Survey of rice (*Oryza sativa* L.) production ecosystems in northern Ghana confirms low risk of exposure to potential toxic elements from local grain consumption

Eureka E.A. Adomako [a], Kow Aboagye-Ghunney[a], and Prince Owusu[b]

[a]Department of Plant and Environmental Biology, University of Ghana, P.O. Box LG 55, Legon, Accra, Ghana; [b]Institute for Environment and Sanitation Studies, University of Ghana, P.O. Box LG 59, Legon, Accra, Ghana

Corresponding author: **Eureka E.A. Adomako** (email: eadomako@ug.edu.gh)
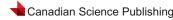
Abstract

Expanding local rice production to meet consumer demand is a priority action under the Government of Ghana's Planting for Food and Jobs initiative. While studies on yield-enhancing interventions abound, fewer studies focus on food safety issues (e.g., the potential toxic element status of the production ecosystems). This study was, therefore, conducted to bridge the knowledge gap. Chemical analyses were conducted on water, soil, and rice grain samples from different production ecosystems in the Northern and Upper East regions of Ghana. Statistical analysis of the data showed that soil and rice grain arsenic concentrations were significantly higher ($P < 0.001$) in the Upper East region. In the Northern region, mean cadmium concentration in rice grains from the irrigated lowland fields (0.023 ± 0.003 mg/kg) was significantly higher than in grains from the rainfed fields. All recorded concentrations of rice grain arsenic, cadmium, and lead were, however, within permissible limits, indicating a low risk of dietary exposure. The observed differences in concentrations within and between regions suggest that soil texture and other geogenic factors could influence the potential toxic element status of the rice production ecosystems. Regular monitoring is, therefore, recommended to maintain the safety of Ghana's locally produced rice for human consumption.

Key words: rice production, *Oryza sativa*, food safety, potential toxic element, Ghana

1. Introduction

Rice (*Oryza sativa* L.) is an important staple for more than half of the world's population (GRiSP 2013) and is considered as a priority crop under the Planting for Food and Jobs (PFJ) initiative launched by the Government of Ghana in 2017 (Pauw 2022). It is grown in all the agro-ecological zones and administrative regions of Ghana, with regions in the northern part of the country—notably, Northern, Upper East, and Upper West—accounting for half of local production (MoFA-IFPRI 2020). Despite a steady growth of about 11% per annum between 2008 and 2019, local rice production in Ghana continues to fall about 50% short of consumer demand (MoFA-IFPRI 2020) due to an increasing shift in dietary preferences from the indigenous staples (mainly cassava, yam, and maize) to rice. This has been attributed to urbanization, the ease of cooking rice compared to other local dishes, and changes in consumer habit as people become wealthier (Al-Hassan et al. 2008; Anabila 2015; MoFA-IFPRI 2020). Per capita consumption of milled rice in Ghana was estimated to have increased from 13.3 kg/annum in 1990 to 32.0 kg/annum in 2015 (SRID-MoFA 2017) and was projected to reach 45 kg/annum by 2025 (Van Oort et al. 2015). SRID-MoFA (2021), however, reported an increase in per capita consumption of milled rice from 40.4 kg/annum in 2016 to 51.5 kg/annum in 2020, thus ex-ceeding the earlier projection by Van Oort et al. (2015). According to Kushitor (2021), rice has replaced maize as the primary cereal in Ghana. Studies have also shown a higher preference for imported rice than locally produced rice (Anabila 2015; Graham-Acquaah et al. 2020; Ragasa et al. 2020). Factors that determine consumers' choice include taste, appearance (good-looking grains), aroma, absence of foreign materials, and packaging (Adomako et al. 2011; Ehiakpor et al. 2017).

To address concerns regarding foreign exchange imbalances due to high dependence on rice imports and Ghana's vulnerability to price volatility in the international rice market, both the National Rice Development Strategy of 2009 (reviewed in 2015) and the government's PFJ initiative aim at expanding local rice production to meet consumer demand (Ragasa and Chapoto 2017; MoFA-IFPRI 2020; Onumah et al. 2022; Pauw 2022). National food and agriculture policy interventions directed at meeting the ambitious targets for local rice output have focused on facilitating access to farm inputs, mainly improved seed and fertilizers (Tanko et al. 2019; Zakaria et al. 2021; Pauw 2022). Rice research in Ghana is, therefore, skewed towards seed improvement interventions aimed at enhancing yield and pest/disease resistance (Abebrese et al. 2019; Fordjour et al. 2020; Tawiah et al. 2022). Efforts have also been made to better understand the

effects of different fertilizer/nutrient management regimes (Sarkodee-Addo et al. 2021; Fuseini and Benjamin 2022) and the socio-economic factors that influence farmers' adoption of improved rice varieties and other productivity enhancing technologies (Tanko and Ismaila 2021; Azumah et al. 2022; Quaye et al. 2022; Tanko 2022). In contrast, fewer studies have been conducted on the status of potential toxic elements (PTEs), e.g., arsenic (As), cadmium (Cd), and lead (Pb), in Ghana's rice production ecosystems. This could be attributed to the absence of national or regional rice testing policies. Such studies are, however, necessary since consumers can only derive the full benefits of the nutritional value of this important food staple when it is safe for consumption.

