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RESEARCH PAPER

Assessing the effect of carbide waste-contaminated soil on the growth and yield of maize (*Zea mays* L.)

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Key Message: This study demonstrates that carbide waste improved growth and yield of maize when applied at the rate of 20 g/kg in pots, with permissible level of grain heavy metals. Carbide waste can therefore be used as soil amendment for maize cultivation at 20 g/kg. It had negative impact on growth and yield of the crop from 40-80 g/kg.

Abstract

Maize is a critical global staple crop but its productivity is often constrained by soil fertility issues, including waste contaminants. This study investigated the impact of soil contaminated with carbide waste (CW), an industrial by-product rich in calcium hydroxide, probably as a soil amendment to enhance maize growth and yield. Maize was grown in soils amended with 0-160 g/kg of CW in a screen house study replicated 5 times in completely randomized design. Plants (100%) survived at 20 g/kg; 40% at 40 g/kg; and 20% at 60-80 g/kg; with 0% survival under 100-160 g/kg. CW insignificantly ($p>0.05$) improved plant height, stem girth, number of leaves, leaf size, number of roots and root length at 20 g/kg, and reduced them significantly ($p<0.05$) at 40-80 g/kg compared to the control. CW also significantly increased vegetative biomass and grain yield at 20 g/kg with significant reduction at 40 g/kg while those that survived at 60-80 g/kg did not produce grains. Grain moisture content increased insignificantly at 20-40 g/kg with ash highest at 40 g/kg. Crude fiber decreased at higher concentrations, and crude protein increased with increasing application level, peaking at 40 g/kg. N, P, K and Ca increased significantly with increasing waste reflecting enhanced nutrient uptake. CW led to grain heavy metal accumulation but below permissible limit in foods. CW at 20 g/kg can be used to enhance maize production while higher concentrations should be avoided as are capable of detrimental effect on the crop with grains' elevated heavy metal concentrations.

Keywords: Carbide waste, Heavy metals, Soil amendment, Yield, *Zea mays*

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Introduction

Maize (*Zea mays*) is one of the most important staple crops globally, serving as a primary source of food, fodder, and industrial raw material (Ahmad & Ahmad, 2018; Rubab et al., 2020; Mehmood et al., 2022; Azam et al., 2023). It is cultivated extensively in various climatic conditions and is integral to the agricultural economy in many countries (FAO, 2021). However, maize production faces several challenges, including soil fertility management, which significantly influences crop growth and yield (Cairns et al., 2021; Rezaei et al., 2023). One emerging area of research is the impact of industrial by-products, such as carbide waste, on soil properties and crop performance. Carbide waste is a by-product of acetylene gas production, primarily composed of calcium hydroxide [$Ca(OH)_2$] and other impurities (Atma & Souahi, 2021). Studies by Guo et al. (2024) showed that various methods of disposal of carbide waste such as landfill, incineration and chemical stabilization pose environmental challenges due to its alkaline nature and potential for soil contamination. Despite its challenges, researchers are increasingly exploring the potential of utilizing carbide waste as a soil amendment to enhance agricultural productivity while mitigating its environmental impact.

Traditional soil amendments including application of organic matters, lime, and gypsum, often times offer distinct benefits to improve soil conditions for crop production (Garbowski et al., 2023). The utilization of industrial by-products, like carbide waste, as amendments in agriculture to adjust soil pH is gaining attention due to their cost-effectiveness and waste recycling potential (Azeez et al., 2022). The potential benefits of carbide waste in agriculture are attributed to its high calcium content, which can ameliorate soil acidity, a common issue in tropical and subtropical regions where maize is predominantly grown (Han et al., 2023). Soil acidity limits nutrient availability and microbial activity, adversely affecting plant growth and yield. By raising soil pH, carbide waste could enhance nutrient uptake and microbial activity, promoting better crop performance (Nie et al., 2024).

