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Valorisation of co-products into a biopesticide: A sustainable solution for cowpea cultivation in North Cameroon

Abstract. Co-product-based biopesticides constitute a more environmentally friendly, safe, and sustainable alternative. This study aimed to evaluate the efficacy of a biopesticide formulated from co-products (neem litter, eucalyptus litter, mango juice, rice bran) and lactobacilli on cowpea in the localities of Houla Djalingo and Badjouma. The methodology employed a completely randomised experimental design consisting of nine microplots of 25 m^2 each, established at two sites (Badjouma and Houla Djalingo), following the field cultivation method. The biopesticide was also formulated based on formulation methods described in the literature. It was subsequently characterised physicochemically and applied to the cowpea crop in the field on a weekly basis for three months. Its efficacy was assessed by monitoring pest dynamics over 12 weeks across biopesticide-treated plots (PTB), chemical pesticide-treated plots (PTC), and untreated control plots (PTT). Finally, seed yield and biomass (fresh and dry) were determined. The study yielded results revealing a notable reduction in pest pressure in the PTB plots. These plots recorded the highest seed weights and

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yields (8.6 ± 0.36 kg and 3,253 kg/ha at Houla Djalingo; 9.63 ± 0.14 kg and 3,646 kg/ha at Badjouma) and were the least affected by pest attacks compared to the PTC and PTT plots. The findings of this study can be used by farmers, agricultural extension services, and agrochemical industries to develop and disseminate a biological alternative to chemical pesticides, as well as by researchers and policymakers to support research programmes and regulatory frameworks promoting more sustainable agriculture

Keywords: agriculture; formulation; efficacy; pests; treated plots

INTRODUCTION

Agriculture in the North region of Cameroon faces significant constraints, such as climatic shocks (intensified drought spells, flooding, etc.), which, coupled with the excessive use of chemical pesticides, cause enormous environmental problems. To address this, integrating biopesticides based on co-products and natural substances into agricultural production systems could help reduce chemical input use while enhancing the sustainability and resilience of crops to the various variations observed.

Cowpea (*Vigna unguiculata*) cultivation is a pillar of agriculture and food security in sub-Saharan Africa, particularly in Northern Cameroon, where it constitutes an essential source of protein and income for local populations. A. Faye *et al.* (2024) reported that this observation is crucial in regions where smallholder farmers rely heavily on this crop for their income and dietary protein. However, this crop regularly faces pest attacks and phytosanitary diseases that compromise yields and harvest quality. The automatic reliance on chemical pesticides, although effective, over time poses serious problems of pest resistance, toxic environmental residues, and risks to human health. E. Fenibo *et al.* (2022) reported that the intensive use of synthetic pesticides causes adverse environmental effects, with ecological repercussions as well as impacts on human health. For this reason, it is important to consider effective and less environmentally polluting solutions such as biopesticides. W. Hasan (2024) reported that the use of biopesticides has intensified considerably worldwide, particularly within sustainable agricultural systems, in response to the undesirable effects of chemical pesticides on human health, biodiversity, and ecosystems. Unlike synthetic pesticides, biopesticides are derived from natural sources such as plants, microorganisms, or biological substances, and act through varied mechanisms including inhibition, repellency, or activation of plant defences. Furthermore, some biopesticides have demonstrated additional beneficial effects, such as stimulating plant growth and inducing systemic resistance, which has brought them closer to biostimulants. X. Chen *et al.* (2025) reported that, by producing various enzymes, secondary metabolites, and volatile organic compounds, *Trichoderma* effectively suppresses plant pathogens, promotes root development, and primes plant immune responses, with growing recognition as both a biostimulant and a biocontrol agent. W. Hasan (2024) reported that this versatility makes biopesticides particularly relevant for organic farming and integrated pest management strategies. In this context, the formulation of biopesticides developed from natural agents, along with their future optimisation, appears as a promising alternative for reducing negative impacts. Optimising formulations is essential to ensure stability, bioavailability, and prolonged efficacy of the product, thereby enabling better crop protection against pests and diseases. The use of biopesticides derived from natural products therefore appears to be a sustainable and environmentally friendly alternative. These products limit the negative impact of chemical treatments while maintaining effectiveness in pest control. For this study, a formulation composed of the following ingredients was used: neem and eucalyptus litter, rice bran, mango juice, fresh milk, and demineralised water, conferring biocidal properties to the formulation as reported by G. Barboucha *et al.* (2024), and A. Thamizharasan *et al.* (2024).

This study therefore aimed to determine whether the formulated biopesticide can constitute a viable solution for improving integrated crop management, while taking into account the local agro-climatic characteristics and cultivation practices. Hence the main objective: to evaluate the efficacy of a biopesticide formulated from co-products and lactobacilli on cowpea, in the localities of Houla Djalingo and Badjouma.

MATERIALS AND METHODS

This study was conducted at two sites located in two subdivisions (arrondissements) of the North region of Cameroon (Houla Djalingo, in the Bibemi subdivision, and Badjouma, in the Pitoa subdivision). Figure 1 presents a map of these sites. These sites were selected because they feature extensive agricultural land and floristic diversity (Pahimi *et al.*, 2020).

