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EVALUATION OF THE FERTILIZER POTENTIAL OF BLACK SOLDIER FLY LARVAL FRASS OBTAINED BY THE PROCESSING OF MULTIPLE ORGANIC WASTES IN AGRICULTURE IN CAMEROON: EFFECTS ON PLANT GROWTH PARAMETERS AND MAIZE KERNEL NUTRIENT COMPOSITION

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ABSTRACT: *The growing utilization of inorganic fertilizers results in the depletion of a minimal quantity of essential elements, including phosphorus, nitrogen, and potassium. The residual fraction is discharged into the environment as organic waste, posing a threat to the ecosystem.The black soldier fly larvae (BSFL) have been acknowledged as a solution for the increasing problem of organic waste. BSFL provides numerous benefits, including their current use of waste material, known as frass, as an organic fertilizer. The aim of this study is to examine the fertilizing properties of frass and its effects on plant growth parameters and nutrient concentration in maize kernels when consumed. This will be compared to other cultivation methods including synthetic fertilizers, conventional compost, and no compost. Following a 90-day timeframe, a comprehensive analysis was performed to assess the growth characteristics and nutrient composition within the kennels. The results of this study indicate that frass positively affects plant growth and has a favorable blend of nutrients, as previously demonstrated by studies investigating the nutrient levels in maize. This study showcased the capacity of utilizing frass as a carrier to boost agricultural output and enhance the accessibility of particular nutrients in plants. Further investigation is required to substantiate these conclusions. The widespread use of black soldier fly larvae in the agricultural sector in poor countries, particularly in Sub-Saharan Africa, has the capacity to have a beneficial effect on integrated sustainable agriculture and the achievement of Sustainable Development Goals 2, 11, and 12.*

KEYWORDS: Organic waste valorisation**,** Organic fertilizer, Black soldier fly larvae frass; plant growth parameters; nutrient concentration; Organic sustainable agriculture.

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INTRODUCTION

In sub-Saharan Africa, the urban population is rising rapidly, and by 2050, roughly half of the African population is projected to reside in urban areas (United Nations, 2014). This extraordinary urbanization has increasingly negative effects on developing nations (Achankeng, 2003). Among the effects of urbanization in developing country cities are an increase in waste output, both in terms of quantity and diversity, and a strain on the domestic agricultural sector due to the rising demand for food, to list a few. Sustainability is severely impacted by waste and food availability (Ojha et al., 2020). The growth in waste generation in Africa is anticipated to be so substantial, coupled with the inadequacy of waste management services in the majority of African countries, where the average MSW collection rate is only 55%, that Africa will overshadow any decrease in waste generation in other regions worldwide United Nation Environment Program (UNEP 2018). On average, 57% of MSW generated in Africa is organic waste, the majority of which is now dumped but could provide countries with enormous socioeconomic potential. Increasing demand for food puts pressure on the domestic agricultural sector. The emergence of urban agriculture in Cameroon began with the currency devaluation crisis of 1993 and accelerated in 2008, the year of the crisis commonly referred to as the "2008 Hunger Riots." Today, urban agriculture is a key component of Cameroon's metropolitan landscape. In a society where urbanization rates are reaching 50%, urban agriculture has paradoxically intensified, posing a number of difficulties (Sogang & Monkouop, 2022). Farmers have come to rely largely on imported synthetic fertilizers to alleviate land strain and optimize production techniques (De Bon et al., 2010). The use of Black Soldier Fly Larvae (BSFL) is well-known for playing a crucial role in resolving the aforementioned issues associated with urbanization, with high volumes of organic wastes through their valorisation (da Silva & Hesselberg, 2020; Kim et al., 2021; Lalander et al., 2019; Pastor et al., 2015; Singh & Kumari, 2019; Surendra et al., 2020), and with the novel use of the BSFL frass (a by-product or residue of the valorisation of organic waste) as an organic fertilizer or soil conditioner as a substitute for inorganic fertilizer (Agustiyani et al., 2021; Basri et al., 2022; Beesigamukama et al., 2020; Choi & Hassanzadeh, 2019; Gebremikael et al., 2022). The use of the BSFL Frass though novel is currently being explored.

Bortolini et al. (2020) found that BSFL frass possesses compost-like qualities with several benefits; BSFL frass contains chitin that enriches the soil microbiota (Schmitt & de Vries, 2020). The quick composting of organic waste by BSFL produces compacted BSFL frass with high concentrations of macronutrients (NPK), micronutrients, and organic matter that is readily available for agricultural use (Attiogbe et al., 2019; Bortolini et al., 2020; Gao et al., 2019; Sarpong et al., 2019), this frass is immediately available for agricultural application. High phosphorus concentrations in the BSFL frass promote nitrogen accumulation in plants (Klammsteiner et al., 2020), the BSFL frass contains chitin that naturally produces antimicrobial peptides that serve as a defense barrier for the plant (Choi & Hassanzadeh, 2019), and the BSFL frass contains a population of beneficial microorganisms for plant uptake (Choi & Hassanzadeh, 2019; Gold et al., 2020).