Several studies have investigated the use of carbide waste in various crops. For instance, Oni et al. (2021) reported that carbide waste application enhanced growth and yield of oyster mushroom (*Pleurotus ostreatus*). Similarly, Abiya et al. (2018) observed enhanced growth and yield of cowpea (*Vigna unguiculata*) with carbide waste amendment. These findings suggest a potential for similar benefits in maize cultivation, which requires further investigation. Maize is particularly responsive to soil amendments due to its high nutrient demand and sensitivity to soil pH (Zhang et al., 2023). Improved soil pH through carbide waste application could enhance the availability of essential nutrients such as phosphorus, which is often limited in acidic soils (Abbas et al., 2024). Additionally, calcium from carbide waste may improve soil structure by promoting aggregate formation, thereby enhancing root development and water infiltration (Tang et al., 2024).

Despite the potential benefits, there are concerns regarding the use of carbide waste in agriculture. The high pH of carbide waste can lead to soil alkalinity, adversely affecting plant growth if not properly managed (Atma & Souahi, 2021). Moreover, impurities in carbide waste, such as heavy metals, could pose a risk of soil contamination and subsequent entry into the food chain (Pirsaheb et al., 2022). Scientific literature exists on effects of carbide waste on some crops like oyster mushroom (Oni et al., 2021) and cowpea (Abiya et al., 2018), while little or none has been reported on maize, a knowledge gap the research intended to fill. The choice of maize was premised on being a crop grown on virtually every vacant space around homes, where indiscriminate discharge of carbide waste is prevalent among Nigerian welders and panel beaters, apart from home gardens. In addition, maize is a major staple crop in short supply; it therefore becomes necessary to determine safe application rates for its growth and yield improvement by carbide waste. This research aimed to investigate the impact of carbide waste on growth and yield as well as grain nutritional composition and heavy metal contents of maize. The study hoped to contribute to the understanding of sustainable agricultural practices using industrial by-products.

Materials and Methods

Collection of materials for the study

Carbide waste and soil were obtained from Akungba-Akoko, Ondo State, Nigeria; the carbide waste was obtained from dumpsites of panel beaters at mechanic villages to make a composite sample. This was done to achieve a representative for all the sites. The soil was collected using soil auger from an arable farmland at Adekunle Ajasin University farm. The maize seeds were obtained from the Federal College of Agriculture, Akure, Ondo State, Nigeria.

Soil analysis

The soil samples were shade-dried, passed through 2 mm sieve, and analysed for physical and chemical properties following standard methods (Association of Official Analytical Chemists [AOAC], 1990) before use for planting. Total N was analyzed using the macro Kjeldahl procedure; organic carbon by Walkley and Black procedure with percentage derived by multiplying organic carbon content by 1.72; and pH using soil: water ratio of 1: 2 with a pH meter. Available phosphorus was got through the Bray 1 method; exchangeable acidity by titration method; exchangeable K, Na, Ca, Al and Mg by extraction with 1 M ammonium acetate at pH 7.0; and the amount of K and Na was measured using a Corning Flame Photometer with appropriate filter, while Ca, Al and Mg were determined using a Perkin-Elmer Atomic Absorption Spectrophotometer (AAS). The electrical conductivity was read with a conductivity meter.

Carbide waste analysis

Carbide waste was analyzed for chemical composition according to the aqua regia method (Atma & Souahi, 2021). It was dried in an oven at 60 °C for 48 hours. pH was measured in a 1: 2.5 solid: water ratio. Al_2O_3, CaO, Fe_2O_3, MgO and SO_3 were assayed using X-ray fluorescence (CubiX XRF/PANalytical). Heavy metals were analyzed with 1 g of dried and crushed sample digested by a wet digestion method using an open system with a refluxing condenser. Dried samples were weighed into the mineralization vessel, and 3 ml concentrated hydrochloric acid plus 1 ml of concentrated nitric acid was added. The mixture was boiled until a clear solution was obtained, and allowed to cool at room temperature. The resulting solution was quantitatively transferred into a calibrated flask and made to 25 ml with distilled water. Heavy metals were analyzed by flame atomic absorption spectroscopy FAAS (Shimadzu AA6600).