In other parts of the world—particularly in Asia—several studies have been conducted in rice production systems, all of which point to environmental regulation as a key determinant of PTE concentrations in rice grain (Williams et al. 2006; Adomako et al. 2009; Lu et al. 2009; Ali et al. 2020). To date, the study by Adomako et al. (2010) is the largest field survey of PTE concentrations in Ghanaian rice production ecosystems. It did not, however, include rice fields in northern Ghana due to time and resource constraints. This study was, therefore, conducted to expand the scope to include rice fields in northern Ghana, build on the existing data, and validate earlier findings regarding the safety of Ghana's locally produced rice for human consumption.

2. Method

2.1. Study sites

Field surveys were conducted in the Tolon District of the Northern Region and the Kassena–Nankana East Municipality of the Upper East Region of Ghana. A total of 18 study sites representing three types of rice production ecosystems in northern Ghana—rainfed upland (RU), rainfed lowland (RL), and irrigated lowland (IL)—were surveyed. The selected study sites were all cultivated with the same rice variety (AGRA rice)—an aromatic variety widely grown in northern Ghana.

In the Northern Region, three RU and three RL sites were selected from research fields belonging to the Council for Scientific and Industrial Research—Savanna Agricultural Research Institute (CSIR-SARI) at Nyamkpala and three IL sites were selected from fields around the Golinga Dam. In the Upper East region, three IL sites were selected from fields around the Tono Dam, along with three RU and three RL sites belonging to local farmers in Navrongo. Communication with the local farmers and CSIR-SARI scientists revealed that fertilizers were applied in all the study sites to enhance plant growth.

2.2. Sample collection

At each sampling site, soil samples were collected using a 5 cm diameter soil auger to core beside the base of mature rice plants to a depth of 20 cm. Matured rice grains (110–140 days after sowing) were also harvested from the same locations as the soil samples. The grain samples were placed in brown paper envelopes, while soil samples were put into resealable polyethylene bags. All the envelopes and bags were sealed and appropriately labelled to ensure correct matching of soil and grain samples from the same location.

At the IL study sites located around the Golinga and Tono Dams, water samples were collected from irrigation canals supplying the rice fields into 500 mL plastic bottles that had been pre-washed with detergent, soaked and washed in 10% nitric acid (HNO_3) for 24 h, rinsed thoroughly with double distilled water, and oven-dried overnight (Eaton et al. 2005). In the Northern region, additional water samples were collected from Bontanga (a rice irrigation site close to Golinga), and in the Upper East Region, reference samples were obtained from a borehole dug for domestic purposes at Navrongo. Prior to collection of the water samples, on-site rinsing of the plastic bottles was done three times with the water to be sampled. For total recoverable metal analysis, each sample was acidified with 5 mL of HNO_3 to a pH below 2.0 according to USEPA Method 3005 developed by the United States Environmental Protection Agency (USEPA 1992). The collected water samples were sealed and appropriately labelled to indicate the sampling location and sample number. They were immediately stored in an ice chest at 4 °C to protect against the effects of light and extreme heat that could alter the water chemistry by enhancing microbial activity. On transfer to the laboratory, the water samples were kept in a refrigerator at 4 °C for 48 h pending analysis.

2.3. Sample preparation and analysis

Soil samples were air-dried at room temperature for 5–7 days, then disaggregated with a porcelain mortar and pestle, and sieved to 2 mm prior to analysis. Soil physicochemical properties—namely pH, electrical conductivity (EC), and particle size distribution—were all determined using standard protocols (Van Reeuwijk 2002). Rice grain samples were manually dehusked and oven-dried at 90 °C for 48 h in a brown envelope until constant dry weight. They were then milled into powdery form in a blender and sieved to 1 mm. Water samples were taken out of the freezer 24 h prior to analysis and allowed to thaw at room temperature.

2.3.1. Acid digestion of water samples

For determination of total As, Cd, and Pb concentrations in the water samples, 40 mL of each sample was measured into a 250 mL digestion flask and 15 mL of HNO_3 was added before heating on a block digester (Behrotest® K8) at 45 °C for 1–2 h. Each sample digest was then filtered on cooling with a Whatman No. 42 filter paper into a 100 mL volumetric flask and topped up to the mark with deionised water (USEPA 1992).

2.3.2. Digestion of soil samples

For total element detection in the soils, 1.0 g of each sample was measured into a digestion tube to which 10 mL of ternary mixture—500 mL of HNO_3, 50 mL of concentrated sulphuric acid (H_2SO_4), and 20 mL of perchloric acid ($HClO_4$)—were added and then placed on a hot plate at 95 °C under a fume hood for 30 min. After cooling, the soil digests were

Table 1. Certified and measured concentrations of Arsenic (As), cadmium (Cd), and lead (Pb) in standard reference materials (SRM) used for quality control.

