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Scientific Article

Yield of jambu crop fertilized with biofertilizer and fish farming effluent

Rendimento da cultura do jambu adubado com biofertilizante e efluente de piscicultura

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ABSTRACT – The cultivation of jambu (*Acmella oleracea*) is widely spread in the Amazon region, primarily due to its use in cuisine, pharmaceutical industry, and cosmetics. The cultivation is predominantly carried out by family farming, using animal manure for fertilization. Biofertilizers and aquaculture effluents are increasingly available on rural properties and, while they can become environmental pollutants, they also present an excellent alternative for crop fertilization. The objective of this study was to evaluate the use of aquaculture effluent and biofertilizer on the yield of jambu (*A. oleracea*). The experiment was conducted in the municipality of Castanhal, Pará, in a completely randomized experimental design with six treatments: T1 – well water without fertilization (control); T2 – aquaculture effluent; T3 – 25% biofertilizer diluted in water; T4 – 50% biofertilizer diluted in water; T5 – 75% biofertilizer diluted in water; and T6 – 100% biofertilizer, with four replications. Parameters evaluated included fresh and dry mass of leaves, stems, inflorescences, and roots, proportions between plant organs, and yield. The main results showed that the 75% biofertilizer concentration treatment achieved the highest values for fresh leaf mass (195.06 g) and stem mass (383.33 g). The obtained values indicate that, considering the characteristics of the biofertilizer and soil used, it is advantageous to use concentrations above 50%. The use of undiluted biofertilizer negatively affects jambu production.

Keywords: *Acmella oleracea*. Horticultural. Yield.

RESUMO – O cultivo do jambu (*Acmella oleracea*) é amplamente difundido na Amazônia, principalmente pelo uso na culinária, na indústria farmacêutica e cosmética. O cultivo é feito, predominantemente, pela agricultura familiar, com uso de esterco animal na adubação. Biofertilizantes e efluentes de piscicultura estão cada vez mais disponíveis nas propriedades rurais, podendo se tornar poluidores do ambiente, no entanto podem ser excelente alternativa na adubação de cultivos. O objetivo do estudo foi avaliar o uso de efluente de piscicultura e de biofertilizante no rendimento de jambu (*A. oleracea*). O experimento foi conduzido no município de Castanhal, Pará, no delineamento experimental inteiramente casualizado, com seis tratamentos, sendo: T1 – água de poço sem adubação (controle); T2 – efluente de piscicultura; T3 - 25% de biofertilizante diluído em água; T4 - 50% de biofertilizante diluído em água; T5 - 75% de biofertilizante diluído em água e T6 - 100% de biofertilizante, com quatro repetições. Foram avaliados os parâmetros de massa fresca e seca de folhas, caules, inflorescências e de raízes, proporções entre órgãos da planta e produtividade. Os principais resultados alcançados mostraram que o tratamento 75% de concentração do biofertilizante obteve os maiores valores para massa fresca de folhas (195,06g) e de caule (383,33g). Os valores obtidos indicam que, considerando as características do biofertilizante e do solo utilizados, é vantajoso utilizar concentrações acima de 50%. O uso de biofertilizante sem diluição interfere negativamente na produção de jambu.

Palavras-chave: *Acmella oleracea.* Olerícola. Produtividade.

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INTRODUCTION

The cultivation of jambu (*Acmella oleracea*) is widespread in the Amazon region, primarily due to its culinary use in traditional dishes such as tucupi-based meats and tacacá broth, in which the leaves and stems of the plant are fundamental ingredients (SAMPAIO et al., 2022). Its distinctive flavor, marked by pungency and anesthetic properties that induce a tingling sensation in the mouth and throat, provides unique characteristics to regional cuisine (SAMPAIO et al., 2019).

Beyond its traditional culinary applications, jambu has recently garnered significant industrial interest, particularly in the beverage, cosmetic, and pharmaceutical sectors, leading to a substantial expansion in cultivated areas (BORGES et al., 2021). This growing interest is attributed to the presence of the bioactive alkamide spilanthol, whose properties have attracted increasing attention across diverse industries (BARBOSA et al., 2016). Given that nutrition directly influences plant secondary metabolism and that industrial demands prioritize the production of raw materials without synthetic chemical inputs, research must provide results on organic production systems that ensure both yield and quality for both fresh consumption and industrial processing.