Experimental location and setup

The experiment was carried out at the screen house of Plant Science and Biotechnology Department, Adekunle Ajasin University, Akungba-Akoko, Ondo State, Nigeria. During the experiment, the screen house had an average morning temperature and humidity of 22.30-24.90 °C and 60.20-80.40%, respectively while that of afternoon was 24.60-28.10 °C and 50.50-70.60%. There was one seedling per pot containing 7 kg soil with each treatment replicated five times in a completely randomized design, and it lasted for 4 months. Treatments include 0 (control), 20, 40, 60, 80, 100, 120, 140 and 160 g of CW per kg of topsoil

Data collection

Plant height was measured from the surface of the soil to the plant apical bud using a meter rule. Stem girth was measured at the 2 cm point from the base of the plants using a digital vernier caliper (model 0-200 mm). Leaf length and breadth were measured using a meter rule, and leaf area was calculated. The number of leaves and ears were counted manually on each plant. Ear length and diameter were measured using a meter rule, and a rope spread around it respectively. Root growth was determined by measuring the root length using a meter rule after uprooting, and the number of roots was counted manually. Fresh and dry mass of plant parts were assessed using an electronic weighing balance.

Laboratory analysis of maize grains

Dried maize grains were ground into fine powder for analysis. Fibre content was determined by boiling the sample in 1.25% H_2SO_4 and 1.25% NaOH, followed by washing and drying. Other parameters of proximate composition were analyzed using the standard methods of AOAC (1990) in which the mixture was boiled until a clear solution was obtained, and allowed to cool at room temperature. The resulting solution was quantitatively transferred into a calibrated flask and completed to 25 ml with distilled water. Moisture, crude protein, crude fat, carbohydrate and ash contents were calculated using relevant formulas. N was analyzed using the macro Kjeldahl method, while P was determined using ammonium-vanadomolybdate reagent and a calibration curve. Potassium and sodium contents were assayed through flame emission photometry. Magnesium and calcium contents were by Ethylenediaminetetraacetic acid (EDTA) titration. Fe Cu, Zn and Pb were determined using Atomic absorption spectrophotometer (Buck 210).

Statistical analysis

All data were subjected to One-way Analysis of Variance, and means were separated with Duncan Multiple Range Test using the Statistical Package for Social Sciences (SPSS) version 24.0.

Results

Soil used for planting and carbide waste

The soil used for planting was a sandy clay loam adequate for maize cultivation with physic-chemical characteristics shown in Table 1. According to Table 2, the carbide waste was high in calcium oxide (CaO) and contained all the selected heavy metals (Cu, Fe, Pb and Zn).

Table 1 Physico-chemical parameters of soil used for planting

Parameter	Value
Sand (%)	57.50
Clay (%)	29.37
Silt (%)	13.13
Soil textural class	Sandy clay loam
Soil pH	6.53
Electrical conductivity EC (%)	0.39
Organic matter (%)	1.56
Available N (mg/kg)	0.17
Available P (mg/kg)	20.11
Available K (cmol/kg)	0.22
Available Na (cmol/kg)	0.37
Available Ca (cmol/kg)	5.78
Available Al (cmol/kg)	20.58
Available Mg (cmol/kg)	2.23

Table 2 Chemical composition of carbide waste used for the experiment

Parameter	Analysis of carbide waste
Al_2O_3 (%)	2.67
CaO (%)	68.04
Fe_2O_3 (%)	1.13
MgO (%)	0.57
SO_3 %)	0.60
Cu (mg/kg)	48.55
Fe (mg/kg)	2300.12
Pb (mg/kg)	4.26
Zn (mg/kg)	27.11