		As	Cd	Pb
ISE Sample 999	Certified value (mg/kg)	0.772 ± 0.344	0.040 ± 0.020	4.710 ± 1.157
	Measured value (mg/kg)	0.852 ± 0.223	0.048 ± 0.031	4.907 ± 0.235
	Mean recovery (%)	95.3	99.6	98.7
NIST SRM 1547	Certified value (mg/kg)	0.062 ± 0.014	0.0261 ± 0.0022	0.869 ± 0.018
	Measured value (mg/kg)	0.066 ± 0.014	0.0203 ± 0.0021	0.877 ± 0.021
	Mean recovery (%)	97.6	99.3	99.6

filtered with a Whatman No. 42 filter paper into 100 mL volumetric flasks and topped up to the mark with deionised water (Perkin-Elmer 1996).

2.3.3. Digestion of rice samples

For determination of total rice grain As, Cd, and Pb concentrations, 0.5 g of each milled and sieved sample was weighed into a 100 mL conical flask and 5 mL of H_2SO_4 was added and left to react overnight. Subsequently, the samples were placed on a hot sand bath at 95 °C and, after about 20 min, hydrogen peroxide (H_2O_2) was added dropwise until the samples were clear in colour indicating complete digestion. On cooling, the rice grain digests were also filtered into 100 mL volumetric flasks and topped up to the mark with deionised water (Novozamsky et al. 1983).

2.3.4. Determination of elemental concentrations

Total elemental concentrations in all the samples were measured using the PerkinElmer PINAAcle 900T Atomic Absorption Spectrophotometer (AAS). Cd and Pb concentrations were determined using flame atomic absorption spectrophotometry, while As was determined using the flow injection analysis—atomic absorption spectrometry (hydride generation) technique. Air-acetylene gas was used as the source of fuel for Cd and Pb, while argon gas was used for As (Perkin-Elmer 1996).

2.3.5. Quality control

For quality assurance, standards prepared from stock solutions of each element, as well as blanks, were used to calibrate the AAS prior to analysis. This was repeated after every set of 10 sample measurements to ensure precision and accuracy of the analytical results. As part of the quality control protocol, duplicate samples of a standard reference material (SRM) of moist clay—Wageningen Evaluating Programs for Analytical Laboratories International Soil-Analytical Exchange Reference material (ISE Sample 999)—were included in every batch of soil sample digestion and analysis to guarantee the accuracy of the data. In the case of the rice samples, a SRM of peach leaves (SRM 1547) from the National Institute of Standards and Technology was used in the absence of a rice SRM. The certified and measured concentrations of the respective elements in the SRMs are presented in Table 1.

2.4. Data analysis

The Gen-Stat statistical package (version 12) was used for all statistical analyses. Comparison of means for the different rice production ecosystems was by one-way Analysis of variance (ANOVA) at a significance level of 5% ($P \leq 0.05$). Comparison of data obtained for the two regions was by a simple t test, also at a 5% significance level. Post hoc tests were conducted for data with $P \leq 0.05$ using Fisher's least significant difference.

3. Results

3.1. Soil Physicochemical properties

Data on soil pH, EC, and particle size distribution for the various rice production ecosystems in the Northern and Upper East region are presented in Table 2. The lowest mean pH of soils from the Northern Region was recorded at the IL field sites (5.4 ± 0.3) while the highest was at the RL field sites (6.1 ± 0.7). Similarly, soils from the IL field sites in the Upper East region had the lowest mean pH of 5.1 ± 0.1. Statistical analysis of the data showed no significant difference in soil pH across the different production ecosystems (Table 2). As with soil pH, no significant difference was observed in mean EC values across the three rice production ecosystems in both the Northern and Upper East regions (Table 2).

With respect to particle size distribution, no significant difference was observed in soils from the Upper East Region, all of which had a clay loam texture. In the Northern region, however, a significant difference ($P < 0.001$) was observed in the sand and silt composition of soils from the different production ecosystems. The soil texture at the RU and RL field sites was silt loam, while at the IL field sites it was sandy loam (Table 2).

3.2. Elemental concentrations in water samples

Mean concentration of Pb was below detection limit in all the water samples, except for those from Tono, which had a mean Pb concentration of 0.011 mg/L (Table 3). Mean As concentration ranged from 0.004 ± 0.002 mg/L in water from the Navrongo borehole to 0.006 ± 0.003 mg/L in water samples collected from the Tono irrigation site, but differences were not statistically significant (Table 3). Although Cd concentrations in water samples from the Upper East region were below detection, detectable levels were recorded in samples from the Bontanga and Golinga IL fields in the Northern region (Table 3).