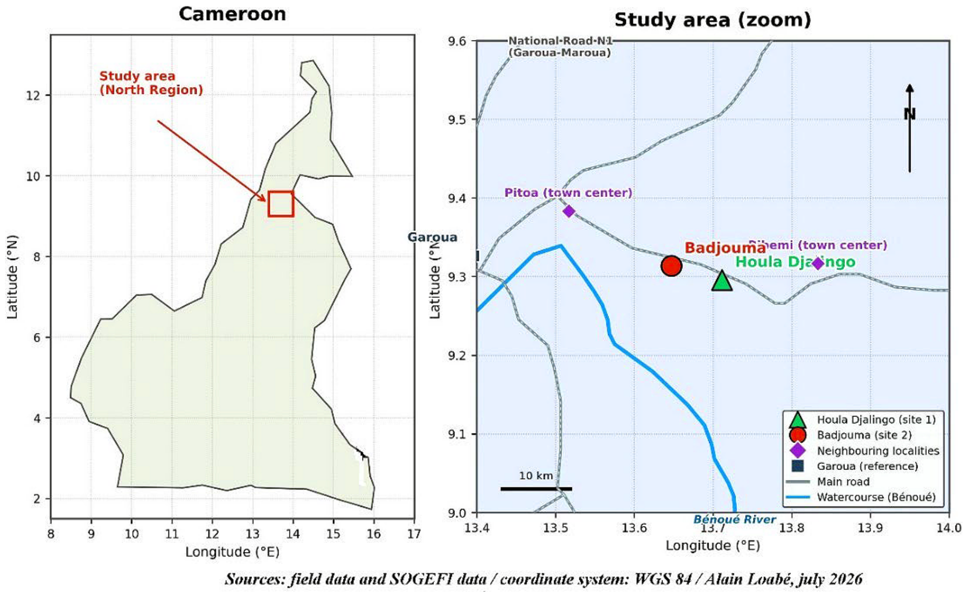

Figure 1. Study sites location map

Source: developed by the authors

The equipment and tools used for the experiments included, among others:

- 1 HANNA brand pH meter;
- 4 knapsack sprayers for crop treatment, deployed at each site (cowpea variety 'BR1').

As biological material, the formulated biopesticide and the cowpea variety 'BR1' (a variety with a 80 to 85 day cycle) developed by the Institute of Agricultural Research for Development (IRAD) were used. A chemical material, a conventional pesticide (acetamiprid, a systemic neonicotinoid insecticide commercially available on local markets), was used at each site. For this study, conducted in accordance with current national phytosanitary regulations, a completely randomised experimental design based on Fisher's block method was implemented at two sites (Badjouma and Houla Djalingo), following the field cultivation method described by the H. Liniger *et al.* (2011). These sites feature tropical ferruginous soils, as indicated by the study by J. Nguetnkam (2004). This cultivation method relay on the integrated and sustainable management of soil, varieties, nutrients, pests, and water supported by regular monitoring to optimise agricultural production while preserving natural resources. Three replicates were carried out for each treatment (TB, TC, and TT) at each site. A layout comprising 9 micro-plots of 25 m^2 each was thus established, including: three micro-plots treated with the formulated biopesticide (PTB), three micro-plots treated with a conventional pesticide (acetamiprid) (PTC), and three micro-plots receiving no treatment, designated as control plots (PTT). Three such layouts were set up at each site. In each micro-plot, 2 cowpea seeds ('BR1' variety, developed by the Institute of Agricultural Research for Development (IRAD)) were sown to achieve a density of 200 planting holes per 25 m^2 plot; this corresponded to a 50 cm × 25 cm spacing with two plants per hole (50 cm between rows and 25 cm between holes), resulting in a micro-plot containing 10 rows and 200 planting holes. The formulated biopesticide and the conventional pesticide (acetamiprid) were applied directly to the cowpea plants on the experimental plots using micro-sprayers at a weekly frequency (450 mL of biopesticide and 450 mL of acetamiprid applied weekly to plots PTB and PTC, respectively) over a period of 3 months. Figure 1 below illustrates this experimental setup.

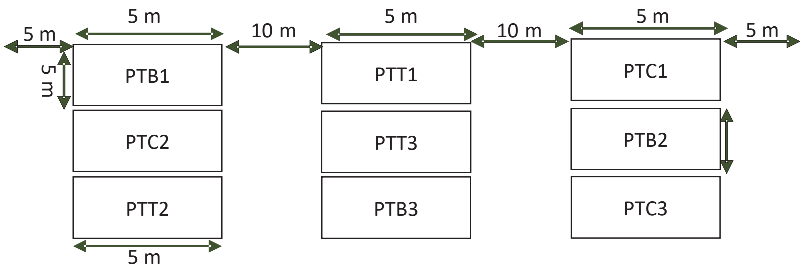

Figure 2. Experimental design established at each locality

Note: PTB1 and PTB2 – biopesticide-treated plots; PTC1 and PTC2 – chemical pesticide-treated plots; PTT1 and PTT2 – untreated control plots

Source: developed by the authors

The resulting formulation consisted of: neem leaf litter (15 kg), rich in azadirachtin, a bioactive compound with well-documented insecticidal and fungicidal properties; eucalyptus leaf litter (15 kg), containing essential oils, particularly eucalyptol, which confer insecticidal, antibacterial/antimicrobial, antioxidant, and repellent activities; mango juice (5 L), serving as an energy source through its natural sugars and promoting microbial fermentation; rice bran (46 kg), providing carbohydrates, proteins, and minerals essential for the survival and activity of microorganisms within the biopesticide; fresh milk (10 L), supplying lactic acid bacteria (*Lactobacillus* spp.), which are key microorganisms responsible for enhancing the efficacy of the biopesticide by stimulating fermentation and the production of antimicrobial metabolites and demineralised water (30 L), which provides a suitable medium for fermentation and supports the growth of beneficial microorganisms.

