Agronomic Management of Sesame (*Sesamum indicum* L.) in an Agroecosystem of Mayabeque Province

Manejo Agronómico del Cultivo de Ajonjolí (*Sesamum indicum* L.) en un Agroecosistema de la Provincia Mayabeque

Manejo Agronómico da Cultura do Gergelim (*Sesamum indicum* L.) em um Agroecossistema da Província Mayabeque

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Abstract

Agroecological production alternatives are a priority for food production with minimal environmental damage. Sesame (*Sesamum indicum* L.) is in high demand both nationally and internationally, primarily for its culinary and medicinal uses. Crop yields in Cuba are low, and despite high national demand, research to address this situation is scarce. The objective of this study was to evaluate planting distance and the effect of the biostimulants Bioenraiz Plus® and seaweed extract on the growth and yield of sesame grown in raised beds on a typical eutric leached red ferralitic soil in Mayabeque province. Two experiments were conducted: one to evaluate three plant spacings (0.30, 0.60 and 0.80 m) in raised beds, and another to determine the effect of the biostimulants on agricultural yield and its components in sesame. The indicators evaluated were growth variables and yield components. The results obtained showed the feasibility of planting sesame in raised beds, confirming a spacing of 0.60 m between plants as the most promising. These indicators increased significantly with the application of bioactive products, both independently and in combination.

Keywords: biofertilizer, algae, IAA, growth, yield.

Resumen

Las alternativas de producciones agroecológicas son una prioridad para la producción de alimentos con el mínimo daño al ambiente. El ajonjolí (*Sesamum indicum* L.) presenta una gran demanda tanto a nivel nacional como internacional, principalmente por su uso en el sector culinario y medicinal. Los rendimientos del cultivo en Cuba son bajos y, a pesar de la alta demanda nacional, las investigaciones para revertir esta situación son escasas. El objetivo de este trabajo fue evaluar la distancia de plantación y el efecto de los bioestimulantes Bioenraiz Plus® y el extracto de algas en el crecimiento y rendimiento del ajonjolí, cultivado en parcelas, sobre un suelo Ferralíticos Rojos Lixiviados típico eútrico en la provincia Mayabeque. Se condujeron dos experimentos: uno para evaluar tres distancias entre plantas (0.30, 0.60 y 0.80 m) en canteros y otro experimento para determinar el efecto de los bioestimulantes en el rendimiento agrícola y sus componentes en ajonjolí. Los indicadores evaluados fueron variables de crecimiento y los componentes del rendimiento. Los resultados obtenidos mostraron la posibilidad de plantar ajonjolí en canteros, ratificando la distancia entre plantas a 0.60 m como la más promisoria. Estos indicadores se incrementaron significativamente con la aplicación de productos bioactivos de forma independiente y combinada.

Palabras clave: biofertilizante, algas, AIA, crecimiento, rendimiento.

Resumo

As alternativas de produções agroecológicas são uma prioridade para a produção de alimentos com o mínimo dano ao ambiente. O gergelim (*Sesamum indicum* L.) apresenta uma grande demanda tanto a nível nacional como internacional, principalmente pelo seu uso no setor culinário e medicinal. Os rendimentos da cultura em Cuba são baixos e, apesar da alta demanda nacional, as pesquisas para reverter esta situação são escassas. O objetivo deste trabalho foi avaliar a distância de plantio e o efeito dos bioestimulantes Bioenraiz Plus® e do extrato de algas no crescimento e rendimento do gergelim, cultivado em parcelas, sobre um solo Ferralíticos Vermelhos Lixiviados típico eútrico na província Mayabeque. Conduziram-se dois experimentos: um para avaliar três distâncias entre plantas (0.30, 0.60 e 0.80 m) em canteiros e outro experimento para determinar o efeito dos bioestimulantes no rendimento agrícola e seus componentes em gergelim. Os indicadores avaliados foram variáveis de crescimento e os componentes do rendimento. Os resultados obtidos mostraram a possibilidade de plantar gergelim em canteiros, ratificando a distância entre plantas a 0.60 m como a mais promissora. Estes indicadores incrementaram-se significativamente com a aplicação de produtos bioativos de forma independente e combinada.

Palavras-chave: biofertilizante, algas, AIA, crescimento, rendimento.

Introduction

Sesame (*Sesamum indicum* L.) is native to Ethiopia and is produced in India, China, and Japan; it has currently expanded to the Central American region. It constitutes one of the oldest oilseed crops and is of the greatest economic and nutritional relevance worldwide. Its seed is used in the production of the highest quality oil for human consumption (Chile et al., 2022).

Sesame oil is one of the best for culinary uses, canning, and pharmaceutical preparations due to its physical characteristics. The main sesame-producing countries include India, China, Myanmar, and Sudan, which account for 70 % of world production (Majdalawieh and Mansour, 2019; Wei et al., 2022).