Table 2. Physicochemical properties of soil from different rice production ecosystems.

| Soil property | Region | Rice production system | | | P-value |
		Rainfed upland (n = 3)	Rainfed lowland (n = 3)	Irrigated lowland (n = 3)	
pH	Northern	5.6 ± 0.3	6.1 ± 0.7	5.4 ± 0.3	0.248
	Upper East	5.3 ± 0.2	5.2 ± 0.2	5.1 ± 0.1	0.387
EC (μScm^{-1})	Northern	55.0 ± 7.4	76.7 ± 41.8	85.3 ± 42.3	0.572
	Upper East	127.8 ± 73.3	55.8 ± 29.2	61.8 ± 15.6	0.190
% Sand	Northern	18.0 ± 0.6[a]	16.3 ± 2.5[a]	58.7 ± 8.4[b]	< 0.001
	Upper East	23.7 ± 3.1	28 ± 5.3	26 ± 1.0	0.391
% Silt	Northern	73.0 ± 0.6[a]	74.7 ± 2.9[a]	33.0 ± 8.7[b]	< 0.001
	Upper East	47 ± 3.0	43.3 ± 3.1	44.3 ± 2.9	0.361
% Clay	Northern	9.0 ± 1.2	9.0 ± 1.7	8.3 ± 0.6	0.761
	Upper East	29.3 ± 2.5	28.7 ± 2.3	29.7 ± 2.1	0.867
Texture	Northern	Silt loam	Silt loam	Sandy loam	–
	Upper East	Clay loam	Clay loam	Clay loam	–

Note: Means in the same row with the same superscript are not statistically different at $P \leq 0.05$. EC, electrical conductivity.

Table 3. Elemental concentrations in water from rice irrigation channels and borehole.

Sampling site	Region	As (mg/L)	Cd (mg/L)	Pb (mg/L)
Golinga (n = 3)	Northern	0.005 ± 0.001	0.008 ± 0.003	BD
Bontanga (n = 3)	Northern	0.005 ± 0.001	0.009 ± 0.004	BD
Tono (n = 3)	Upper East	0.006 ± 0.003	BD	0.011 ± 0.019
Navrongo Borehole (n = 2)	Upper East	0.004 ± 0.002	BD	BD
P-value		0.070	–	–

Note: BD, below detection; As, arsenic; Cd, cadmium; Pb, lead.

3.3. Elemental concentrations in rice field soils

The mean concentrations of As, Cd, and Pb in soils sampled from the various rice production ecosystems in the Northern and Upper East regions are presented in Table 4. For both the Northern and Upper East regions, one-way ANOVA of the soil As data showed that differences in the mean concentrations across the three production ecosystems were not statistically significant (Table 4). In the Upper East region, a mean soil As concentration of 0.053 mg/kg was recorded in all the production ecosystems. This was about three times higher than the highest mean soil As content (0.016 ± 0.012 mg/kg) recorded in the Northern region IL fields (Table 4). A simple t test found the differences between the two regions with regard to soil As concentration to be significant at $P < 0.001$.

While Cd concentration was below detection limit in all the soil samples from the Upper East region, mean Cd concentrations in soils from the Northern region ranged from 0.014 ± 0.003 mg/kg for the RU fields to 0.042 ± 0.019 mg/kg for the IL fields. The observed differences in mean soil Cd concentration for the three rice production ecosystems in the Northern region were, however, not statistically significant (Table 4).

Table 4 shows that in all the three rice production ecosystems, the Northern region recorded a relatively higher mean Pb concentration than the Upper East region. A t test performed to compare the Pb concentrations between the two regions, however, showed that the differences were not statistically significant ($P = 0.10$). One-way ANOVA of the soil Pb data also showed no statistical differences between the rice

production ecosystems in both the Northern and Upper East regions (Table 4).

3.4. Elemental concentrations in rice grain samples

In the Northern region, rice grain As concentration was highest in the RU fields with a mean of 0.005 ± 0.001 mg/kg (Table 5). Rice grains sampled from the Upper East region had higher mean concentrations of As, which ranged from 0.061 ± 0.002 mg/kg for the RU fields to 0.063 ± 0.003 mg/kg for the RL fields and to 0.064 ± 0.006 mg/kg for the IL fields (Table 5). For both regions, one-way ANOVA showed no significant difference between rice production ecosystems with regard to rice grain As concentration (Table 5). A simple t test, however, found the observed differences between the two regions with respect to rice grain As to be significant ($P < 0.001$).

Rice grain Cd concentration in all samples from the Upper East region were below detection limit (Table 5). In contrast, detectable levels were found in samples from the Northern region with means reaching a maximum of 0.023 ± 0.003 mg/kg for the IL fields. One-way ANOVA performed on the Northern region rice grain Cd data yielded a P-value of 0.013 (Table 5), indicating that the differences between the three production ecosystems with regard to rice grain Cd content are statistically significant.

For both the Northern and Upper East regions, one-way ANOVA of the mean rice grain Pb concentrations recorded in the three production ecosystems showed no significant differences (Table 5). However, a t test performed to compare

Table 4. Elemental concentrations in soil from different rice production ecosystems.