In spite of these advantages, certain experiments involving the application of BSFL frass to a variety of plant species have revealed slowed plant development and decreased biomass production (Basri et al., 2022). Presently, organic fertilizers are not commonly used in intensive agriculture, nor are the effects of BSFL frass on crops in Cameroon well understood. Organic fertilizers are typically required in relatively high quantities, making their application challenging for farmers (Agustiyani et al., 2021). The use of insect BSFL frass as organic

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fertilizer is a relatively new concept that can be implemented in large quantities due to the BSFL ability to feed voraciously (Diener et al., 2009; Song et al., 2021) on the various available organic waste streams in developing countries (Ddiba et al., 2022). The estimation by Salomone et al. (2017) stated that the BSFL treatment of 30 tonnes of food waste per day produced 33.3% (9990 kg/day) BSFL frass. Consequently, 1 ton of garbage will generate 333 kilograms each day. Adoption of a new concept or product as fertilizer in any farming system necessitates information on how it affects crop development, yield, nutrient uptake, and efficiency utilization in comparison to existing fertilizers. Maize (Zea mays) is the most widely cultivated agricultural commodity in sub-Saharan Africa, providing sustenance for approximately 50% of the economically active populace. This cereal in its natural or modified state is consumed daily by more than 12 million individuals, or two-thirds of the populace, in Cameroon, where it is the most widely cultivated grain (Etoundi & Dia, 2008; Tarla, 2014). To investigate the use of BSFL frass as a novel organic fertilizer, experiments were conducted to determine the nutrient composition of frass, the effect of this fertilizer on plant development (growth parameters), and a comparison between the nutrients found in corn kernels grown on grass and synthetic fertilizers.

Consequently, this research aims to shed additional light on the performance of BSFL frass through establishing its nutrient composition and contribution to plant growth as a suitable replacement for inorganic/synthetic fertilizer in Cameroon's agriculture sector.

LITERATURE REVIEW

In Africa, urban populations are expanding faster than in any other region of the globe. Africa's population is predicted to increase from 1.3 billion in 2020 to 2.5 billion in 2050. It is probable that the new urban population will demand greater access to dairy and livestock products, as well as cereals, vegetables and fruits, fats, oils, and sugars, compared to the previous generation, which primarily resided in rural areas. Feeding the cities of Africa and providing access to high-quality food presents a formidable challenge. Nonetheless, this represents a significant opportunity for the continent's sixty million farms.

There is an occurrence of food insecurity due to the continued growth in population as predicted (currently around 7 billion) and the prediction of continued growth (exceeding 9 billion by the middle of the 21st century) (Van Bavel, 2013), and urbanization (Kousar et al., 2021). Food insecurity has become a critical issue that must be resolved, as it poses a significant threat to the attainment of sustainable development goals (SDGs) (Echendu, 2022). As a strategy for food security, urban agriculture is practiced by a large number of formerly rural Africans now living in cities (Davies et al., 2021). The UNDP (Schübeler et al., 1996), for instance, noted that urban agriculture could considerably contribute to combating urban hunger and malnutrition by providing greater and more consistent access to fresh, nutrient-dense food at a lower cost than market purchases. The prevalence of Urban agriculture (AU) has led to the continuous and excessive use of inorganic fertilizer to ensure maximum crop yield and continued soil fertility (Krasilnikov et al., 2022). However, the excessive use of inorganic fertilizer is known to have negative impacts such as soil organic matter degradation (Salehi et al., 2017), soil acidity (Padhi et al., 2020) and environmental pollution (Lin et al., 2019) and high cost in energy (Hernández et al., 2016). Due to the negative effects of inorganic fertilizers, researchers have sought alternatives to chemical fertilizers that enhance the sustainability of

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agricultural ecosystems without reducing productivity. Hence, the development of organic agriculture. Organic agriculture aims to contribute to the improvement of sustainability, which is defined as the successful management of agricultural resources to satisfy human needs while maintaining or improving environmental quality and conserving natural resources for future generations (Muhie, 2022). Improving soil structure and fertility through the use of crop rotations, organic manure, and recycling the nutrients by using crop residues (straws, stovers, and other non-edible parts) either directly as compost and mulch or through livestock as farmyard manure just to list a few are known to make organic agriculture techniques ecologically sustainable (Nderitu, n.d.). This supports the use of organic waste in agriculture as it increases soil organic matter concentration (Chen et al., 2019), promotes soil microbial growth and activity and enhances soil physical characteristics (Hossain et al., 2017). Organic waste compost promotes a healthy soil structure (Tejada et al., 2009), and is a vital source of nutrients for plants and microorganisms (Palaniveloo et al., 2020), thereby increasing crop yield (Hernández et al., 2014). Composting techniques such as vermicomposting (Komakech, 2014; Liégui et al., 2021), onsite composting (Guo et al., 2018), and Aerated (Turned) Windrow composting (Gopikumar et al., 2020) have been extensively studied and reported as composting techniques whose compost can be used as organic fertilizer. The utilization of black soldier fly larvae in composting has been greatly promoted due to their capacity to consume an extensive range of organic wastes, including non-edible components and crop residue (Amrul et al., 2022). This is because the larvae facilitate nutrient recycling via frass, which can subsequently be repurposed as organic fertilizer. Despite the considerable potential of the research on frass fertilizer, it remains an innovative concept, especially in the sub-Saharan African region.

MATERIALS AND METHODS

Compost

Three weeks of adding water and stirring the pile accelerated the biodegradation of a mixture of yard garbage, household food waste, and various fruits and vegetables, resulting in the compost utilized in the study.

BSF frass

The BSFL frass fertilizer was a product created from the BSFL valorisation of fruits and vegetables (banana, mango peels, avocado, potato peels, etc.), abattoir waste, and pig manure (a combination of Pig Style waste and pig feces/dumplings) processed at the University of Dschang Cameroon-affiliated integrated organic waste treatment plant. The resulting frass' moisture content was reduced to ≤ 30% (Daiz et al., 2007) by air drying as wet BSFL frass lacks the features of mature compost, as it has high ammonium concentration and limited porosity (Basri et al., 2022), which could inhibit plant growth when applied as a soil amendment (Liu et al., 2013).