The litter and rice bran were mixed until homogeneous on a clean tarpaulin. A solution composed of fresh milk, mango juice, and well water was prepared and then sprayed onto this mixture, which was subsequently stirred for 5 to 10 minutes. All the ingredients were placed into a hermetically sealed plastic drum and compacted layer by layer to expel trapped air and promote anaerobic fermentation. The drum was then tightly sealed and stored in a shaded location, protected from direct sunlight, for 25 days without being moved or stirred throughout the fermentation process. The ambient temperature was maintained between 25 and 35°C. A solid, dark brown product was obtained at the end of this fermentation period.

For biopesticide activation, 5 kg of the fermented product were mixed with 5 L of demineralised water, 2 L of mango juice, and 5 L of fresh cow's milk. The mixture was transferred into a 200 L hermetically sealed plastic drum, which was then filled to capacity with non-chlorinated water. After being tightly sealed, the drum was stored in a shaded location, protected from direct sunlight, for 7 days without being moved or stirred, thereby ensuring anaerobic fermentation. The resulting whitish suspension was subsequently filtered and packaged into 30 L containers (6 containers), yielding a biopesticide ready for field application. The formulated biopesticide was applied directly to cowpea crops using a backpack sprayer in the experimental plots once a week for 3 months. A total volume of 450 mL of biopesticide and 450 mL of acetamiprid was applied weekly to the PTB and PTC plots, respectively. Nitrogen content was determined using the Kjeldahl method (Bremner, 1965); phosphorus content was determined using the colorimetric method (Olsen *et al.*, 1954); and potassium content was determined using the ammonium acetate extraction method (Thomas, 1982). The pH of the biopesticide was determined using the method described by AFNOR (2001), and electrical conductivity was determined using the method described by AFNOR (1994).

The inventory process for the main pests was carried out in these plots every 2 weeks over the 12-week experimental period. Pests were inventoried on the stems, leaves, and flowers of the plants under experimentation, captured, and transported to the Animal Production section laboratory of Institute of Agricultural Research for Development in Garoua for identification using the identification manual of M. Kodandaraam *et al.* (2025). In each treatment (TB, TC, TT), 3 plants were randomly tagged for pest counting in each microplot. In total, 54 plants were tagged during this experiment. The inventory process for the number of attacked leaves consisted of tagging cowpea plants before and after flowering, and counting, in each of the PTB, PTC, and PTT plots, the number of attacked leaves on 3 randomly identified plants at the flowering stage and on 3 other plants identified at the fruiting stage. This was followed by the identification of the type of symptom observed and the type of pest present. In total, 108 plants were tagged and used for this experiment (54 plants at the Houla Djalingo site at the flowering and fruiting stages, and 54 plants at the Badjouma site at the flowering and fruiting stages). Parameters such as dry and fresh biomass and seed yield per treatment were determined. The following formula, based on V. Carangal *et al.* (1971) and adapted by H. Ajeigbe *et al.* (2012), was used to calculate seed yield:

$$\text{Yield (Kg/ha)} = \frac{Seed\ weight\ \left(\frac{Kg}{plot}\right) X (100-MC)}{(100-H)} \mathrm{X} \frac{10{,}000}{Harvested\ area/plot}, \quad (1)$$

where MC – seed moisture content at harvest (%); H – required moisture content of cowpea seeds during storage, equal to 12%; 1 hectare – 10,000 m^2.

Data collected during this study were analysed using the statistical software R version 4.4.2 and Excel software version 2013. Mean comparison tests were performed to determine the number of pests in the PTB, PTC, and PTT plots; to inventory the number of attacked leaves in these plots at the flowering and fruiting stages; and to determine biomass yield. A two-way ANOVA was also used, with significance thresholds of 0 ‘’, 0.001 ‘’, 0.01 ‘’, 0.05 ‘’, 0.1 and ‘’ 1, to examine the effect of site and treatment on the number of pests across the study localities, and the effect of phenological stage and plot type on the number of attacked plants in these localities. The study was conducted in accordance with the ethical standards of the Convention on Biological Diversity (1992) and Convention on International Trade in Endangered Species of Wild Fauna and Flora (1973).

RESULTS AND DISCUSSION

Table 1 presents the results obtained from the analysis of the biopesticide. It has an acidic pH of 3.8, reflecting a high potential acidity of the applied solution. This pH value lies above those generally reported in the literature for plant- or microbial-based biopesticides. B. Kariyanna *et al.* (2024) reported that formulations combining birbira seed powder and neem leaves exhibited a mean pH of 5.6. The pH of 3.8 obtained in this study can be attributed to the presence of organic-acid-producing lactobacilli and to the nature of the substrates used (neem and eucalyptus litter, mango juice, rice bran). According to N. El-Wakeil (2013), the acidity of the product may play a beneficial role at the leaf surface level by promoting the stability of certain metabolites, which are recognised for their natural insecticidal properties. The measured electrical conductivity was 216 µS/cm, indicating a low to moderate dissolved ion content. This value reflects the limited presence of ionic solutes such as mineral salts (K^+, Ca^{2+}, Mg^{2+}) or dissociated organic acids, notably originating from the fermentation of plant substrates such as mango juice, rice bran, and neem/eucalyptus litter.