Plant survival and growth

There was 100% survival of plants at 20 g/kg of carbide waste. This was decreased to 40% at 40 g/kg and 20% at 60-80 g/kg, with no survival under 100-160 g/kg application (Table 3). Carbide waste improved plant height, stem girth, leaf length and leaf breadth at 20 g/kg, but these improvements were not significant ($p>0.05$) compared to the control. However, significant reductions ($p<0.05$) in these growth parameters were recorded at higher concentrations (40-80 g/kg) compared to the control. The number of leaves also increased at a lower concentration (20 g/kg) but decreased significantly ($p<0.05$) at higher concentrations (40-80 g/kg). Root development was significantly affected by carbide waste with lower concentration (20 g/kg) causing minimal effects, while higher concentrations (40-80 g/kg) resulted in significant ($p<0.05$) reduction in number of roots in comparison to the control treatment.

Plant biomass

The fresh weight of maize leaves, stems and roots were significantly influenced by carbide waste (Table 4). The fresh and dry weight of plant parts as well as total biomass was increased significantly ($p<0.05$) at 20 g/kg while 40-80 g/kg carbide waste led to significant ($p<0.05$) reduction in all the parameters relative to the control treatment.

Yield parameters

Table 5 shows that carbide waste had a detrimental impact on maize yield, particularly at high concentrations. Ear production and growth were suppressed by carbide waste, which increased with increasing level in the soil. The number of ears was highest in the control, with minimal reduction at 20 g/kg. Ear length, ear diameter and ear dry weight followed the same trend of reduction with increasing concentration of the waste, with significant differences ($p<0.05$) between plants grown in contaminated soil and the ones free from it. Grain yield parameters including number of grains, grain fresh and dry weight as well as 1000-grain weight showed improvement, though not significant over the control at 20 g/kg, higher concentrations of 40-60 g/kg led to a significant ($p<0.05$) decline in comparison to the control. Even though ears were produced at 60-80 g/kg carbide waste, no grains were recorded in them.

Grain nutritional/proximate composition

The nutritional and proximate composition of maize grains varied significantly with increasing carbide waste application level (Table 6). Moisture content increased slightly at 20 and 40 g/kg compared to the control. Ash content was highest at 40 g/kg, indicating enhanced mineral content at the level. Crude fiber, compared to the control, decreased at higher concentrations. Crude protein increased progressively as soil carbide waste increased, peaking at 40 g/kg, and surpassing the control value, while carbohydrate content declined significantly ($p<0.05$) at 40 g/kg in comparison with the control. The nutritional composition also showed notable variations. Nitrogen, phosphorus, potassium and calcium contents increased significantly with carbide waste, exceeding the control values and reflecting enhanced nutrient uptake.

Grain heavy metal accumulation

Exception Fe, heavy metal contents increased with increasing application level of carbide waste but only Pb showed a significant difference ($p<0.05$) when compared to the control treatment (Table 7). The concentrations were, however, below permissible limits recommended by the National Agency for Food and Drug Administration and Control (NAFDAC) in Nigeria, Food and Agricultural Organization as well as World Health Organization (WHO, 2002).

Discussion

The findings of this study reveal that maize exhibits a differential tolerance to carbide waste, with low application rate (20 g/kg) enhancing growth parameters. Plants survived up to 60-80 g/kg but not without growth suppression. High concentrations of 100-160 g/kg led to complete mortality of the plant. This suggests that maize has a threshold for carbide waste tolerance, beyond which its physiological processes are adversely affected. The increase in plant height, stem girth, leaf length, and breadth at lower concentration of 20 g/kg indicates that maize benefits from the calcium enrichment and pH amelioration associated with carbide waste. This agrees with Abbas et al. (2024) position who found that carbide waste application significantly improved soil pH and nutrient availability in acidic soils. Similarly, Chindaprasirt et al. (2023) demonstrated that the reaction of calcium carbide with water releases hydroxide ions, increases soil pH and promotes nutrient solubility. The observed decline in growth at high concentrations suggests that excessive alkalinity can disrupt nutrient uptake and metabolic activities in line with the findings of Barrow & Hartemink (2023). They reported that high pH levels interfere with the availability of essential micronutrients like iron and manganese, leading to poor seedling development.

