waste disposal, sewage sludge application, pesticides, herbicides, and fertilizers (Akele et al., 2017). Among environmental contaminants, heavy metals are particularly concerning due to their toxicity, persistence, and ability to bioaccumulate in soil and plants, leading to potential human health risks (Mihretu et al., 2021; Fan et al., 2017). The increasing emphasis on food safety has prompted researchers to evaluate the potential hazards associated with dietary exposure to heavy metals, which now represent one of the most pressing global environmental and health challenges (Rai et al., 2019).

The degree to which food crops absorb heavy metals largely depends on soil properties, including organic matter content, clay fraction, pH, mineral composition, and cation exchange capacity (Adjei-Mensah et al., 2021). Chronic exposure to elevated levels of toxic metals through food or dietary supplements can adversely affect human health (Woldetsadik et al., 2020). Apart from natural geological sources, anthropogenic factors such as industrialization, mining, improper fertilizer and pesticide use, and irrigation with contaminated water have further intensified heavy metal pollution in agricultural soils (Guo et al., 2020). Unlike organic contaminants, toxic metals such as As, Cd, Pb, Sn, Al, and Hg are non-biodegradable and can persist in soil for long periods, thereby accumulating to harmful levels and posing a threat to food safety and human health (Sibuar et al., 2022). Notably, teff serves as a valuable dietary source of essential minerals, particularly calcium (Ca), iron (Fe), manganese (Mn), and zinc (Zn), which are found in considerable concentrations (Koubová et al., 2018).

Despite its nutritional importance, limited studies have been conducted in Ethiopia to assess heavy metal concentrations in teff (Dame, 2020; Gebregewergis, 2020; Mulugeta & Mohammed, 2015). However, no comprehensive assessment has been reported on the levels of heavy metals and associated health risks across red, white, and mixed teff varieties cultivated in the Becho (Tullu Bollo) district. Therefore, the present study aims to quantify the concentrations of selected metals (Fe, Co, Ni, Zn, Mn, Cd, Pb, Cr, and Cu) in these teff varieties and to evaluate the potential health risks posed to local consumers. The findings are expected to provide baseline data for future investigations into the human health implications of long-term exposure to heavy metals through teff consumption in the study area. This study specifically focuses on the analysis of heavy metal content in teff samples collected from the Becho district, Ethiopia.

MATERIALS AND METHODS

Description of the study area

The study was conducted in the Becho district of the Oromia region of Ethiopia (Fig. 1). It is located in the southwestern territory of Shewa and is bordered by Saden Sodo to the south, Woliso to the west, Dawo to the northwest, Elu to the north, and Tole to the east. The capital of Becho is Tulu Bolo.