Multiple formulations of soil conditioners/organic fertilizers were applied to maize growing under open-air cultivation

In open field agriculture, numerous formulations of soil conditioner were applied to maize plants growing in ultisol (Ultisols are reddish, clay-rich, acidic soils that sustain mixed forest

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vegetation before cultivation) soil. The trials consisted of six treatments containing the key component of the BSF frass and four replications of each treatment. The seed was sown in soil, and starting fertilizer was subsequently applied to enhance the early development of each maize plant for 21 days. The starting fertilizer was introduced to elevate the soil Ph which was this maximizing crop yield as the soil analyzed was found to have a Ph value of 6.43 while the optimum soil Ph necessary for maize growth ranges between 6.5 -7.5 Ministry of Agriculture and Rural Development, Cameroon (MINADER, 2023).

As treatments, six unique growth mediums were used:

- Soil (as a control)
- Soil fertilized with NPK (the equivalent of 18 grams of NPK applied at the base of each plant)
- Compost (mainly household food waste)
- Bsfl treated fruits and vegetables (banana, mango peels avocado, potato peels etc) (the equivalent of 40 grams applied at the base of each plant)
- BSFL-treated abattoir waste (the equivalent of 40 grams applied at the base of each plant).
- BSFL treated with pig manure (the equivalent of 40 grams applied at the base of each plant)

F&F	AWF	PWF	IF	Com	S
S	Com	AWF	PWF	IF	F&VF
AWF	PWF	IF	Com	S	F&VF
Com	S	F&VF	AWF	PWF	IF

Key: F&VF: Fruits and Vegetable frass, AWF: Abattoir waste frass, PWF: Pig waste frass, Com: Compost, IF: Inorganic fertilizer, S: Soil

Fig 1: Planting Scheme

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NB: The purpose of the planting scheme was to ensure the accuracy of the data and disprove the theory that the results were due to one part of the land/soil being more fertile than another.

Each treatment was introduced on corn sown on $2m^2$ of land

Upon completion of the experiments, agronomic variables including plant height, leaf length, width, quantity of kernels on maize plants, and size of maize cubs were identified. Additionally, the nutrient content of the grain was ascertained to provide an estimation of the nutritional value of the maize that was cultivated under the different treatment conditions.

Nutrient content analysis in frass and maize kernels

The macronutrient, micronutrient, heavy metals and chemical composition content in the maize kernels were measured after harvest.

The analysis of the macronutrients, Nitrogen, Phosphorus and Potassium content in the frass and maize samples, were analyzed using the modified khedjal method (Campbell & Hanna, 1937), UV-Visible Spectrophotometry (Wiyantoko et al., 2018) and flame photometry (Ullah et al., 2022), respectively. Organic Carbon was analyzed using the Walkley et Black method which is predicated on the concept that potassium dichromate oxidizes the soil's carbon. The heavy metals were analyzed using atomic absorption spectrometry (AAS) (Biziuk et al., 2001). The nutritional content of starch and sugar were analyzed using UV-Visible Spectrophotometry (Bahdanovich et al., 2022), and ash analyzed through the use of a muffle furnace (Harris et al., 2017).

Statistical Analysis

The effect of numerous soil conditioner formulations on the growth of maize plants was tested 90 days (3 months) after planting. Observed characteristics of the growth of maize plants included plant height, leaf length and width, cob length, and number of kernels per cob as well as the nutrients of frass and nutrients found in the maize kernels. Using descriptive statistics and SPSS 21, correlational graphs and histograms were generated using experimental data.

Results and Discussion

Following the conclusion of the waste valorisation process conducted by the BSFL, an assessment was made of the impacts of various compost formulae or soil conditioners on the growth characteristics of maize plants, as well as their nutrient and mineral composition. The outcomes of this illustrative experiment will be displayed and discussed in the following section.

Frass composition

As an organic fertilizer, BSF frass may provide additional benefits to the soil. In addition to contributing the three fundamental nutrients (N, P, K) to the soil, BSFL frass also contributes to the soil ecosystem as its organic fertilizer counterparts. It provides large quantities of organic matter, which decomposes and releases plant-usable nutrients essential for rich, fertile soil qualities, typically distinct from the effects of inorganic fertilizers. Table 1, which depicts the nutrient composition of the BSFL frass, reveals a relatively high proportion of organic matter, thereby improving soil structure, which results in increased water infiltration and increased water-holding capacity of the soil, promotes root growth in more permeable soil and,

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consequently, better plant health, and permits more significant movement of mobile nutrients (such as nitrates) to the root, which is consistent with (Briar et al., 2011; T. Liu et al., 2016).

Table 1: Frass Composition

	Parameters	Unit	NC	PSWF	AWF	PFF	FVF
01	Total Nitrogen	% or g/100g of dry matter	4.2	1.41	3.1	2.63	1.81
02	Total Phosphorus	% or g/100g of dry matter	1.03	1.84	1.92	1.97	1.92
03	Total Potassium	% or g/100g of dry matter	11.25	$1.2*10^{-4}$	0.096	6	0.047
04	Organic matter /Carbon	% or g/100g of dry matter	62.7	52.07	45.6	57	50
05	Magnesium	Mg/100g of dry matter	5.12	34.1	16.2	13.12	15.62
06	Cadmium	Mg/100g of dry matter	0.19	0.2	0.2	0.15	0.2
07	Lead	Mg/100g of dry matter	5	0.5	0.64	0.5	0.52
08	Mercury	Mg/100g of dry matter	Trace	Trace	Trace	Trace	Trace

NC: Normal Compost, PSf: Pig Style waste frass, AWF: Abattoir Waste frass, PFF: Pig Feces frass, FVF: Fruits and Veggies frass.