J. Raman *et al.* (2022) reported that low electrical conductivity may also indicate a moderately osmotic environment, which is favourable for the viability of beneficial microorganisms such as the lactobacilli present in the formulation. According to J. López-Rubio *et al.* (2025), liquid organic fertilisers and fermented extracts with high salt contents often exhibit electrical conductivity values exceeding 1,000 µS/cm, placing the formulated biopesticide within a low-conductivity range that is compatible with regular use in organic farming.

Table 1. Physicochemical characterisation of the manufactured biopesticide

Parameters	Electrical conductivity (mV)	Protein (mg/mL)	Nitrogen (mg/L)	Phosphorus (mg/L)	Potassium (mg/L)
Contents	216	0.18 ± 0.092	239.69 ± 0.25	330.57 ± 0.11	133.94 ± 0.06

Source: developed by the authors

The protein content of the formulated biopesticide was 0.18 mg/mL, representing a moderate concentration for a liquid formulation. According to R. Patil *et al.* (2000) and A. Carvalho & V. Gomes (2011), this concentration is sufficient for proteins to function as defensive agents or modulators of interactions with insect pests. Recent study by D. Walters *et al.* (2005) have shown that plant extracts with protein concentrations ranging from 0.1 to 0.5 mg/mL may contain bioactive molecules, including lectins, protease inhibitors, and antifungal peptides, which are capable of disrupting insect digestion and activating the plant's systemic defence responses.

The analysis results of the formulated biopesticide reveal relatively noteworthy levels of major nutrients: nitrogen (239.69 mg/kg), phosphorus (330.57 mg/kg), and potassium (133.94 mg/kg). These values indicate that, beyond its expected role in pest protection, the biopesticide could also exert a biostimulant action, thereby contributing to the growth and robustness of treated plants. Nitrogen (N) is a fundamental nutrient for the synthesis of amino acids, proteins, chlorophyll, and enzymes. Its presence in the biopesticide at a concentration of 239.69 mg/kg could promote vegetative plant growth, particularly in poor soils or under abiotic stress conditions. According to P. Calvo *et al.* (2014), nitrogen-rich organic extracts improve leaf biomass and enhance plant enzymatic activity. The phosphorus content obtained (330.57 mg/kg) also suggests a potential improvement in root development, energy efficiency, and flowering. Phosphorus is an essential component of ATP and plays a key role in energy transfer and cell division. According to Y. Rouphael & G. Colla (2020), it is also associated with enhanced tolerance to abiotic stresses, particularly drought, as well as improved seed quality. The inclusion of potassium in a biopesticide formulation thus reinforces the synergy between phytosanitary protection and the stimulation of plant physiology. These results confirm that the formulated biopesticide plays a dual role: on one hand, a bioactive action against pests, and on the other, a biostimulant effect that could optimise plant growth and resistance under the agroecological conditions of the North region of Cameroon. Converting these contents to percentages yields the following values: 0.024% nitrogen (N), 0.033% phosphorus (P), and 0.013% potassium (K). The low concentration observed in formulation may be explained by the nature of the plant materials used, the absence of prolonged fermentation, or a technological objective focused on biocidal rather than fertilising effects. This suggests that the product could be more effective as a biostimulant or as a supplement within an integrated fertilisation programme, rather than as a primary source of nutrients. W. Dwi Purnamawati & U. Abdullah (2022) demonstrated that the use of biopesticides in combination with fertigation practices could offer a better approach for improving plant health and soil fertility.

The results obtained over the 12 weeks of treatment reveal temporal and spatial variability in treatment efficacy against pest pressure at the Houla Djalingo and Badjouma sites. Overall, the biopesticide treatment (TB) led to a progressive reduction in pest numbers, particularly between weeks 0 and 4 at Houla Djalingo, confirming satisfactory initial efficacy. This observation is consistent with the results obtained by J. Nboyine *et al.* (2026), who demonstrated the effectiveness of botanical extracts in the early management of cowpea pests. At Badjouma, however, the untreated control (TT) and the chemical treatment (TC) showed better results at the beginning of the experiment (weeks 0 to 2), which could be explained by site-specific pedoclimatic conditions or lower initial residual activity of the biopesticide at this site. According to J. Adesina *et al.* (2016), the performance of biopesticides can be influenced by soil moisture, ambient temperature, and microbial activity, all of which affect the stability of active compounds. Between weeks 4 and 8, the chemical treatment (TC) proved particularly effective at both sites. This period (weeks 4 to 8) is generally marked by an increase in pest attacks on cowpea. The effectiveness of TC during this period can be attributed to its fast-acting and persistent synthetic formulation. In contrast, the TB treatment showed intermediate but non-negligible efficacy during this interval, falling between the TC and TT treatments. The period from week 8 to 10 was marked by a resurgence in the effectiveness of the TB treatment, which proved superior to both the TC and TT treatments, particularly at Houla Djalingo. This performance may be explained by a cumulative effect over time or by progressively better adaptation of the biopesticide within this site's ecosystem. At the end of the cycle (weeks 10 to 12), a very significant decrease in pest numbers was observed in both the TB and TC treatments at both experimental sites. This shows that pest control methods, whether biological or chemical, are capable of managing infestation. However, the persistence of pests in the untreated control (TT) underscores the importance of phytosanitary intervention. Ultimately, the locally formulated biopesticide represents a viable alternative, particularly for integrated pest management, with efficacy approaching that of chemical products during certain phases of the target crop's development cycle. Figure 3 presents the number of pests recorded at different weeks (from week 0 to week 12) across the different treatments established (TB, TC, and TT).