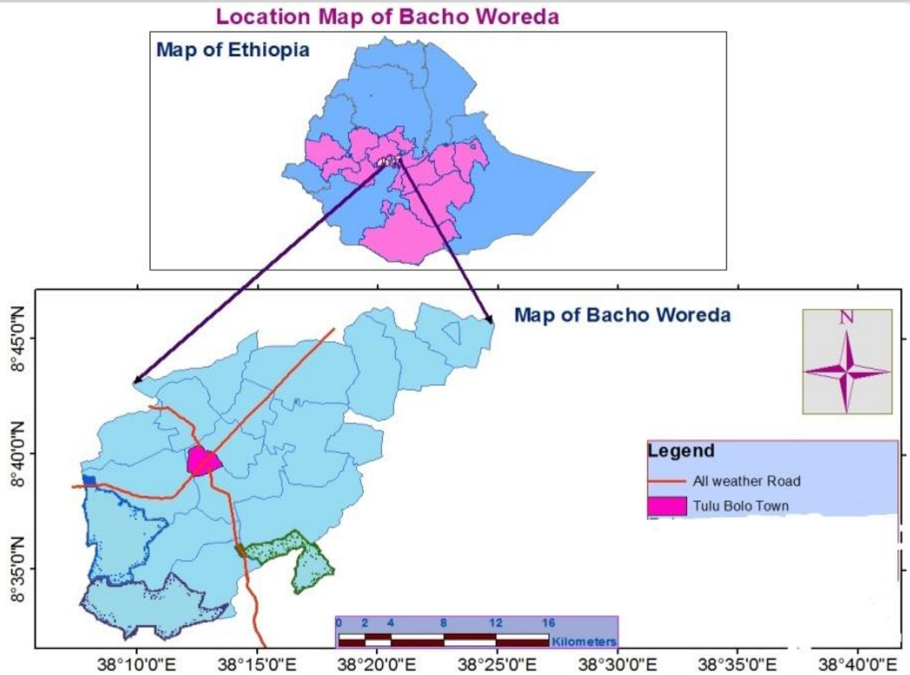

Fig.1. Location map of the study area

Sample collection and preparation

Three varieties of teff grains red, white, and mixedwere obtained from the local market in Becho (Tullu Bollo). The samples were randomly sourced from different farmers selling within the market. For each teff type, approximately 0.25 kg of grain was collected from twelve separate suppliers originating from the Becho district. The sub-samples were then combined according to their variety to produce about 3 kg of composite samples for each teff type. After collection, the samples were placed in polyethylene bags and transported to the Chemistry Laboratory at the University of Gondar. To eliminate surface dust and other adhering particles, the teff grains were thoroughly washed with distilled water. The cleaned samples were air-dried, milled into fine powder, and sieved to a particle size of 0.5 mm. The resulting powdered teff was then sealed in clean, dry polyethylene bags and stored under airtight conditions until further digestion and analysis.

Reagents and standards

All reagents used in this study were of analytical grade, and deionized water was employed for all analytical procedures. Concentrated nitric acid (HNO_3, 70%) and perchloric acid ($HClO_4$, 70%) obtained from Research Lab Fine Chem. Industries (Mumbai, India) were utilized for digestion of the sample matrix. Standard stock solutions containing 1000 mg/L of each target metal (Buck Scientific Puno. Graphic™) were used to prepare calibration standards and for spike recovery experiments. Prior to use, all plastic containers were pre-cleaned by soaking in 20% HNO_3 for 24 hours, followed by thorough rinsing with deionized water. Similarly, glassware was treated by immersion in 10% HNO_3 for 24 hours, rinsed several times with deionized water, and dried in a clean, dust-free environment before analysis.

Digestion of teff samples

Wet acid digestion is a commonly applied technique for releasing metal ions from complex organic matrices into solution, primarily by adjusting digestion parameters such as reagent volume ratios, temperature, and digestion duration. The process is considered complete when the resulting solution becomes clear and colorless. In this study, different digestion conditions were tested for teff samples using mixed acids of HNO_3 and $HClO_4$ with variations in volume, temperature, and time, following the approach outlined by Gebregewergis et al. (2020). Under the optimized conditions, 2 g of oven-dried and homogenized teff powder were transferred into a 100 mL round-bottom flask containing 6 mL of an acid mixture (HNO_3:$HClO_4$ = 5:1, v/v). The digestion was first carried out at 120°C for 30 minutes and then continued at 300°C for an additional 2.5 hours. After digestion, the flasks were allowed to cool for 10 minutes at room temperature with the condenser attached, followed by another 5 minutes after its removal. The digested mixture was diluted with deionized water and filtered into a 50 mL volumetric flask using Whatman No. 1 filter paper (25 mm). The flask was rinsed with deionized water, and 1% lanthanum nitrate solution was added before making up to the mark with deionized water. Blank samples were prepared using the same procedure and digested in triplicate. All digested solutions were stored under refrigeration until analysis of metal concentrations using Inductively Coupled Plasma–Optical Emission Spectroscopy (ICP-OES).

Instrumental parameters were optimized for maximum sensitivity following the manufacturer's guidelines. Calibration curves were prepared for each target element using appropriate standard solutions, and all measurements were carried out in triplicate. The same analytical protocol was employed for the analysis of blank digests to ensure quality control.

