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Role of the Kogle-zanga biopesticide in improving amaranth leaf production in Loumbila

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ABSTRACT

Amaranth is a widely consumed traditional vegetable with high nutritional value. However, its production is constrained by both biotic and abiotic factors, which cause significant field damage. To address this issue, farmers often rely on a variety of pesticides, many of which are unregistered and pose risks to both humans and the environment. Hence, there is an urgent need to find alternatives to these synthetic products. In this context, the present study was undertaken to improve amaranth production using Kogle-zanga, a biopesticide. A completely randomized block design with four replications and four treatments was used. The biopesticide's efficacy was assessed based on pest attack levels, plant growth and development, and leaf yield. The results showed that Kogle-zanga effectively controlled pests. The T3 dose (70 mL/ha) had a more favorable effect on growth, development, and leaf yield compared to the T1 (50 mL/ha) and T2 (60 mL/ha) doses. Among the tested doses, T3 (70 mL/ha) was the most effective. Additionally, the biopesticide enabled amaranth to achieve its potential yield of 1–2 t/ha. Therefore, promoting the use of this biopesticide among producers for amaranth leaf cultivation is essential to protect human health and the environment.

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INTRODUCTION

Burkina Faso is characterised by a Sudano-Sahelian climate and an economy strongly dependent on agricultural and pastoral activities. Agriculture plays a central role in the national economy and remains a major driver of economic growth. It currently contributes approximately 18–19% of the gross domestic product (GDP) (INSD, 2025), while the services sector was the principal contributor to the 4.9% economic recovery recorded in 2024. Agricultural activities continue to be the primary source of employment in the country, with 98.7% of the agricultural workforce employed in the informal sector (INSD, 2025).

With cereal production estimated at 6.1 million tonnes (FAO, 2023), agriculture remains a cornerstone of both the economy and food security in Burkina Faso. Agricultural production is largely dominated by cereals, particularly millet, sorghum, maize, rice and fonio, which occupy more than 60% of cultivated land and contribute over 55% of total crop production nationwide (INSD, 2025). The sustained production levels recorded in recent years further underscore the strategic importance of cereal-based farming systems in the country (FAO, 2023).

This situation is partly due to a long-standing agricultural policy that has prioritised the promotion of food and cash crops to the detriment of fruit and vegetable production. This trend persists today, as subsidies for cereal inputs continue to account for the largest share of the national agricultural budget (INSD, 2025). According to the World Bank (2023), the agricultural sector contributed 1.9 percentage points to the 4.9% economic growth recorded in 2023 and represented 18.59% of the national gross domestic product (GDP). Vegetable crops, particularly onions, tomatoes and cabbages, constitute the second largest group of primary crops after cereals in Burkina Faso. These crops contribute substantially to both food security and the livelihoods of rural households (INSD, 2025). Their production has increased steadily in recent years, largely driven by the expansion of irrigated farming systems and the growing use of agricultural inputs, including fertilisers and pesticides. Improvements in farming practices and the adoption of high-yielding varieties have also contributed to this upward trend (FAO, 2023).

Among these vegetable species, amaranth (*Amaranthus* spp.) is an important traditional leafy vegetable valued for its high nutritional potential and widespread consumption (Gelaye, 2023; Netshimbupfe *et al.*, 2023). In addition to its leaves, the seeds are also consumed in various forms (Ajayi *et al.*, 2016; Alemayehu *et al.*, 2015). More generally, leafy vegetables constitute an essential component of diets in many parts of the world, particularly in Africa, Asia and Oceania, where they make significant contributions to nutritional intake and are also used in traditional medicinal practices (Abolaji *et al.*, 2016; Al-Mamun *et al.*, 2016; Bhat *et al.*, 2015). However, amaranth production is frequently constrained by a wide range of biotic pressures, particularly pest infestations, which are among the major causes of yield losses (Ezeh *et al.*, 2015; Mureithi *et al.*, 2017; Seni, 2018). To manage these pests, producers frequently depend on the intensive and often indiscriminate application of synthetic chemical pesticides (Drabo *et al.*, 2017, 2021). Nevertheless, the excessive use of chemical fertilisers and pesticides may adversely affect both the agronomic performance of amaranth and its culinary quality (Ahouangninou *et al.*, 2011; Nampeera *et al.*, 2019). Moreover, the intensive application of synthetic pesticides poses considerable risks to human health and the environment, including contamination of soils and water resources (Acharya *et al.*, 2025), poisoning of producers and consumers (Romba *et al.*, 2020), and the progressive erosion of biodiversity (Knauer *et al.*, 2026). A recent study estimated that the annual avoidable health and environmental costs associated with toxic chemicals in food systems amount to approximately USD 3 trillion (Systemiq, 2025). In addition, the repeated and uncontrolled use of insecticides contributes to the development of resistance among several pest species, thereby reducing treatment efficacy over time and increasing production costs (Bian *et al.*, 2026). These constraints represent a major challenge for agricultural production systems, particularly for vegetable crops that depend heavily on phytosanitary interventions (Schatz *et al.*, 2026).