In Cuba and other tropical countries, sesame is cultivated under diverse edaphoclimatic conditions, but its yield remains limited compared to other oilseed crops, which has motivated multiple investigations aimed at optimizing agronomic practices and the use of biological inputs.

Due to the great need of our country to produce fats, farmers are required to pay more attention to this oilseed crop. The economic analysis of this crop, when compared to peanuts, is very advantageous, since its yields range from 0.51 to 1.2 t ha^{-1} (Febles, 2021).

Several studies have shown that planting distance significantly influences the vegetative and reproductive development of sesame; simultaneously, the application of bioactive products such as biofertilizers, plant extracts, and growth-promoting microorganisms have shown positive effects on germination, plant vigor, resistance to abiotic stress, and grain quality (Rodríguez et al., 2018).

In this sense, researchers from the Bioactive Products Group of the National Institute of Agricultural Sciences (INCA) and the Cuban Institute of Research on Sugar Cane Derivatives (ICIDCA) have undertaken the task of developing new biostimulants to increase crop growth and development.

Among the main biostimulants that can improve plant growth and development are seaweed extracts (EAM) and Bioenraiz Plus®. These products have demonstrated their potential in seed germination, seedling vigor, root growth and morphology, early flowering, delayed senescence, fruit ripening, crop yield, and nutritional quality of the edible product (González et al., 2020; Espinosa, Hernández and González, 2021).

Most research and experiments focus on evaluating these factors in isolation, without sufficiently exploring the interaction between planting distance and the use of bioactive products under controlled experimental conditions; therefore, the objective of this work was to evaluate planting distance and the effect of the biostimulants Bioenraiz Plus® and seaweed extract on the growth and yield of sesame in Mayabeque province.).

Materials and Methods

The research was conducted during the third quarter of 2025 at the "Las Mercedes" farm, belonging to the "Noelio Capote" CCS, located on the Conde highway, in the popular council of Loma de Travieso, Jaruco municipality, Mayabeque province, located at coordinates 23.10648°N and 81.95808°W.

Influence of planting arrangement on agricultural yield in sesame cultivation

The experiment was set up during the period from August to November 2025. Sesame seeds of the Acarigua blanco variety, obtained from a producer of the "Noelio Capote" CCS, were used as plant material.

The study was conducted in plots of 4 rows of 5 meters in length. A randomized block design was used with three treatments and three replications per treatment (Table 1).

Table 1. Treatments used for the study of the influence of planting arrangement on sesame yield.

Treatment	Planting arrangement (m)
1	0.80 x light stream
2	0.60 x light stream
3	0.30 x light stream

Soil preparation was carried out with animal traction, performing the required operations until the land was ready for planting; this was done manually, with the arrangements, depositing the seeds in a light stream per row at a depth of approximately 0.05 m. The cultural practices carried out throughout the cycle were weed control by cultural methods (mechanical control) and irrigation was applied according to crop needs (MINAG, 2020).

At 90 days after emergence, the following morphoagronomic indicators were evaluated on 5 random plants in each of the replications:

Plant height (cm): Measured using a graduated ruler, from the base of the stem to the apical bud.

Productive zone (cm): Measured using a graduated ruler, from the base of the stem to the apical bud.

Unproductive zone (cm): Determined by subtracting the productive zone from the plant height.

Stem diameter (cm): Determined with a digital vernier caliper, starting 2 cm above the root collar.

At harvest, to evaluate the yield components, the following were determined: number of capsules per plant, number of plants per square meter, weight of 100 seeds (g), and yield in kg m^{-2}.

Effect of bioactive products on agricultural yield in sesame cultivation

The research was conducted during the winter cycle (December-February) of 2025-2026 in areas of the "Las Mercedes" farm of the "Noelio Capote" CCS.

The experiment was conducted under a randomized block design in plots of 4 rows 5 meters in length, with four treatments and three replications per treatment. Table 2 shows the treatments under study.

Table 2. Treatments used for the study of the influence of bioactive products on sesame yield.

Treatment	Description
1	Seeds soaked in water (Control)
2	Seeds soaked in Bioenraiz Plus® ($2\ mL\ L^{-1}$, 30 min)

Treatment	Description
3	Foliar spray of 2 % seaweed extract (Dose 20 mL plant $^{-1}$)
4	Seeds soaked in Bioenraiz Plus® (2 mL L^{-1}, 30 min) + 2 % seaweed extract (foliar)

Foliar applications of seaweed extract were performed at 15 and 30 days after plant emergence. All sprays were carried out early in the morning (8-9 am), to take advantage of stomatal opening in plant leaves; all were done manually using a 16 L capacity backpack sprayer with a cone nozzle at constant pressure. Additionally, two weedings and slight hilling were performed.

Soil preparation and other cultural practices were carried out following the technical norms for sesame cultivation (MINAG, 2020).