Method performance and validation

The limit of detection (LOD) for each metal was calculated as the sum of the mean blank signal and three times the standard deviation derived from nine blank measurements. Instrumental detection limits were taken from the manufacturer's specifications for each analyzed element. The limit of quantification (LOQ) was determined from triplicate analyses of nine reagent blanks that underwent the same digestion procedure as the teff samples. Method validation was performed through a spiking experiment, where known concentrations of standard metal solutions were added to the samples. Both spiked and unspiked samples were subjected to identical acid digestion and analytical conditions, and the percentage recovery of each analyte was calculated to assess method accuracy and precision.

Health risk assessment of metals due to teff consumption

The evaluation of health risk assessment to estimate cancer and non-cancer risks from exposure to heavy metals (Fe, Mn, Zn, Cu, Ni, Co, Cr, Pb, and Cd) in teff was based on the US EPA Human Health Assessment method (USEPA, 2011). Although there are many routes by which humans are exposed to heavy metals, including drinking, soil uptake, skin contact, and inhalation routes, ingestion has been identified as the main route contributing to more than 90% of health risks (Guo et al., 2020). The Target Hazard Quotient (THQ) and Hazard Index (HI) have been used to describe potential human health risks (Guadie et al., 2022).

Non-carcinogenic analysis

Hazard Index (HI): An HI value below 1 stands for no significant risk of non-carcinogenic effects, while an HI value of 1 or more shows the occurrence of non-carcinogenic effects (Morakinyo et al., 2021).

Target Hazard Quotient (THQ): A THQ value below 1 signifies that no adverse health risk will occur, while a THQ value of 1 or more indicates that non-cancer effects may occur (Morakinyo et al., 2021).

where THQ is a non-carcinogenic risk and is dimensionless. EF is the exposure frequency (365 days/year), ED is the exposure duration (68 years), and RfD (Oral reference doses) were 0.001, 0.004, 0.3, 0.04, 0.14, 0.02, 0.7, 0.043 and 1.5 mg/kg/d for Cd, Pb, Zn, Cu, Mn, Ni, Fe, Co and Cr, respectively (USEPA IRIS, 2011) (Temiotan et al., 2018). ATn is the averaging time for non-carcinogens (365 days/year × ED) (United States Environmental Protection Agency, (USEPA), 2011).

A THQ < 1 signifies that no adverse health risk will occur, while THQ ≥1 signifies that non-cancer effects will occur (Morakinyo et al., 2021).

Hazard Index (HI): HI value was obtained by adding the THQ values of each metal, and the health risk posed by more than one metal is added together and referred to as the hazard index (HI) (USEPA 2011), and calculated through Eqn.3:

$$HI = \sum THQ \qquad (3)$$

HI < 1 stands for no significant risk of non-carcinogenic effects, while HI ≥1 shows the occurrence of non-carcinogenic effects (Morakinyo et al., 2021).

Carcinogenic (Target cancer risk, TCR) analysis

The USEPA Regional Screening Levels (RSLs) Risk-Based Concentration Table (USEPA, 2021) method was used to estimate TCR. TR was calculated based on Eqn.4:

$$\text{TCR} = \frac{\text{C} \times \text{IR} \times 10^{-3} \times \text{CPSo} \times \text{EF} \times \text{ED}}{\text{Bw} \times \text{ATn}} \qquad (4)$$

where CPSo is the carcinogenic potency slope, oral (mg/kg BW-day^{-1}). Ant is the averaging time carcinogen (365 days/year × 68 years). Since Mn, Fe, Co, Cu, and Zn do not cause any carcinogenic effects as their CPSo have yet to be established (USEPA, 2011) (Javed & Usmani, 2016), Thus, only the TR values of Ni, Cd, Cr, and Pb were calculated to show the carcinogenic risk. The CPS_C oral cancer slope factor for Cd, Cr, Ni, and Pb was 0.38, 0.5, 1.7, and 0.0085 (mg/kg/day)$^{-1}$, respectively (Gebeyehu & Bayissa, 2020).

Statistical analysis

The generated data were exposed to Microsoft Excel 2016 and SPSS 20.0. Pearson's correlation analysis, one-way ANOVA, and LSD were performed to examine the interrelation between the HMs in the teff samples. The level of statsical significance was set to $p < 0.05$.