Organic production systems have gained increasing prominence in vegetable cultivation for culinary purposes, but there is a rising demand to supply industry needs, as the acquisition of organic products has become a key requirement for this sector (SOUZA et al., 2015). The development of organic farming practices is fundamentally based on soil restoration and conservation, natural pest and disease control, minimal tillage, weed management, mulching, crop rotation, and the use of on-farm inputs such as organic fertilizers (AURIGLIETTI; PAULA JUNIOR; MICHELLON, 2024).

The increased yield associated with organic fertilizers in tropical soils stems from their protective effects, micronutrient enrichment, enhanced nutrient availability, and promotion of soil aggregation (PRIMAVESI, 2016). Organic fertilizers also offer a broader spectrum of essential nutrients with rapid availability, reducing the risk of deficiencies (SOUZA et al., 2015).

Although much of the state of Pará consists of naturally low-fertility soils, such as Yellow Latosols, which require soil amendments and fertilizers for improvement, research seeks technologies and management methods to enhance fertility for agricultural production, particularly in organic systems (BRASIL; CRAVO; VIEGAS, 2020). Organic matter in highly weathered soils plays a crucial role not only in nutrient supply but also in improving chemical, physical, and biological soil properties (PEREIRA; COSTA; CARVALHO, 2021).

Various rural organic residues are used in organic fertilization. In aquaculture, effluent from fish farms requires appropriate treatment to avoid environmental pollution and can be applied in fertigation or as a supplemental fertilizer (BRASIL; CRAVO; VIEGAS, 2020). According to Saraiva and Preto (2023), integrated production systems can enhance water-use efficiency, increasing fish and vegetable yields without additional water consumption. This approach prevents effluent discharge into watercourses while providing a natural fertilizer for crop cultivation.

Another reusable organic residue is biodigester effluent, produced through anaerobic biomass fermentation in biodigesters. This anaerobic biofertilizer is highly valuable for agriculture and can be derived from various organic sources, which influence its characteristics (GOTARDO, MANTOVANI, 2021).

Studies on aquaculture effluent and biofertilizers have demonstrated varying effects on crops but confirmed their benefits for both soil and plant yield (SARAIVA; PRETO, 2023). Abdelraouf and Ragab (2017) found that wheat irrigated with aquaculture effluent supplemented with nitrogen outperformed freshwater-irrigated crops.

Farmers in the region often employ mixed organic and chemical fertilization (HOMMA et al., 2011). Borges et al. (2016) reported higher yields with chemical fertilizers compared to organic ones. However, the present study recorded higher fresh shoot biomass than the cited authors.

Effluent can also complement manure fertilization, as its microorganisms accelerate nutrient release, enhancing short-cycle crop performance (SÁTIRO, ZACARDI, ALMEIDA NETO, 2022). However, attention is needed to avoid excessive nutrient accumulation, which may lead to soil degradation over time (BRASIL, 2005; PRIMAVESI, 2016).

Organic cultivation can yield superior results compared to conventional and hydroponic systems. The use of biofertilizers to improve soil nutrition may rival other organic recommendations (PRIMAVESI, 2016; SARAIVA; PRETO, 2023; MOURA et al., 2020).

Thus, this research aimed to evaluate jambu production under an organic system using biofertilizer and aquaculture effluent for crop fertilization.

MATERIALS AND METHODS

The experiment was conducted from July to October 2022 in the municipality of Castanhal, northeastern Pará State, Brazil, at geographic coordinates 1°19’24.48” S, 47° 57’38.20” W. The regional climate is classified as Am (tropical monsoon) according to the Köppen-Geiger system (ALVARES et al., 2014).

Microclimatic characterization was performed using data from the National Institute of Meteorology (INMET, 2022), sourced from the meteorological station located at IFPA Castanhal campus. The evaluated parameters included air temperature, relative humidity, and rainfall (Figures 1A and 1B).