At 90 days and at harvest, growth and yield variables were evaluated on 10 random plants within the useful plot.

Growth variables

- ✓ Plant height (cm): Recorded from the soil surface to the terminal apex, using a measuring tape.
- ✓ Stem diameter (mm): Stem diameter was measured with a vernier caliper at 10 cm above the ground.
- ✓ Number of leaves: Counted from the first lower leaf to the last leaf at the plant apex.

Yield component variables

- ✓ Number of capsules per plant: Total capsules per plant in the useful plot were counted.
- ✓ Capsule length (cm): Measured with a measuring tape on 10 physiologically mature capsules from each of the 10 selected plants in each useful plot. Measured from the peduncle to the apical part.
- ✓ Number of seeds per capsule: The number of seeds contained in five capsules per plant, from five plants in the useful plot, was determined. Each capsule was placed in individual bags to achieve optimal drying and subsequently counted to determine the average value.
- ✓ Yield (kg ha^{-1}): Each useful plot was harvested, using the plants from the two central rows. Seed weight was recorded and expressed in kg ha^{-1} adjusting moisture to 13 %, according to the equation proposed by Aguirre and Peske (1988):

$$Pf = Pi\,(100-Hi) / (100-Hf) \quad \text{Eq. 1}$$

Where:

Pf: Final weight (kg)

Pi: Initial weight (kg)

Hi: Initial moisture content (%)

Hf: Final moisture content (13 %)

To determine if the data met the homogeneity of variance, Cochran's test was performed, and to verify normal distribution, the Kolmogorov-Smirnov test was applied. The data obtained were analyzed using Simple Classification ANOVA. The resulting means were compared with Duncan's Multiple Range Test at p ≤ 0.05 when significant differences existed between treatments. Data was processed with the Statgraphics Centurion XVI (2009) program under the Windows 7 operating system.

Economic assessment

The economic analysis was determined by calculating the costs and value of production obtained in the experiment, considering the production proposal for the crop under study used by small and medium-sized producers (MINAG, 2020).

The following indicators were determined per treatment: Value of production obtained (VP) (according to the sale price CUP kg); Added value of production (VAP); and Profit obtained (B).

Results and Discussion

Influence of planting arrangement on agricultural yield in sesame cultivation

The results of emergence and survival percentages of sesame plants as a function of planting arrangement (Table 3) showed that at 7 and 120 DAS, the highest germination and survival percentages occurred with the 0.60 m distance (T2), followed by T3 and T1, except at 14 DAS where there was no difference between treatments.

The results obtained reflect that the distance between plants has a direct effect on the agronomic behavior of the sesame crop. T2 showed significant advantages over the other treatments in the initial growth stages. This could be related to better moisture retention and uniform soil temperature, factors that favor the metabolic activation of the sown seeds. This behavior was also documented by Bellido Ramírez (2025), who indicated that shorter planting distances generate optimal conditions for germination, survival, and crop establishment.

Table 3. Influence of planting arrangement on sesame germination and survival.

Treatments	Germination (%)		Survival (%)
	7 DDS	14 DDS	
T1	38.33 b	63.33	**120 DDS**
T2	40.00 a	68.33	80.00 b
T3	21.67 c	61.67	90.00 a
Esx	5.74***	2.06 n. s	73.33 c

DAS: days after showing; Planting arrangement (m): T1: 0.80, T2: 0.60, T3: 0.30. Treatment means with the same letters do not differ significantly at p<0.05 according to Duncan.

Regarding survival on 120 DAS, T2 also stood out with 90 % living plants. This suggests that density did not generate harmful competition but allowed efficient bed coverage. This result is consistent with studies by Weldemichael et al. (2022), who demonstrated that adequate density improves microclimatic stability and reduces water stress in the crop.

These results are attributed to greater soil coverage, better moisture retention, and a more favorable microclimate in plots with higher density, greater competition between plants, factors that reduce abiotic stress and favor crop establishment. These findings reinforce the agronomic recommendation to adopt narrow planting spacing as an effective strategy to improve initial sesame yield.

Plant height is a variable that allows us to measure crop growth. Yagodin et al. (2009) indicate that this can be affected by the combined action of four factors: light, heat, humidity, and planting distance. This agrees with Maradiaga (2024), who states that increasing population densities increases plant height, since stems become thinner, internodes longer, and consequently plants are taller.

The results for the mean values of morphoagronomic indicators evaluated in sesame plants at 90 DAS at different plant distances are presented in Table 4.

Table 4. Influence of planting arrangement on sesame morphoagronomic indicators.

Treatments	Plant height (cm)	Stem diameter (mm)	Productive zone	Unproductive zone
1	1. 43	8. 46	0. 64c	0. 73
2	1. 51	8. 91	0. 79a	0. 72
3	1. 37	7. 87	0. 72b	0.73
ESx	n. s	n. s	0.02***	n. s

Planting arrangement (m): T1: 0.80, T2: 0.60; T3: 0.30. Treatment means with the same letters do not differ significantly at $p<0.05$ according to Duncan.