The frass samples exhibited varying levels of critical elements required for plant growth. In accordance with the findings of Gärttling and Schulz (2019), it can be observed that pig-style waste frass exhibits a lower Nitrogen content compared to regular compost. Specifically, conventional compost demonstrates the highest Nitrogen content, whole pig-style waste frass exhibits the lowest Nitrogen content. The frass has a relatively high organic matter content; nevertheless, it is lower compared to the typical compost. This finding contradicts the results reported by Elissen et al. (2023), which may be attributed to the depletion of easily available organic matter in the black soldier fly larvae (BSFL) frass as a consequence of its stabilization process, as suggested by Visvini et al. (2022). The concentration of heavy metals, specifically cadmium, lead, and mercury, in the frass is comparatively low. This observation aligns with the findings of Basri et al. (2022), who characterized black soldier fly larvae (BSFL) as a type of microorganism that has the ability to accumulate heavy metals in their tissues, resulting in frass with a diminished heavy metal content.

The organic fertilizers provided by BSFL (BSF frass) provide essential elements that facilitate plants in fulfilling their nutrient needs. These nutrients are known to be relatively insufficient in conventional soil, hindering optimal plant growth. Based on the research conducted by Poveda (2021), a thorough examination of various frass types, including but not limited to black soldier fly (BSF) frass, revealed that insect frass has the potential to enhance soil fertility by providing essential nutrients, particularly nitrogen, which can be readily absorbed by plants. Additionally, insect frass may contain plant growth-promoting biomolecules and microorganisms, among other beneficial components.

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Maize growth parameters of maize per growth soil conditioner/enhancer

Compared to NPK treatments, standard compost, and the control (no compost), the effect of diverse organic frass fertilizer on maize growth was distinct. The following findings emerged from research on the effect of several soil conditioners on maize growth indices. The maize grown in soils treated with chemical fertilizers had the tallest stalks and highest average number of kernels (281cm and 490, respectively), followed by abattoir frass and fruits and vegetable frass with stalk heights of 275cm and 272cm, and kernel numbers of 475 and 400, respectively. Globally, the maize stalk height and quantity of kernels in soils made of frass are much greater than in soils with regular or no compost.

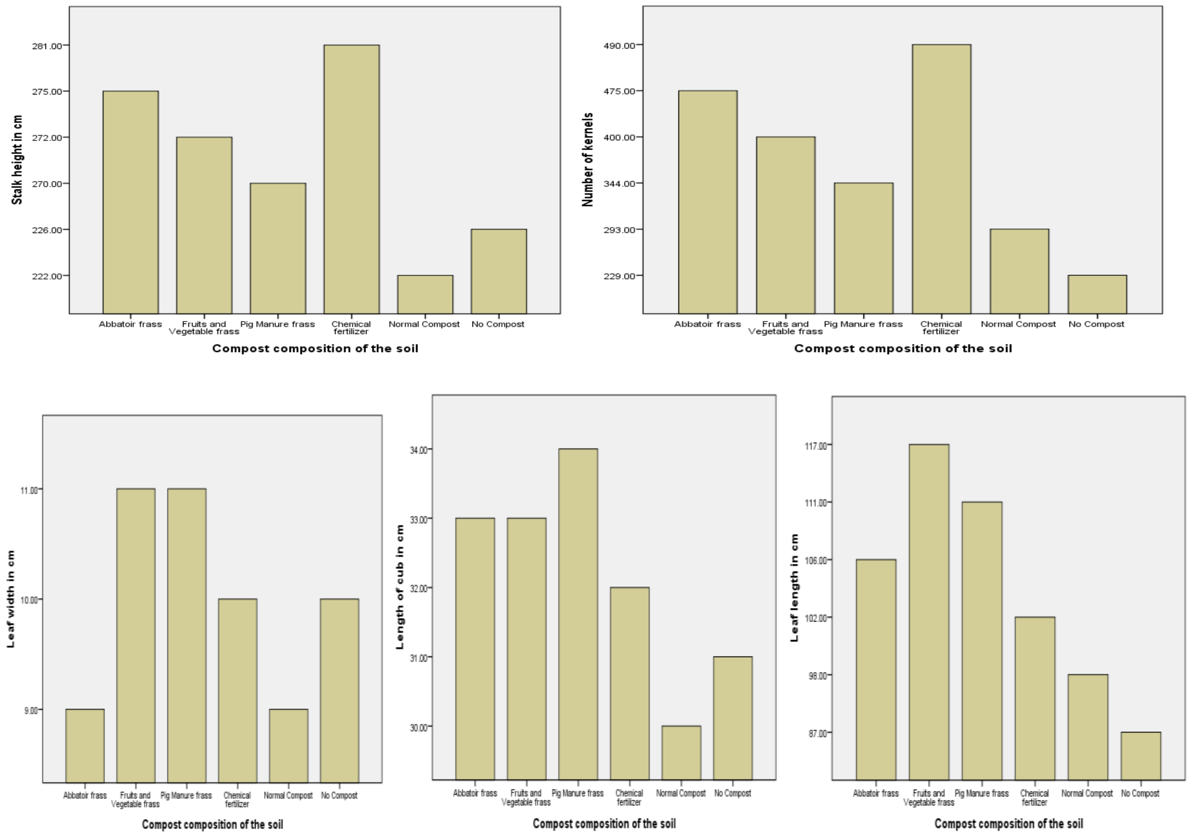

Figure 2: Comparative charts of corn growth parameters

The maize plants cultivated in soils composed of fruits and vegetable frass exhibited the greatest leaf length and width, measuring 117cm and 11cm, respectively. Following this, maize grown in soils consisting of pig manure frass displayed slightly shorter leaf lengths and widths, measuring 111 cm and 11 cm, respectively. In comparison, the leaf lengths of plants grown in soils enriched with abattoir frass were the third longest, measuring 106cm, while soils treated with chemical fertilizer resulted in the third longest leaf widths, measuring 10cm. The dimensions of maize leaves in soil frass exhibit a significant increase in both length and width compared to soils with standard or absent compost. When comparing the two, it was seen that the synthetic fertilizer outperformed frass in two growth indices, namely stalk height and number of kernels. On a global scale, it was seen that the application of frass resulted in superior growth enhancement compared to synthetic fertilizer and regular compost, even when no additional substances were used in conjunction with regular compost. This conclusion

