EFFECT OF COMPLEMENTARY APPLICATION OF BIOPRODUCTS ON THE PRODUCTIVITY AND SEED QUALITY OF COWPEA (*Vigna unguiculata* cv. INIFAT-93) †

[EFECTO DE LA APLICACIÓN COMPLEMENTARIA DE BIOPRODUCTOS EN LA PRODUCTIVIDAD Y CALIDAD DE SEMILLAS DE FRIJOL CAUPÍ (*Vigna unguiculata* cv. INIFAT-93)]

Yoerlandy Santana-Baños[1], Michel Ruiz-Sánchez[2], Sergio Carrodeguas-Díaz[1], Edenys Miranda-Izquierdo[1], Miriam Sánchez-Vega[3], Pablo Preciado-Rangel[4*] and Edgar Omar Rueda-Puente[5*]

[1] Universidad de Pinar del Río "Hermanos Saíz Montes de Oca". Calle Martí No. 300, Barrio Segundo Sur, entre 27 de noviembre y González Alcorta, Pinar del Río, Cuba. CP 24100.
Email: yoerlandy83@gmail.com; sergioc@upr.edu.cu; emiranda@upr.edu.cu
[2] Asesor Técnico de la empresa Imperio de Agroinsumos del Sur SA de CV. Cd Isla, Veracruz, Col. La Gravera, Calle María Morelos y Pavón entre 5 de mayo y Guadalupe Victoria #163, México. Email: mich762016@gmail.com
[3] Universidad Autónoma Agraria "Antonio Narro", Departamento de Parasitología. Saltillo, Coahuila, México. Calzada Antonio Narro, No. 1923, Saltillo, Coahuila, México, C.P. 25315. Email: miriam.sanchez@uaaan.edu.mx
[4] Tecnológico Nacional de México-Campus Instituto Tecnológico de Torreón. Antigua Carretera Torreón-San Pedro km 7.5, Torreón, Coahuila, México. Email: ppreciador@yaho.com.mx
[5] Universidad de Sonora, Departamento de Agricultura y Ganadería. Bulevar Luis Encinas y Rosales sin número, ciudad Hermosillo, Sonora, México, C.P. 83000. Email: edgar.rueda@unison.mx*
** Corresponding author*

SUMMARY

Background: Bioproducts represent a promising alternative for sustainable agriculture, notable for their ability to stimulate plant growth and development, which positions them as valuable tools in current production systems. **Objective:** To evaluate the effect of complementary application of EcoMic®, QuitoMax® and CBFERT bioproducts on the productivity and seed quality of cowpea (*Vigna unguiculata* cv. INIFAT-93). **Methodology:** The research was conducted in experimental plots at the University of Pinar del Río (Cuba), using a randomized complete block design with four replications. Four treatments were evaluated: 1) 100% chemical fertilization (control); 2) 50% chemical fertilization plus EcoMic®; 3) 50% chemical fertilization plus QuitoMax® + CBFERT; and 4) 50% chemical fertilization plus the combination of all three bioproducts. Atharvest, biological productivity variables, agricultural yield components, and seed quality parameters (biomass and dimensions) were measured. **Results:** Analyses revealed that bioproduct treatments showed significant results: they enabled a 50% reduction in chemical fertilizer use, increased dry biomass production by 24%, and achieved agricultural yields exceeding 1.2 t ha^{-1}. Regarding seed quality, biomass increased by 20-32% while maintaining dimensional variations below 6% compared to the control treatment. **Implications:** It is feasible to substantially reduce chemical fertilizer use in cowpea cultivation through complementary application of bioproducts, while maintaining or even improving crop production and quality parameters. **Conclusions:** Application of 50% chemical fertilization in combination with either EcoMic® or QuitoMax® + CBFERT significantly increased the biological and agricultural productivity of cowpea, ensuring seed

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ORCID = Y. Santana-Baños: https://orcid.org/0000-0003-3793-7828; **M. Ruiz-Sánchez:** http://orcid.org/0000-0002-7406-4715; **S. Carrodeguas-Díaz:** https://orcid.org/0000-0003-2139-4531; **E. Miranda-Izquierdo:** https://orcid.org/0000-0002-5728-4601; **M. Sánchez-Vega:** https://orcid.org/0000-0001-9866-9244; **P. Preciado-Rangel:** https://orcid.org/0000-0002-3450-4739; **E.O. Rueda-Puente:** https://orcid.org/0000-0002-9724-0558

quality comparable to that obtained with complete chemical fertilization. These results demonstrate the remarkable potential of these bioproducts for implementing more sustainable and efficient agricultural production systems.

Key words: biomass; grain legume; crop yield; sustainable agricultura.