The planting arrangements used in this study (Table 4) did not significantly influence plant height in any of the treatments evaluated, since no statistical differences were detected, due to the planting distance effect, which partially coincides with what was indicated by Manzzani and Cobo (2009), who show some effect on this variable for branched varieties and no effect on the non-branched Aceitera variety.

The results coincide with those reported by Ávila (2010), who, when evaluating different densities, stated that with increasing planting distance plant height did not increase, with average values between 1.30 to 1.37 m in height.

According to Bajaña (2022), the average plant height varies in a range of 1.64 to 2.67 m, with giant and indeterminate growth varieties reaching up to 3 m in height. This is a characteristic that undergoes modifications with climate and locality conditions.

According to Manzzani and Cobo (2009), sesame plant height varies from 0.70 m to 3 m, which indicates that the heights achieved fall within the range mentioned by these authors.

When evaluating stem diameter, no significant difference was observed between treatments (Table 4), with values ranging from 7.87 to 8.91 mm in diameter.

Zárate et al. (2011) mention a mean diameter of 1.6 cm for sesame and that when there is a lower plant population per hectare, plant development is favored with more robust stems.

Almeida (2015) indicates that the average stem diameter is 13 mm evaluated at a height of 50 cm; therefore, the value obtained in the present study is slightly lower. He also affirms that sesame stem diameter is a varietal characteristic, but among plants of the same variety, diameter can be affected by plant density influence.

When analyzing the values of the productive zone of the plant, treatment 2 with a planting distance of 0.60 m obtained the best results, with significant differences between treatments, meaning that a shorter planting distance results in a greater vegetative reproduction area (Table 4). González and Causarano (2014) mention that the height of the first branching is directly affected by the environment and cultural management, such as seed spacing in planting, among others, coinciding with the results obtained.

When evaluating the unproductive zone of the plants, no significant differences were found between treatments, so planting distance does not influence the height of the first pair of nodes of the plant; these results do not coincide with Fernández et al. (2016), who mention that the height of the first branching is directly affected by the environment and cultural management, such as seed spacing in planting, among others.

Yield components

When determining the number of capsules per plant, T2 presented the highest number of capsules per plant, with significant differences from the rest of the treatments (Table 5). These results do not agree with what was expressed by Rodríguez et al. (2018) when evaluating different planting densities in sesame and finding that at greater planting distances, the number of capsules per plant increases.

Table 5. Effect of planting density on the evaluated yield components.

Treatments	Number of capsules plant^{-1}	Number of plants x m^{2}	Weight of 100 seeds (g)
1	23b	20c	0. 29
2	31a	28b	0. 30
3	22b	39a	0. 28
Esx	2. 31***	2. 11***	n. s

Planting arrangement (m): T1: 0.80, T2: 0.60; T3: 0.30.
Treatment means with the same letters do not differ significantly at $p<0.05$ according to Duncan.

According to Chile et al. (2022), the number of capsules per plant varies depending on the growth type of the variety, and these can produce 1 to 3 capsules per axil, being one of the components that most affects final yield. The behavior of this variable is affected by environmental factors and crop management.

When quantifying the number of plants per square meter, a clear difference was evident between treatments, due to the planting densities used (Table 5).

In the weight of 100 seeds per treatment (Table 5), no significant differences were detected. The weight of 100 seeds is a character that is genetically determined. For the sesame crop, it varies according to the variety in a range of 0.22 to 0.37 g. Furthermore, it has been determined that varieties react strongly to lack of soil moisture (Wang et al., 2023).

In this regard, Ruiz et al. (2023) states that this variable demonstrates the capacity to translocate nutrients accumulated by the plant during its vegetative development to the grain in the reproductive stage.

When evaluating yield in kg m^{-2} (Table 6), significant differences were found between treatments, with treatment 2 showing the best results with a yield of 0.12 kg m^{-2}.

In this regard, it is stated that the greater the number of plants that reach harvest time, the greater the yield of the harvested product. Furthermore, Quevedo and Rafael (2021) indicate that yield is influenced by population, space, and an optimal planting distance to evaluate the maximum yield of a variety.

When estimating yield in kg per plot and yield in kg ha^{-1} (Table 6), among the treatments, the best results were achieved with the 0.60 m plant spacing treatment (T2), with values of 2.9 kg and 812.1 kg ha^{-1} respectively, with significant differences from the rest of the treatments.

Table 6. Sesame agricultural yield.

Treatments	Yield (kg m^{-2})	Yield per plot (kg)	Yield (kg ha^{-1})
1	0. 08c	1. 3c	457. 2c
2	0. 12a	2. 9a	812. 1a
3	0. 1b	1. 9b	527. 8b
Esx	0. 007***	0. 009***	2. 62**

Planting arrangement (m): T1: 0.80, T2: 0.60; T3: 0.30. Treatment means with the same letters do not differ significantly at p<0.05 according to Duncan.