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substantiates the outcomes of other contemporary studies, wherein the application of insect frass fertilizer had positive effects on the growth of herbs, vegetables, and grains (Beesigamukama et al., 2020; Borkent & Hodge, 2021; Hodge & Conway, 2022; Schmitt & de Vries, 2020).

a. Pig manure

b. Chemical fertilizer

c. Fruits and vegetable frass

d. Abattoir waste frass

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e. No Compost f. Normal Compost

Figure 3: Pictures of the maize grown on the different treatments

The observation was made that corn cultivated with abattoir waste yielded the largest kernels, with corn grown on pig manure following closely behind. In contrast to the maize planted on abattoir frass, which displayed anomalous characteristics, the maize grown on all soil conditioners exhibited no malformations. The corn harvested from FV frass exhibited a higher density despite the fact that the cob was significantly smaller. The maize planted using chemical fertilizers had smaller kernels devoid of any abnormalities and, on average, a higher number of kernels than maize produced using different frass forms. The maize cultivated on unamended soil exhibited the lowest kernel yield, whereas the maize grown on conventional compost demonstrated a slightly higher yield. The study conducted by Chen et al. (2016) showed that the maize planted in frass exhibited the greatest kernel size. This particular characteristic is essential in maize breeding programmes, as it directly influences grain yield. Enhancing agricultural productivity has been crucial in addressing the challenge of feeding an expanding global population while mitigating the environmental impact associated with food production.

Corn kernel composition

Maize is the third most crucial food grain after wheat and rice, and its demand is increasing due to its multiple uses, such as food sources for both humans and livestock (feed), and particularly due to its increased use in biofuel production (Erenstein et al., 2022). The numerous uses of maize are considered sufficient justification for investigating the chemical composition of this vital grain, whose composition, for instance, determines its applications. For instance, if maize is grown for the production of starch, glucose-sugar, syrup, or alcohol, the cereal should contain a high proportion of carbohydrates (Hopkins, 2015). The analysis of the composition of the corn kernels grown on the different types of BSFLf in comparison with that grow on inorganic fertilizer, normal compost and on no compost which was performed to ascertain that the composition of corn grown frass is not considerably different from that grown of chemical fertilizer yielded the following results.

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Table 2: Corn kernel composition

Num	Parameters	Unit	PMF	AbF	NC	FVF	CF	NoC
01	Total Nitrogen	% or g/100 g of dry matter	1.64	1.53	2.08	1.58	2.58	2.0
02	Total Potassium	% or g/100 g of dry matter	0.45	0.44	0.42	0.41	0.4	0.35
03	Phosphorus	% or g/100 g of dry matter	1.77	1.82	1.79	1.81	1.82	1.64
04	Calcium	% or mg/100 g of dry matter	66.5	54.5	45.5	50.5	52.0	30
05	Magnesium	% or mg/100 g of dry matter	0.01	2.95	467	47.8	48	161
06	Zinc	% or mg/100 g of dry matter	2.0	2.9	1.7	1.33	2.9	0.62
07	Iron	% or mg/100 g of dry matter	35	7.9	27.8	33.3	15.8	22.7
08	Lead	mg/kg	ND< LO Inst (0,01)	ND< LO Inst (0,01)	ND< LO Inst (0,01)	ND< LO Inst (0,01)	ND< LO Inst (0,01)	ND< LO Inst (0,01)
09	Cadmium	mg/kg	ND < LO Inst (0,002)	ND < LO Inst (0,002)	0.15	ND < LO Inst (0,002)	ND < LO Inst (0,002)	ND < LO Inst (0,002)
10	Manganese	mg/kg	ND< LO Inst (0,001)	5.45	0.9	1.65	ND< LO Inst (0,001)	ND< LO Inst (0,001)
11	Starch	%	72.3	72.8	73.1	72.6	72.8	72.1
12	Sugar	%	1.24	1.3	1.32	1.22	1.25	1.4
13	Ash	%	1.29	1.5	1.32	1.27	1.27	1.28
14	Organic matter/ carbon	%	65.93	68.62	74.46	74.96	67.5	58.85

PMF: Pig manure frass, AbF**:** Abattoir frass, NC : Normal compost ; FVF : Fruits and vegetable frass; CF: Chemical fertilizer; No C: No compost.

ND: Non-Detected; LO Inst: Instrumental detection unit

This study demonstrated that the composition of maize cultivated on the various frass treatments macronutrients (N, P, and K) concentrations in maize grown in the different media are variable. Still, they are present in the correct proportions for the synthesis of proteins. These results are consistent with those reported by Boone et al. (1984).