Element	Region	Rainfed upland	Rainfed lowland	Irrigated lowland	*P*-value
		Soil PTE concentration in mg/kg			
As	Northern	0.003 ± 0.001	0.006 ± 0.004	0.016 ± 0.012	0.458
	Upper East	0.053 ± 0.003	0.053 ± 0.005	0.053 ± 0.003	0.985
Cd	Northern	0.019 ± 0.010	0.014 ± 0.003	0.042 ± 0.019	0.309
	Upper East	BD	BD	BD	–
Pb	Northern	0.394 ± 0.156	0.843 ± 0.087	0.600 ± 0.268	0.282
	Upper East	0.193 ± 0.159	0.614 ± 0.236	0.432 ± 0.138	0.270

Note: PTE, potential toxic element; BD, below detection; As, arsenic; Cd, cadmium; Pb, lead.

Table 5. Elemental concentrations in rice grain from different production ecosystems.

	Region	Rainfed upland	Rainfed lowland	Irrigated lowland	*P*-value
		Rice production system			
Grain As (mg/kg)	Northern	0.005 ± 0.001	0.004 ± 0.002	0.004 ± 0.000	0.580
	Upper East	0.061 ± 0.002	0.063 ± 0.003	0.064 ± 0.006	0.699
Grain Cd (mg/kg)	Northern	0.001 ± 0.001	0.011 ± 0.006	0.023 ± 0.003	0.013
	Upper East	BD	BD	BD	–
Grain Pb (mg/kg)	Northern	0.083 ± 0.015	0.092 ± 0.020	0.104 ± 0.041	0.671
	Upper East	0.024 ± 0.022	0.077 ± 0.045	0.025 ± 0.022	0.141

Note: BD, below detection; As, arsenic; Cd, cadmium; Pb, lead.

mean Pb concentrations in rice grains from the Upper East region to those from the Northern region showed that the latter were significantly more enriched with Pb ($P = 0.002$). Mean concentration of Pb in rice grains from the Northern region ranged from 0.083 ± 0.015 mg/kg in the RU fields to 0.104 ± 0.041 mg/kg in the IL fields (Table 5).
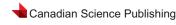
4. Discussion

Rice is known to grow under a wide soil pH range of 4.2–8.5, with the most favourable range falling between 5.5 and 7.0. The soil pH values recorded in this study were, therefore, within acceptable limits and similar to the range reported by Opuni et al. (2018) for rice fields in the Volta region of Ghana. The soil EC values also fall within the acceptable range for plant growth reported by Munns and Tester (2008).

The concentrations of As and Pb recorded in water samples from the study sites were less or equal to the WHO's provisional guideline value of 10 μg/L (0.01 mg/L) for both elements in drinking water (WHO 2011). Adomako et al. (2010) also found relatively low concentrations of As (0.67–3.23 μg/L) in surface waters used for rice irrigation in southern Ghana, except in water from gold mining impacted rice fields in the Ashanti region. With respect to Cd concentration in the water samples, differences in geology and water–rock interactions could account for the observed differences between the Northern and Upper East regions (Baba and Gündüz 2017). Usually, Cd concentrations in unpolluted natural waters fall below 0.001 mg/L, but phosphate-based fertilizers constitute a major source of diffuse Cd pollution (WHO 2011) and may also account for the observed concentrations in water samples from the Northern region. This hypothesis would, however, require further investigation since fertilizer was applied in both regions. Besides, information on timing and

frequency of application was not obtained for the current study.

Soil As, Cd, and Pb concentrations recorded in the current study are all within the permissible limits of 0.1–55 mg As/kg (Wenzel 2013), <10 mg Pb/kg (Davies 1995), and <1 mg Cd/kg (Alloway 1995) for uncontaminated soils. The observed difference between the Northern and Upper East region soils, with respect to As concentration, could be due to differences in their particle size distribution. Soil texture is known to influence soil As content with clayey soils being generally higher in As than sandy soils (Liu et al. 2005). The higher As content of the Upper East region soils is, therefore, attributable to their higher percentage of clay content (Table 2). Similarly, geogenic factors, such as weathering of the underlying parent rocks, may account for the Cd in the Northern region soils since the recorded concentrations were statistically comparable across the three different rice production systems within the region.

Rice grain As concentration showed a trend similar to that observed in the rice field soils, with values being significantly higher in grains from the Upper East region. Since the same rice variety was sampled from both regions, this could be attributed to a higher transfer of As to rice grain from the Upper East region soils that were also significantly higher in As than the Northern region soils. The previous study of rice fields in southern Ghana by Adomako et al. (2010) also found a close link between soil and grain As concentrations with rice harvested from mining-impacted soils recording higher grain As concentrations. The rice grain As concentrations observed in the current study were, however, below the maximum permissible limit of 0.2 mg As per kg of polished rice set by the Codex Alimentarius Commission (CAC 2014) and the maximum permissible limit of 0.15 mg/kg legislated in China (Khosravi-Darani et al. 2022). Although rice grain Cd concen-

trations also fell below the maximum limit of 0.2 mg/kg set for polished rice in the European Union (Commission Regulation 2006), the significant differences across rice production systems in the Northern region (Table 5) indicate that Cd concentrations in soil and irrigation water contributed to rice grain Cd content. It is worthy of note that although rice grain Pb concentrations were also found to be significantly higher in the Northern region than in the Upper East region, the values fell below the maximum limit of 2 mg per kg of cereals set in the European Union (Commission Regulation 2006). Thus, with regard to As, Cd, and Pb concentrations, the rice grains sampled for the current study are safe for human consumption.