Reduction in number of roots and root length in this experiment can be attributed to root being the part in direct contact with the contaminant in the soil. Carbide waste must have caused extreme alkalinity with negative impact on the root. This agrees with the discovery of Shamsabad et al. (2021) who found that extreme alkalinity limits root function, affecting overall plant performance. Also, Bolan et al. (2003) reported that excessive application of carbide waste can compromise root health by damaging root tissues, reducing nutrient absorption, increasing susceptibility to root diseases, and causing root necrosis and decreased root vitality, ultimately negatively impacting overall plant health. This might have been responsible for reduction recorded in root fresh and dry weight of plants growth in carbide waste-contaminated soils in this study. Similar effects have been reported in studies on other industrial waste applications. For instance, Sharma and Sharma (2019) found that moderate levels of industrial waste enhanced root elongation, whereas excessive concentrations inhibited root development due to toxicity.

Growth improvement at low concentration of 20 g/kg might have caused by the plant’s potential mechanisms for tolerance. This mechanism in maize could include enhanced calcium uptake, root exudation to regulate pH, and differential gene expression for stress response as earlier reported by Zhong et al. (2022). They further noted that soil microbial activities, including nitrogen cycling, are sensitive to alkalinity, which may indirectly affect maize growth positively by altering soil microbiota. The inhibition of nitrification at high carbide waste levels might be responsible for its death according to Singh et al. (2021) who demonstrated that excessive industrial waste disrupts nitrogen metabolism in plant roots. The biomass responses further support the threshold tolerance hypothesis, with optimal fresh and dry weights observed at 20 g/kg. The reduction in biomass at higher concentrations aligns with that of Ajayi & Olaitan (2018), who attributed oxidative stress and metabolic disruption to excessive industrial waste applications. This was further substantiated by Chandra et al. (2019), who noted that while moderate industrial waste enhances biomass accumulation, excessive applications compromise photosynthesis and water retention. Furthermore, calcium availability from carbide waste at moderate levels may improve cell wall integrity, enhancing plant resilience to environmental stresses, as suggested by research on similar calcium amendments (Kumar et al., 2021).

Reproductive development in maize also exhibited sensitivity to carbide waste concentrations. The decline in ear and grain development beyond 20 g/kg highlights the impact of excessive alkalinity on reproductive success. This agrees with Olatunji et al. (2022), who reported that high industrial waste concentrations disrupt reproductive structures in maize due to phytotoxicity. Similarly, Patel et al. (2020) found that elevated waste levels inhibit starch and protein synthesis, leading to reduced 1000-grain weight. The inhibition of starch synthesis under high alkalinity conditions may stem from disruptions in key enzymatic pathways, as previously documented in studies on plant metabolic responses to extreme soil conditions (Ekanem & Idowu, 2017).

In terms of nutrient composition, moderate carbide waste concentrations enhanced crude protein and ash content, indicating improved nutrient assimilation. This finding aligns with that of Kumar et al. (2021), who found that nitrogen and phosphorus from industrial waste improve protein synthesis in crops. However, declines in carbohydrate content at higher waste levels suggest photosynthetic inhibition, as also reported by Ekanem & Idowu (2017). The observed increases in phosphorus, potassium, and calcium at moderate concentrations suggest enhanced nutrient availability, supporting Singh et al. (2020), who demonstrated that industrial waste could supply essential macronutrients to plants. Increased food nutrients are crucial for human health, supporting growth, development, energy production, and disease prevention, impacting everything from immune function to cognitive abilities (WHO, 2002).

