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Agronomic efficiency of fermented compost fertilization in organic production of single-head broccoli

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ABSTRACT

This study evaluated the agronomic efficiency of bokashi-type fermented compost, formulated with brewery residue (RC), wheat bran (FT) and castor bean meal (FM), in the production of single-head broccoli under organic management conditions. Two field trials were conducted in Baixada Fluminense, Rio de Janeiro, considering three cultivars (Legacy, Veratto and Coliseu) and five doses of fermented compost (0, 100, 200, 300 and 400 kg/ha of N). The experiment was conducted in a randomized complete block design with a split-plot arrangement and four replications. The results showed differences in the performance of the cultivars according to the fertilizer doses and climatic conditions. The cultivars Veratto and Legacy stood out in terms of yield, reaching the highest yields at the dose of 400 kg of N ha⁻¹, whereas Coliseu showed a linear dose-response. The use of compost was effective in meeting the crop's nutritional requirements, promoting yield levels consistent with commercial standards, despite adverse weather conditions that influenced the development pattern of the cultivars.

Keywords: *Brassica oleracea* var. *italica*, bokashi, brewery residue.

RESUMO

Eficiência agrônômica da fertilização com composto fermentado na produção orgânica de brócolis americano

Este estudo avaliou a eficiência agrônômica do composto fermentado tipo Bokashi, formulado com resíduo de cervejaria (RC), farelo de trigo (FT) e farelo de mamona (FM), na produção de brócolis americano em condições de manejo orgânico. Foram conduzidos dois ensaios de campo na Baixada Fluminense, Rio de Janeiro, considerando três cultivares (Legacy, Veratto e Coliseu) e cinco doses do composto fermentado (0, 100, 200, 300 e 400 kg/ha de N). O delineamento experimental foi de blocos casualizados, dispostos em parcelas subdivididas, com quatro repetições. Os resultados evidenciaram diferenças no desempenho das cultivares em função das doses de adubação e das condições climáticas. As cultivares Veratto e Legacy destacaram-se em termos de produtividade, alcançando os maiores rendimentos na dose de 400 kg/ha de N, enquanto Coliseu apresentou resposta linear ao aumento das doses. O uso do composto mostrou-se eficiente para atender às exigências nutricionais da cultura, promovendo produtividade compatível com os padrões comerciais, apesar das condições climáticas adversas, que influenciaram no padrão de desenvolvimento das plantas das respectivas cultivares.

Palavras-chave: *Brassica oleracea* var. *italica*, bokashi, resíduo de cervejaria.

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Single-head broccoli (*Brassica oleracea* var. *italica*) is one of the vegetables with high demand in the organic market. In order to increase the supply of this vegetable, expanding the periods suitable for cultivation is necessary. This has already been partially achieved through the release of early-maturing and low-chill cultivars (Seabra Junior *et al.*, 2014; Torres *et al.*, 2020). Encouraging cultivation in regions closer to the organic consumer market is also essential. Among the potential areas is Baixada Fluminense, due to its proximity to the metropolitan region of the city of Rio de Janeiro. This region presents annual average temperatures of 24°C. However, during summer, temperatures above 42°C can be observed (Macedo *et al.*, 2022).

To develop organic production, the availability of agricultural inputs that comply with current legislation and are accessible in terms of supply and cost is essential. Nitrogen (N) is one of the limiting nutrients, since the

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application of synthetic nitrogen fertilizers is restricted (Oliveira *et al.*, 2014; Aguiar *et al.*, 2024). To overcome this limitation, nitrogen sources that meet organic farming legislation need to be evaluated, as well as new formulations developed and doses adjusted, aiming to guarantee the sustainability of production systems.

Among the inputs of great interest are fermented bokashi composts. This compost is a valuable input for organic farming, especially due to the fact that it can be produced on-site, which reduces input acquisition costs and promotes sustainability through organic waste recycling (Aguiar *et al.*, 2024; Erdal *et al.*, 2025). The production process involves organic material fermentation, in which normally beneficial yeasts or microorganisms are added, resulting in a fertilizer rich in nutrients and with properties that enhance the biological attributes of the soil (Goulart, 2023; Vieira Filho *et al.*, 2023).