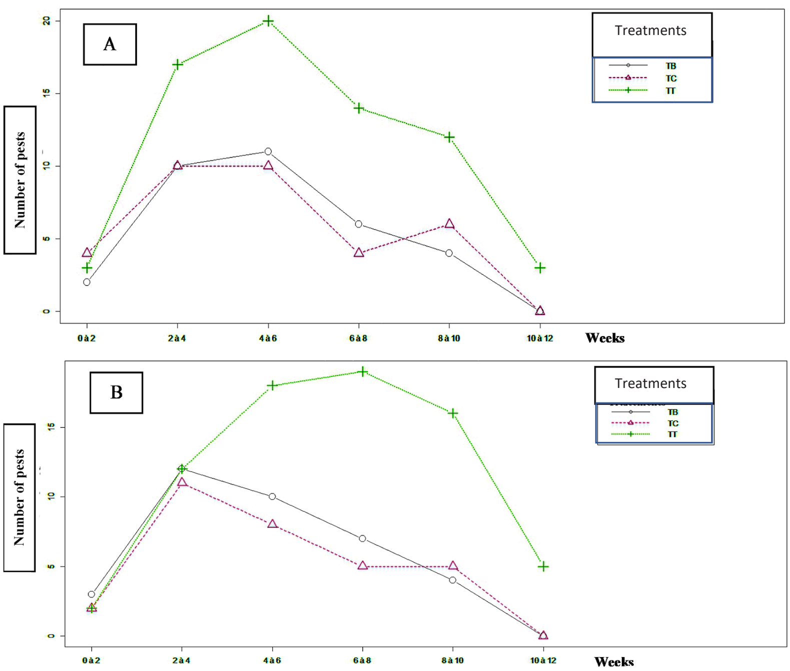

Figure 3. Number of pests recorded according to treatments and time

Note: A – Houla Djalingo site; B – Badjouma site

Source: developed by the authors

Table 2 presents the two-way analysis of variance (ANOVA) conducted to examine the effect of site and treatments on the number of pests at the Houla Djalingo and Badjouma localities. Analysis of Table 2 shows a significant main effect of treatment, with a p-value below 0.05. This indicates a real and measurable difference between the means of the different treatments applied, regardless of the site where the experiment took place. Site shows a p-value of 0.96,557, indicating no significant difference between sites. The environmental or geographical conditions of the sites did not influence the study's outcome. The Site × Treatment interaction (p = 0.96,557) demonstrates that the treatments responded in the same way across all sites. The effectiveness of a treatment does not depend on location. The efficacy of the treatments tested in this study proved independent of local environmental variables, as evidenced by the absence of a significant site effect (p = 0.92,601) and of a significant site-treatment interaction (p = 0.96,557). This uniformity in biological response suggests stability of the treatments across varied agroecological conditions, a finding consistent with the observations of I. Dugje *et al.* (2009) regarding the reproducibility of technical protocols for cowpea protection. The absence of interaction indicates that treatment performance is not conditioned by geographical specificities, thereby reinforcing the robustness of the recommendations derived from these trials. This spatial stability was also highlighted by P. Neuenschwander *et al.* (2003), who noted that, to be adopted by farmers, a technical innovation must demonstrate consistent efficacy beyond local microclimatic variations. Thus, the generalisation of the evaluated treatments can be considered without major adjustments related to plot location.

Table 2. Two-way analysis of variance (ANOVA) conducted to examine the effect of site and treatments on the number of pests

	Sum Sq	Df	F value	Pr(>F)
Site (Houla Djalingo and Badjouma)	0.25	1	0.0,088	0.92,601
Treatments (TB, TC, TT)	304.89	2	5.3,479	0.01032*
Site: Treatments	2	2	0.0,351	0.96,557
Residuals	855.17 30			

Note: signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
Source: developed by the authors

Figure 4 presents the number of attacked cowpea leaves at the 2 sites according to the plant's developmental stages. The results obtained at the Badjouma and Houla Djalingo sites reveal a differentiated dynamic of foliar attacks depending on the phenological stages of cowpea (flowering stage and fruiting stage) and the treatments applied (PTB: biopesticide, PTC: chemical pesticide, PTT: control). At both sites, the flowering stage was marked by a high number of attacked leaves, particularly in the untreated control plots (PTT), with means around 171 at Badjouma and 173 at Houla Djalingo. This finding confirms the observation of E. Egho (2011) that the flowering stage is a particularly vulnerable phase in cowpea development, during which young and tender tissues are especially attractive to several foliar insect pests, including flower thrips (*Megalurothrips sjostedti*) and the black cowpea aphid (*Aphis craccivora*). Application of the biopesticide (PTB) showed a significant reduction in attacks, with means around 116 attacked leaves and low variability at both sites. This could be explained by the effectiveness of the biopesticide's bioactive compounds in repelling or inhibiting pest development. Similar findings were reported by A. Oso & M. Kolade (2025), who showed that neem-based biopesticides or botanical extracts reduce pest incidence on leguminous crops. At the fruiting stage, an overall decline in attacks was observed, particularly in the treated plots (PTB and PTC), with means around 75 (PTB) at both Badjouma and Houla Djalingo, and 110 to 114 (PTC). This trend can be explained by the migration of pests toward the reproductive organs (pods), which become more attractive at this stage, resulting in reduced pressure on the foliage. The control plots (PTT) still showed a high level of attack (approximately 120 attacked leaves), although less pronounced than at the flowering stage. This underscores the importance of phytosanitary protection even at the end of the cycle, as late attacks can affect pod filling. The PTB and PTC treatments effectively reduced attacks compared to the control, but the biopesticide (PTB) showed greater consistency and lower variability, suggesting more stable protection. These results are consistent with those of A. Oparaeke (2006), who observed comparable or even superior efficacy of biopesticides on cowpea, with the added advantage of not affecting the biodiversity of beneficial organisms.

