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Lactofen and benzyladenine combined with phosphorus doses on the growth and productivity of soybean plants[1]

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ABSTRACT

In this study, we aimed to evaluate the effects of the growth regulators lactofen and benzyladenine, combined with phosphorus doses, on soybean cultivation. Soybeans with an average harvest cycle of 134 days were used. The design was a randomized block factorial scheme with 12 treatments: growth regulators (control, lactofen herbicide 600 ml ha^{-1}, and benzyladenine hormone 150 ml ha^{-1}) and phosphorus doses (control, 75, 100, 120 kg ha^{-1}), with three replicates. The following parameters were evaluated: number of productive nodes, number of pods, grains per pod, grain productivity, weight of 1000 grains, shoot dry mass, and root dry mass. The use of benzyladenine resulted in higher values for the number of nodes, shoot dry mass, root dry mass, and grain productivity than lactofen and the control, regardless of the phosphorus dose used. The variables analyzed generally responded linearly to phosphorus doses, and applying 120 kg ha^{-1} of P_2O_5 generally provided the best results. We recommend the use of benzyladenine, together with a phosphorus dose of 120 kg ha^{-1}, to improve soybean productivity.

Keywords: growth regulator, herbicide, hormone, plant.

INTRODUCTION

Soybeans are among the most important legumes in the global market, with production of 420.78 million tons in the 2024/25 harvest.[1] This grain is considered a flex crop, with multiple uses (human food, animal feed, fuel, and industrial) and is subject to price volatility in the global market.[2,3] Brazil is currently the largest producer of soybeans in the world. According to the National Supply Company (CONAB), grain production reached 177,123.6 million tons for the 2025/26 harvest.[4]

With the high demand for soybean production, several technologies are currently on the market aimed at achieving high productivity, focusing mainly on stimulating the plant's production components to express themselves to the maximum possible.[5] Among these technologies is the use of practices that stop the growth of the plant's height and induce the formation of lateral branches. This promotes the formation of reproductive nodes, resulting in more flowers and pods per plant.[6]

The use of herbicides has yielded positive results as growth regulators in soybean crops.[7,8] In this sense, some authors have verified that the application of Lactofen in soybean production increases plant productivity.[7-11] It is believed that this herbicide acts on plant growth by inhibiting the protoporphyrinogen oxidase (PROTOX) enzyme. Although this enzyme does not directly participate in photosynthesis, it causes the accumulation of photodynamic compounds that negatively interfere with photosynthesis, respiration, and the electron transport chain,[12] reducing lodging in soybean plants and resulting in increased grain yield and its components.[13]

Other products with plant growth-regulator activity have been used in soybean cultivation. Benzyladenine is a hormone that acts to control plant development and growth through mechanisms similar to those of plant regulators naturally produced by plants (cytokinins, gibberellins, auxin, and ethylene). These regulators modify the hormonal balance of plants, promoting increased production, improving quality, and facilitating harvesting.[14-16]

Although the application of growth regulators to plants favors the emission of lateral branches and the increase in reproductive structures, they can increase the demand for energy in the form of ATP, whose synthesis depends directly on the availability of phosphorus.[17] Thus, under low phosphorus availability, the plant may not sustain the increase in the number of reproductive structures, resulting in flower abortion and lower productive efficiency.[18]

On the other hand, under adequate phosphorus conditions, the action of regulators can be enhanced, promoting greater flower setting and grain filling. However, few studies have evaluated the effects of growth regulators at varying levels of phosphorus in soybean cultivation. Therefore, this study aimed to evaluate the interaction between the growth regulators lactofen and benzyladenine associated with phosphorus doses in soybean cultivation.