Although a wide range of formulations for bokashi-type fermented compost can be formulated, a common principle is observed: the mixture of raw materials with a high nitrogen content combined with carbon-rich materials (Hata *et al.*, 2020). The most common or traditional formulation involves combining wheat bran, rich in carbon, with castor bean meal or cake, which contains a high nitrogen content (Oliveira *et al.*, 2014; Xavier *et al.*, 2019). Despite this, recent results highlight the potential of using other materials to replace, totally or partially, castor bean cake, such as legume biomass meal (Goulart, 2023; Aguiar *et al.*, 2024); and wheat bran, as brewery residue (Souza Júnior *et al.*, 2023). After defining the formulation, identifying the most appropriate doses for each crop and production system is important.

Given the above, this study aimed to evaluate the effects of a fermented compost, formulated with brewery residues, wheat bran and castor meal, on the single-head broccoli development. The authors tested five doses of the compost, defined based on nitrogen input, aiming to verify its agronomic efficiency. In addition, we evaluated the response of three commercial cultivars in relation to different doses of compost and performance of these combinations in two different growing seasons, under the weather conditions of Baixada Fluminense-RJ.

MATERIAL AND METHODS

Field trials were carried out at Setor de Horticultura of UFRRJ, located in the municipality of Seropédica, in Baixada Fluminense, RJ. Initially, soil samples classified as Planosol according to the Brazilian Soil Classification System were collected and analyzed (pH: 5.4; Ca = 1.9 cmol_c/dm³; Mg = 0.48 cmol_c dm³; Al = 0.1 cmol_c dm³; H+Al = 1.98 cmol_c dm³; V = 57%; CTC = 4.6 cmol_c dm³; P = 226 mg/dm³; K = 101 mg/dm³). Based on the soil analysis, 0.14 kg/m² of CaO was applied for liming.

Two trials were carried out: the first trial was carried out from May 02 to August 08, 2023 (E1); the second was from June 19 to September 04, 2023 (E2). In both trials, broccoli was grown in seedbeds measuring 1.20 m wide and 0.20 m high, covered with white plastic mulch. Before mulch application, the area was demarcated for the five doses of bokashi fertilization, 10 days before seedling transplant, and for the installation of two drip irrigation lines.

The compost was formulated using malt spent grains as the brewery residue (RC), wheat bran (FT), and castor bean meal (FM), in a 50:10:40 ratio (% w/w) of RC:FT:FM, respectively. Due to the high moisture content of the brewery residue, 10% wheat bran was included to improve compost stabilization. The materials were homogenized and Embiotic® active yeast (*Lactobacillus plantarum* and *Saccharomyces cerevisiae*) was added. The activation and dilution of the yeast were carried out according to Vieira Filho *et al.* (2023). The mixture obtained was stored in 50-L barrels, incubated at 28.5°C. After 21 days, the barrels were opened and the samples were taken out in order to have the water content, pH and total contents of C, N, P, K, Ca and Mg determined (Table 1) (Goulart, 2023). The authors used five doses of bokashi (0; 4.72; 9.44; 14.16; and 18.88 t/ha), calculated using the total N content in the fertilizer (4.41%) identified in a chemical analysis, in order to supply 0, 100, 200, 300 and 400 kg/ha of N, respectively.

Three broccoli cultivars used were: Legacy (Seminis), Veratto (Topseed) and Coliseu (Feltrin). These cultivars were identified as late, medium and early maturing ones. The seedlings were sown in a greenhouse, in expanded polystyrene trays of 128 cells, filled with Carolina Soil Orgânico® substrate. At 35 days after sowing, the seedlings were transplanted to seedbeds, spaced 0.6 x 0.6 m.

Both trials included the same sources of variation: five Bokashi doses and three cultivars. The experiment was arranged in a randomized complete block design with a split-plot arrangement, with four replications. The cultivars were distributed in plots and the doses in split-plots, 17.40 and 2.88 m², respectively. An additional spacing of 0.5 m was included between subplots. Each split-plot contained eight plants, the four central split-plots were selected for evaluations. The plants were managed according to usual practices for the crop (Melo, 2015; Nick & Borém, 2022), following specifications for organic management.

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Table 1. Contents of N, P, K, Ca, Mg and pH value in the Bokashi fermented compost, quantities applied per unit area in the different treatments and respective amounts of nutrients provided. Seropédica, UFRRJ, 2023.