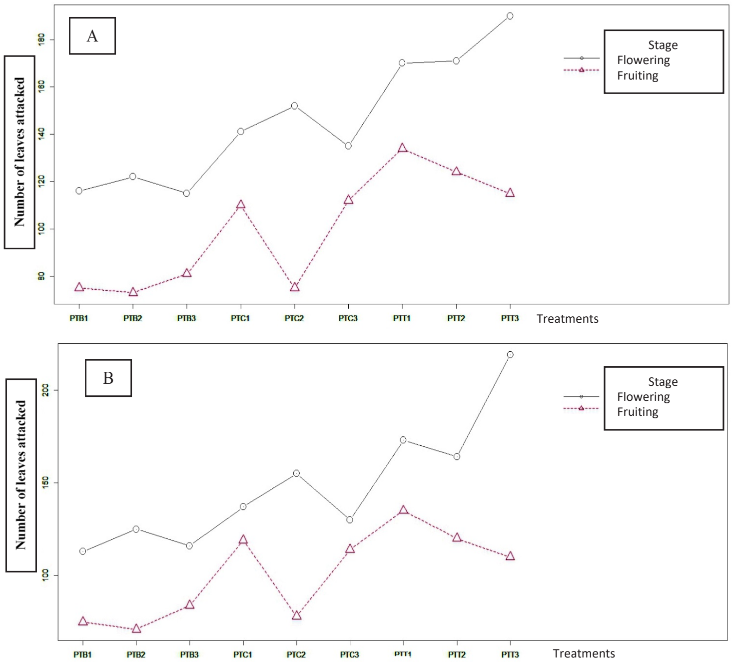

Figure 4. Leaves attacked by pests at the two sites at the flowering and fruiting stages
Note: A – Badjouma site; B – Houla Djalingo site
Source: developed by the authors

Table 3 presents the two-way analysis of variance (ANOVA) conducted to examine the effect of phenological stage and plot type on the number of attacked plants at the Houla Djalingo and Badjouma localities. Analysis of this table shows a highly significant difference ($p < 0.001$) between the cowpea developmental stages and between the different experimental plots established, with regard to the number of attacked plants. The determining influence of phenological stage on the number of attacked plants ($F = 630.189$; $p < 0.001$) corroborates classical observations on cowpea, where susceptibility to pests varies drastically over the course of the crop cycle. These results are consistent with those of I. Dugje *et al.* (2009), who demonstrated that cowpea passes through phases of critical vulnerability, particularly during flowering and fruiting (pod formation). At these stages, the plant redirects its nitrogen resources toward the reproductive organs, making it a preferred target for major pests such as *Megalurothrips sjostedti* (flower thrips). The plot effect ($p < 0.001$) and the stage × plot interaction observed in this study can be explained by the environmental heterogeneity described in cowpea agrosystems across sub-Saharan Africa. As highlighted by A. Togola (2017), pest pressure on cowpea is strongly influenced by plot-level microclimate (relative humidity, sunlight exposure) and the presence of alternative host plants along field edges. The significant interaction suggests that certain plots (such as the PTT type in this study) offer niche conditions favouring a demographic explosion of pests precisely at the fruiting stage, while others remain relatively protected (PTB and PTC). This complex spatiotemporal dynamic confirms the need, as advocated in the work of P. Neuenschwander *et al.* (2003) on integrated pest management, to move beyond fixed treatment schedules and instead adopt a plot-targeted monitoring strategy in order to optimise cowpea yield while reducing pesticide use.

Table 3. Two-way analysis of variance (ANOVA) conducted to examine the effect of phenological stage and plot type on the number of attacked plants

	Sum Sq	Df	F value	Pr(>F)
Plot (PTB1, 2 and 3; PTC1, 2 and 3; PTT1, 2 and 3)	18,880.0	8	76.061	2.714e-12 ***
Stage (flowering and fruiting)	19,553.4	1	630.189	1.845e-15 ***
Plot: Stage	4,560.9	8	18.374	3.533e-07 ***
Residuals	558.5 18			

Note: signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
Source: developed by the authors