5. Conclusion

This paper corroborates findings of the Adomako et al. (2010) study on the PTE status of rice production ecosystems in Ghana. It can be concluded that the country's rice field soils and surface waters used for rice irrigation are generally low in PTE concentrations. The earlier report of low concentrations of As in rice grains produced in non-gold mining areas of the country (Adomako et al. 2010) has also been confirmed by the current study. The low PTE status of the country's rice production ecosystems, along with the recorded ranges of soil pH and EC values, indicates their suitability to support the expansion of local rice production to meet the targets set in the National Rice Development Strategy and the PFJ initiative. The call to improve appearance and packaging of locally produced rice grains to enhance their competitiveness against imported brands (Adomako et al. 2011; Diako et al. 2011; Ehiakpor et al. 2017) is, therefore, valid and worth heeding. Geogenic factors including soil texture and water–rock interactions may, however, enhance As and Cd enrichment in soils and irrigation waters, which could result in higher rice grain As and Cd content. Regular monitoring of PTE concentrations in the country's major rice production ecosystems would ensure that the grains produced meet global food safety standards.

Acknowledgements

Article information

Editor
Hubert de Guise

History dates

Copyright

Data availability
Data generated or analysed during this study are available from the corresponding author upon reasonable request.

Author information

Author ORCIDs
Eureka E.A. Adomako https://orcid.org/0000-0002-6135-1248

Author contributions
Conceptualization: EEAA, KA
Data curation: EEAA, KA
Formal analysis: EEAA, KA
Investigation: EEAA, KA
Methodology: EEAA, KA, PO
Resources: EEAA, KA
Supervision: EEAA
Validation: EEAA, PO
Visualization: EEAA
Writing – original draft: EEAA, KA
Writing – review & editing: EEAA, PO

Competing interests
The authors declare no competing interests.

References

Abebrese, S.O., Yeboah, A., Dogbe, W., Dartey, P.K.A., Akromah, R., Gracen, V.E., et al. 2019. Evaluation of yield, reaction to diseases, and grain physical attributes of some introduced rice hybrids in Ghana. International Journal of Agronomy, **2019**: 3926765. doi:10.1155/2019/3926765.

Adomako, E.E., Deacon, C., and Meharg, A.A. 2010. Variations in concentrations of arsenic and other potentially toxic elements in mine and paddy soils and irrigation waters from southern Ghana. Water Quality, Exposure and Health, **2**: 115–124. doi:10.1007/s12403-010-0029-0.

Adomako, E.E., Solaiman, A.R.M., Williams, P.N., Deacon, C., Rahman, G.K.M.M., and Meharg, A.A. 2009. Enhanced transfer of arsenic to grain for Bangladesh grown rice compared to US and EU. Environment International, **35**(3): 476–479. doi:10.1016/j.envint.2008.07.010. PMID: 18757098.

Adomako, E.E., Williams, P.N., Deacon, C., and Meharg, A.A. 2011. Inorganic arsenic and trace elements in Ghanaian grain staples. Environmental Pollution, **159**: 2435–2442. doi:10.1016/j.envpol.2011.06.031. PMID: 21775037.

Al-Hassan, R., Agbekpornu, H.G., and Sarpong, D.B. 2008. Consumer preferences for rice quality characteristics in Accra and the effects of these preferences on price. Agricultural and Food Science Journal of Ghana, **7**: 575–591.

Ali, W., Mao, K., Zhang, H., Junaid, M., Xu, N., Rasool, A., et al. 2020. Comprehensive review of the basic chemical behaviours, sources, processes, and endpoints of trace element contamination in paddy soil–rice systems in rice-growing countries. Journal of Hazardous Materials, **397**: 122720. doi:10.1016/j.jhazmat.2020.122720. PMID: 32387828.

Alloway, B.J. 1995. Heavy metals in soils. 2nd ed. Blackie, London.

Anabila, P. 2015. Exploring branding as a strategy to boost local rice patronage: evidence from Ghana. The IUP Journal of Brand Management, **12**(1): 60–78.

Azumah, S.B., Lamptey, C.Y., Sulemana, N., Donkoh, S., Zakaria, A., and Maanikuu, P.M.I. 2022. An explorative study on the adoption and disadoption of improved rice varieties among farmers in the Northern

region of Ghana. Journal of Experimental Biology and Agricultural Sciences, **10**(2): 323–334. doi:10.18006/2022.10(2).323.334.