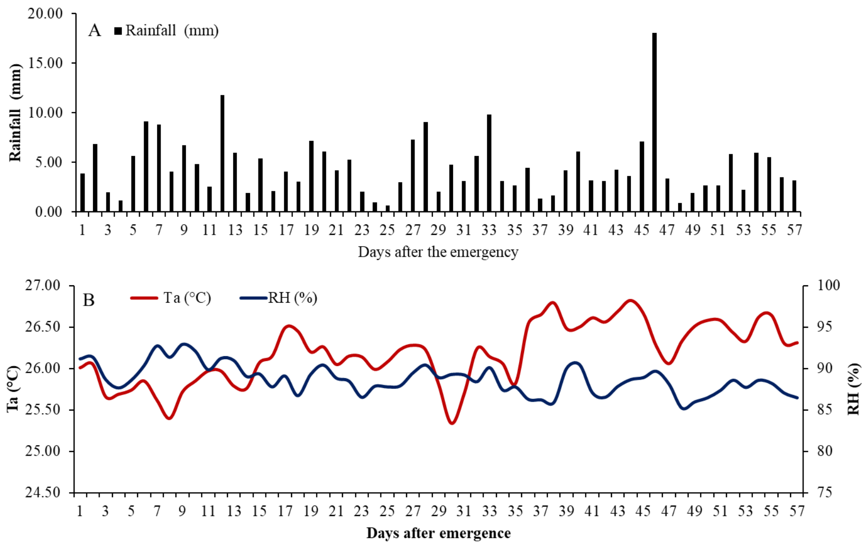

Figure 1. Rainfall (A), Air temperature (T_a) and Relative humidity (RH) (B). Source: INMET, 2022.

The climatic conditions during the study period were favorable for the research, as they provided optimal conditions for species development. Over the 57-day field experiment, total rainfall in the region reached 262.15 mm (Figure 1A), with only two days recording precipitation exceeding 10 mm. Under these conditions, it was confirmed that the treatments were not affected by leaching or dilution processes after application. The average temperature of 26.18 °C (±0.36) and relative humidity of 88.74% (±1.77) (Figure 1B) were also favorable, falling within the ideal range for species development (GUSMÃO; GUSMÃO, 2013).

The selected site had remained fallow for over five years and was covered with low-growing grass vegetation. For field preparation, the area was first cleared using a backpack brush cutter, followed by soil tillage with a disc harrow and leveling with a land plane. The raised beds were then constructed using a rotary tiller, with each bed measuring 1.20 m² in area and 0.2 m in height, spaced 0.8 m apart.

Prior to experiment establishment, composite soil samples were collected from the 0-0.2 m depth layer for chemical analysis (Table 1). This same sampling procedure was repeated at the conclusion of the experimental period. All laboratory analyses were conducted at Embrapa Eastern Amazon's research facilities.

Table 1. Soil analysis results before preparation for the experiment setup with fertilization in jambu (*Acmella oleracea* (L.) R.K. Jansen).

pH		C	OM	N	P	K	Ca	Ca+Mg	H+Al
		mg/dm^3		%	mg/dm^3		$cmol_c/dm^3$		
4.81		3.88	6.70	0.06	2.94	13.00	0.7	0.90	4.39
Cu	Fe	Mn	Zn	Na	Total CEC	Effective CEC	Base Saturation (V)		Aluminum Saturation (m)
mg/kg				mg/dm^3	$cmol_c/dm^3$		%		
0.29	466.36	5.70	0.97	3.65	5.34	1.48	17.79		35.83

During soil preparation for planting, no acidity correction or pre-planting fertilization was performed to avoid interfering with treatment effects. Only the treatments were applied during the crop development period. The first application of effluent and biofertilizer treatments was carried out seven days after seedling transplantation.

The experiment was conducted in a completely randomized design with four replications and six treatment sources. The evaluated treatments were: T1 - control (well water without fertilization); T2 - aquaculture effluent; T3 - 25% biofertilizer diluted in water; T4 - 50% biofertilizer diluted in water; T5 - 75% biofertilizer diluted in water; T6 - 100% biofertilizer.