Figure 5 presents the fresh and dry biomass yields obtained at the 2 sites according to treatment. The assessment of dry and fresh biomass provides an important quantitative measure of the vegetative development of the selected crop (cowpea), enables detection of differences in efficacy between treatments (TB, TC, and TT), and strengthens the robustness of the scientific analysis conducted. The data obtained at the 2 experimental sites (Houla Djalingo and Badjouma) reveal consistent trends across phenological stages and applied treatments, highlighting the positive effect of the formulated biopesticide (PTB) on cowpea vegetative growth. At the flowering stage, the biopesticide-treated plots (PTB) recorded the highest fresh biomass production at both sites, with means of 3.15 kg (Houla Djalingo) and 3.12 kg (Badjouma). In contrast, the untreated control plots (PTT) and those treated with the chemical pesticide (PTC) showed lower values, with the control plots slightly outperforming the chemically treated ones (2.75 kg at Houla Djalingo and 2.59 kg at Badjouma, versus 2.37 kg at Houla Djalingo and 2.33 kg at Badjouma for the chemical treatment). These results suggest that the biopesticide not only exerts a protective effect against pests but may also stimulate plant growth, likely owing to secondary compounds or nutrients present in small amounts within the formulation, as reported in some recent studies, like that of E. Foyinsolami (2022). At the fruiting stage, an increase in fresh biomass was observed, particularly in the PTB plots (3.65 kg at Houla Djalingo and 3.66 kg at Badjouma) and in the PTC plots (2.7 kg at Houla Djalingo and 2.6 kg at Badjouma), reflecting continued growth favored by reduced pest pressure. The PTT plots, on the other hand, showed a decline in fresh biomass (2.1 kg at Houla Djalingo and 2 kg at Badjouma), indicating the cumulative impact of pests in the absence of phytosanitary protection. A similar trend was observed for dry biomass. At the fruiting stage, the PTB plots showed the highest dry biomass (0.91 kg at Houla Djalingo and 0.91 kg at Badjouma), followed by the PTC plots (0.58 kg at Houla Djalingo and 0.58 kg at Badjouma) and the PTT plots (0.48 kg at Houla Djalingo and 0.48 kg at Badjouma). This result is important because dry biomass provides a more reliable measure of actual yield potential (independent of moisture content). It reflects a sustained agronomic efficacy of the biopesticide, even at an advanced developmental stage. According to N. Akram *et al.* (2022), biological treatments based on plant extracts improve crop physiology through synergistic effects, including protection against biotic stress and enhanced photosynthesis. Furthermore, O. Zakari *et al.* (2018) showed that neem-based biopesticides and other plant extracts increase cowpea biomass yields by up to 25% compared to chemical pesticides, while being less toxic to beneficial organisms. The pattern PTB > PTC > PTT in terms of dry biomass at fruiting reflects a cumulative positive effect of the biopesticide on cowpea growth. The chemical pesticide applied to the PTC plots showed a partial effect, attributable to targeted efficacy but also to residual phytotoxic effects. The untreated control plots (PTT) had the lowest values, underscoring the negative impact of pests in the absence of protection.

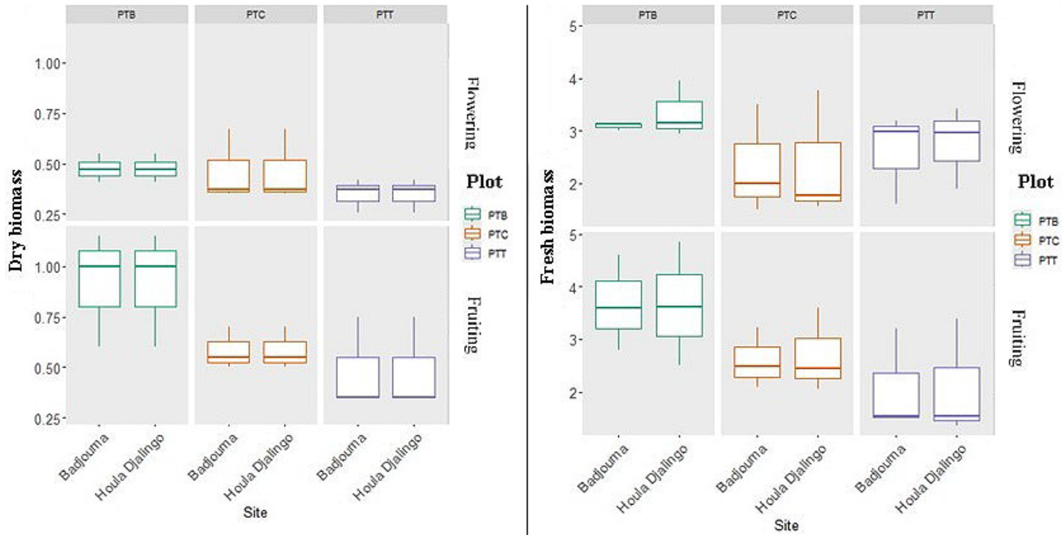

Figure 5. Fresh and dry biomass at the two sites according to treatments
Source: developed by the authors

Table 4 presents the seed yields obtained for each treatment (TB, TC, and TT) at the 2 experimental sites of Houla Djalingo and Badjouma. The results obtained show that the TB treatment, based on the formulated biopesticide, achieved the highest cowpea seed yields, higher than those of the TC treatment and markedly higher than those of the TT treatment at both experimental sites. These results confirm the efficacy of biopesticides in controlling cowpea pests and are consistent with the work of B. Ahmed *et al.* (2009), who showed that certain plant extracts and biological biopesticides can effectively reduce pest populations while preserving beneficial organisms. The seed yields obtained with the TC treatment may be attributable to the emergence, at a certain point during the experiment, of resistance, as well as to deleterious effects on beneficial organisms and a limited duration of crop protection. This result was also reported by P. Jeschke *et al.* (2011). The yields obtained for the TT treatment, compared to the first 2 treatments, highlight the substantial yield losses associated with the absence of phytosanitary protection.

Table 4. Seed yields (Kg/ha) obtained at each site according to treatments

No.	Site	Treatments	Yield, kg/ha
1	Houla Djalingo	TB	3,253
2	Houla Djalingo	TC	2,513
3	Houla Djalingo	TT	1,250
4	Badjouma	TB	3,646
5	Badjouma	TC	2,700
6	Badjouma	TT	1,720

Source: developed by the authors

The results obtained in this section amply demonstrate the efficacy of the formulated biopesticide via the applied TB treatment. The biopesticide therefore appears to be a better option for environmental management compared to synthetic pesticides.