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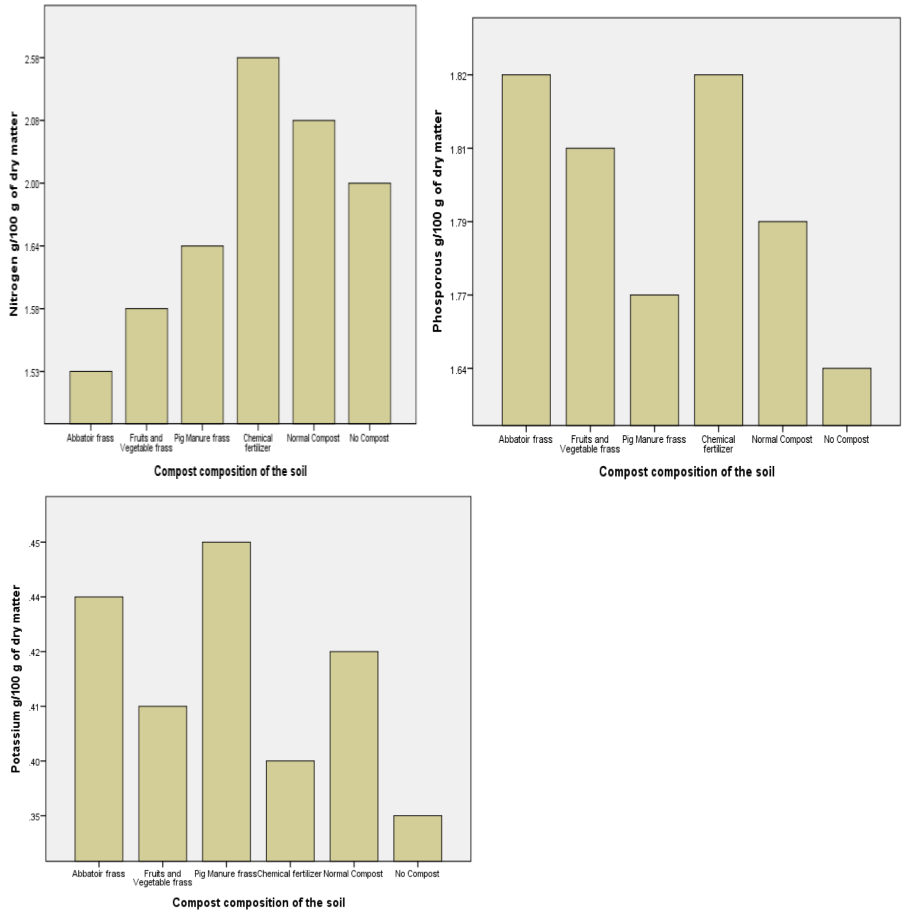

Fig 4a: Comparative charts of the composition in corn kernel (NPK).

Considerable variations in the concentrations of micronutrients (calcium, magnesium, zinc, and iron) were observed in maize kernels cultivated under varied treatment conditions. The calcium concentration in maize kernels cultivated using different frass treatments and chemical fertilizer exhibits the highest calcium levels, falling within the reported normal range for calcium content in maize (Gallego-Castillo et al., 2021). Conversely, the maize kernels grown on ordinary compost and no compost display the lowest calcium concentrations. The concentrations of Magnesium in the kernels cultivated with regular compost and no compost and those grown with chemical fertilizer exhibited higher levels. In contrast, the lowest quantities were observed in the different frass treatments. The zinc availability in mature maize at the point of intake is relatively low across all treatments, consistent with the findings published by Cheah et al. (2020). The samples with the highest zinc content are AbF, CF, and PMF. According to a previous study conducted by Aparecida et al. (2011), the levels of Iron in maize cultivated under various conditions fall within the range of typical zinc concentrations observed in maize kernels. The observed phenomenon can be attributed to a rise in the iron concentration during the composting process, as indicated by the presence of frass. This discovery aligns with the conclusions given by Akinbile and Yusoff (2012). Typically, the levels of heavy metals such as lead (Pb), cadmium (Cd), and manganese (Mn) are found to be below detectable limits. However, among the tested samples, AbF exhibits the highest concentration of manganese, followed by FVF and ordinary compost. According to a study by Nasiru et al. (2016), manganese exhibits the highest concentration among heavy metals found