Table 3 Effect of carbide waste contaminated soil on growth parameters of maize

Growth parameter	Application rate (g/kg)								
	0	20	40	60	80	100	120	140	160
Survival (%)	100.00	100.00	40.00	20.00	20.00	0.00	0.00	0.00	0.00
Number of leaves	7.60 ± 0.40^{a}	8.00 ± 0.45^{a}	3.00 ± 1.84^{b}	1.40 ± 0.40^{b}	0.60 ± 0.20^{b}	-	-	-	-
Plant height (cm)	160.46 ± 12.44^{a}	176.36 ± 10.21^{ab}	66.10 ± 40.69^{ab}	30.64 ± 30.64^{b}	9.20 ± 9.20^{b}	-	-	-	-
Stem girth (cm)	6.36 ± 0.17^{a}	5.42 ± 0.17^{a}	2.04 ± 1.25^{ab}	1.00 ± 1.00^{b}	0.28 ± 0.28^{b}	-	-	-	-
Leaf length (cm)	64.18 ± 3.49^{a}	84.66 ± 12.14^{ab}	31.28 ± 9.21^{b}	12.74 ± 12.74^{b}	6.92 ± 6.92^{b}	-	-	-	-
Leaf breadth (cm)	7.20±0.33a	7.78 ± 0.60^{a}	2.96 ± 1.81^{b}	1.24 ± 1.24^{b}	0.50 ± 0.50^{b}	-	-	-	-
Number of roots	29.40 ± 4.06^{b}	31.60 ± 3.33^{b}	8.80 ± 5.40^{a}	4.40 ± 4.40^{a}	3.00 ± 3.00^{a}	-	-	-	-
Root length (cm)	52.84 ± 4.36^{b}	68.84 ± 14.08^{b}	12.72 ± 8.47^{a}	3.24 ± 3.24^{a}	3.86 ± 3.86^{a}	-	-	-	-

Values are means ± standard error for 5 replicates. Means with similar alphabet(s) in superscript on same row are not significantly different ($p \geq 0.05$) from each other (Duncan Multiple Range Test).

Table 4 Effect of carbide waste contaminated soil on vegetative biomass of maize

Growth parameter (g)	Application rate (g/kg)								
	0	20	40	60	80	100	120	140	160
Leaf fresh weight	25.80 ± 5.17^{b}	45.80 ± 21.32^{c}	9.00 ± 12.45^{ab}	4.40 ± 9.84^{a}	0.80 ± 1.80^{a}	-	-	-	-
Stem fresh weight	81.80 ± 22.11^{b}	133.60 ± 29.93^{c}	37.00 ± 52.51^{a}	11.40 ± 25.49^{a}	2.60 ± 5.81^{a}	-	-	-	-
Root fresh weight	22.00 ± 10.17^{b}	45.40 ± 16.74^{a}	8.20 ± 11.67^{ab}	2.60 ± 5.84^{a}	1.00 ± 2.24^{a}	-	-	-	-
Leaf dry weight	8.54 ± 1.45^{ab}	20.06 ± 10.96^{c}	3.20 ± 4.44^{ab}	1.60 ± 3.58^{a}	-	-	-	-	-
Stem dry weight	44.14 ± 12.97^{b}	58.02 ± 18.21^{b}	16.00 ± 23.02^{a}	4.60 ± 10.29^{a}	0.40 ± 0.89^{a}	-	-	-	-
Root dry weight	10.10 ± 6.26^{b}	21.34 ± 8.45^{c}	3.80 ± 5.22^{a}	1.00 ± 2.24^{a}	-	-	-	-	-
Total biomass	62.72 ± 18.73^{b}	99.40 ± 24.89^{a}	23.00 ± 32.36^{a}	7.20 ± 16.10^{a}	0.40 ± 0.89^{a}	-	-	-	-

Values are means ± standard error for 5 replicates. Means with similar alphabet(s) in superscript on same row are not significantly different ($p \geq 0.05$) from each other (Duncan Multiple Range Test).