CONCLUSIONS

At the conclusion of this study, whose main objective was to evaluate the efficacy of a biopesticide formulated from coproducts and lactobacilli on cowpea (*Vigna unguiculata*) at 2 localities in the North region of Cameroon, a biopesticide was formulated and exhibited a pH of 3.8, reflecting a high potential acidity of this solution. It has a measured electrical conductivity of 216 µS/cm, indicating a low content of dissolved ions and reflecting the presence of organic and mineral ions derived from the ingredients used (flavonoids, alkaloids, organic acids, etc.). The results obtained from the analysis of the biopesticide show that it contains: 239.69 mg/L of nitrogen, 330.57 mg/L of phosphorus, and 133.94 mg/L of potassium. These quantities correspond to relatively low percentage contents of these elements (0.024% nitrogen (N), 0.033% phosphorus (P), and 0.013% potassium (K)). These concentrations suggest that the biopesticide, although primarily intended for crop protection, may also provide a very modest amount of nutrients to plants. The inventory of the main pests in the PTB, PTC, and PTT plots, based on the number of pests recorded at different weeks (from week 0 to week 12) across the different treatments established (TB, TC, and TT), reveals temporal and spatial variability in treatment efficacy against pest pressure at the Houla Djalingo and Badjouma sites. The absence of treatment favours continuous proliferation of insect pests, with a direct impact on yield. The locally formulated biopesticide represents a viable alternative, with efficacy approaching that of chemical products during certain phases of the crop cycle. The number of attacked cowpea leaves at the two sites (Badjouma and Houla Djalingo), assessed as a function of plant developmental stage, reveals a differentiated dynamic of foliar attacks depending on cowpea's phenological stages (flowering stage and fruiting stage) and the treatments applied (PTB: biopesticide, PTC: chemical pesticide, PTT: control). The fresh and dry biomass yields obtained at the two sites according to treatment reveal consistent trends across phenological stages and applied treatments, highlighting the positive effect of the formulated biopesticide (PTB) on cowpea vegetative growth. The seed weights obtained in the PTB, PTC, and PTT plots at both sites show that the biopesticide-treated plots (PTB) exhibit the highest seed weights at both sites, Houla Djalingo and Badjouma. The number of pods obtained in each plot according to the different treatments follows the same hierarchy: PTB plots > PTC plots > PTT plots. The results obtained after calculating seed yields show that the TB treatment, based on the formulated biopesticide, achieved the highest cowpea seed yields, higher than those of the TC treatment and markedly higher than those of the TT treatment at both experimental sites. These results confirm the efficacy of biopesticides in controlling cowpea pests.

Looking ahead, this study opens several avenues for future research and action: conducting multi-site, multi-year trials across different agroecological zones to confirm the robustness of the results and to better understand environmental variability; adjusting the dosage of active molecules and exploring the addition of natural adjuvants to enhance both the phytosanitary efficacy and the nutritional contribution of the biopesticide to plants; conducting GC-MS/MS or LC-MS/MS chromatographic analyses, to determine the molecular composition of the biopesticide; and exploring low-cost manufacturing processes, including the use of local resources, to make the biopesticide more accessible and competitive relative to conventional inputs.

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CONFLICT OF INTEREST

None.

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Використання побічних продуктів для створення біопестициду: сталий підхід до вирощування вігни в Північному Камеруні

Анотація. Біопестициди на основі побічних продуктів є більш екологічно безпечною, нешкідливою та сталою альтернативою. Метою цього дослідження було оцінити ефективність біопестициду, розробленого на основі побічних продуктів (опалого листя німу, опалого листя евкаліпта, соку манго, рисових висівок) та лактобактерій, на посівах вігни в населених пунктах Хула Джалінго та Баджума. Методологія передбачала використання повністю рандомізованого експериментального дизайну, що складався з дев'яти мікроділянок площею 25 м² кожна, закладених на двох дослідних ділянках (Баджума та Хула Джалінго), відповідно до методу польового вирощування. Біопестицид також було розроблено відповідно до методів його приготування, описаних у науковій літературі. Надалі його було піддано фізико-хімічній характеристиці та щотижня протягом трьох місяців застосовували на посівах вігни в польових умовах. Ефективність оцінювали шляхом моніторингу динаміки чисельності шкідників протягом 12 тижнів на ділянках, оброблених біопестицидом (PTB), хімічним пестицидом (PTC), та на необроблених контрольних ділянках (PTT). На завершальному етапі визначали врожайність насіння та біомасу (свіжу і суху). Результати дослідження продемонстрували помітне зниження рівня ураження шкідниками на ділянках PTB. На цих ділянках зафіксовано найвищу масу насіння та врожайність (8,6 ± 0,36 кг і 3253 кг/га у Хула Джалінго; 9,63 ± 0,14 кг і 3646 кг/га у Баджумі), а також найменший рівень пошкодження шкідниками порівняно з ділянками PTC та PTT. Отримані результати можуть бути використані фермерами, службами сільськогосподарського дорадництва та агрохімічною промисловістю для розроблення і поширення біологічної альтернативи хімічним пестицидам, а також дослідниками та розробниками аграрної політики для підтримки наукових програм і нормативно-правових механізмів, спрямованих на розвиток більш сталого сільського господарства

Ключові слова: сільське господарство; рецептура; ефективність; шкідники; оброблені ділянки