RESULTS AND DISCUSSION

Method performance and validation

The results of the spiked experiment and the sensitivity of the method are presented in Table 1. The LOD values were 0.039, 0.009, 0.015, 0.021, 0.0004, 0.003, 0.0003, 0.0022, and 0.00014 mg/kg, while the LOQ values were 0.13, 0.03, 0.05, 0.07, 0.0.013, 0.01, 0.001, 0.0072, and 0.0047 mg/kg for Fe, Mn, Zn, Cu, Cr, Co, Ni, Pb and Cd, respectively. The percentage recovery of analyzed metals in the spiked samples ranged from 88.65% to 118.80% (Table 1), which is within the acceptable range of recoveries of 80-120% for metal analysis (Ebere et al., 2020). For this reason, the spiking tests showed good precision and accuracy of the validated method for heavy metal measurement in the three teff samples.

Table 1: Recovery test (%R) LOD (mg/kg), and LOQ (mg/kg) of analyzed heavy metals in three varieties of Teff samples.

Elements	Fe	Mn	Zn	Cu	Cr	Co	Ni	Pb	Cd
Red	115.43	88.65	116.74	118.80	116.78	112.27	110.08	108.61	96.42
Mixed	109.7	107.95	112.23	107.75	106.27	115.88	103.08	106.8	95.45
White	105.11	95.83	108.43	103.03	118.8	116.79	118.33	118.80	98.33
LOD	0.039	0.009	0.015	0.021	0.0004	0.003	0.0003	0.0022	0.00014
LOQ	0.13	0.03	0.05	0.07	0.0013	0.01	0.001	0.0072	0.0047

The levels of HMs in Teff samples

The estimated levels of Fe, Mn, Zn, Cu, Cr, Co, Ni, Pb, and Cd in the examined teff gnains are shown in Table 2. Fe (330.10 mg/kg) in large amount followed by Mn (299.16 mg/kg), Zn (40.52 mg/kg), Cu (5.51 mg/kg), Pb (0.370), Co (0.350 mg/kg), Ni (0.0022 mg/kg), Cd (0.021 mg/kg) and Cr (0.0020 mg/kg) in red teff. The concentration of Mn (222.10 mg/kg) was the highest in mixed teff, followed by Fe (207.07 mg/kg), Zn (44.60 mg/kg), Ni (19.73 mg/kg), Cu (8.03 mg/kg), Cr (2.50 mg/kg), Pb (0.403 mg/kg), Cd (0.338 mg/kg), and Co (0.0024 mg/kg).

The concentration of Mn (157.67 mg/kg) was the largest in the white teff sample, followed by Fe (83.67 mg/kg), Zn (25.88 mg/kg), Cu (2.84 mg/kg), Co (0.05 mg/kg), Cd (0.0023 mg/kg), Ni (0.0015 mg/kg), and Cr (0.0014 mg/kg). However, Pb in white teff was found to be below LOD. Among the three the red, white and mixed teff samples, the amount of heavy metals were relatively lowest in the white teff sample. Except for Pb in red and mixed teff and Cd in mixed teff, the levels of all heavy metals were lower compared to alloable values by WHO/FAO (Tegegne, 2015). Based on one-way (ANOVA), Fe, Mn, Zn, Cu, and Co showed significant differences ($p<0.05$) in all teff samples (Table 2). The t-test show no significant differences ($p>0.05$) for concentrations of Pb in red and mixed teff samples.

Table 2: Mean concentration (mg/kg) of HMs (Mean ±SD, n = 3) in Teff samples analyzed by ICP-OES.

Metals	Red	Mixed	White	Min.	Max.	WHO/FAO
Fe	330.10±3.78a	207.07±2.23b	83.67±2.74c	83.67	330.10	425.5
Mn	299.16±5.97a	222.10±2.79b	157.02±4.46c	157.02	299.16	500
Zn	40.52±0.11a	44.60±1.87b	25.88±1.08c	25.88	44.60	99.4

Cu	5.51±1.01a	8.03±0.47b	2.84±0.42c	2.84	8.03	73.3
Cr	0.0020±0.001a	2.50±0.4b	0.0014±0.0004a	0.0014	2.50	2.3
Co	0.350±0.08a	0.024±0.004b	0.05±0.01c	0.024	0.35	50
Ni	0.0022±0.001a	1.973±0.186b	0.0015±0.001a	0.0012	19.73	67
Pb	0.370±0.03a*	0.403±0.01a*	BDL	0.0022	0.403	0.3
Cd	0.021±0.002a	0.338±0.04b	0.023±0.01a	0.022	0.338	0.2

The values in the same row accompanied by letters were stastically different ($p< 0.05$) confidence levels computed by one-way ANOVA, BDL = below detection limit, and a = paired samples t-test for Pb concentration in red and mixed teff. HMs=heavy metals.