MATERIAL AND METHODS

The experiment was conducted at Mata do Paraíso Farm, located in the municipality of Santana da Vargem, southern Minas Gerais, Brazil (21°20'80" S and 45°51'78" W), at an altitude of 853 m. According to the Köppen-Geiger climate classification, the region presents a Cwa climate, characterized by dry winters and rainy summers. During the experimental period, the average air temperature ranged from 22.5 to 26.3 °C, and cumulative rainfall reached 1,009 mm (Figure 1). The historical average rainfall for the region during the same period was included in Figure 1 to allow comparison with the climatic conditions observed during the experiment.

The soil of the experimental area was classified as a Typical Dystrophic Red Latosol according to the Brazilian Soil Classification System (SiBCS), with a clay content of approximately 550 g kg^{-1}. Soil samples were collected from the 0.0–0.20 m layer for chemical characterization (Table 1).[19]

Based on soil analysis, liming was performed with dolomitic limestone, with a relative neutralizing value (PRNT) of 90%, aiming to increase base saturation from 37% to 70%. A total of 4.0 t ha^{-1} of limestone was applied. Magnesium and boron were also uniformly applied throughout the experimental area using magnesium oxide (200 kg ha^{-1}) and ulexite (30 kg ha^{-1}), respectively.

The plant material consisted of soybean (*Glycine max* L.) cultivar Monsoy 6410 IPRO. The seeds were treated and inoculated according to the manufacturer's recommendations using *Bradyrhizobium japonicum* strains SEMIA 5079 and SEMIA 5080, with 20 doses applied, each corresponding to 50 mL of inoculant, and one dose of *Azospirillum brasilense* strains AbV5 and AbV6.

Potassium fertilization was conducted at a rate of 200 kg ha^{-1} of K_2O. All fertilization practices were performed in accordance with soil analysis results and regional recommendations for soybean production.

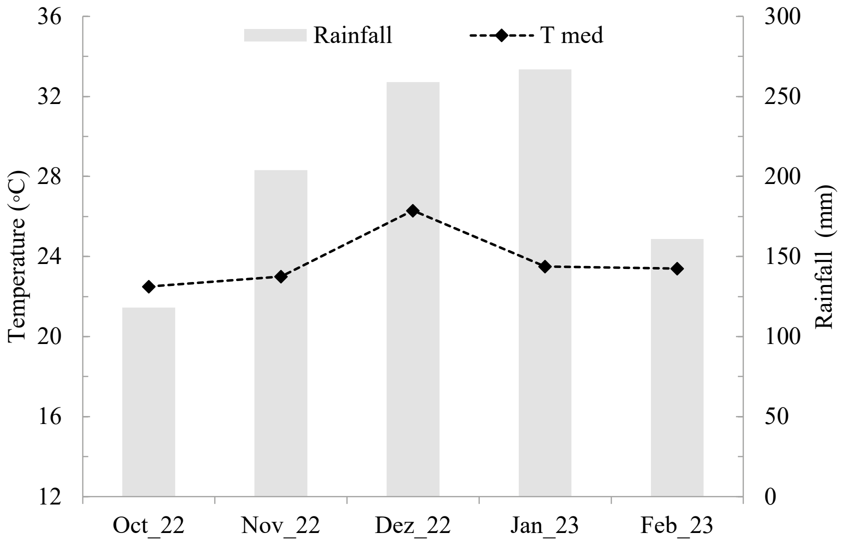


Figure 1. Air temperature and rainfall in the experimental period.

Table 1. Initial chemical characterization of the soil in the experimental area

pH	OM	P- Mehlich	K^+	Ca^{2+}	Mg^{2+}	Al^{3+}	H+Al	SB	CEC
	%	mg dm^{-3}	cmol$_c$ dm^{-3}						
4.9	3.5	10	0.36	3.0	1.3	1	7.9	4.7	12.6
V	**m**	**P-rem**	**$S\text{-}SO_4^{2-}$**	**B**	**Cu**	**Fe**	**Mn**	**Zn**	
%		**mg L^{-1}**	**mg dm^{-3}**						
37	18	7	17	0.7	2.5	20	20	10	

OM – Organic matter; P rem - Remaining phosphorus; H+Al – Potential acidity; SB – Sum of bases; CEC - Cation exchange capacity at pH 7.0; V – Base saturation; m - Aluminum saturation.