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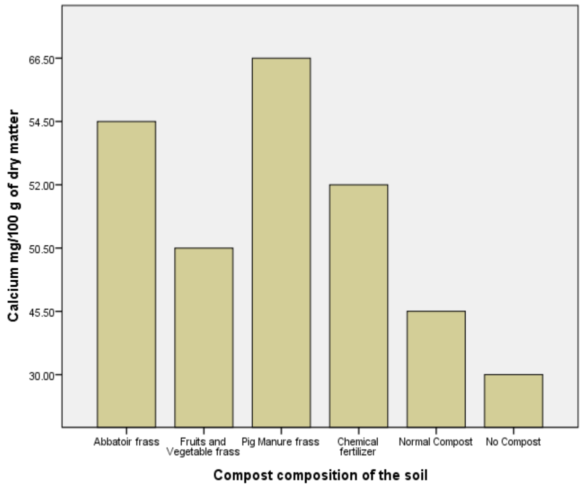
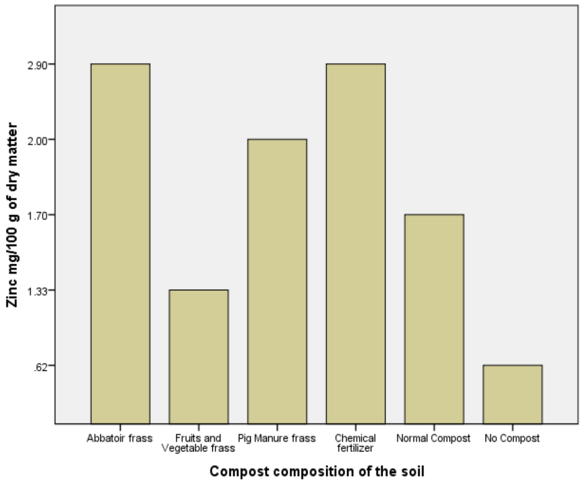
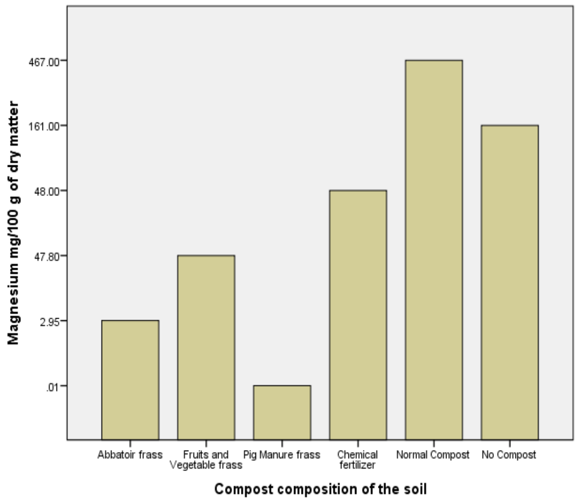
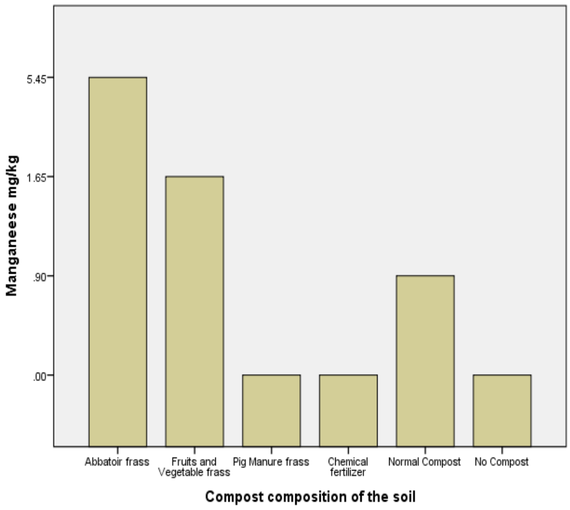
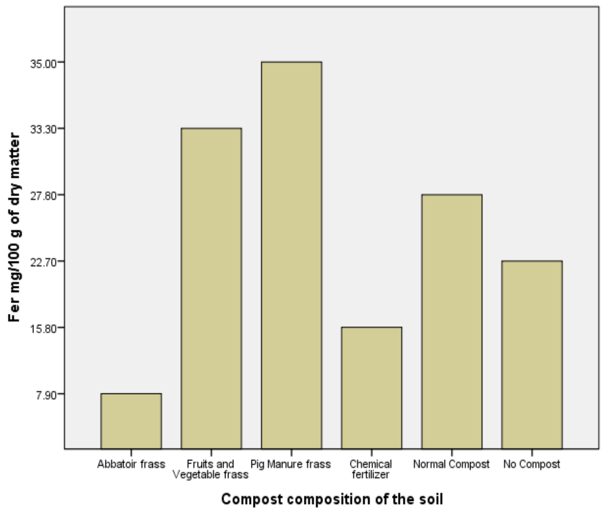
in abattoir waste. This finding aligns with the hypothesis that the organic manure, specifically frass, present in this waste may serve as a vector for enhancing the bioavailability of specific nutrients in plants.











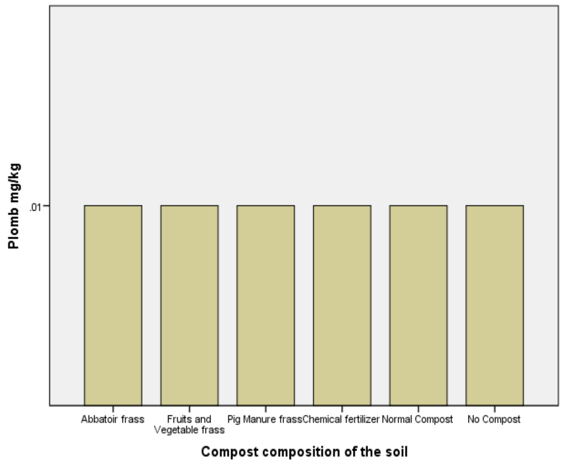


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Figure 4b: Comparative charts of the composition in corn kernel (micronutrients and Heavy metals).

The amounts of starch, sugar, ash, and organic carbon in the different kernel samples are all within the acceptable range (Figure 4c) for maize kernels, as reported by previous studies by (Langyan et al., 2022; Liu et al., 2016).

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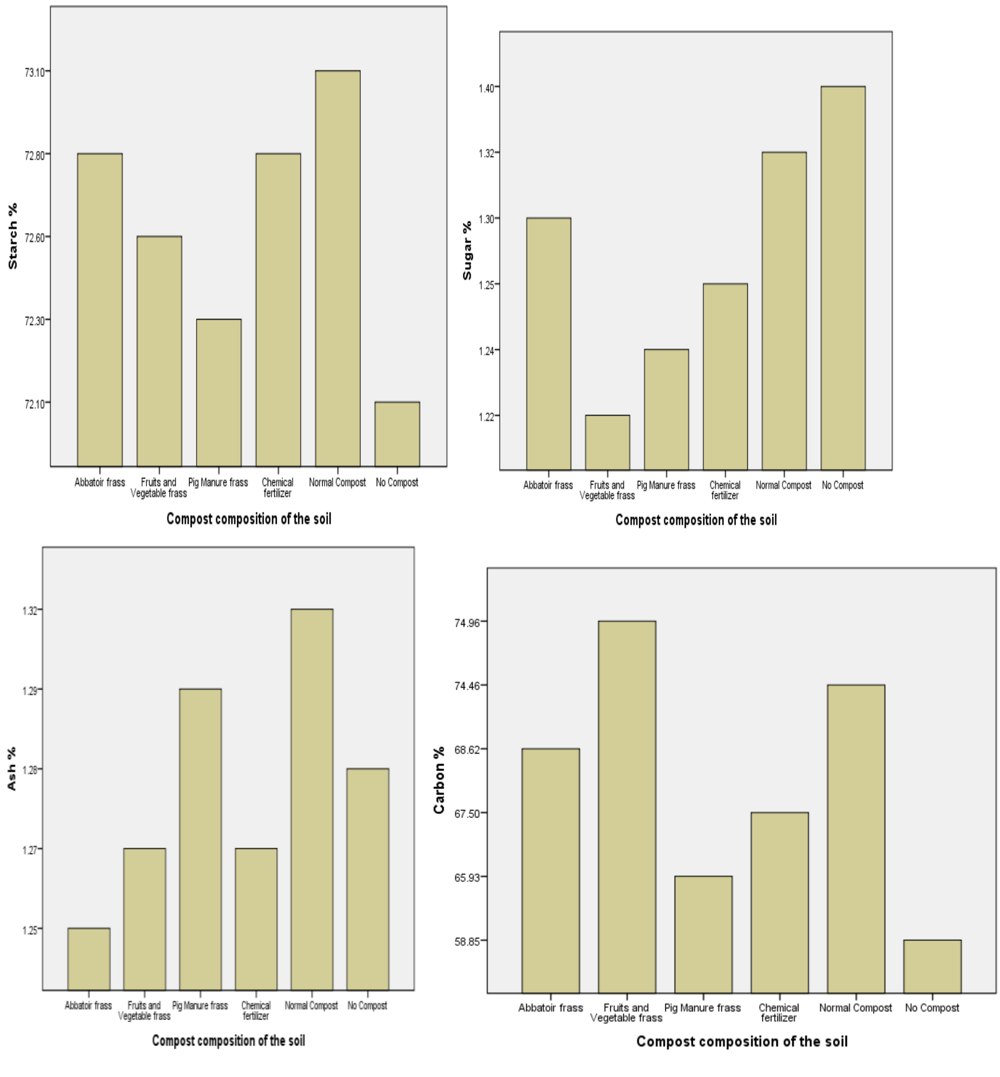