RESUMEN

Antecedentes: Los bioproductos constituyen una alternativa prometedora para la agricultura sostenible, destacando por su capacidad para estimular el crecimiento y desarrollo vegetal, lo que los posiciona como herramientas valiosas en los sistemas de producción actuales. **Objetivo:** Evaluar el efecto de la aplicación complementaria de los bioproductos EcoMic®, QuitoMax® y CBFERT sobre la productividad y calidad de semillas de frijol caupí (*Vigna unguiculata* cv. INIFAT-93). **Metodología:** La investigación se desarrolló en parcelas experimentales de la Universidad de Pinar del Río (Cuba), empleando un diseño de bloques al azar con cuatro réplicas. Se evaluaron cuatro tratamientos: 1) fertilización química al 100% (control); 2) 50% de fertilización química más EcoMic®; 3) 50% de fertilización química más QuitoMax® + CBFERT; y 4) 50% de fertilización química más la combinación de los tres bioproductos. En el momento de la cosecha se midieron variables de productividad biológica, componentes del rendimiento agrícola, así como parámetros de calidad de semilla (biomasa y dimensiones). **Resultados:** Los análisis revelaron que los tratamientos con bioproductos mostraron resultados significativos: permitieron reducir en un 50% el uso de fertilizantes químicos, incrementaron en un 24% la producción de biomasa seca y alcanzaron rendimientos agrícolas superiores a 1.2 t ha^{-1}. En cuanto a la calidad de las semillas, se observó un aumento en su biomasa entre 20-32%, manteniendo variaciones dimensionales inferiores al 6% en comparación con el tratamiento control. **Implicaciones:** Es factible reducir sustancialmente el empleo de fertilizantes químicos en el cultivo de frijol caupí mediante la aplicación complementaria de bioproductos, logrando mantener e incluso mejorar los parámetros productivos y cualitativos del cultivo. **Conclusiones:** La aplicación del 50% de la fertilización química en combinación con EcoMic® o QuitoMax® + CBFERT incrementó significativamente la productividad biológica y agrícola del frijol caupí, garantizando una calidad de semilla comparable a la obtenida con fertilización química completa. Estos resultados evidencian el notable potencial de estos bioproductos para implementar sistemas de producción agrícola más sostenibles y eficientes.

Palabras clave: biomasa; leguminosa de grano; rendimiento agrícola; agricultura sostenible.

INTRODUCTION

The cowpea (*Vigna unguiculata* (L.) Walp.), a legume native to Africa with a wide distribution in tropical regions (Boukar *et al.*, 2019; Farooq *et al.*, 2020), has experienced a notable increase in production globally, reaching 8.1 million tons in 14.2 million hectares in 2023, with an average yield of 0.57 t ha^{-1} (FAOSTAT, 2023). In the Caribbean context, particularly in Cuba, this crop has gained relevance as a sustainable alternative to climatic challenges and the need for agricultural diversification (Fernandez *et al.*, 2018). Recent studies demonstrate its adaptability to diverse soil and climate conditions, showing special resilience to moderate droughts and marginal soils (Choudhary *et al.*, 2023), characteristics that position it as a strategic crop for food security in climate change scenarios.

The growing demand for sustainable agricultural practices has driven research into alternatives to conventional chemical fertilization. In Cuba, where limitations in the availability of chemical inputs have become more pronounced (Peña-Calzada *et al.*, 2025), bioproducts are emerging as viable technological solutions. These include: EcoMic® (formulated with selected strains of arbuscular mycorrhizal fungi - AMF), QuitoMax® (a biostimulant based on oligomeric chitosan), and CBFERT (an enriched organic-mineral fertilizer), all registered and produced nationally (MINAG, 2020). Current scientific literature reports that these products can improve nutrient use efficiency by 30–40%, particularly under abiotic stress conditions (Ruiz-Sánchez *et al.*, 2024; García-López *et al.*, 2024).

Among the main research and technology transfer objectives of the "Hermanos Saíz Montes de Oca" University of Pinar del Río in Cuba is the evaluation of vegetative materials that can be applied and produced by the productive sector, especially those that supply staple crops. Rural producers, who are the primary suppliers of grains such as beans, are demanding sustainable production systems that incorporate environmentally friendly agricultural inputs to replace chemical ones over time. Moreover, the main inputs they demand are those consisting of plant growth-promoting microorganisms based on bacteria or fungi, or those formulated with plant extracts or organic bioproducts. It should be noted that, although there are experiences on the biostimulant activity of these organic fertilizers (López-Padrón *et al.*, 2020; Kesell, *et al.*, 2022; Ruiz-Sánchez *et al.*, 2024), few references address their effect on cowpea growth and development in Cuba country, and more knowledge is needed. Therefore, this research evaluated the synergistic effect of these bioproducts formulated with selected strains of arbuscular mycorrhizal fungi - (AMF), QuitoMax® (biostimulant based on oligomeric chitosan) and CBFERT (enriched organic-mineral fertilizer applied complementarily in the cultivation of cowpea bean cv. INIFAT-93.

MATERIALS AND METHODS

Experimental setting and conditions

The study was conducted during the grain production season, which spans from October 2023 to January 2024, in the experimental plots of the "Hermanos Saíz Montes de Oca" University of Pinar del Río, located at coordinates 22°24'48" N and 83°41'16" W, in Cuba. The soil in the experimental area is classified as Yellowish Fersialitic, according to Hernández et al. (2015), exhibiting notable chemical characteristics, including a water pH of 7.2 and an organic matter content of 4.3%. Regarding its physical properties, the soil has a true density of 2.51 g cm^{-3}, a bulk density of 1.36 g cm^{-3}, and a total porosity of 46%, which indicates adequate soil conditions for the development of the experimental crop.

During the experimental period, the climatic conditions recorded by Meteorological Station No. 314 of the Provincial Meteorological Center of Pinar del Río (Cuba) showed an average temperature of 24.0°C, an average relative humidity of 79.2% and a total accumulated rainfall of 198.1 mm (Figure 1).

Experiment design and crop management

Certified cowpea seed cultivar INIFAT-93 was used. Treatments were distributed in a randomized block design with four replicates (Table 1).