Table 5 Effect of carbide waste contaminated soil on yield parameters of maize

Yield parameter/plant	Application rate (g/kg)								
	0	20	40	60	80	100	120	140	160
Number of ears	1.00 ± 0.00^{c}	0.60 ± 0.55^{bc}	0.20 ± 0.45^{ab}	-	-	-	-	-	-
Ear length (cm)	12.40 ± 2.04^{c}	9.80 ± 9.01^{bc}	3.00 ± 6.71^{ab}	-	-	-	-	-	-
Ear diameter (cm)	3.66 ± 0.25^{b}	2.58 ± 2.37^{b}	0.70 ± 1.57^{a}	-	-	-	-	-	-
Ear fresh weight (g)	20.23 ± 3.58^{b}	45.10 ± 21.33^{ab}	17.11 ± 21.01^{c}	-	-	-	-	-	-
Ear dry weight (g)	23.60 ± 4.72^{ab}	32.12 ± 31.02^{b}	7.40 ± 16.55^{c}	-	-	-	-	-	-
Number of grains	116.20 ± 9.78^{ab}	162.00 ± 153.36^{b}	48.20 ± 107.78^{ab}	-	-	-	-	-	-
Grain fresh weight (g)	22.14 ± 2.17^{b}	25.14 ± 24.70^{ab}	7.43 ± 16.61^{c}	-	-	-	-	-	-
Grain dry weight (g)	15.50 ± 1.52^{ab}	17.60 ± 17.29^{ab}	5.20 ± 11.63^{ab}	-	-	-	-	-	-

Values are means ± standard error for 5 replicates. Means with similar alphabet(s) in superscript on same row are not significantly different ($p \geq 0.05$) from each other (Duncan Multiple Range Test)

Table 6 Effect of carbide waste contaminated soil on grain nutritional and proximate compositions of maize

Grain nutritional/ proximate composition	Application rate (g/kg)								
	0	20	40	60	80	100	120	140	160
Moisture (%)	11.04 ± 0.02^{b}	10.45 ± 0.10^{b}	10.90 ± 0.53^{b}	-	-	-	-	-	-
Ash (%)	1.22 ± 0.25^{a}	1.36 ± 0.06^{b}	1.61 ± 0.03^{c}	-	-	-	-	-	-
Crude fibre (%)	1.54 ± 0.02^{c}	1.41 ± 0.01^{a}	1.47 ± 0.03^{b}	-	-	-	-	-	-
Crude fat (%)	1.72 ± 0.03^{c}	1.45 ± 0.03^{a}	1.65 ± 0.03^{b}	-	-	-	-	-	-
Crude protein (%)	9.48 ± 0.07^{a}	10.12 ± 0.03^{c}	10.64 ± 0.02^{d}	-	-	-	-	-	-
Carbohydrate (%)	75.00 ± 0.08^{b}	74.92 ± 0.13^{b}	73.75 ± 0.01^{a}	-	-	-	-	-	-
Nitrogen (N) %	1.29 ± 0.02^{a}	1.56 ± 0.02^{c}	1.72 ± 0.03^{d}	-	-	-	-	-	-
Phosphorus (P)- mg/100g	146.48 ± 0.09^{a}	154.33 ± 0.05^{c}	156.33 ± 0.07^{d}	-	-	-	-	-	-
Potassium (K)- mg/100g	92.48 ± 0.16^{a}	95.60 ± 0.04^{c}	98.38 ± 0.06^{d}	-	-	-	-	-	-
Calcium (Ca)- mg/100g	56.43 ± 0.07^{a}	61.34 ± 0.07^{c}	65.03 ± 0.03^{d}	-	-	-	-	-	-
Magnesium (Mg) -mg/100g	9.16 ± 0.07^{d}	8.92 ± 0.03^{b}	7.42 ± 0.07^{a}	-	-	-	-	-	-

Table 7 Effect of carbide waste contaminated soil on grain heavy metal content of maize and permissible limits in food and vegetables

Grain heavy metal concentration (mg/kg)	Application rate (g/kg)									Permissible limit in food and vegetables	
	0	20	40	60	80	100	120	140	160	WHO (2002)/FAO	NAFDAC
Fe	32.00 ± 0.07^{a}	46.40 ± 0.03^{a}	45.90 ± 0.06^{a}	-	-	-	-	-	-	48.00	-
Cu	11.10 ± 0.04^{a}	18.10 ± 0.03^{a}	19.90 ± 0.02^{a}	-	-	-	-	-	-	30.00	20.00
Zn	28.20 ± 0.15^{a}	31.40 ± 0.06^{ab}	32.90 ± 0.05^{ab}	-	-	-	-	-	-	60.00	50.00
Pb	0.10 ± 0.01^{a}	0.40 ± 0.01^{b}	0.80 ± 0.02^{bc}	-	-	-	-	-	-	2.00	2.00