Baba, A., and Gündüz, O. 2017. Effect of geogenic factors on water quality and its relation to human health around Mount Ida, Turkey. Water, **9**: 66. doi:10.3390/w9010066.

CAC. 2014. Report of the eighth session of the codex committee on contaminants in foods. *In* Proceedings of the Joint FAO/WHO Food Standards Programme, Codex Alimentarius Commission 37th Session, Geneva, Switzerland. Codex Alimentarius Commission.

Commission Regulation (EC) No 1881/2006. 2006. Setting maximum levels for certain contaminants in foodstuffs. Available from https://eur-lex.europ a.eu/legal-content/EN/TXT/?uri=CELEX:02006R1881-20150521 [accessed October, 2022].

Davies, B.E. 1995. Lead. *In* Heavy metals in soils. *Edited by* B.J. Alloway. Blackie, London. pp. 177–198.

Diako, C., Manful, J.T., Johnson, P.N.T., Sakyi-Dawson, E., Bediako-Amoa, B., and Saalia, F.K. 2011. Physicochemical characterization of four commercial rice varieties in Ghana. Advance Journal of Food Science and Technology, **3**(3): 196–202.

Eaton, A.D., Clesceri, L.S., Rice, E.W., Greenberg, A.E., and Franson, M.A.H. (*Editors*). 2005. Standard methods for the examination of water and wastewater, Centennial Edition. 21st ed. American Public Health Association (APHA), Washington, D.C.

Ehiakpor, S.D., Apumbora, J., Danso-Abbeam, G., and Adzawla, W. 2017. Households' preference for local rice in the Upper East Region, Ghana. Advances in Agriculture, **2017**: 1812975. doi:10.1155/2017/1812975.

Fordjour, E., Kim, H.-H., Aye, N.C., Rolly, N.K., Jummah, W.N., Imran, Q.M., et al. 2020. Screening rice (*Oryza sativa*) cultivars for resistance to bacterial leaf blight disease. International Journal of Agriculture and Biology, **24**(5): 1233–1241.

Fuseini, A., and Benjamin, B.K. 2022. Influence of enhanced efficiency fertilizer formulations on rice yield in the Guinea Savanna Zone of Ghana. Journal of Agriculture and Crops, **8**(3): 164–169. doi:10.32861/jac.83.164.169.

Graham-Acquaah, S., Mauromoustakos, A., Cuevas, R.P., and Manful, J.T. 2020. Differences in physicochemical properties of commercial rice from urban markets in West Africa. Journal of Food Science and Technology, **57**(4): 1505–1516. doi:10.1007/s13197-019-04186-7. PMID: 32180647.

GRiSP 2013. Rice Almanac. 4th ed. Global Rice Science Partnership, Los Banos, California.

Khosravi-Darani, K., Rehman, Y., Katsoyiannis, I.A., Kokkinos, E., and Zouboulis, A.I. 2022. Arsenic exposure via contaminated water and food sources. Water, **14**: 1884. doi:10.3390/w14121884.

Kushitor, S.B. 2021. Food availability and food habits among Ghanaians: tracking the dietary transition in Ghana. Nutrition and Health, **29**(1): 157–166.

Liu, W-J., Zhu, Y-G., and Smith, F. A. 2005. Effects of iron and manganese plaques on arsenic uptake by rice seedlings grown in solution culture supplied with arsenate and arsenite. Plant and Soil, **277**: 127–138. doi:10.1007/s11104-005-6453-4.

Lu, Y., Adomako, E.E., Solaiman, A.R.M., Islam, M.R., Deaon, C., Williams, P.N., et al. 2009. Baseline soil variation is a major factor in arsenic accumulation in Bengal delta paddy rice. Environmental Science and Technology, **43**: 1724–1729. doi:10.1021/es802794w.

MoFA-IFPRI. 2020. Ghana's rice market. *In* MoFA-IFPRI market brief No. 2. Ministry of Food and Agriculture (MoFA), Accra, Ghana and the International Food Policy Research Institute (IFPRI).

Munns, R., and Tester, M. 2008. Mechanisms of salinity tolerance. Annual Review of Plant Biology, **59**: 651–681. doi:10.1146/annurev.arplant.59.032607.092911.

Novozamsky, I., Houba, V.J.G., van Eck, R., and van Vark, W. 1983. A novel digestion technique for multi-element plant analysis. Communications in Soil Science and Plant Analysis, **14**: 239–248. doi:10.1080/00103628309367359.

Onumah, E.E., Addey Owusu, P., Mensah-Bonsu, A., and Acquah Degraft, H. 2022. Rice price volatility and transmission: implications for food security in Ghana. Cogent Economics & Finance, **10**(1): 2085605. doi:10.1080/23322039.2022.2085605.

Opuni, N.M., Adomako, E.E.A., and Adomako, J.K. 2018. African Rice (*Oryza glaberrima* Steud) and its wild progenitor (*Oryza barthii* A.Chev.