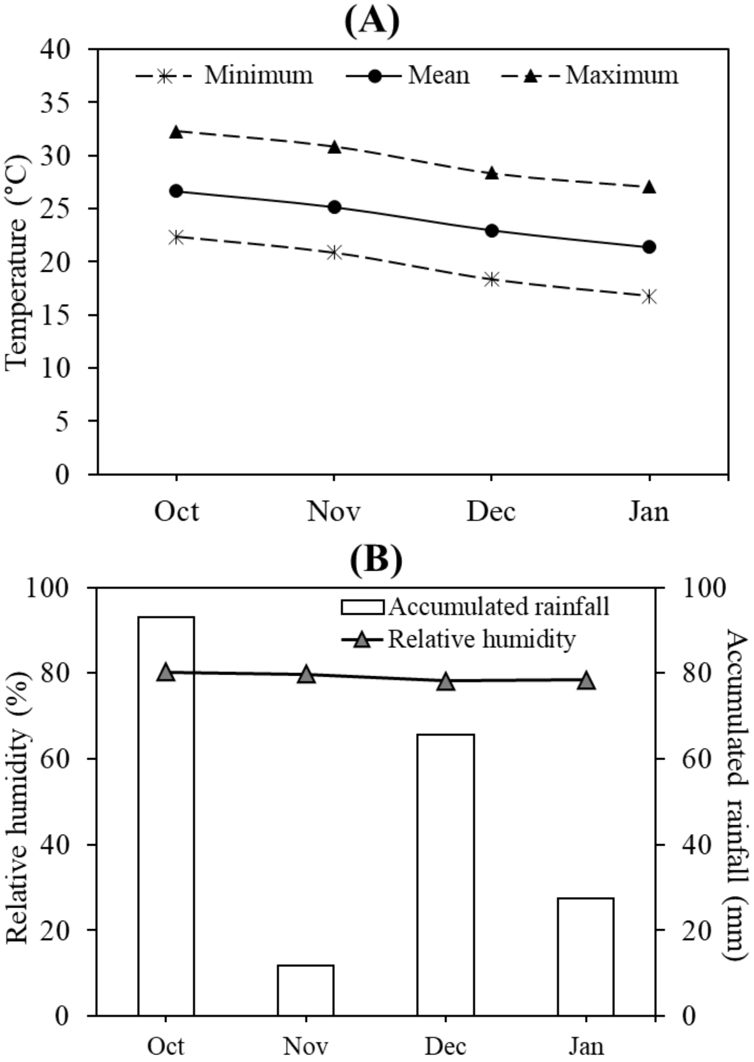

Figure 1. Monthly values of the climate variables during the trial (October 2023 – January 2024). (A) Average temperature, (B) relative humidity and accumulated precipitation.

Table 1. Description of the treatments used in the trial.

Description	initials
Chemical fertilization with complete formula, N-P-K+Mg (12-12-17+5), at a dose of 0.50 t ha^{-1}.	FQ100
50% chemical fertilization + EcoMic® (HMA) inoculation in the seed before sowing.	FQ50+HMA
50% chemical fertilization + foliar applications of QuitoMax® and CBFERT.	FQ50+QM+CB
50% Chemical Fertilization + EcoMic® + QuitoMax® + CBFERT.	FQ50+HMA+QM+CB

Manual sowing was carried out during the second half of October, using a planting frame of 0.50 m between rows and 0.12 m between plants, following the technical recommendations established for cowpea cultivation in Cuba (Figueroa *et al.*, 2014). Biostimulant applications were scheduled at different phenological stages: QuitoMax® (0.1 L ha^{-1} of oligomeric chitosan) at 21 and 28 days after sowing (vegetative stages V3-V4), and CBFERT® (1.0 L ha^{-1} of enriched algal extract) at 21, 28, and 35 days (stages V3-R1). Phytosanitary management included applications of Macron® (cypermethrin 25% + acetamiprid 5%, 0.12 kg ha^{-1}) at two key times to control sucking insects (Bemisia tabaci) and leaf miners (Liriomyza spp.), as established in the official pesticide registry (MINAG, 2022). In parallel, copper oxychloride (1.5 kg ha^{-1}) was applied to manage foliar diseases (MINAG, 2022). All applications were made with a 16 L manual sprayer, calibrated for a flow rate of 200 L ha^{-1}, during the early hours of the morning. The irrigation system used was furrow irrigation, consisting of five applications of 350 m³ ha^{-1} each, which were carried out exclusively during the afternoon hours (between 4:00 p.m. and 6:00 p.m.), achieving a total net depth of 2,700 m³ ha^{-1}, a calculation that included the use of the actual rainfall that occurred during the crop cycle.

Variables evaluated in the trial

Yield and component measurements were made when the grain reached a 14% moisture content at harvest. For each treatment replicate, 10 plants were randomly selected and evaluated for the following parameters: dry mass (g) of stems, pods, and grains, which were obtained by manually separating each component and drying in an oven at 65°C for 72 hours until a constant weight was reached. Additionally, the number of pods per plant (units), pod mass, number of grains per pod (units), and total number of grains per plant were recorded. The final crop yield (t ha-1) was calculated from the total biomass of harvested grains, following all standardised procedures to ensure comparability between treatments.

Evaluation of seed biomass and dimensions

For each treatment, a random sample of 50 seeds was analyzed, accurately measuring their main dimensions using a digital calliper (accuracy 0.01 mm). The length (L), width (W), and thickness (E) of each seed were systematically recorded. These primary data allowed the calculation of three key morphometric indices: 1) arithmetic mean diameter (Da), 2) geometric mean diameter (Dg), and 3) sphericity (Ø), applying the standardized equations proposed by Mohsenin *et al.* (1986) and specified below.

$$D_a = \frac{L + A + E}{3} \quad D_g = (L * A * E)^{1/3} \quad Ø = (\frac{D_g}{L}) * 100$$

Seed biomass was also assessed. Each seed was weighed individually on a precision analytical balance with a resolution of 0.01 g.