Baraki et al. (2020) reported an average yield of 716 kg ha^{-1}. It can be indicated that the results obtained in the present study are very similar to the yield reported by this author. However, Gholamhoseeini et al. (2022) indicate that the yield potential of sesame is 1500 kg ha^{-1}.

In summary, the joint analysis of the results obtained in the different indicators evaluated thus far and the literature review suggests that the 0.60 m plant spacing is an effective agronomic strategy to maximize sesame yield under tropical conditions. This practice not only improves the physiological indicators of the crop but also contributes to the sustainability of the production system by optimizing land use and reducing risks associated with climate and diseases.

Effect of bioactive products on agricultural yield in sesame cultivation

Plant height is a variable that allows us to measure crop growth. Téllez and Ramírez (1999) state that plant height can present variations due to factors such as solar radiation, humidity conditions, and temperature.

When evaluating the effect of the application of different bioactive products and application methods on sesame plant height (Figure 1), differences were obtained between all treatments and the treatment where none were applied (T1).

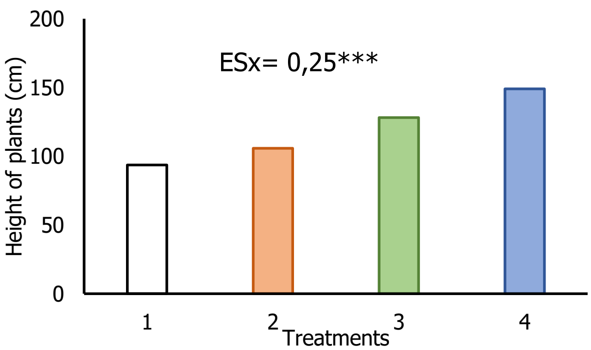

Figure 1. Height of sesame plants treated with different bioactive products.

Note: T1. Seeds soaked in water (Control), T2. Seeds soaked in Bioenraiz Plus® (2 mL L^{-1}, 30 min), T3. Foliar spray of 2 % seaweed extract (Dose 20 mL $plant^{-1}$), T4. Seeds soaked in Bioenraiz Plus® (2 mL L^{-1}, 30 min) + 2 % seaweed extract (foliar). Treatment means with the same letters do not differ significantly at p<0.05 according to Duncan.

The fact that plants where the application of Bioenraiz Plus® in seed imbibition were combined with foliar spray of seaweed extract (T4) reached the greatest heights stood out.

This result confirms the favorable effect of applying growth-stimulating bioactive products in sesame cultivation and the importance of combining application methods, which was evidenced in the plants of treatment T4.

Environmental factors and crop variety influence stem diameter and can affect yields, since this allows the plant to remain erect and facilitates nutrient transport for leaf and capsule formation (Amador, 2004). Regarding stem diameter (Figure 2), significant differences were recorded between the different treatments, with the best results achieved when Bioenraiz Plus® was used by seed imbibition (T2), with differences from the products applied individually.

It is important to note that nitrogen is the element that participates in protein synthesis and cell division (growth) and that a decrease in nitrogen can negatively affect stem diameter growth. These results obtained regarding stem diameters may be due to nitrogen contributions from the bioactive products used, which allowed this response in stem diameter growth.

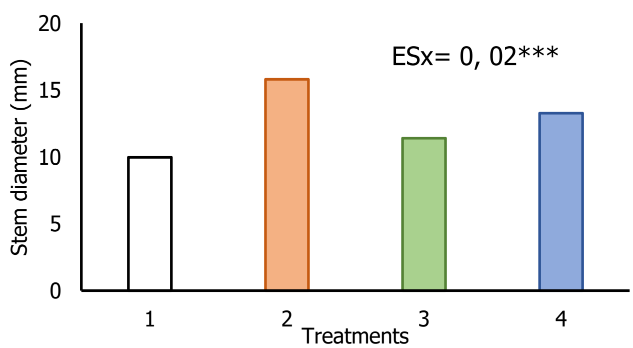

Figure 2. Stem diameter of sesame plants treated with different bioactive products.

Note: T1. Seeds soaked in water (Control), T2. Seeds soaked in Bioenraiz Plus® (2 mL L^{-1}, 30 min), T3. Foliar spray of 2 % seaweed extract (Dose 20 mL $plant^{-1}$), T4. Seeds soaked in Bioenraiz Plus® (2 mL L^{-1}, 30 min) + 2 % seaweed extract (foliar). Treatment means with the same letters do not differ significantly at $p<0.05$ according to Duncan.

Noteworthy is the high content of auxins and gibberellins present in Bioenraiz Plus®, acting simultaneously in control and development and stimulating cell division. Also, the hormone cytokinin in smaller amounts causes cell clusters to transform into apical meristems that induce stem thickness; substances contained in the biostimulant evaluated in this investigation. Furthermore, greater stem diameter can produce a greater number of capsules per plant, due to the storage of reserve substances that provide a greater quantity of nutrients.