In response to the growing challenges associated with synthetic insecticides, increasing attention is being directed towards plant-based biopesticides as sustainable alternatives for crop pest management due to their biodegradability, low environmental impact and compatibility with agroecological and integrated pest management approaches. The present study aimed to evaluate the efficacy of Kogle-zanga, a locally produced biopesticide, on pest damage and the agronomic performance of amaranth crops.

MATERIALS AND METHODS

Presentation of the study area

The study was conducted at the *Yelemani* Association's experimental site in Loumbila, located in the Sudano-Sahelian zone of Burkina Faso, which is characterised by alternating dry and wet seasons (Fig 1). The study took place from June to October 2025 during the rainy season.

Plant material

Seeds from a local variety, *Loumbila* were used as a plant material. These seeds were purchased from Technissem at the Boutapa agricultural shop.

Preparation of biopesticides

Table 1 presents the composition of Kogle-zanga. The ingredients were ground with a mortar and then added to the remaining water. The resulting homogenate was left to macerate for 72 hours. Following maceration, the mixture was filtered. The treatment solution was prepared by diluting 0.5 L of Kogle-zanga in 15 L of water.

Experimental design

The experiment was established as a completely randomized block design with four treatments and four replicates. The treatments corresponded to increasing doses of the biopesticide: T0 (untreated control, 0 mL), T1 (50 mL), T2 (60 mL), and T3 (70 mL). A total of 16 plots, each 1 m², were laid out. A spacing of 1 m was maintained between blocks, while plots within each block were separated by 0.5 m.

Table 1. Composition of Kogle-zanga

Ingredients	Quantity	Remarks
Garlic (*Allium sativum*)	250 g	Fresh
Chili pepper (*Capsicum* spp.)	250 g	Dried
Neem leaves (*Azadirachta indica*)	250 g	Fresh
Ginger (*Zingiber officinale*)	250 g	Fresh
Palm oil (*Elaeis guineensis*)	0.5 L	-
Bar of local soap	250 g	-
Water	7.5 L	Groundwater source

Soil preparation and sowing

Two main experimental plots were delineated and prepared before the experiment. Sowing was carried out manually following soil amendment. The planting layout was established with a spacing of 20 cm between rows and 20 cm between planting holes within rows. Each main plot was subdivided into 16 elementary subplots, each comprising 16 planting holes arranged in a 4 × 4 grid. Consequently, each main plot contained a total of 256 planting holes.

Crop management and pest control

Weeding and hoeing were carried out at 14-day intervals throughout the growing cycle to limit weed competition and maintain adequate soil aeration. Immediately following each weeding operation, compost was applied to enhance soil organic matter content and nutrient availability. Pest management was undertaken using two Kogle-zaanga. Foliar applications were performed 10 days after sowing (DAS) and repeated every 3 days thereafter. Application rates varied according to the treatment level (low, medium, and high). All treatments were applied early in the morning (between 06:00 and 08:00) to minimise evaporative losses.

Data collection

The data collected focused on leaf damage, plant height, plant diameter, and leaf length and width.