Statistical analysis of the results

The data obtained were subjected to verification of statistical assumptions, assessing normality using the Kolmogorov-Smirnov test and homogeneity of variance using the Levene test. Subsequently, a one-way analysis of variance (ANOVA) was performed, complemented by Tukey's multiple comparison test to determine differences between means, using a significance level of 95% ($p \leq 0.05$). All statistical processing was performed using Minitab software (version 17.1.0 for Windows, Minitab 2015), ensuring methodological rigour in the analysis of the results.

RESULTS AND DISCUSSION

Biomass production

Total dry biomass production at harvest exceeded 20 g $plant^{-1}$ in the 50% chemical fertilization treatments combined with EcoMic® (FQ50+HMA) and QuitoMax® + CBFERT (FQ50+QM+CB). However, plants where the three bioproducts were combined with 50% chemical fertilization achieved a lower total biomass than the FQ50+HMA treatment, but similar to that of complete chemical fertilization (FQ100). Pod dry mass was similar in all treatments; whereas grain and stem mass in treatments with complementary application of bioproducts was similar or higher than that obtained with FQ100 (Figure 2).

The dry biomass accumulation values obtained were lower than those reported for the crop (42 g plant^{-1}) under the soil and climate conditions of Villa Clara, Cuba (González *et al.*, 2018). However, in agroecosystems in Pinar del Río, values above 30 g plant^{-1} can also be reached for this cowpea cultivar (Santana-Baños *et al.*, 2023). The production of dry biomass from stems and pods is also important because their incorporation into the soil allows for nutrient recycling and improves the nutrition of the next crop. They have been shown to increase soil organic matter, as well as pH, nitrogen, phosphorus, and potassium values (García *et al.*, 2017; Zayas-Infante *et al.*, 2019; Zhang *et al.*, 2023).

It is worth noting that the proportion of grain biomass ranged from 47% to 50% of the total plant biomass. However, in the treatment combining the three bioproducts (FQ50+HMA+QM+CB), despite obtaining a total biomass comparable to that obtained with complete chemical fertilization (FQ100), a reduction in the proportion of grain and stem biomass was observed, offset by an increase in the proportion of pods. This modification in the distribution of photoassimilates affects the conversion of useful dry biomass. Therefore, some studies on cowpeas corroborate that the dry mass of the shoots is a component related to agricultural yield (Gonçalves *et al.*, 2017).

Agricultural productivity and yield components

The crop yield exceeded 1.2 t ha^{-1} in the FQ50+HMA and FQ50+QM+CB treatments, although in all variants with the application of bioproducts it was similar to or higher than that obtained with complete chemical fertilization (FQ100). It was confirmed that inoculation with arbuscular mycorrhizal fungi (EcoMic®) allows for a 50% reduction in the chemical fertilization, guaranteeing a 24% increase in grain production. This result contributes to the sustainability of production through the partial replacement of chemical fertilization complemented with this biofertilizer (Table 2).b Other authors report similar or higher agricultural yield values in cowpea bean (Santos *et al.*, 2016; Martínez *et al.*, 2020). In Cuba, in particular, yields of between 0.4 and 1.6 t ha^{-1} have been obtained (Báez & Hernández, 2016; González *et al.*, 2018; Santana-Baños *et al.*, 2023).

The potential for promoting cowpea cultivation through the use of biostimulant bioproducts is evident, as they can guarantee alternative grain production in the face of growing consumer demand and the need to replace imports of other traditional grains, such as common beans. The potential of cowpea cultivation under Cuban soil and climate conditions is also reaffirmed (Quintero *et al.*, 2010; Figueroa *et al.*, 2014).

Regarding the components of crop yield (Table 2), significant differences were found between treatments in all variables analyzed. These differences are related to biomass production. The number of pods per plant

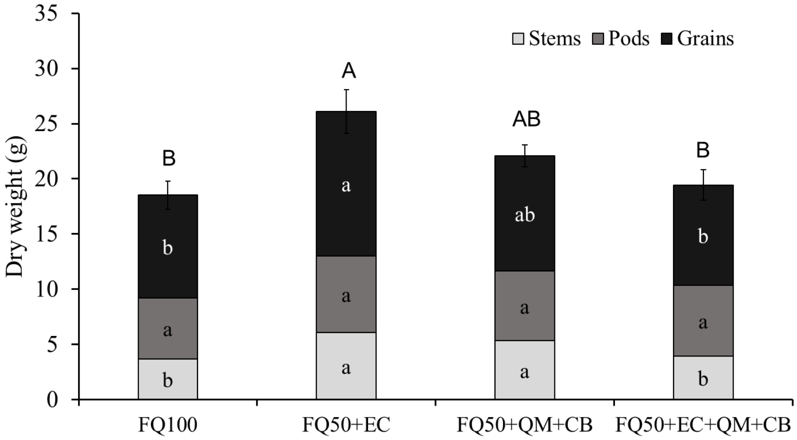

Figure 2. Dry biomass production in cowpea plants. Different letters indicate significant differences (Tukey test, $p \leq 0.05$). Capital letters indicate differences for total dry mass. **FQ100:** Chemical fertilization with a complete formula, N-P-K+Mg (12-12-17+5), at a dose of 0.50 t ha^{-1}. **FQ50+HMA:** 50% chemical fertilization + EcoMic® (HMA) inoculation in the seed before sowing. **FQ50+QM+CB:** 50% chemical fertilization + foliar applications of QuitoMax® and CBFERT. **FQ50+HMA+QM+CB:** 50% chemical fertilization + EcoMic® + QuitoMax® + CBFERT.