Formulation	N	P	K	Ca	Mg	pH
	(g/kg)					
50%RC + 10% FT + 40% FM	44.10	8.05	8.02	4.49	4.03	4.52

Treatments and nutrient supply						
Bokashi dose (t/ha)	Quantity of nutrient supplied (kg/ha)					
	N	P	K	Ca	Mg	
0.00	0	0.00	0.00	0.00	0.00	
4.72	100	52.57	52.38	29.32	26.32	
9.44	200	105.14	104.75	58.64	52.64	
14.16	300	157.71	157.13	87.97	78.96	
18.88	400	210.29	209.50	117.29	105.27	

RC = Brewery residue; FT = Wheat bran; FM = Castor bean meal.

Harvests were performed twice a week, considering well-formed, compact inflorescences, showing diameter >14 cm and with no abnormalities. We evaluated stem height (ALT) with the aid of a graduated ruler. The inflorescence diameter (DI) was obtained using a digital caliper. The fresh mass of the stem (MFC), leaves (MFF) and inflorescences (MFI) were weighed on an analytical balance. The dry mass of the stem (MSC), leaves (MSF) and inflorescences (MSI) were obtained after drying in a forced ventilation oven at 65°C to constant weight. Using the number and average fresh mass of the harvested inflorescences, the authors evaluated the yield, expressed in tons/ha. The variable was obtained using the average fresh mass of the inflorescences (kg) X number of plants per ha/1000. We used a population of 27,778 plants/ha, in a spacing of 0.60 x 0.60 m between rows and plants.

Data were tabulated and analyzed, then, submitted to test of residue normality (Shapiro-Wilk & Lilliefors) and homogeneity of variance (Bartlett & Levene). When the assumptions of analysis of variance were not met ($p > 0.05$), the data were transformed using square-root transformations of Y, $Y + 0.5$, and $Y + 1$, natural logarithm of Y, and Box-Cox family transformations. After the assumptions were met, the data were subjected to analysis of variance (ANOVA), followed by Tukey's test for comparison between cultivars, and by linear and quadratic regression analyses to evaluate the effect of doses ($p < 0.05$). The analyses were performed using R software, version 4.3.1 (R CORE TEAM, 2023), with the ExpDes.pt, nortest, lawstat, and MASS packages.

RESULTS AND DISCUSSION

Planting time, meteorological conditions and plant development

The authors verified satisfactory broccoli production in both trials, noticing a difference between the two growing seasons in relation to cultivar performances and effects of fertilization doses. In trial 1 (E1), the plants were kept in the field from May 02 to August 08, 2023, and harvested from June 27 to July 27 (Cultivar Coliseu), from July 04 to July 20 (Cultivar Veratto) and from July 13 to August 08 (Cultivar Legacy). Throughout the trial, the minimum temperatures were from 15.42 to 26.28°C and maximum temperatures were from 16.94 to 28.37°C; relative humidity ranging from 44.58 to 90.45% and total rainfall 115.6 mm, distributed over 98 days during the trial (Figures 1A, B and C). In trial 2 (E2), the plants were in the field from June 19 to September 04, 2023, and harvested from August 10 to 14 (Cultivar Coliseu), from August 14 to 16 (Cultivar Veratto) and from August 23 to September 04 (Cultivar Legacy). Throughout trial E2, the minimum temperatures were from 15.42 to 28.85°C and maximum temperatures were from 16.94 to 30°C; relative humidity ranging from 36.26 to 90.5% and total rainfall 105.20 mm, distributed over 72 days during the trial (Figures 1D, E and F). In both trials, the temperature conditions were above what was identified as ideal for the crop, which is from 15 to 24°C (Melo, 2015), especially in E2 (Figures 1D and E).