The experimental area had been cultivated with grain crops for approximately three years before the study, consisting of one year under conventional tillage followed by two years under a no-tillage system. The cropping history included corn cultivation during the first two years and soybean cultivation in the season immediately preceding the experiment.

Planting was performed on October 10, 2022, using a Jummil model 2670 mechanical planter. Each experimental plot consisted of six planting rows, spaced 0.50 m apart and 5 m long, totaling 15 m² per plot. For agronomic evaluations, the four central rows were considered the usable area, discarding the two lateral rows as borders. In addition, 0.5 m at each end of the plots was disregarded, resulting in a usable area of 8 m² (4 rows × 4 m length).

The experiment was conducted in a randomized complete block design (RCBD), consisting of three growth regulators (control, benzyladenine hormone, and lactofen herbicide) combined with four phosphorus doses (0, 75, 100, and 120 kg ha^{-1} of P_2O_5), totaling 12 treatments, with three replicates, comprising 36 plots.

In this study, an experiment was conducted to adjust nitrogen (N) doses at planting time, using the highest phosphorus dose as the reference to equalize the amount of this nutrient among the treatments. Nitrogen adjustment was performed using urea (46% N), applied along with the planting fertilizer via a planter. Phosphorus was supplied via MAP (polymethyl methacrylate) at doses of 0, 75, 100, and 120 kg ha^{-1} of P_2O_5. Thus, all treatments remained equivalent in nitrogen, isolating the effects of the different phosphorus doses applied.

Foliar applications were conducted using a 20-liter backpack sprayer, regulated to a flow rate of 200 liters per hectare, equipped with an application bar and a constant-pressure (CO_2) system to ensure greater precision in solution distribution and uniformity of application between plots. The use of this system allowed for the maintenance of constant pressure throughout the operation, ensuring a uniform application rate, greater dosage control, and adequate coverage of the treated areas, thereby reducing operational variations and increasing the reliability of the experimental results.

Foliar applications were performed at the V4 phenological stage, characterized by the presence of three fully expanded trifoliolate leaves. Spraying took place in the morning with low wind speed to reduce losses due to drift and evaporation.

Foliar applications occurred at the V4 stage because this is a critical phase of vegetative establishment in the soybean crop, during which intense metabolic activity and the definition of productive potential occur.[20]

No visual symptoms of phytotoxicity were observed in the plants after treatment, indicating product selectivity at the doses used. The products used and their doses were: Naja (lactofen 240 g L^{-1}) at 600 ml ha^{-1} and Maxcel (benzyladenine 20 g L^{-1}) at 150 ml ha^{-1}.

The P_2O_5 doses were applied together with the seed during planting using a Jumil model 2670 seeder, in six rows, with 50-centimeter spacing between rows. Other cultural practices, such as weed management and the use of fungicides, foliar fertilizers, and insecticides, were carried out in accordance with the best agronomic practices recommended for soybean cultivation.

To evaluate the production parameters of the experiment, four random plants were removed from each plot, for a total of 144 plants.

The following were evaluated: root dry matter, shoot dry matter, number of productive nodes, number of pods, grains per pod, grains per plant, average weight of 1000 grains, and productivity in kg ha^{-1}. The grains were weighed at 13% moisture, which is ideal for silo storage*, i.e.*, in line with the rest of the farm.