Table 2. Effect of treatments on agricultural yield and its components.

Treatment	RA	VP	MV	NGV	NGP
FQ100	1.12±0,01 b	8.00±1,01 b	1.94±0,15 a	10.45±1,54 a	77.80±10,00 ab
FQ50+HMA	1.52±0,20 a	12.50±1,01 a	1.77±0,03 ab	8.09±1,00 ab	97.10±14,11 a
FQ50+QM+CB	1.23± 0,09ab	11.40±1,10 a	1.63±0,11 b	6.71±1,30 b	72.40±4,03 b
FQ50+HMA+QM+CB	1.10±0,01 b	7.90±1,02 b	1.86±0,14 ab	9.08±1.01 ab	66.20±2,03 b

Different letters indicate significant differences ($p \leq 0.05$). **Legend:** RA= crop yield (t ha^{-1}), VP= pods per plant (u), MV= pod mass (g pod^{-1}), NGV= number of grains per pod (u), NGP= number of grains per plant (u). **FQ100:** Chemical fertilization with a complete formula, N-P-K+Mg (12-12-17+5), at a dose of 0.50 t ha^{-1}. **FQ50+HMA:** 50% chemical fertilization + EcoMic® (HMA) inoculation in the seed before sowing. **FQ50+QM+CB:** 50% chemical fertilization + foliar applications of QuitoMax® and CBFERT. **FQ50+HMA+QM+CB:** 50% chemical fertilization + EcoMic® + QuitoMax® + CBFERT.

was significantly higher in the FQ50+HMA and FQ50+QM+CB treatments. However, some authors report more than 15 pods per plant in cowpea cultivars harvested under Cuban soil and climate conditions (Figueroa *et al.*, 2014; Santana-Baños *et al.*, 2023). Pod weight and grains per pod were favored in the FQ100 treatment, indicating compensation for the number of pods and grains per plant in this treatment. This compensatory balance resulted in values of 66 to 97 grains per plant, ranges consistent with those reported by Santana-Baños *et al.* (2023) for the same variety under different conditions with complete chemical fertilization (100%). Notably, our findings reveal that the combined application of bioproducts enables up to 50% reduction in chemical fertilizer dosage while maintaining yields and demonstrating improved crop nutritional efficiency.

Variability of seed biomass and dimensions

The dry seed biomass reached an overall average of 0.14 g, with significant differences observed only between complete chemical fertilization (FQ100) and the 50% chemical fertilization treatment with the complementary application of the three bioproducts (EcoMic®, QuitoMax®, and CBFERT). The values achieved in the latter treatment expressed greater viability in the seed biomass (Figure 3). The results indicate that it is feasible to reduce chemical fertilization by 50% in the cowpea (INIFAT-93) crop through supplementation with bioproducts (EcoMic®, QuitoMax®, and CBFERT), without negatively affecting the dry biomass of the seeds. The average biomass achieved (0.14 g) exceeds the 0.12 g reported for this cultivar (Fernández *et al.*, 2014). Additionally, the combined treatment demonstrated greater viability compared to complete chemical fertilization (FQ100), supporting its potential to maintain productivity while promoting the sustainability of the agroecosystem.

Analysis of the dimensions of the INIFAT-93 cowpea seeds confirmed that length did not change in the evaluated treatments, reaching values greater than 8 mm; while width and thickness showed significant differences between 100% chemical fertilization and the complementary application of EcoMic®, along with 50% chemical fertilization. It is also noteworthy that the values achieved for seed width and thickness exceeded 5.6 and 4.5 mm, respectively (Table 3).

Studies conducted on red and black cowpea genotypes reported seed length values of less than 7.1 mm. However, width and thickness ranged from 5.0 mm to 5.5 mm and 4.1 mm to 5.1 mm, respectively (Hamid *et al.*, 2016).

The estimation of the arithmetic mean diameter showed similar values in all treatments. However, for the geometric mean diameter, significant differences were found between 100% chemical fertilization (6.35 mm) and the complementary application of EcoMic® along with 50% chemical fertilization (6.10 mm). Furthermore, the sphericity of INIFAT-93 cowpea seeds was observed to range between 69% and 71%, with no significant variations between treatments (Table 3). These results are similar to those reported in cowpea collections in Mexico, where the arithmetic mean diameter and geometric mean diameter were 6.48 and 6.27 mm, respectively, and sphericity ranged between 56% and 79% (Morales-Morales *et al.*, 2019).

The results obtained confirm that the treatments did not cause changes in seed shape. Furthermore, despite the statistical differences found in the width, thickness, and geometric diameter of the seeds, the observed variations represented a reduction of less than 6% in these dimensions. Therefore, future trials should include evaluation of seed germination and seedling emergence vigor.