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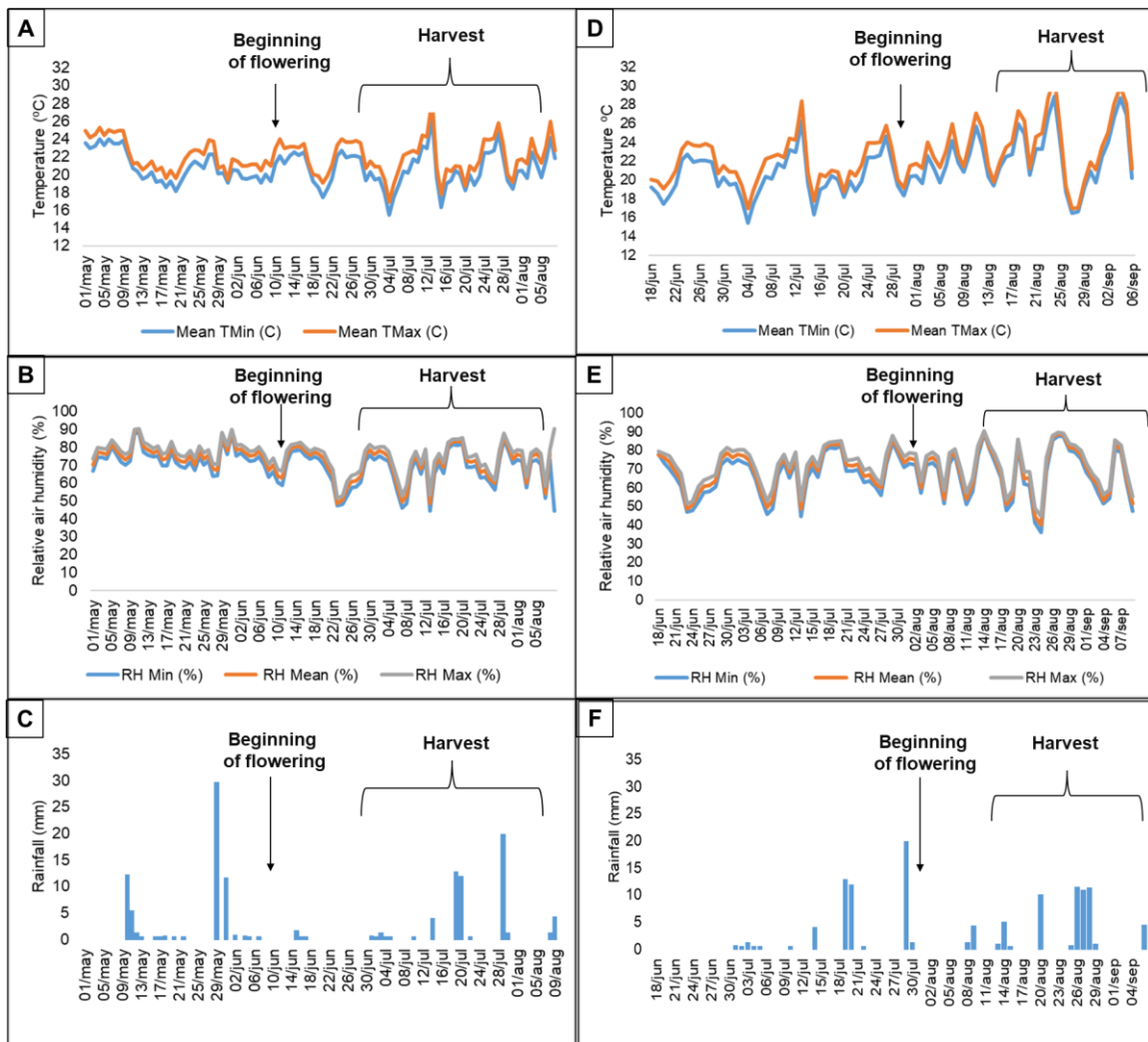


Figure 1. Minimum and maximum temperatures (°C), relative air humidity (%) and rainfall (mm) recorded in the first (A, B, C) and second (D, E, F) trials done from May 02 to August 08 and June 19 to September 04, 2023 respectively. Seropédica, UFRRJ, 2023.

The mild temperatures and the better distributed rainfall in the beginning of the plant cycle in E1 were key factors for optimal plant development and productivity and quality gains. Harvests were performed under drier conditions, which favored greater integrity of the inflorescences (Figures 1A, B, C). In E2, the authors observed an increase in temperature values close to 30°C, sharp fluctuations in air humidity, and rainfall occurring during most of the inflorescence formation and harvest period (Figure 1D, E, F). These conditions negatively affected both plant development and the formation and appearance of the inflorescences, resulting in shorter harvest periods, which was also discussed by Santos *et al.* (2020).

Excessive rainfall and high temperatures favor the occurrence of pests and diseases in broccoli, especially during harvest time, and affect negatively the inflorescences in terms of diameter, fresh mass, color and texture, and post-harvest preservation (Nick & Borém, 2022). Understanding the performance of broccoli cultivars in specific environmental contexts allows to select the most suitable cultivar and planting time, aiming for gains in productivity and inflorescence quality (Seabra Junior *et al.*, 2014; Santos *et al.*, 2020).