Productivity was determined by harvesting a 5 m² sub-area within the usable area, followed by weighing the grains and correcting for moisture. The data were extrapolated to kg ha^{-1} (equation 1).

$$Productivity\ (kg\ ha^{-1}) = \frac{P\ x\ (100 - U)}{(100 - U_p)}\ x\ \frac{10{,}000}{A} \quad \text{(eq. 1)}$$

Where:

P = weight of grains harvested in the plot (kg)

U = grain moisture at the time of weighing (%)

U_p = standard grain moisture (for soybeans, 13% was adopted)

A = area of the plot (m²)

10,000 = conversion factor from square meter to hectare

The data were evaluated using analysis of variance (ANOVA) with the Sisvar statistical program, and the means were compared using Tukey's test at 5% probability and polynomial regression.[21]

RESULTS

The use of growth regulators and phosphorus doses influenced ($p < 0.05$) all evaluated parameters in soybeans, except for grains per pod. There was a significant interaction ($p < 0.05$) between growth regulation and phosphorus doses for all variables analyzed, except grains per pod, indicating that the response to treatments depended on the level of phosphorus applied (Table 2).

The use of the benzyladenine hormone resulted in higher values ($p < 0.05$) for the variables number of nodes, grain productivity, shoot dry mass, and root dry mass compared to lactofen and the control, regardless of the phosphorus dose used (Table 3). For the variables number of pods and weight of 1000 grains, the benzyladenine hormone yielded better results than lactofen and the control, particularly at the higher phosphorus doses.

The variables analyzed generally responded linearly to phosphorus doses, and applying 120 kg ha^{-1} of P_2O_5 generally provided the best results (Figure 2). Regarding grain productivity, values ranged from 2,021.4 to 6,924.0 kg ha^{-1} in the treatments with the application of 0 and 100 kg ha^{-1} of P_2O_5, respectively.

DISCUSSION

The significant interaction observed between growth regulators and P_2O_5 doses indicates that the physiological response of soybeans is directly conditioned by the plant's nutritional status. Phosphorus plays a central role in energy metabolism, being essential for ATP formation, nucleic acid synthesis, and root development.[22] Therefore, its availability directly influences the plant's ability to respond to hormonal stimuli.

Cytokinins regulate various physiological and biochemical processes across multiple plant organs, including cell proliferation and differentiation, as well as plant responses to stress conditions. Due to their fundamental role in plant cell division, directly regulating protein synthesis during mitosis, cytokinins promote root growth, shoot development from internodes, chloroplast maturation, initiate callus formation, and stimulate plant responses to various biotic and abiotic stresses, as well as to nutrients, preventing cell degeneration, signaling protein synthesis, and increasing the activity of protective enzymes.[23]

Table 2. Significance values (p-values) obtained from the analysis of variance for the main effects of the growth regulators (GR), phosphorus doses (P doses), and their interaction (GR × P doses) on the analyzed variables

Variable	(p-value)			CV[1] (%)
	GR[1]	P doses	GR× P doses	
Number of nodes	<0.0001	<0.0001	<0.0001	1.26
Number of pods	<0.0001	<0.0001	<0.0001	3.07
Grains per pod	0.1337	0.1050	0.0740	2.10
Grain productivity	<0.0001	<0.0001	<0.0001	1.63
Weight of 1000 grains	<0.0001	<0.0001	<0.0001	0.73
Shoot dry mass	<0.0001	<0.0001	<0.0001	1.20
Root dry mass	<0.0001	<0.0001	0.0016	5.64

[1]GR. growth regulator, [2]CV. coefficient of variation.

Table 3. Variables analyzed in soybeans with a combination of growth regulators and phosphorus doses