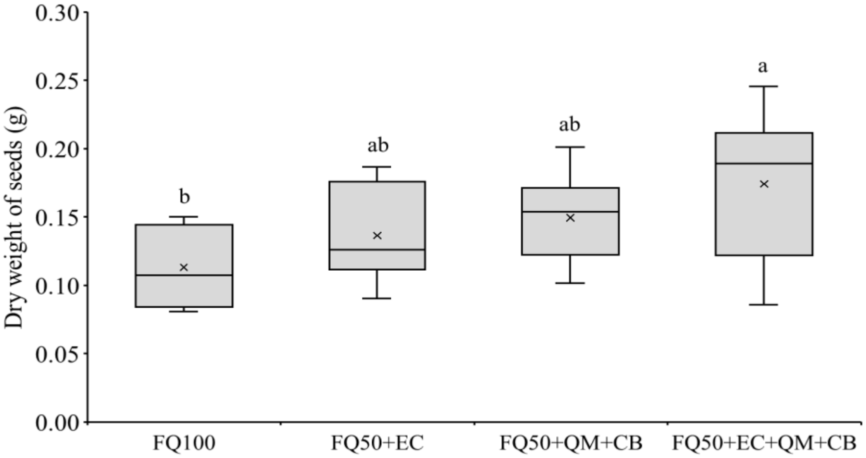

Figure 3. Dry biomass of INIFAT-93 cowpea seeds by treatment. Different letters indicate significant differences (Tukey test, $p \leq 0.05$). **FQ100:** Chemical fertilization with a complete formula, N-P-K+Mg (12-12-17+5), at a dose of 0.50 t ha^{-1}. **FQ50+HMA:** 50% chemical fertilization + EcoMic® (HMA) inoculation in the seed before sowing. **FQ50+QM+CB:** 50% chemical fertilization + foliar applications of QuitoMax® and CBFERT. **FQ50+HMA+QM+CB:** 50% chemical fertilization + EcoMic® + QuitoMax® + CBFERT.

Table 3. Length, width and thickness of INIFAT-93 cowpea seeds.

Tratamiento	L	A	E	Da	Dg	Ø
FQ100%	8,92±0,04a	5,95±0,10a	4,84±0,04 a	6,57±0,10 a	6,35±0,10 a	71,33±1,08 a
FQ50%+HMA	8,82±0,09a	5,66±0,04b	4,55±0,07 b	6,34±0,15 a	6,10±0,06 b	69,16±1,10 a
FQ50%+QM+CB	8,89±0.03a	5,72±0,03b	4,69±0,13 ab	6,43±0,07 a	6,20±0,07 ab	69,76±1,04 a
FQ50%+HMA+QM+CB	8,78±0,11a	5,80±0,05ab	4,71±0,10 ab	6,43±0,08 a	6,21±0,07 ab	70,81±1,03 a

Different letters indicate significant differences ($p \leq 0.05$). **Legend:** ns = not significant, * significant. Legend: L = length (mm), A = width (mm), E = thickness (mm), Da = arithmetic diameter (mm), Dg = geometric diameter (mm), Ø = sphericity (%). FQ100: Chemical fertilization with complete formula, N-P-K+Mg (12-12-17+5), at a dose of 0.50 t ha^{-1}. **FQ100:** Chemical fertilization with a complete formula, N-P-K+Mg (12-12-17+5), at a dose of 0.50 t ha^{-1}. **FQ50+HMA:** 50% chemical fertilization + EcoMic® (HMA) inoculation in the seed before sowing. **FQ50+QM+CB:** 50% chemical fertilization + foliar applications of QuitoMax® and CBFERT. **FQ50+HMA+QM+CB:** 50% chemical fertilization + EcoMic® + QuitoMax® + CBFERT.

Overall, the results demonstrate that the combined use of biostimulants such as EcoMic®, QuitoMax®, and CBFERT with a 50% reduction in chemical fertilization can maintain or even improve specific yield components in cowpea cultivation (Rocha *et al*., 2019). From a physiological perspective, this response is explained by the fact that the mycorrhizal fungi in EcoMic® enhance phosphorus and water use efficiency (Begum *et al*., 2019), while the oligosaccharides in QuitoMax® modulate gene expression related to flowering (Mukhtar-Ahmed *et al*., 2020). The FQ50+HMA treatment showed the highest yield (1.52 t ha^{-1}), consistent with studies reporting that mycorrhizae can increase legume productivity by up to 40% with reduced fertilizer input (He *et al*., 2022). However, a compensatory effect was observed where a higher number of pods reduced individual grain weight, a pattern recently documented in cowpea varieties under nutritional stress (Goufo *et al*., 2017). The lower efficacy of the combined treatment with three bioproducts may be due to interference in hormonal signalling pathways, a phenomenon reported with the simultaneous application of multiple biostimulants (Sharma *et al*., 2022).

CONCLUSIONS

The application of 50% chemical fertilization together with EcoMic® or QuitoMax® + CBFERT increased the biological and agricultural productivity of cowpea and ensured seed quality comparable to that obtained with complete chemical fertilization, demonstrating the potential of these bioproducts for sustainable agricultural production. It is concluded that bioproduct treatments increased yield by 18% to 27% compared to the control, with maximum values of 1.45 t ha^{-1} in the triple combination. The physiological quality of the seeds is significantly improved ($p<0.05$), evidenced by increases of 22% to 35% in 1000-seed weight and 15% to 25% in germination. Finally, it is worth noting that these findings are consistent with recent reports on the positive effects of AMF on phosphorus and chitosan uptake. They propose developing ecophysiological studies under different soil and climate conditions, thereby defining the conditions under which it is effective and proposing it to the productive sector.