Harvest point of the three cultivars

The three cultivars tested in the trials differed in cycle length and harvest timing. Coliseu was the earliest cultivar in both trials, being harvested between 56 and 86 days after transplant in E1 and between 52 and 56 days after transplant in E2. Cultivar Veratto was identified as intermediate, being harvested between 63-79 days and 56-58 days after transplant, in E1 and E2, respectively. Legacy was the latest cultivar, being harvested between 72 and 98 days and between 65 and 72 after transplant, in E1 and E2, respectively (Figure 2A and B). We noticed, for the three cultivars, shorter harvest period from E1 to E2, due to more adverse weather conditions in

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E2 and earlier harvests due to changes in the development pattern of flower buds and greater susceptibility to rot due to high humidity.

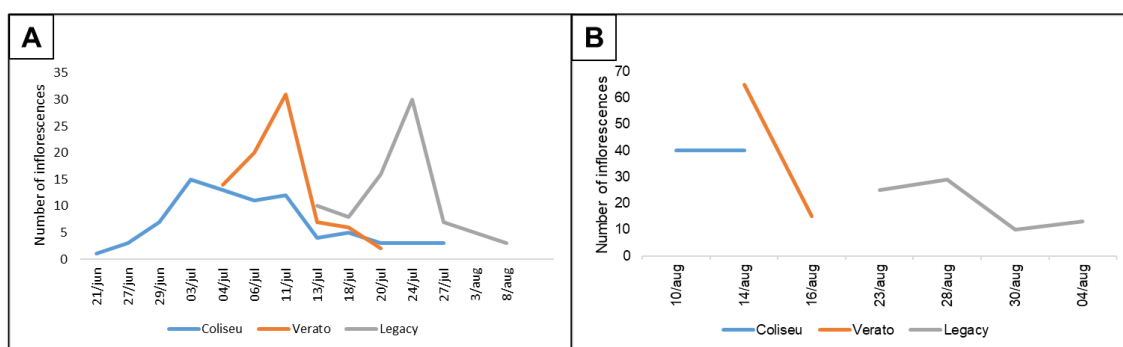


Figure 2. Number of inflorescences harvested throughout trial 1 (A) and trial 2 (B) done from May 02 to August 08 and June 19 to September 04, 2023, respectively. Seropédica, UFRRJ, 2023.

The cultivars were harvested following two different patterns in the respective trials (Figures 2A, B). In E1, the earliest cultivar (Coliseu) was the first one to be harvested, and harvest period was extended until the cycle was over, reaching a peak on July 4th. Right after, the medium maturing cultivar (Veratto) was harvested, reaching a peak on July 13th. Before finishing harvesting these two cultivars, the late cultivar (Legacy) started to be harvested too, having reached its peak on July 27th. This pattern proved to be highly relevant to small producers, since we could demonstrate the importance of diversifying the broccoli cultivars (Seabra Junior *et al.*, 2014; Arruda Junior *et al.*, 2015), as one more strategy to optimize the product availability in Baixada Fluminense region.

In E2, despite the same sequence among the cultivars, the same harvest pattern was not observed due to stresses resulting from less favorable conditions. As a result, the harvest periods were much shorter, with a gap from August 16th to 24th. In other words, considering this planting date and these three cultivars, it would not be possible to guarantee a regular supply of broccoli for such an extended period as in E1.

In E1, the plants showed the expected traits for each cultivar, and the inflorescences had good commercial characteristics, as described by Melo (2015): compact structure and intense green coloration. Coliseu inflorescences had medium-sized beads, whereas the other two cultivars exhibited finer beads. However, the same did not occur in E2, as, due to adverse weather conditions, the authors noticed higher frequency of inflorescences with bracts (Santos *et al.*, 2020), especially in Legacy, the latest cultivar.

Effect of fertilization and cultivation

The three cultivars, Legacy, Veratto and Coliseu, showed a consistent response pattern to bokashi doses in both trials, mainly for vegetative development, inflorescence diameter, inflorescence mass, and average yield.

In E1, the authors observed a significant cultivar effect on all the evaluated analyses (Table 2); significant effect of the compost dose on all the variables, except ALT and MSC and, significant effect of the interaction cultivar X dose of the compost on MFC, DI and MFI and MSI.

In E2, the authors observed a significant cultivar effect on NF, MFC, MSC and MSF, DI, MFI and MSI; significant effect of the compost dose on all the variables, except ALT and MFC and; significant effect in the interaction of cultivar X dose of the compost on ALT, MSF, MFI and MSI.