Leaves are important organs since the photosynthesis process occurs in them, where nutrients that influence crop growth, development, and yield are concentrated. The results obtained in this study (Figure 3) demonstrate that there are no significant statistical differences between bioproduct applications, their combinations, and the control in the number of leaves per plant.

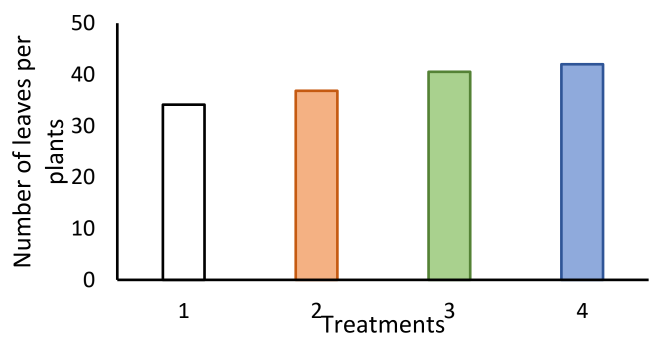

Figure 3. Number of leaves of sesame plants are treated with different bioactive products.

Note: T1. Seeds soaked in water (Control), T2. Seeds soaked in Bioenraiz Plus® (2 mL L^{-1}, 30 min), T3. Foliar spray of 2 % seaweed extract (Dose 20 mL $plant^{-1}$), T4. Seeds soaked in Bioenraiz Plus® (2 mL L^{-1}, 30 min) + 2 % seaweed extract (foliar). Treatment means with the same letters do not differ significantly at $p<0.05$ according to Duncan.

It was to be expected that due to the high nitrogen contents present in the biostimulants, the plants would present greater leaf production, which does not coincide with the results obtained by Centeno and Poveda (2010), when evaluating three organic fertilizers, who found significant differences between treatments, a different behavior from the results found in this investigation, where no statistical differences were recorded.

According to Olive and Cano (2012), the non-significant response found when determining the number of leaves per plant may be because the crop had already expressed all its genetic potential in correspondence with its biological cycle, giving way to other physiological processes such as flower and capsule formation.

In summary, the positive effect caused by Bioenraiz Plus® and seaweed extract on these growth indicators of the evaluated sesame plants was verified, with the combinations of seed imbibition with Bioenraiz Plus® and foliar spray of seaweed extract obtaining the most important results.

Yield component variables

The number of capsules per bud varies from one to three depending on the variety. The number of capsules per plant is influenced by environmental factors and soil fertility level, which evidences that any alteration of these affects this variable (Silvero, 2021).

Figure 4 shows the results obtained for the number of capsules per plant. The best results were obtained in the treatments where bioactive products were present, with significant differences from the control. Among them, the combination of their combined application over independent applications stands out with significant differences.

According to Olivas and Munguía (2000), a greater number of leaves per plant results in a greater number of capsules per plant, which differs in the experiment from the results of these variables obtained.

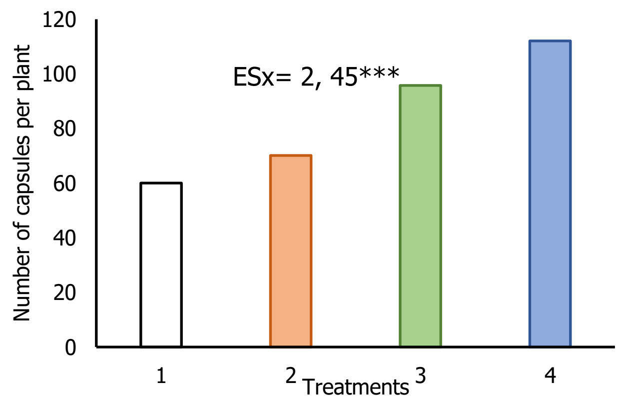

Figure 4. Influence of treatments on the number of capsules per plant.

Note: T1. Seeds soaked in water (Control), T2. Seeds soaked in Bioenraiz Plus® (2 mL L^{-1}, 30 min), T3. Foliar spray of 2 % seaweed extract (Dose 20 mL $plant^{-1}$), T4. Seeds soaked in Bioenraiz Plus® (2 mL L^{-1}, 30 min) + 2 % seaweed extract (foliar). Treatment means with the same letters do not differ significantly at $p<0.05$ according to Duncan.

The results obtained coincide with the results found by Téllez and Ramírez (1999), who reported significant differences because, by increasing the doses of bioactive products, the availability of nutrients for the plant increases, which are essential in capsule formation.