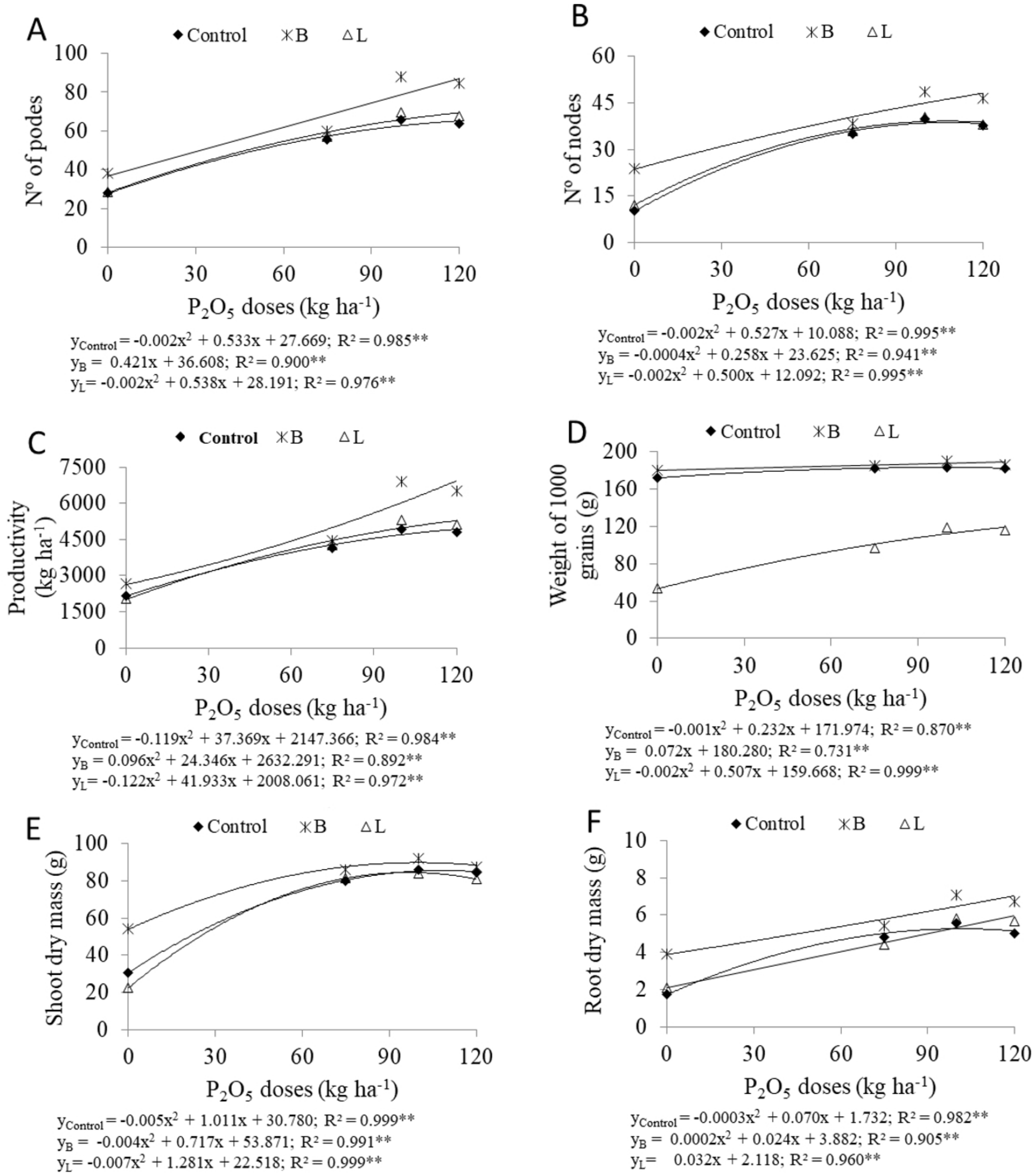
Variables	Growth regulators	P doses (kg ha^{-1})			
		0	75	100	120
Root dry mass	Control	1.75b	4.83b	5.58b	5.00c
	Lactofen	2.08b	4.41b	5.83b	5.66b
	Benzyladenine	3.91a	5.41a	7.08a	6.75a
Shoot dry mass	Control	30.83b	79.75b	86.08b	84.33b
	Lactofen	22.50c	81.50b	84.00c	80.91c
	Benzyladenine	54.00a	86.08a	92.00a	87.16a
Number of nodes	Control	12.16b	35.75b	40.25b	38.08b
	Lactofen	10.16c	35.08b	39.83b	37.58b
	Benzyladenine	23.83a	38.16a	48.58a	46.25a
Number of pods	Control	27.83b	55.58b	65.58c	63.83b
	Lactofen	28.41b	57.00a	69.83b	67.50b
	Benzyladenine	38.16a	59.91a	87.91a	84.58a
Grams per pod	Control	1.87a	1.70a	1.70a	1.72a
	Lactofen	1.88a	1.69a	1.70a	1.71a
	Benzyladenine	1.77b	1.67a	1.72a	1.72a
Grain productivity (kg ha^{-1})	Control	2,160.0b	4,148.4b	4,925.4c	4,818.6c
	Lactofen	2,021.4b	4,260.0b	5,326.8b	5,120.4b
	Benzyladenine	2,681.4a	4,469.4a	6,924.0a	6,525.0a
Weight of 1000 grains	Control	172.00b	182.33a	183.66b	182.33b
	Lactofen	159.70c	183.33a	186.00b	184.33ab
	Benzyladenine	180.00a	185.00a	190.66a	186.66a