In E1, Legacy showed the highest vegetative development (Table 2 and Figure 3A). This performance is due to the fact that this cultivar has a longer cycle. The longer cycle allowed higher biomass accumulation, confirming the pattern described in literature (Seabra Junior *et al.*, 2014). In general, fertilization has not affected plant height or MFC, with only a cultivar effect (Table 2). This result showed that an increase in N is not a determining factor for plant height, as it was also reported by Torres *et al.* (2020). So that, this variable is not a good indicator of broccoli's response to nitrogen fertilization.

In E2, the cycle was shorter for the three cultivars: 70, 58 and 52 days for Legacy, Veratto and Coliseu, respectively. The environmental conditions which were less favorable for plant development (Melo, 2015) resulted in a general reduction in plant development (Table 2 and Figure 4), especially for MFF in Legacy, due to a shorter cycle and reduced biomass accumulation.

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Table 2. Cultivar effect of the single-head broccoli on height (ALT) and stem dry mass (MSC), number of leaves (NF), fresh mass (MFF) and dry (MSF) of leaves in trial 1 (May 02 to August 08, 2023); and on stem fresh mass (MFC), MSC, NF, MFF and inflorescence diameter (DI) in trial 2 (June 19 to September 04, 2023). Trials performed in the field under organic management and fertilized with doses of bokashi fermented compost Seropédica, UFRRJ, 2023.

Cultivar	Trial 1				
	Stem		Leaf		
	ALT (cm)	MSC (g)	NF	MFF (g)	MSF (g)
Legacy	30.37 a	45.36 a	25.15 a	1113.65 a	119.26 a
Veratto	20.69 b	25.72 b	18.58 b	875.50 a	83.17 b
Coliseu	17.49 c	19.13 c	18.28 b	719.63 a	67.77 c

Cultivar	Trial 2				
	Stem		Leaf		
	MFC (g)	MSC (g)	NF	MFF (g)	DI (cm)
Legacy	464.40 a	39.69 a	23.46 a	639.31 a	17.22 a
Veratto	277.88 b	20.82 b	16.97 b	849.00 a	16.26 ab
Coliseu	200.00 c	17.30 b	16.80 b	772.52 a	15.17 b

*In each trial, averages followed by the same letter in the column do not differ from each other by Tukey test ($p < 0.05$).