These measurements were taken on 10 randomly selected plants on the 23rd, 30th and 37th days after planting (DAP) using a tape measure and yield parameters.

Economic evaluation

The economic viability of the different treatments was evaluated using the benefit–cost ratio (BCR) and return on investment (ROI), calculated according to the methodological framework of Hounnou and Ouedraogo (2025). These indicators were used to assess treatment profitability by relating the benefits generated to the associated production costs.

Statistical analysis

Microsoft Excel 2019 was used for data entry. Analyses of variance (ANOVA) were performed using XLSTAT 2016, and mean comparisons were conducted using Newman-Keuls test at the 5% significance level.

RESULTS

Effect of treatments on the degree of insect damage

The analysis of pest damage levels on amaranth at three time points (D23, D30, and D37) revealed that all treatments (T1, T2, T3) reduced damage severity relative to the untreated control (T0) (Table 2). At DAR23, treatments T1 (2.30), T2 (1.90), and T3 (1.87) had significantly lower damage levels than the control (4.57), with a *p*-value of 0.005 indicating a highly significant difference. However, at the later dates (D30 and D37), although treated plots continued to show lower damage levels than the control (10.72 and 19.12, respectively), the differences were no longer statistically significant ($p > 0.05$). These results indicate that Kogle-zanga is effective in the short term (up to 23 days after transplanting), but its efficacy diminishes over time, likely due to the degradation of active compounds or the recolonisation of pests in the plots.

Table 2. Temporal changes in the number of affected leaves following treatment application from 23 to 37 days after transplanting

Treatments	DA23T	DA30T	DA37T
T0	4.57^{a}	10.72^{a}	19.12^{a}
T1	2.30^{b}	9.52^{a}	16.97^{a}
T2	1.90^{b}	8.32^{a}	15.95^{a}
T3	1.87^{b}	8.57^{a}	11.90^{a}
Pvalue	0.005	0.251	0.225

Legend: T0 (untreated control, 0 mL); T1 (50 mL); T2 (60 mL); T3 (70 mL); DAP: days after transplanting. Within each column, means sharing the same letter are not significantly different at the 5% significance level (Student–Newman–Keuls test). S: significant ($p < 0.05$); NS: not significant ($p > 0.05$)

Table 3. Plant height (cm) variation by treatment (23–37 days after planting)

Treatments	DA23T	DA30T	DA37T
T0	9.80^{c}	45.00^{a}	47.85^{a}
T1	10.12^{c}	47.25^{a}	45.50^{a}
T2	11.52^{b}	51.25^{a}	45.12^{a}
T3	13.55^{a}	55.50^{a}	44.00^{a}
Pvalue	0.0001	0.316	0.967

Legend: T0 (untreated control, 0 mL); T1 (50 mL); T2 (60 mL); T3 (70 mL); DAP: days after transplanting. Within each column, means sharing the same letter are not significantly different at the 5% significance level (Student–Newman–Keuls test). S: significant ($p < 0.05$); NS: not significant ($p > 0.05$)

Variation in plant height across treatments

Table 3 presents the analysis of amaranth plant height at three time points (JAR23, JAR30, and JAR37) and reveals a mixed outcome. At JAR23, a highly significant difference was observed ($p = 0.0001$): treatment T3 (70 ml) produced the greatest height (13.55 cm), significantly exceeding that of the control T0 (9.80 cm) and T1 (10.12 cm), while T2

(11.52 cm) occupied an intermediate position. These results indicate that the highest dose of the Kogle-zanga biopesticide promoted early plant growth. However, at the later time points (JAR30 and JAR37), no statistically significant differences were detected between treatments ($p > 0.05$), although the treated plots, particularly T3, consistently showed slightly greater heights (55.50 cm at JAR30 and 44.00 cm at JAR37) compared to the control (45.00 cm and 47.85 cm, respectively).