Chile et al. (2022) evaluated the effect of different organic compounds on sesame cultivation, obtaining the best results with the application of organic compounds due to the presence of phosphorus and potassium, which help the plant assimilate the necessary nutrients and improve the organoleptic characteristics and fruit quality.

In the results found for the capsule length variable (Figure 5), no significant differences were found between treatments when applying biostimulants, but there were differences between the treatments with biostimulants and the control.

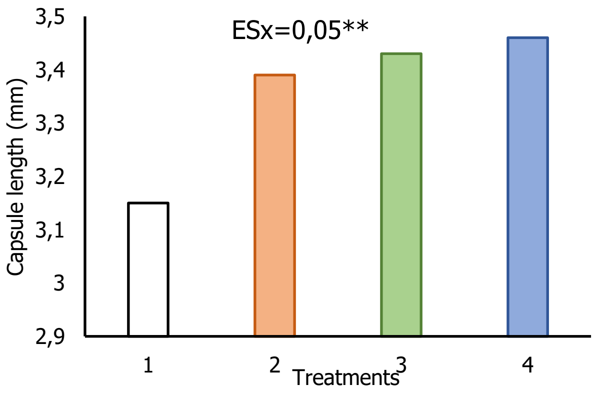

Figure 5. Capsule length (mm) by influence of treatments.

Note: T1. Seeds soaked in water (Control), T2. Seeds soaked in Bioenraiz Plus® (2 mL L^{-1}, 30 min), T3. Foliar spray of 2 % seaweed extract (Dose 20 mL $plant^{-1}$), T4. Seeds soaked in Bioenraiz Plus® (2 mL L^{-1}, 30 min) + 2 % seaweed extract (foliar). Treatment means with the same letters do not differ significantly at $p<0.05$ according to Duncan.

Rivera (2022) demonstrates that with the application of biostimulants, significant differences are obtained in capsule length variables, prevailing with higher values than the treatment without application, results that coincide with those obtained in this investigation.

When analyzing the number of seeds per capsule as a function of treatments (Figure 6), the best results were obtained with the combined application of Bioenraiz Plus® by seed imbibition with subsequent foliar spray of seaweed extract, with significant differences from the rest of the treatments.

Vargas and Blanco (2002) assert that the number of seeds per capsule is a genotypic characteristic specific to each variety and varies within a limited range according to environmental conditions and crop agronomic management.

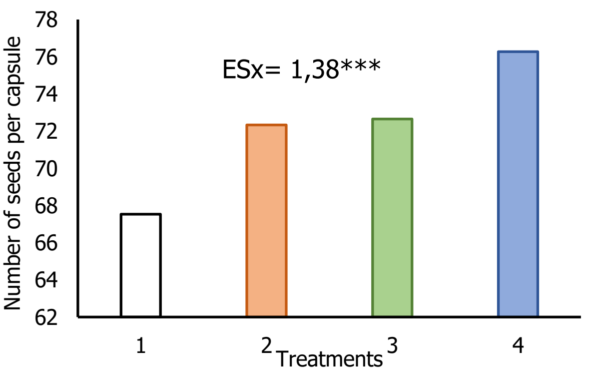

Figure 6. Influence of treatments on the number of seeds per capsule.

Note: T1. Seeds soaked in water (Control), T2. Seeds soaked in Bioenraiz Plus® (2 mL L^{-1}, 30 min), T3. Foliar spray of 2 % seaweed extract (Dose 20 mL $plant^{-1}$), T4. Seeds soaked in Bioenraiz Plus® (2 mL L^{-1}, 30 min) + 2 % seaweed extract (foliar). Treatment means with the same letters do not differ significantly at $p<0.05$ according to Duncan.

Centeno and Poveda (2010) affirm that in many cases fruit development depends on flower pollination and the activity of other growth substances. Capsules are derived from compound ovaries, that is, ovaries formed by two or more united carpels. Each carpel produces a variable number of seeds.

These same authors assert that the essential elements for the formation of growth substances are phosphorus, which helps the plant assimilate the necessary nutrients for its development, and potassium, which helps improve the organoleptic characteristics and fruit quality. These nutrients are available to the plant in the biostimulant products used.

On the other hand, Chile et al. (2022) indicate that the best vegetative growth of plants was obtained when biostimulants containing nitrogen were applied, which allowed a larger photosynthetic area and therefore more photosynthates, and the translocation of these photosynthates contributed to the efficiency of the reproductive parts, resulting in a greater number of capsules, greater number of seeds per capsule, and greater capsule weight.

Yield is the main variable in any crop and determines the efficiency with which plants make use of existing resources in the environment combined with the genetic potential of the variety. The results for this variable (Figure 7) indicate that the highest yields are obtained with the combined application of the biostimulants used, with significant differences from independent applications and the control.