Values are means ± standard error for 3 replicates. Means with similar alphabet(s) in superscript on same row are not significantly different ($p \geq 0.05$) from each other (Duncan Multiple Range Test). Samples not available are indicated with –

Protein, for instance, acts as a building block for tissues, muscles, and organs, supporting growth and repair, and playing vital roles in bodily processes like enzyme and hormone production, and immune function. Carbohydrates serve as the body's primary energy source, fueling activities like brain function and muscle activity. Dietary fiber promotes digestive regularity, aiding in weight management, and potentially reducing the risk of chronic diseases like heart disease, diabetes, and certain cancers. Minerals like Ca, Mg and K support vital functions like building strong bones and teeth, regulating body fluids, and converting food into energy. However, reductions in magnesium and iron at high concentrations point to competitive nutrient uptake issues, as described by Anwar et al. (2019). This competition for nutrient uptake in alkaline soils may further compromise overall plant vigor and productivity. Reduction in nutrients can lead to their deficiencies, resulting in various health problems (Abbas et al., 2024).

The presence of heavy metals in maize grains must have been caused by their presence in carbide waste. This is capable of posing contamination risks as observed in studies by Adeoye & Balogun (2018), who reported toxic metal accumulation in crops grown with industrial wastes. The significant increase in lead content with carbide waste application raises concerns regarding heavy metal contamination. This aligns with findings by Adeoye & Balogun (2018) that highlighted the risks of toxic metal accumulation in crops. The observed variability in copper and zinc bioavailability further corroborates Alam et al. (2016), who noted that industrial waste amendments alter micronutrient dynamics. Though the concentrations fell within permissible limits in food in this experiment, long term accumulation may pose health risk to animals and man. According to WHO (2002), long-term exposure to heavy metals can cause various health problems, including neurological damage, organ dysfunction, and increased cancer risk, with certain metals like lead and cadmium having particularly long-lasting effects. Specifically, lead can cause neurological, cardiovascular, and reproductive issues, especially in children. Acute and chronic symptoms of lead poisoning include kidney, brain, reproductive organ, and central nervous system damage. While copper is essential for human health, excessive intake can lead to liver and kidney damage, gastrointestinal issues, and potentially, skin cancer, peripheral neuropathy, and vascular disease. While zinc is an essential trace element, excessive exposure can lead to toxicity, primarily affecting the gastrointestinal and respiratory systems, potentially causing conditions like metal fume fever and interfering with copper and iron absorption. Though iron (Fe) is an essential micronutrient for human health, its excess can lead to conditions like hemochromatosis, causing organ damage, while its deficiency can cause anemia.

Conclusion and recommendations

Carbide waste has shown potential as a soil amendment for maize cultivation up to 20 g/kg application rate. Application at 40 g/kg and above did have negative effects on the plant, as maize didn't survive beyond 80 g/kg concentration. Even though it survived at 60-80 g/kg, grains were not produced. Grain heavy metal concentrations of plants grown in carbide waste-contaminated soils were higher than those free from the waste, a pointer to the need for comprehensive risk assessments before widespread carbide waste utilization in agriculture to mitigate potential long-term contamination effects. Therefore, the use of carbide waste for soil amendment at 20 g/kg is recommended for maize production for improved yield, and particularly as heavy metal in the grains are still within permissible level in food. However, further studies on exploring remediation strategies to achieve reduced heavy metal uptake is necessary for health safety concerns. Also, future research should focus on investigating the long-term effects of carbide waste on field trials, and assessing its impact on crops under different environmental conditions.

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