Variation in plant diameter according to treatment

The analysis of amaranth plant height at three time points (D23, D30, and D37) is presented in Table 4 and reveals treatment differences that vary over time. At D23, no significant difference was detected between treatments ($p = 0.057$), although the T3 dose (70 ml) showed a slightly higher value (0.52) compared to the others (approximately 0.35–0.37). At D30, the difference became highly significant ($p = 0.005$): treatment T3 achieved the greatest height (2.45), significantly surpassing the control T0 (1.20), T1 (1.32), and T2 (1.75). These results indicate that the highest dose significantly promoted plant growth at this intermediate stage. Finally, at D37, the difference was very highly significant ($p = 0.000$): treatments T1 (2.50), T2 (2.37), and T3 (4.92) all showed heights greater than the control (4.75). Overall, these findings confirm the positive effect of Kogle-zanga on amaranth growth, with a particularly marked impact at the T3 dose.

Table 4. Variation in plant diameter according to treatment from 23 to 37 days after planting

Treatments	DA23T	DA30T	DA37T
T0	0.35^a	1.20^b	4.75^a
T1	0.37^a	1.32^b	2.50^b
T2	0.37^a	1.75^b	2.37^b
T3	0.52^a	2.45^a	4.92^b
Pvalue	0.057	0.005	0.000

Legend: T0 (untreated control, 0 mL); T1 (50 mL); T2 (60 mL); T3 (70 mL); DAP: days after transplanting. Within each column, means sharing the same letter are not significantly different at the 5% significance level (Student–Newman–Keuls test). S: significant ($p < 0.05$); NS: not significant ($p > 0.05$)

Table 5. Changes in the length and width of the plants from the 23rd to the 37th day after planting

Treatments	Length DA23T	Length DA30T	Length DA37T	Width DA23T	Width DA30T	Width DA37T
T0	8.07^b	24.25^b	28.05^b	4.67^a	8.95^b	6.75^b
T1	10.02^b	23.57^b	29.82^b	4.45^a	9.75^b	6.85^b
T2	9.56^b	22.10^b	30.25^b	3.80^a	10.87^a	7.37^b
T3	12.32^a	38.92^a	44.50^a	4.72^a	11.50^a	23.52^a
Pvalue	0.002	0.001	0.0001	0.242	0.011	0.0001

Legend: T0 (untreated control, 0 mL); T1 (50 mL); T2 (60 mL); T3 (70 mL); DAP: days after transplanting. Within each column, means sharing the same letter are not significantly different at the 5% significance level (Student–Newman–Keuls test). S: significant ($p < 0.05$); NS: not significant ($p > 0.05$)

Effect of treatments on leaf length and width

Analysis of amaranth leaf dimensions (length and width) revealed a clearly positive effect of Kogle-zanga, which was particularly pronounced at the T3 dose (70 ml) (Table 5). For leaf length, highly significant differences were observed at all time points ($p = 0.002$ at DAR23; $p = 0.001$ at DAR30; $p = 0.0001$ at DAR37). At DAR23, T3 produced the greatest length (12.32), significantly exceeding the other treatments (range: 8.07–10.02). This gap widened further at DAR30 (T3: 38.92 vs. 22.10–24.25 for others) and at DAR37 (T3: 44.50 vs. 28.05–30.25), confirming the sustained stimulatory effect of the high dose on leaf elongation. Regarding leaf width, differences became significant from DAR30 onward ($p = 0.011$) and were highly significant at DAR37 ($p = 0.0001$). At DAR30, T2 (10.87) and T3 (11.50) showed greater widths than T0 (8.95) and T1 (9.75). At DAR37, the difference was striking: T3 (23.52) far exceeded all other treatments (range: 6.75–7.37).