Fig 4c: Comparative charts of the composition in corn kernel

Based on the obtained findings, it is possible to assert that a correlation exists between the nutritional content of the waste substrate, which serves as input for waste treatment, and the producing frass. Furthermore, this association extends to the nutrient composition of the plant cultivated using this treatment.

In order to ascertain the creation of frass that is abundant in specific nutrients, it is imperative to conduct research on the diverse composition of frass in correlation with substrate composition. This research aims to establish the potential utilization of black soldier fly larvae (BSFL) frass as a means of biofortification in the field of agriculture. The objective of

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biofortification is to enhance the bioavailability of crucial elements, such as zinc and iron, in the consumable parts of agricultural crops through the application of genetic selection or agronomic interventions.

CONCLUSION

The utilization of black soldier fly larvae as an organic waste treatment has gained significant popularity as a waste management strategy, primarily due to its potential as a protein source and biodiesel feedstock, as well as its ability to enhance plant development when its waste treatment residue, known as frass, is employed as an organic fertilizer. In the context of the developing world, where population growth and urbanization are occurring at a rapid pace, a range of detrimental environmental consequences have emerged. These include urbanization, the excessive generation of trash, and heightened levels of food insecurity, which in turn have prompted an increase in urban agriculture. The black soldier fly larvae have been recognised as a potential remedy for the aforementioned environmental challenges due to their ability to efficiently process large quantities and diverse organic waste. Additionally, the waste residue produced by these larvae, known as frass, can be utilized to mitigate the overreliance on inorganic fertilizers. This is particularly relevant in societies where the promotion of urban agriculture is necessary to address food security concerns. Previous studies have shown evidence that the frass produced by black soldier fly larvae (BSFL) has a beneficial impact on both plant development and yield. Furthermore, it has been observed that the application of BSFL frass does not adversely affect the nutrient content in the kernel. This integrated agricultural approach is considered to be of significant importance in achieving sustainable agricultural practices. The utilization of black soldier fly larvae (BSFL) frass in urban agriculture not only acts as a viable alternative to chemical fertilizers but also plays a significant role in advancing the Sustainable Development Goals of Zero Hunger (SDG 2), Sustainable Cities and Communities (SDG 11), and Responsible Consumption and Production (SDG 12).

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Data Availability statement

The supporting data for this study's conclusions are included in this work, and further information can be obtained by contacting the corresponding author upon request.

Author Contribution statement

The idea was conceived by T.A.Mk. T.A.Mk formulated the theory and conducted the calculations. T.A.Mk, O.T, and K.MA confirmed the validity of the methodology. O.T and

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K.MA reviewed the findings of this study. Every author engaged in a discussion about the outcomes and made contributions to the ultimate manuscript.

Declaration of Interest Statement

Manuscript Title: **EVALUATION OF THE FERTILIZER POTENTIAL OF BLACK SOLDIER FLY LARVAL FRASS OBTAINED BY THE PROCESSING OF MULTIPLE ORGANIC WASTES IN AGRICULTURE IN CAMEROON: EFFECTS ON PLANT GROWTH PARAMETERS AND MAIZE KERNEL NUTRIENT COMPOSITION**

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- Dr Marc Anselme Kamga,

Declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this article.

The authors declare the following financial or non-financial interests which may be considered as potential conflicts of interest:

The Ph.D. programme of Ms. Marykathleen Agbornawbi Tambeayuk is being funded by African Union Commission through his flagship institution Pan African University (PAU). The Pan African University seeks to nurture quality and exemplify excellence in Africa.

Plant Ethics

Zea mays was collected in Ahala, Yaounde on the agricultural land used for the experimental setup. The plant material was identified by the researcher Tambeayuk Agbornawbi, and a voucher specimens were deposited at the Ministry of Agriculture and Rural Development with IDs defined as follows (PMf: Pig manure frass, Abf: Abattoir frass, Fruits and vegetable frass, CF: chemical fertilizer, Normal C: Compost NoC: No compost,) based on the soil treatments used in the experiment.

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