Different letters within each evaluated parameter in the column differ from each other by Tukey's test at 5%.

The absence of a significant interaction for the variable grams per pod suggests that this characteristic exhibits less plasticity in response to management conditions, being strongly controlled by genetic factors, as reported by Board and Tan.[24]

Moreira et al.[25] state that soybean productivity is more decisively determined by flowering and the number of pods produced. Thus, the application of cytokinins, such as benzyladenine, can increase the productivity levels of phytochemicals, such as phenolics and flavonoids, compared to plants grown under normal growing conditions.

It was observed that the addition of phosphorus significantly increased the number of plant nodes, a fact that can be observed even in the control group, which showed an increase of more than three times the number of nodes when the lowest phosphorus dose of 70 kg ha^{-1} was used. Evaluating reproductive node formation is important because the greater the node formation, the greater the number of flowers and pods per plant and, consequently, the final productivity.[6,25]



Control: without the application of a growth regulator; B: benzyladenine hormone growth regulator; L: lactofen herbicide growth regulator.

Figure 2. Phosphorus doses in variables evaluated in soybeans: (A) number of pods, (B) number of productive nodes, (C) grain productivity, (D) weight of 1000 grains, (E) shoot dry mass, and (F) root dry mass.

The aerial part is part of plant architecture and is directly involved in controlling growth and inducing branching. It is a determining factor in productivity because it relates to production components such as the number of stems and nodes.[10]

It was found that adding phosphorus increased the dry weight of the roots, a change visible even in the control group, without the addition of growth regulators or herbicides. According to Borcioni et al.,[26] management that allows for an increase in root mass is ideal for the plant to exploit better the absorption and transport of nutrients available in the soil.

Mangena[27] also found that the use of benzyladenine promoted greater plant growth, productivity, and biomass in soybean cultivation, thus demonstrating that the product can indeed improve soybean productivity. It is worth noting that adding 100 kg ha^{-1} of phosphorus yielded the best results for all characteristics evaluated.

Phosphorus is an important macronutrient for plants and a major limiting factor for plant development and growth, primarily because it is involved in photosynthesis.[28] However, its incorrect use in high doses can damage the aquatic environment, leading to eutrophication of this ecosystem.[29] Therefore, determining the ideal dose for plant cultivation is essential.

Some studies aimed at determining the phosphorus dose for soybeans have found a quadratic effect as phosphorus doses increase. In this sense, Souza et al.[30] found that the ideal dose for obtaining better soybean productivity and its increments is between 80 and 120 kg ha^{-1}, and that there is already a decrease in production and reproductive and physiological characteristics at the dose of 120 kg ha^{-1}, as observed in this study and in the study by Guerra et al.[31]

Values of 185 g to 190 g were observed for the weight of a thousand grains in the treatment where 100 kg ha^{-1} was used. The positive results observed with the use of benzyladenine associated with phosphorus differ from those reported by Moreira et al.,[25] who observed that this growth regulator affected the soybean plant's development. These authors found that the weight of a thousand grains in the control group was 174.9 g, higher than in the benzyladenine-treated group, which recorded 146.0 g in a thousand grains. According to Souza et al.,[32] this result may be due to the reduction in plant height caused by plant growth regulators.