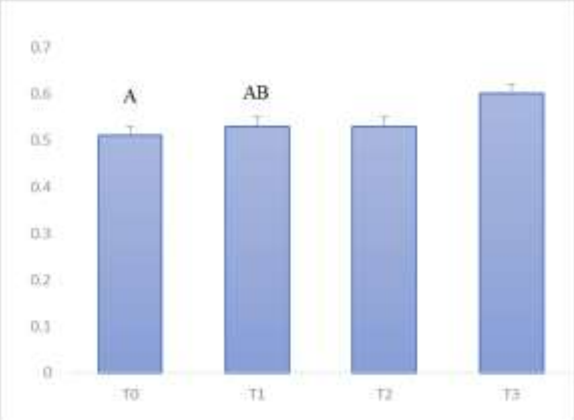

Fig. 1. Crops yield on different traetments

Impact of treatments on crop yields

The graph shows amaranth yields for treatments T0 to T3 (Fig 2). Treatment T3 (70 mL) achieved the highest yield (0.60 kg/m²), significantly exceeding the control T0 (0.51 kg/m²), as indicated by the distinct letter superscripts. Treatments T1 (0.53 kg/m²) and T2 (0.53 kg/m²) showed intermediate yields that were statistically similar to each other but not significantly different from the control. These results indicate that the highest dose of Kogle-zanga (T3) significantly enhances amaranth yield compared to the untreated control.

Economic evaluation of amaranth across different treatments

Table 6 presents the economic analysis of the different treatments. Treatment T3 (70 ml) achieved the highest yield (1,321 kg/ha) and the highest gross revenue (660,263 CFA francs/ha), while also generating the highest net profit (494,080 CFA francs/ha), despite total variable costs of 221,300 CFA francs/ha. Its revenue-to-cost ratio (RVC) of 0.76 and return on investment (ROI) of 1 indicate that each franc invested returns one franc in profit, although the RVC remains below the conventional break-even threshold of 1.5. Treatment T1 (50 ml) also had an ROI of 1, with an RVC of 0.19, but produced a lower net profit (339,971 CFA francs/ha) than T3. The untreated control (T0) showed the lowest yield (993 kg/ha) and an RVC of zero (0), while treatment T2 (60 ml) recorded the lowest yield (932 kg/ha), with a very low RVC of 0.05 and an ROI of 0.61, rendering it economically unattractive. Overall, although T3 is the most effective treatment agronomically and generates the highest gross income and net profit, its RVC below 1.5 suggests limited profitability by conventional standards.

Table 6. Economic profitability of amaranth across different treatments

Treatments	Total variable costs (FCFA/ha)	Yield (kg/ha)	Gross revenue (FCFA/ha)	Gross profit (FCFA/ha)	Net profit (FCFA/ha)	RVC	ROI (%)
T0	209500	993	466115	387000	309260	0	0.47
T1	156100	1091	496500	504163	339971	0.19	1
T2	198700	932	545609	346909	320318	0.05	0.61
T3	221300	1321	660263	524815	494080	0.76	1

DISCUSSION

This study confirms that biopesticides are a promising natural alternative for crop protection due to their insecticidal properties, accessibility, and perceived safety (De Sousa *et al.*, 2025).

Recent research highlights their low environmental impact and reduced toxicity to non-target organisms, reinforcing their value for sustainable agriculture (Kostina-Bednarz *et al.*, 2025).

The results further support the safety profile of biopesticides, as their agricultural use poses minimal risk to applicators and the environment. In a systematic review of 134 studies, De Sousa *et al.* (2025) demonstrated that biopesticides pose minimal risks to humans and vertebrates.

It was found that *kogle zanga* significantly reduced pest damage to amaranth compared to the untreated control. All doses tested were more effective than the control, with a marked reduction in damaged leaf, indicating direct insecticidal activity. The low damage levels in the treated plots reflect strong pest susceptibility, which may be attributed to the multiple modes of action of Kogle-zanga (Kostina-Bednarz *et al.*, 2025). This finding is consistent with (Akhter *et al.*, 2023), who showed that an aqueous neem seed extract applied to tomatoes significantly reduced lepidopteran damage relative to the untreated control, with an antifeedant effect similar to that of a synthetic insecticide.

The efficacy of aqueous plant extracts primarily relies on their rapid absorption by plant tissues and their ability to induce systemic resistance in the host plant. Recent work on Apiaceae extracts demonstrated this mechanism, showing that they trigger molecular changes associated with enhanced immunity (De Kock *et al.*, 2025). The dose-response relationship observed in our trial is also consistent with Rajagopal *et al.* (2022), who found that aqueous extracts of *Acacia concinna* and *Lantana camara* exhibit synergistic insecticidal activity against scale insects, underscoring the potential of plant secondary metabolites. With respect to their mode of action, botanical extracts typically inhibit key nervous system enzymes, notably acetylcholinesterase, as shown for *Rosmarinus officinalis* (Kashyap and Reddy, 2025).