The mean concentration of Fe obtained from this study was higher than previously reported values in white, red, and mixed teff samples from Ethiopia (Mulugeta & Mohammed, 2015). However, except for Mn (20–45 mg/kg), the concentrations of Fe (252-1195 mg/kg), Zn (73–90 mg/kg), Cu (13–15 mg/kg), Cd (0.8–1.8 mg/kg), and Pb (1.8–2.8 mg/kg) in white, red, and mixed teff samples were higher than in the present study (Gebregewergis et al., 2020).The similar report indicated that the concentration of Fe (330.10 mg/kg) in red teff was higher than the concentrations (217–239 mg/kg) reported by Habte et al. (2020), but comparable in mixed and white teff. The concentrations of Mn (56–99 mg/kg) in all types of teff grains were lower than in the present study (Habte et al., 2020). The concentrations of Zn (35–85 mg/kg) were slightly higher than in the present study. A study conducted in the in the southern part of Ethiopia showed that the concentrations of Fe and Zn in the three varieties of teff were comparable with the findings of the present study. The levels of Mn and Cu in both teff samples were higher and lower than reported values, respectively. Lead concentrations were also higher than reported by Habte et al. (2020). Similarly, the levels of metals were analyzed in teff (red and white) pursched from Addis Ababa market, Ethiopia (Dame, 2020). The findings of the levels of Fe, Mn, Zn, Cu, Co and Pb in this study were lower than the reported values by Dame (2020). However, the levels of Cr, Cd and Pb were higher than reported by Dame (2020).

Reports in Bolivia, the USA, and Europe showed the concentrations of Fe, Zn, Pb, Cd, and Mn in white and mixed teff were lower than the results of this study. While, the concentrations of Cr, Cu, Co and Ni reported by Koubová et al. (2018) were higher than the values of our study (Koubová et al., 2018), In addition, reported data by Neela & Fanta (2020) showed that concentrations of Fe (763 mg/kg), Mn (924 mg/kg), Zn (363 mg/kg), and Cu (81 mg/kg) in red teff were greater than the present study. According to Pearson's correlation table 3, the concentrations' strong correlations of Fe with Cd, Co, and Ni; Mn with Zn; Cu with Cr, Ni, and Pb; Cr with Ni and Pb; Co with Cd; Ni with Pb in red teff; Fe with Cu and Ni; Mn with Zn, Co, Pb and Cd; Cu with Cr and Ni; Cr with Cd and Ni; Co with Cd, Zn and Pb,Cd with Pb, and Zn with Cd and Pb in mixed teff, and Fe with Mn and Ni; Zn with Cr; Cu with Cr, Co, Ni, and Cd; Cr with Co and Cd, and Co with Cd in white teff were reported. This correlation could suggest the metals were sorced from similar origion (Guadie et al., 2022). While, strong negative correlations were detected between Mn with Cu, Cr, Ni, and Pb and Zn with Cu, Cr, Ni, and Pb in red teff; Fe with Mn, Zn, and Cd; Mn with Cu and Ni; and Zn with Cu and Ni in mixed teff, and Fe with Z, Cr, and Co; Mn with Zn, Cr, Co, and Cd; and Zn with Ni in teff, which indicates the different origin of metals (Adefa & Tefera, 2020).

Table 3: Pearson's correlation matrices for heavy metals in three teff samples.