Karpstein Junior and Waureck[33] observed a negative linear effect on one-thousand-grain weight in soybean cultivation using different doses of Lactofen (0.5, 0.75, 1.0, and 1.25). However, despite the negative effects of the doses, the authors found a mass ranging from 0.222 to 0.238 g, which is higher than that found in this study.

The number of pods was positively affected by the application of the plant growth regulator, regardless of the phosphorus dose used. These results differ from those reported by Souza et al.,[32] who observed no effect of benzyladenine on the number of pods in soybean plants. Marianno[34] stated that some factors can affect the number of pods per soybean plant, including the stage of application, for which the authors recommend R1. In this study, the application occurred at the V4 stage; at this stage, plants exhibit greater foliar absorption capacity and response to growth regulators, allowing for greater influence of the treatments on vegetative development and subsequent formation of productive structures.[20]

In this study, the use of Lactofen did not improve many of the characteristics evaluated, as it was similar to the control in some cases, mainly in terms of productivity. Some studies have reported that Lactofen has beneficial effects on soybeans. Martins et al.,[35] also evaluated the use of the herbicide Lactofen with the phytohormone kinetin on morphoagronomic traits, carbohydrate partitioning, and productivity in soybeans. The application of Lactofen at V6 influenced the morphoagronomic characteristics and increased soybean productivity by 312 kg ha^{-1}.

Productivity increased with the use of phosphorus, resulting in a gain of approximately 94%, that is, from 2,160.0 kg ha^{-1} to 4,148.4 kg ha^{-1}. This value can be recorded when comparing the control group with the phosphorus dose of 75 kg ha^{-1}. This value corresponds to an increase of 1,988.4 kg ha^{-1}, which is much higher than that observed by Martins et al.,[35] thus highlighting the importance of phosphorus in production.

The average yield of soybean crops in the Santana da Vargem region and southern Minas Gerais varies with the level of technology adopted and the local edaphoclimatic conditions. According to surveys by the National Supply Company (CONAB), the average regional productivity is around 3,000 to 3,600 kg ha^{-1}, values compatible with medium- to high-technology production systems predominant in the region.[4]

According to Martins et al.,[35] the average increase of 312 kg.ha^{-1} in soybeans with the application of Lactofen should be viewed positively, as it is a low-cost product compared to synthetic growth regulators. However, because Lactofen can cause phytotoxicity in soybeans, it is extremely important that no other stress, such as water deficit, occurs after spraying with the product. According to Rosa,[36] the recovery of the canopy through the growth of new leaves that did not come into contact with the herbicide takes around 20 days under normal conditions.

The discrepancies found between the results obtained in this study and others conducted mainly with Lactofen are explained by Karpstein Junior and Waureck,[33] who stated that some soybean cultivars have high productive potential due to advances in breeding, but it is not always possible to extract their full potential due to numerous factors, one of which is the excessive growth of some cultivars, possibly resulting in crop lodging.

There is also the influence of environmental factors, sowing seasons, the cultivar's growth habits, its maturation group, and phenological stages of product application. These particularities can generate different results.[25]

The results show that the agronomic efficiency of growth regulators is directly conditioned by an adequate phosphorus supply, highlighting the importance of integrated management of fertilization and physiological practices to maximize soybean productive performance.

CONCLUSION

Based on the results obtained, we recommended using the growth regulator benzyladenine together with a phosphorus dose of 120 kg ha^{-1} to improve soybean productivity.

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DATA AVAILABILITY STATEMENT

The authors declare that all data are contained within the article.

AUTHOR CONTRIBUTIONS

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