This disruption of the pest nervous system, along with associated structural changes, likely accounts for the substantial reduction in damage observed on treated plots. The sustained efficacy of Kogle-zanga throughout the trial may be explained by the presence of relatively stable compounds, such as the glycoalkaloids of *Solanum incanum*, which retain 61% of their activity after 56 days (Mahenge *et al.*, 2026), in contrast to volatile terpene-based extracts, whose effectiveness diminishes rapidly.

The significantly higher amaranth yield observed with the T3 dose of Kogle- zanga (70 mL) compared to the untreated control confirms the agronomic efficacy of this biopesticide. Its ability to control pest infestation levels facilitated better vegetative growth. These results are in line with those of Akhter *et al.* (2023), who reported that aqueous neem extracts applied to tomatoes reduced lepidopteran damage and enhanced marketable yield, while providing a more favourable cost-benefit ratio than synthetic insecticides. In amaranth specifically, Vorsah *et al.* (2020) found that OMRI-certified biorational treatments reduced *Disonycha glabrata* flea beetle populations by 80%, leading to a marked increase in fresh leaf yield for the Green Callaloo and Red Leaf varieties. Similarly, Babendreier *et al.* (2020) showed that neem-based biopesticides lowered *Spodoptera frugiperda* populations on maize and increased yields relative to untreated controls. Thus, the yield response to Kogle-zanga is consistent with the existing literature on botanical biopesticides. Nonetheless, its large-scale adoption must account for the economic constraints associated with production costs, as previously discussed.

In the untreated control plots, damage observed from plant emergence negatively affected growth and leaf quality, resulting in lower yields. Our results support the observations of Othim *et al.* (2018), who showed that defoliating Lepidoptera are the most damaging pests of cultivated amaranths worldwide, inflicting severe losses from the earliest stages of plant development. The lack of sustainable management strategies, together with the harmful effects of chemical pesticides, therefore highlights the value of alternatives such as the biopesticide Kogle-zanga tested in this study.

The economic evaluation indicates that the T3 dose yields the highest gross income (RVC = 0.54; RSI = 1). However, with an RVC below 1.5, this dose does not meet the generally accepted break-even thresholds for agricultural adoption. This finding reflects a well-documented constraint: the high cost of biopesticides represents a major barrier to their adoption, particularly in traditional farming systems and among smallholders (Fenibo and Matambo, 2025). A survey from Uganda confirms that affordability and limited availability hinder biopesticide adoption, even when their low-risk profile is perceived favorably (Mayamba *et al.*, 2025). Furthermore, persistent perceptions regarding the cost-effectiveness of biopesticides are identified as a significant challenge to expanding their use in integrated pest management programs (Marrone, 2025). To improve the cost-effectiveness of Kogle-zanga, local production strategies and economies of scale would be necessary, as recommended by Fenibo and Matambo (2025), who stress the importance of economically accessible biopesticides for sustainable agriculture.

CONCLUSION

This study has demonstrated that the biopesticide Kogle-zanga is an effective natural alternative for protecting amaranth crops. Our results show a significant reduction in pest damage in treated plots relative to the absolute control, along with a clear dose-response relationship and direct insecticidal action attributable to multiple mechanisms, including systemic absorption, enzyme inhibition, and compound stability. This biological efficacy led to improved growth parameters and leaf yield, confirming the value of Kogle-zanga as an alternative to chemical pesticides. Nevertheless, the economic analysis indicates that the most effective dose (T3) yields a revenue-to-cost ratio (RVC) below conventional break-even thresholds, underscoring that cost remains a major barrier to the adoption of this technology by smallholders, as documented in other agricultural contexts. Moving forward, local production strategies and economies of scale could enhance the profitability of Kogle-zanga and support its integration into sustainable integrated pest management programs, thereby balancing agronomic efficiency, environmental safety, and economic viability.

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