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REFERENCES

Báez, A. and Hernández, C.A., 2016. Estudio del rendimiento de cultivares de frijol caupí (*Vigna unguiculata* (L.) Walp.) en diferentes épocas de siembra en Camajuani, Cuba. *Revista de Ciencia y Tecnología*, 26(Supl. 1), 11-18. https://www.scielo.org.ar/pdf/recyt/n26s1/n26s1a02.pdf

Begum, N., Qin, C., Ahanger, M.A., Raza, S., Khan, M.I., Ashraf, M., Ahmed, N. and Zhang, L., 2019. Role of arbuscular mycorrhizal fungi in plant growth regulation: Implications in abiotic stress tolerance. *Frontiers in Plant Science*, 10, pp.1068. https://doi.org/10.3389/fpls.2019.01068

Boukar, O., Belko, N., Chamarthi, S., Togola, A., Batieno, J. and Owusu, E., 2019. Cowpea (*Vigna unguiculata*): Genetics, genomics and breeding. *Plant Breeding*, 138(4), pp. 415–424. https://doi.org/10.1111/pbr.12589

FAOSTAT., 2023. Crops and livestock products. Food and Agriculture Organization of the United Nations. https://www.fao.org/faostat

Fernández, L., Shagarodsky, T., Cristóbal, R., Muñoz, L., Gil, J. and Sánchez, Y., 2014. Catálogo de variedades [Catalogue of varieties]. Instituto de Investigaciones Fundamentales en Agricultura Tropical "Alejandro de Humboldt" (INIFAT). https://isbn.cloud/9789597223061/catalogo-de-variedades-comerciales-del-inifat/

Fernandez, M., Nelson, M., Enríquez, L.J., Paneque, P., Díaz, M.M., Figueroa, J.G. and Funes-Aguilar, F., 2018. Cuba's agrifood system in transition: An introduction to the Elementa Special Feature. *Elementa: Science of the Anthropocene*, 6, p.75. https://doi.org/10.1525/elementa.335

Figueroa, Y., Ventura, J.C., Rodríguez, S., Arredondo, I., Albert, J., Gálvez, J.R. and Gavilán, E., 2014. Caracterización de tres nuevas variedades de *Vigna unguiculata* ('IPA 206' e 'IPA 207' y 'GUARIBA') en Cuba. *Centro Agrícola*, 41(2), pp. 65-69. https://biblat.unam.mx/hevila/Centroagricola/2014/vol41/no2/10.pdf

García, M., Rodríguez, N., León, Y. and Acosta, Y., 2017. Influencia de la alternancia de cultivos en las propiedades agroquímicas de un suelo dedicado al tabaco negro en Pinar del Río. *Cuba Tabaco*, 18(2), pp. 3-8. http://www.iitabaco.co.cu/wp-content/uploads/2021/02/Vol-18-1-2017-Digital.pdf

García-López, J.V., Sánchez-Gómez, C. and Ruiz-Sánchez, M.E., 2024. Microbial biostimulants for sustainable agriculture: Current trends and future perspectives. *Frontiers in Plant Science*, 15, pp.1284512. https://doi.org/10.3389/fpls.2024.1284512

Gonçalves, I.S., da Silva, R.R., de Oliveira, G.M., Santiago, E.J.P. and de Oliveira, V.E.A., 2017. Características fisiológicas e componentes de produção de feijão caupi sob diferentes lâminas de irrigação. *Journal of Environmental Analysis and Progress*, 2(1), pp.320-329. https://core.ac.uk/reader/228888274

González, D., Álvarez, U. and Lima, R., 2018. Acumulación de biomasa fresca y materia seca por planta en el cultivo intercalado caupí–sorgo. *Centro Agrícola*, 45(2), pp.77-82. http://scielo.sld.cu/pdf/cag/v45n2/cag11218.pdf

Goufo, P., Moutinho-Pereira, J.M., Jorge, T.F., Correia, C.M., Oliveira, M.R., Rosa, E.A.S., António, C. and Trindade, H., 2017. Cowpea (*Vigna unguiculata* L. Walp.) metabolomics: Osmoprotection as a physiological strategy for drought stress resistance and improved yield. *Frontiers in Plant Science*, 8, p.586. https://doi.org/10.3389/fpls.2017.00586

Hamid, S., Muzaffar, S., Wani, I.A., Masoodi, F.A. and Bhat, M.M., 2016. Physical and cooking characteristics of two cowpea cultivars grown in temperate Indian climate. *Journal of the Saudi Society of Agricultural Sciences*, 15(2), pp.127-134. https://doi.org/10.1016/j.jssas.2014.08.002

He, X., Shao, C., Wu, A., Xia, L., Li, T., Pei, J., Zhang, N. and Wang, Y., 2022. Arbuscular mycorrhizal fungi enhance nutrient acquisition and reduce aluminum toxicity in Lespedeza formosa under acid rain. *Environmental Science and Pollution Research*, 29(20), pp.29904-29916. https://doi.org/10.1007/s11356-021-18248-x

Hernández, A., Pérez, J. M., Bosch, D. and Castro, N., 2015. Clasificación de suelos de Cuba 2015. Ediciones INCA. https://ediciones.inca.edu.cu/files/libros/clasificacionsueloscuba_%202015.pdf

Kesell, I.P., Bautista, N.I., Sierra, F.Z. and Cantillo, E.V., 2022. Efecto de los bioproductos ecomic®, azofert® y quitomax® en frijol común (*Phaseolus vulgaris* L.) en la finca “Monserrate 2”. *Investigación y Ciencia Aplicada a la Ingeniería*, 5(29), pp.56-65. https://ojsincaing.com.mx/index.php/ediciones/article/view/110

López-Padrón, I., Martínez-González, L., Pérez-Domínguez, G., Reyes-Guerrero, Y., Núñez-Vázquez, M. and Cabrera-Rodríguez, J.A., 2020. Las algas y sus usos en la agricultura. Una visión actualizada. *Cultivos Tropicales*, 41(2), pp.e10. https://ediciones.inca.edu.cu/index.php/ediciones/article/view/1554

Martínez, A. M., Tordecilla, L., Grandett, L. M., Rodríguez, M. del V. and Cordero, C. C., 2020. Cowpea bean (*Vigna unguiculata* L. Walp): Socioeconomic and technological perspective in the Colombian Caribbean. *Ciencia y Agricultura*, 17(2), pp.12–22. https://doi.org/10.19053/01228420.v17.n2.2020.10644