& Roehr) under threat in the Volta Region of Ghana. Science and Development, **2**: 10–21.

Pauw, K. 2022. A review of Ghana's planting for food and jobs program: implementation, impacts, benefits, and costs. Food Security, **14**: 1321–1335. doi:10.1007/s12571-022-01287-8.

Perkin-Elmer. 1996. Analytical methods for atomic absorption spectroscopy. The Perkin-Elmer Corporation. Available from http://www1.lasalle.edu/~prushan/Intrumental%20Analysis_files/AA-Perkin%20Elmer%20guide%20to%20all!.pdf [accessed October, 2022].

Quaye, W., Onumah, J.A., Boimah, M., and Mohammed, A. 2022. Gender dimension of technology adoption: the case of technologies transferred in Ghana. Development in Practice, **32**(4): 434–447. doi:10.1080/09614524.2021.2000588.

Ragasa, C., and Chapoto, A. 2017. Limits to green revolution in rice in Africa: the case of Ghana. Land Use Policy, **66**: 304–321. doi:10.1016/j.landusepol.2017.04.052.

Ragasa, C., Andam, K.S., Asante, S.B., and Amewu, S. 2020. Can local products compete against imports in West Africa? Supply- and demand-side perspectives on chicken, rice, and tilapia in Ghana. Global Food Security, **26**: 100448. doi:10.1016/j.gfs.2020.100448.

Sarkodee-Addo, E., Tokiwa, C., Bonney, P., Aboagye, D.A., Yeboah, A., Abebrese, S.O., et al. 2021. Biofertilizer activity of *Azospirillum* sp. B510 on the rice productivity in Ghana. Microorganisms, **9**(9): 2000. doi:10.3390/microorganisms9092000.

SRID-MoFA 2017. Agriculture in Ghana: facts and figures, 2016. Statistics Research and Information Directorate (SRID) of the Ministry of Food and Agriculture (MoFA), Accra, Ghana.

SRID-MoFA 2021. Agriculture in Ghana: facts and figures, 2020. Statistics Research and Information Directorate (SRID) of the Ministry of Food and Agriculture (MoFA), Accra, Ghana.

Tanko, M. 2022. Nexus of risk preference, culture and religion in the adoption of improved rice varieties: evidence from Northern Ghana. Land Use Policy, **115**: 106040. doi:10.1016/j.landusepol.2022.106040.

Tanko, M., and Ismaila, S. 2021. How culture and religion influence the agriculture technology gap in Northern Ghana. World Development Perspectives, **22**: 100301. doi:10.1016/j.wdp.2021.100301.

Tanko, M., Ismaila, S., and Sadiq, S.A. 2019. Planting for Food and Jobs (PFJ): a panacea for productivity and welfare of rice farmers in Northern Ghana. Cogent Economics & Finance, **7**(1): 1693121. doi:10.1080/23322039.2019.1693121.

Tawiah, I., Darko Asante, M., Oppong, A., Asare, K., Amadu, B., Gyameyah, D., et al. 2022. Genetic control of resistance to rice yellow mottle virus disease in two rice crosses. Journal of Crop Improvement, **36**(1): 40–56. doi:10.1080/15427528.2021.1905757.

USEPA. 1992. Method 3005A: Acid digestion of waters for total recoverable or dissolved metals for analysis by FLAA or ICP spectroscopy. United States Environmental Protection Agency, Washington, D.C. Available from https://www.epa.gov/hw-sw846/sw-846-test-method-3005a-acid-digestion-waters-total-recoverable-or-dissolved-metals [accessed October, 2022].

Van Oort, P.A.J., Saito, K., Tanaka, A., Amovin-Assagba, E., Van Bussel, L.G.J., Van Wart, J., et al. 2015. Assessment of rice self-sufficiency in 2025 in eight African countries. Global Food Security, **5**: 39–49. doi:10.1016/j.gfs.2015.01.002.

Van Reeuwijk, L.P. 2002. Procedures for soil analysis. 6th ed. International Soil Reference and Information Center, Wageningen.

Wenzel, W.W. 2013. Arsenic. *In* Heavy metals in soils, environmental pollution book series. Vol. 22. 3rd ed. *Edited by* B.J. Alloway. Springer, Dordrecht.

WHO. 2011. Guidelines for drinking-water quality. 4th ed. World Health Organization, Switzerland.

Williams, P.N., Islam, M.R., Adomako, E.E., Raab, A., Hossain, S.A., Zhu, Y-G., et al. 2006. Increase in rice grain arsenic for regions of Bangladesh irrigating paddies with elevated arsenic in groundwaters. Environmental Science and Technology, **40**: 4903–4908. doi:10.1021/es060222i.

Zakaria, A., Alhassan, S.I., Kuwornu, J.K.M., and Azumah, S.B. 2021. Beyond participation: the effect of fertilizer subsidy on the adoption of certified seeds among rice farmers in Northern Ghana. European Journal of Development Research, **33**(3): 684–709. doi:10.1057/s41287-020-00293-w.