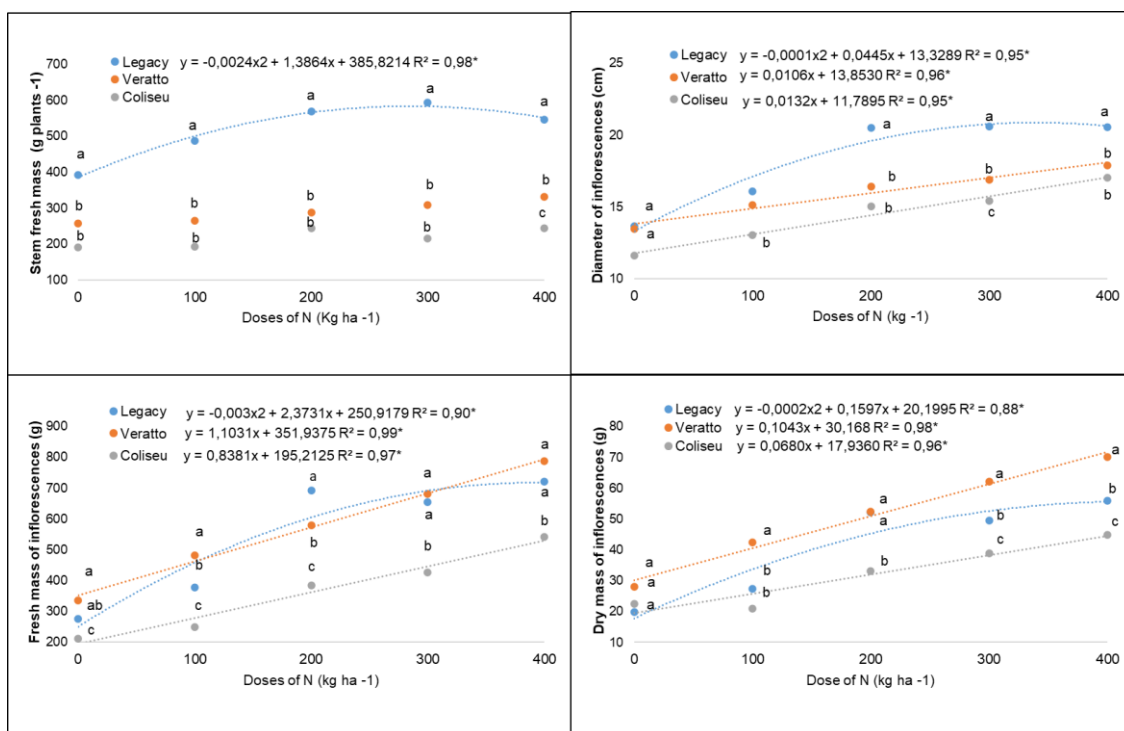


Figure 3. Interaction effect among N doses, using different doses of bokashi fermented compost and three broccoli cultivars (Legacy, Veratto and Coliseu) on stem fresh mass (A), diameter (B), fresh mass (C), dry mass (D) of inflorescences in trial 1 done from May 02 to August 08, 2023 under field conditions. Seropédica, UFRRJ, 2023. *Significant at 5% probability ($p < 0.05$).

The interaction between N doses and cultivars highlights the different responses in relation to the traits of each cultivar. In both trials, Legacy and Veratto showed quadratic response for the increase of bokashi doses, with gains in DI and accumulation of MFC, MFI and MSI in E1 (Table 2 and Figure 3A); and ALT and accumulation of MSF, MFI and MSI in E2 (Table 2 and Figure 4A). In general, the highest accumulations were observed at intermediate doses (200 to 300 kg/ha of N). The earliest cultivar Coliseu showed a linear response for the increase of doses, with positive increases in MFI and MSI, especially at doses up to 300 and 400 kg/ha of N. The differences in the responses of the cultivars are probably due to variations in the nutrient absorption process in relation to the plant's cycle and vigor.

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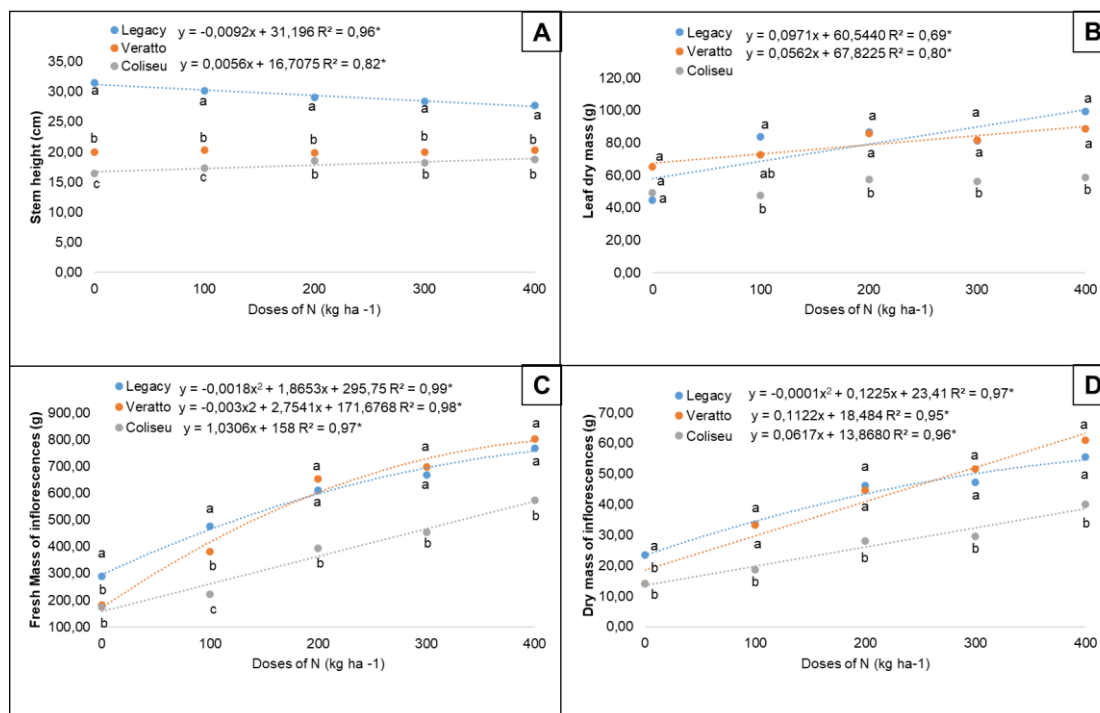


Figure 4. Interaction effect among N doses, using different doses of bokashi fermented compost and three broccoli cultivars (Legacy, Veratto and Coliseu) on stem height (A), leaf dry mass (B), fresh mass (C) and dry mass (D) of inflorescences in trial 2 done from June 19 to September 04, 2023 under field conditions. Seropédica, UFRRJ, 2023. *Significant at 5% probability ($p < 0.05$).