MINAG., 2020. Manual práctico para uso de bioproductos y fertilizantes líquidos. Departamento de Suelos y Fertilizantes. Ministerio de la Agricultura. https://docplayer.es/196853526-Manual-practico-para-uso-de-bioproductos-yfertilizantes-liquidos-enero-2020.html

MINAG., 2022. Lista oficial de plaguicidas autorizados Año 2022. Registro Central de Plaguicidas. Ministerio de la Agricultura. https://www.minag.gob.cu/wp-content/uploads/2023/06/Lista-Oficial-de-Plaguicidas.pdf

Minitab, Inc., 2015. Getting started with Minitab 17. https://www.minitab.com/en-us/support/documentation/

Mohsenin, N.N., 1986. Physical properties of plant and animal materials: Structure, physical characteristics, and mechanical properties. Gordon and Breach. https://api.pageplace.de/preview/DT0400.9781000122633_A40550031/preview-9781000122633_A40550031.pdf

Morales-Morales, A.E., Andueza-Noh, R.H., Márquez-Quiroz, C., Benavides-Mendoza, A., Tun-Suarez, J.M., González-Moreno, A. and Alvarado-López, C. J., 2019. Caracterización morfológica de semillas de frijol caupí (*Vigna* *unguiculata* L. Walp) de la Península de Yucatán. *Ecosistemas y Recursos Agropecuarios*, 6(18), pp.463-475. https://doi.org/10.19136/era.a6n18.2171

Mukhtar-Ahmed, K.B., Khan, M.M.A., Siddiqui, H. and Jahan, A., 2020. Chitosan and its oligosaccharides, a promising option for sustainable crop production: A review. *Carbohydrate Polymers*, 227, pp.115331. https://doi.org/10.1016/j.carbpol.2019.115331

Peña-Calzada, K., Palau-Rodríguez, C.M., Hernández-Beltrán, Y., Casimiro-Rodríguez, L., Calero-Hurtado, A., Silva-Fernandes, T.F. and Rodríguez, J.C., 2025. La agroecología y su impacto en la sostenibilidad agrícola y el cambio climático: evolución en Cuba. *Revista de la Facultad de Ciencias*, 14(1), pp.39-69. https://doi.org/10.15446/rev.fac.cienc.v14n1.115264

Quintero, E., Gil, V.D., García, J.C., Rodríguez, G. and Fernández, L., 2010. Potencialidades del caupí para la rápida compensación de pérdidas de la producción de frijol por desastres naturales. *Centro Agrícola*, 37(3), pp. 5-9. https://biblat.unam.mx/hevila/Centroagricola/2010/vol37/no3/1.pdf

Rocha, I., Ma, Y., Souza-Alonso, P., Vosátka, M., Freitas, H. and Oliveira, R.S., 2019. Seed coating: A tool for delivering beneficial microbes to agricultural crops. *Frontiers in Plant Science*, 10, pp.1357. https://doi.org/10.3389/fpls.2019.01357

Ruiz-Sánchez, M., Muñoz Hernández, Y., Rodríguez Pérez, R., López-Ahumada, G., Dórame Miranda, R., López Corona, B. and Rueda Puente, E., 2024. Organic potato production with the application of bioagroinputs in Los Palacios, Cuba. *Tropical and Subtropical Agroecosystems*, 27(3), pp.106. https://doi.org/10.56369/tsaes.5456

Santana-Baños, Y., Carrodeguas, S., Sosa, L., Rodríguez, F. L., Lopetegui, C. M. and Díaz, M., 2023. Agronomic response of cowpea cultivars [*Vigna unguiculata* (L.) Walp.] in San Juan y Martínez, Cuba. *Cultivos Tropicales*, 44(1), pp.e02. https://ediciones.inca.edu.cu/index.php/ediciones/article/view/1688/3452

Santos, L.L.deS., Gomes Filho, A., Leandro, R.I., Carvalho, F.M.de, Gomes, P.L. and Soares, A.S., 2016. Desempenho agronômico de variedades de feijão-caupi produzidas em regime irrigado e sob déficit hídrico no semiárido mineiro. *Agri-Environmental Sciences*, 2(1), pp.1-14. https://doi.org/10.36725/agries.v2i1.197

Sharma, R., Kumar, A., Kaur, H., Sharma, K., Verma, T., Chauhan, S., Lakhanpal, M., Choudhary, A., Singh, R.P., Reddy, D.M., Venkatapuram, A., Mehta, S. and Husen, A., 2024. Current understanding and application of biostimulants in plants: An overview. In A. Husen (Ed.), Biostimulants in plant protection and performance . Elsevier. pp. 1-20 https://doi.org/10.1016/B978-0-443-15884-1.00003-8

Zayas-Infante, S., Boeckx, P. and Vargas-Rodríguez, H., 2019. Comportamiento productivo en agroecosistemas de intercalamiento yuca-frijol en el municipio “Calixto García”, provincia Holguín. *Cultivos Tropicales*, 40(1), pp.e03. http://scielo.sld.cu/pdf/ctr/v40n1/1819-4087-ctr-40-01-e03.pdf

Zhang, X., Zhang, D., Sun, W. and Wang, T., 2023. The effectiveness of arbuscular mycorrhizal fungi on enhancing phosphorus acquisition in crops: A meta-analysis. *Soil Biology and Biochemistry*, 178, pp.108965. https://doi.org/10.1016/j.soilbio.2022.108965