		Fe	Mn	Zn	Cu	Cr	Co	Ni	Pb	Cd
Red Teff	Fe	1								
	Mn	-0.122	1							
	Zn	-0.514	0.914	1						
	Cu	0.133	-0.987	-0.919	1					
	Cr	-0.088	-0.978	-0.809	0.975	1				
	Co	0.982	0.070	-0.340	-0.059	-0.277	1			
	Ni	0.585	-0.876	-0.996	0.882	0.756	0.419	1		
	Pb	0.024	-0.995	-0.870	0.994	0.994	-0.168	0.825	1	
	Cd	0.967	0.135	-0.278	-0.124	-0.339	0.998	0.359	-0.232	1
Mixed Teff	Fe	1								
	Mn	-0.988	1							
	Zn	-0.958	0.953	1						
	Cu	0.656	-0.642	-0.845	1					
	Cr	0.101	-0.082	-0.381	0.817	1				
	Co	-0.941	0.948	0.806	-0.363	0.240	1			
	Ni	0.585	-0.569	-0.792	0.996	0.866	-0.277	1		
	Pb	-0.930	0.937	0.787	-0.334	0.271	0.999	-0.247	1	
	Cd	-0.738	0.751	0.515	0.024	0.596	0.923	0.115	0.934	1
White Teff	Fe	1								
	Mn	0.817	1							
	Zn	-0.998	-0.775	1						
	Cu	0.061	-0.526	-0.130	1					
	Cr	-0.643	-0.967	0.587	0.726	1				
	Co	-0.542	-0.927	0.482	0.806	0.992	1			
	Ni	0.739	0.216	-0.784	0.717	0.041	0.165	1		
	Cd	-0.447	-0.881	0.383	0.866	0.973	0.994	0.273	-	1

Health risk assessment of heavy metals in teff grains

The THQ values of Fe (1.306 mg kg^{-1} day^{-1}) in red teff, Mn in red teff (5.914 mg kg^{-1} day^{-1}), mixed (4.393 mg kg^{-1} day^{-1}) and white (3.107 mg kg^{-1} day^{-1}), and Ni (1.279 mg kg^{-1} day^{-1}) in mixed teff were all above 1, suggesting that ingestion of these heavy metals in these teff samples might pose serious risks to the local population.

The HI values for red (8.302), mixed (8.840), and white teff (3.950) were all above 1, indicating that adults are exposed to these metals, which leads to potential adverse health risks in the study area.

Table 4 shows the values of EDI, THQ, HI, and CR of non-carcinogenic and carcinogenic risks to adults caused by consumption of red, mixed, and white teff. The highest EDI values in red teff were found for Fe, Mn, and Co, the highest EDI values in mixed teff were recorded for Zn, Cu, Cr, Ni, Pb, and Cd. However, among the three varaities, the lowest EDI for all metals was found in white teff.

The THQ values of Fe, Mn, Cr, Co, Ni, Zn, Cu, Pb, and Cd were recorded as 1.306, 0.375,$3.9x10^{-6}$, 0.023, $3.0x10^{-4}$, 5.914, 0.373, 0.250, and 0.061; 0.819, 4.393, 0.413, 0.550, 0.175, $1.5x10^{-3}$, 1.279, 0.275, and 0.940; and 0.331, 0.240, 0.200, $2.6x10^{-6}$, $3.0x10^{-3}$, $2.1x10^{-4}$, ND, and 0.064 mg kg^{-1} day^{-1} in red, mixed, and white teff, respectively. The THQ values of Fe (1.306 mg $kg^{-1}day^{-1}$) in red teff, Mn in red teff (5.914 mg $kg^{-1}day^{-1}$), mixed (4.393 mg $kg^{-1}day^{-1}$) and white (3.107 mg $kg^{-1}day^{-1}$), and Ni (1.279 mg $kg^{-1}day^{-1}$) in mixed teff were higher than 1, suggesting that ingestion of these heavy metals in these teff samples might pose serious risks to the local population. The variations between the THQ values could be attributed to the variations in different geographic locations (Guo et al., 2020).

The HI (total THQ) of red, mixed, and white teff isaccount for by the THQ values of Mn and Fe. The HI values for red (8.302), mixed (8.840) and white teff (3.950 samples were > 1, indicating that adults are exposed to these metals, which leads to potential adverse health risks in the study area.