Table 3. Average yield of three single-head broccoli cultivars fertilized with different N doses (0, 100, 200, 300 and 400 kg/ha) provided by different doses of bokashi fermented compost (0; 4.72; 9.44; 14.16; and 18.88 t/ha), respectively, in field trial conditions under organic management, from May 02 to August 08 (trial 1) and June 19 to September 04 (trial 2) in 2023. Seropédica, UFRRJ, 2023.

Cultivar	N Doses (kg/ha)				
	0	100	200	300	400
	Yield (t/ha)				
Trial 1					
Legacy	7.67 ab	10.51 b	19.24 a	18.18 a	20.05 a
Veratto	9.31 a	13.38 a	16.07 b	18.91 a	21.86 a
Coliseu	5.88 b	6.92 c	10.69 c	11.87 b	15.04 b
Trial 2					
Legacy	8.00 a	13.21 a	16.94 a	18.54 a	21.36 a
Veratto	5.03 b	10.60 b	18.12 a	19.41 a	22.27 a
Coliseu	4.87 b	6.18 c	10.94 b	12.62 b	15.96 b

*In each trial, averages followed by the same letter in the column do not differ from each other by Tukey test ($p < 0.05$).

For inflorescence diameter, which is a very important commercial trait, cultivar Legacy stood out in both trials. In E1, Legacy produced inflorescences with higher diameter (Figure 3B), corroborating the values observed by Seabra Junior *et al.* (2014) and Vidigal *et al.* (2021) for longer cycle cultivars. In E2, despite the shorter cycle duration, DI in Legacy was also superior, followed by Veratto and Coliseu (Table 2). However, commercial valuation in relation to higher DI in Legacy was negatively impacted by the increased frequency of bracts between the florets, caused by heat stress during the flowering phase (Santos *et al.*, 2020), as previously mentioned.

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The average yield of the three cultivars were significantly influenced by the doses of bokashi (Table 3). In E1, the highest productivities were verified in Veratto (21.86 t/ha) and Legacy (20.05 t/ha) at a dose of 400 kg/ha of N. In E2, the productivity was slightly superior in Veratto, followed by Legacy, 22.27 t/ha and 21.36 t/ha, respectively, at a dose of 400 kg/ha of N. Coliseu, which shows shorter cycle and smaller size, showed lower productivity in relation to Veratto and Legacy in both trials, with maximum values of 15.04 t/ha and 15.96 t/ha, respectively, at a dose of 400 kg/ha of N. These values are consistent with the standard described in literature, which showed lower productivities for shorter cycle cultivars (Seabra Junior *et al.*, 2014).

For market suitability, which values inflorescence weighing 300 to 400 g (Melo, 2015), Legacy and Veratto achieved these weight standards with a dose of 100 kg/ha of N. Coliseu, which presented smaller inflorescences, would require doses starting at 200 kg/ha of N, meaning higher fertilization costs to reach the same MFI standard (Table 2). However, showing shorter size and shorter cycle, gains in productivity could be desired with greater plant density (Arruda Junior *et al.*, 2015; Macedo *et al.*, 2022). These results reinforce the need for fertilization management tailored to the specific traits of each cultivar, especially regarding cycle and size, as well as spacing adjustments for smaller cultivars, such as Coliseu.

We can conclude that growing organic broccoli in Baixada Fluminense Region is suitable, especially from May to August, when the weather conditions are more favorable for the crop. Furthermore, planting the three cultivars tested at the beginning of May allows for efficient staggering of the harvests of high-quality inflorescences. Using a fermented compost obtained from a formulation with brewery, wheat bran and castor bean cake showed to be suitable for growing and production of single-head broccoli, providing plants with necessary nutrients for development and production at commercial level. The three cultivars, Legacy, Veratto and Coliseu, responded positively to fertilization doses used in these trials, reaching maximum productivity at a dose equivalent to 400 kg/ha of N, which demonstrates the effectiveness of the fermented compost in promoting growth and productivity in broccoli inflorescences.

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