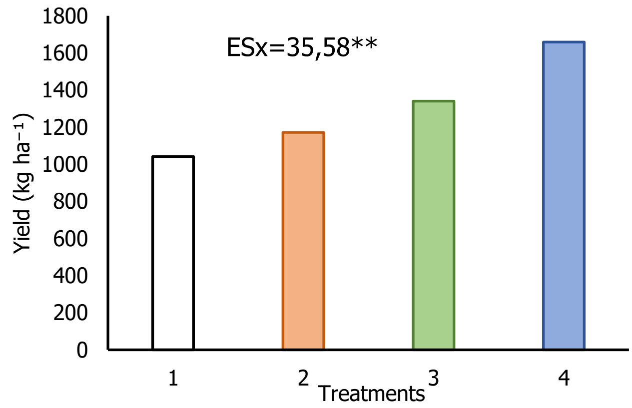

Figure 7. Yield (kg ha^{-1}) by influence of treatments.

Note: T1. Seeds soaked in water (Control), T2. Seeds soaked in Bioenraiz Plus® (2 mL L^{-1}, 30 min), T3. Foliar spray of 2 % seaweed extract (Dose 20 mL plant^{-1}), T4. Seeds soaked in Bioenraiz Plus® (2 mL L^{-1}, 30 min) + 2 % seaweed extract (foliar). Treatment means with the same letters do not differ significantly at $p<0.05$ according to Duncan.

These results coincide with those reported by Siguencia and Saritama (2022), when conducting a study on sesame growth and yield under the action of two biostimulants, where significant differences in yield were reported between treatments with biostimulant application and the control.

Montoya et al. (2019) assert that the application of biostimulants led to obtaining higher values in all yield variables, demonstrating the possibility of using these as partial substitutes for chemical fertilizers in sesame nutrition.

In summary, yield is the result of the combination of genetic and ecological factors, as well as the interaction of genotypic and phenotypic characteristics with the environment, including within the latter the influence of human activity through crop management. Therefore, environmentally friendly crop management using bioactive products constitutes an alternative to be considered in conventional agriculture.

Economic assessment

For the economic analysis, the expenses incurred during the crop cycle in each treatment were considered. The indicator used was the number of practices performed and their costs per treatment, in addition to the product dose used considering its application method compared to the reference control (T1); the remaining phytotechnical practices were the same for all treatments.

Table 7 shows the results of the economic analysis based on the expense calculations, where the best treatment was the combined application of seed imbibition with Bioenraiz Plus® and foliar application of seaweed extract (T4).

Table 7. Estimated economic assessment of the application of bioactive products to sesame.

Treatments	Yield (kg ha^{-1})	VP (cup)	VAP (cup)	B
1	1041. 68	98 500. 00	-	-
2	1171. 72	121 500. 00	24 000. 00	1. 24
3	1340. 14	161 000. 00	63 500. 00	1. 65
4	1658. 56	204 000. 00	106 950. 00	2. 09
Esx	1041. 68	98 500. 00	-	

Note: Value of production obtained (VP), Added value of production (VAP), Profit obtained (B). T1. Seeds soaked in water (Control), T2. Seeds soaked in Bioenraiz Plus® (2 mL L^{-1}, 30 min), T3. Foliar spray of 2 % seaweed extract (Dose 20 mL plant^{-1}), T4. Seeds soaked in Bioenraiz Plus® (2 mL L^{-1}, 30 min) + 2 % seaweed extract (foliar).

Although treatment 4 presented the highest costs due to the product doses used, the highest profits were achieved compared to the traditional treatment and the rest of the treatments, where the different bioproducts were used independently, demonstrating the positive effect of the combination of bioactive products used.

The lowest values in the evaluated indicators were obtained in the control treatment and among the treatments where Bioenraiz Plus® was applied independently; to which it was applied by seed imbibition.

The economic assessment analysis in this study demonstrates that there is economic feasibility in productive management, indicating the possibility of using a strategy with the application of growth-stimulating bioproducts to increase yields in sesame cultivation.

The conceived economic analysis allowed an integral assessment of the results obtained from the productive point of view, since those treatments (T3 and T4) that presented the best behavior in terms of yield and quality also showed superior economic efficiency indicators.

This alternative represents a benefit from the economic, social, and environmental point of view, fundamentally in those sown areas with difficulties in nutrient supply, with minimal possible impact on production. In this way, response is given to the strategic objectives proposed by the 2030 Agenda for Sustainable Development in Cuba and to Law 148/2022 on Food Sovereignty and Food and Nutritional Security of Cuba (SSAN) (Official Gazette of the Republic of Cuba, 2022).

Conclusions

An assessment of sesame crop yields and their components across the tested planting densities revealed that a planting distance of 0.80 m yielded the highest values, with an average yield of 812.1 kg ha^{-1}.

The various bioactive products applied, and their combinations stimulated sesame plant growth. The best results and greatest benefits were achieved by combining seed imbibition with foliar spraying.

The findings demonstrate the potential of these biostimulants to serve as partial substitutes for chemical fertilizers in sesame nutrition.

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