The TCR carcinogenic risk to adults caused by red, mixed, and white teff consumption is indicated in Table 4. The TCR value of Cd was the highest followed by Ni, Pb, and Cr for red teff; while for mixed teff, Ni displayed the highest TCR value, followed by Cr, Cd, and Pb. However, Cd has the highest TCR in white teff followed by Ni and Cr. As can be seen in Table 4, Ni demonstrated the highest role in the total TCR value in mixed teff. Based on the some report, TCR category is described as low if TCR $\leq 10^{-6}$; 10^{-4} to 10^{-3} is moderate; 10^{-3} to 10^{-1} is high, and $\geq 10^{-1}$ is very high (Javed & Usmani, 2016). In this study Ni (0.0935) and Cr ($3.5x10^{-3}$) in mixed teff show high cancer risk for the exposed population, and Cd ($3.6x10^{-4}$) shows a moderate effect (Song et al., 2021). However, the TCR values of red teff ranged from $1.0x10^{-5}$ to $8.5x10^{-6}$; in mixed teff TCR ranged from $9.4x10^{-6}$ to 0.0935, and white teff ranged from$1.3x10^{-6}$ to $2.4x10^{-5}$. Except for Ni, Cr, and Cd in mixed teff, the carcinogenic risk for Ni, Cd, Pb, and Cr was between the 10^{-6} and 10^{-4} ranges. These results revealed that the intervals signify the predicted tolerable lifetime risks for carcinogens (Peters et al., 2018).

Table 4: The EDI values for consumers, THQ, and TCR of trace metals due to consumption of teff.

Metal	Red Teff			Mixed Teff			White Teff		
	EDI	THQ	TCR	EDI	THQ	TCR	EDI	THQ	TCR
Fe	0.914	1.306		0.573	0.819		0.232	0.331	
Mn	0.828	5.914		0.615	4.393		0.435	3.107	
Zn	0.112	0.373		0.124	0.413		0.072	0.240	
Cu	0.015	0.375		0.022	0.55		8.0x10-3	0.200	

Cr	5.8x10-6	3.9x10-6	2.9x10-6	7x10-3	0.175	3.5x10-3	3.9x10-6	2.6x10-6	1.3x10-6
Co	9.7x10-4	0.023	-	6.6x10-5	1.5x10-4	-	1.3x10-4	3.0x10-3	
Ni	6.1x10-6	3.0x10-4	1.0x10-5	0.055	1.279	0.0935	4.2x10-6	2.1x10-4	7.1x10-6
Pb	1.0x10-3	0.250	8.5x10-6	1.1x10-3	0.275	9.4x10-6	-	-	-
Cd	6.1x10-5	0.061	2.3x10-5	9.4x10-4	0.94	3.6x10-4	6.4x10-5	0.064	2.4x10-5
HI		8.302			8.84			3.95	
$\sum TCR$			4.44x10-5			9.74x10-2			3.24x10-5

CONCLUSION

In this study, the levels of 9 heavy metals in red, mixed, and white teff samples in the Becho area were estimated by using ICP-OES. The levels of all metals except Pb in red and mixed teff and Cd in mixed teff were within the safe limit set by the WHO/FAO allowable limits. The individual THQ values except for Fe and Mn in red teff, Mn and Ni in mixed teff, and Mn in white teff were all below 1 for adults consuming teff, suggesting a tolerable level of non-carcinogenic adverse risk. The HI values of heavy metals in all teff samples exceeded 1, which may cause potential health risks, including cancer for the exposed adult population in the area. Iron and Mn in red, mixed, and white teff and Ni in mixed teff were the most significant contributors to total THQ or HI values for the exposed population. The values of TCR in this study, Ni and Cr in mixed teff, suggest high cancer risk in the exposed population, and Cd was in the range of moderate effect. The data and findings gave a clear picture of trace metal concentrations and their associated health risks in teff samples consumed by the inhabitants of the study areas. There is significant health effects to the population from consuming teff at the study areas. Thus, health risks of the studied metals should not be ignored.

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Conflict of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Ethics Approval

All experimental procedures did not include any animal or human element

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