The treatments were applied twice weekly in the late afternoon using a perforated watering can, with 12 liters of the corresponding solution applied per plot. The volume was evenly distributed across the entire area of each plot, and no irrigation was performed on treatment application days. On other days, irrigation was conducted using well water through a plastic hose sprinkler system, with equal irrigation time maintained for all plots. A total of 15 treatment applications were completed during the field experiment period.

Jambu seedlings were produced in 128-cell seedling trays containing coconut fiber substrate. Each cell received 10 -12 seeds (achenes) of *Acmella oleracea* (L.) R.K. Jansen, a variety characterized by larger inflorescences and the most widely cultivated and commercialized in the region. Germination occurred within 4-5 days after sowing, with seven seedlings maintained per cell.

Transplantation was performed 10 days after seedling emergence. In the field, plants were protected with 50% shade cloth for three days to facilitate acclimation to the permanent location.

Each planting unit consisted of a group of seven seedlings from one tray cell. The spacing between groups was 0.25 m × 0.20 m, totaling 20 groups per plot, with the six central groups considered as the useful area.

Weed control was performed through hand weeding every eight days, between beds and within plots. No pest infestations requiring phytosanitary control were observed. The water used for planting was obtained from a semi-artesian well located near the experimental area. For characterization purposes, water analysis was conducted (Table 2).

Table 2. Limnological characteristics of well water from UFRA's Castanhal School Farm, used in the jambu (*Acmella oleracea* (L.) R.K. Jansen) fertilization research activities.

pH	O_2	T (1)	TDS (2)	Cond. (3)	NO_3	NH_3	Hardness	Alkalinity
	ppm	°C	ppm	mS/cm	---------- mg/L ----------			
5.0	5.09	28.26	26	0.52	0.002	0.003	0.3	0.5

(1) Temperature; (2) Total Dissolved Solids; (3) Conductivity.

The water used in the experiment had low dissolved element content, with pH 5.0 and electrical conductivity of 0.52 mS/cm (Table 2). The observed values comply with CONAMA Resolution No. 357 (BRASIL, 2005) and ANVISA Ordinance nº 518 (BRASIL, 2004), meeting potability requirements without containing impurities that could have influenced soil chemical characteristics.

The aquaculture effluent was collected from a 260 m² pond stocked with tambaqui (*Colossoma macropomum*) at the Castanhal School Farm (FEC). Collections were performed in the morning, with effluent taken from the tank discharge pipe and stored in sealed containers until use. The first collection coincided with the initial treatment application one week after transplantation, followed by weekly collections until experiment completion.

The biofertilizer was produced through anaerobic digestion in an Israeli-technology biodigester (HomeBiogás) installed adjacent to the FEC cafeteria. The process utilized fresh cattle manure along with food preparation waste. Aquaculture effluent from the previously mentioned source was used to dilute the biomass.

Biofertilizer preparation began two months prior to field experiment implementation. After the second month, the generated biofertilizer was collected from the biodigester and stored in a 2000 L capacity reservoir. Dilutions corresponding to treatments were prepared immediately before each application.

Samples were collected for analysis of both the aquaculture effluent (Table 3) and biofertilizer (Table 4) during the final week of experimental applications. Parameters evaluated included pH, organic matter content, and macro/micronutrient levels at the Terra Agricultural Analysis Laboratory (Goiânia, GO).

Table 3. Characteristics of aquaculture effluent from a tambaqui (*Colossoma macropomum*) rearing tank.

pH	N	P	K		Ca	Mg	S
	mg/L						
7.1	23.0	8.0	10.0		13.0	9.0	63.0
Na	Fe	Mn	Zn	Cu	OM	C organic	C/N
mg/L					%		
2.0	0.079	0.099	0.048	0.001	0.2	0.1	43.4

Table 4. Characteristics of the biofertilizer produced in an Israeli-model biodigester.

pH	N	P	K	Ca	Mg	S
	mg/L					
7.8	787	46	288	178	193	130

Na	Fe	Mn	Zn	Cu	MO	C organic	C/N
mg/L					%		
195	1.2	1.004	0.079	0.013	0.2	0.1	12.7

The C/N ratio was found to be elevated in the effluent, primarily due to its low nitrogen concentration. This nutrient typically occurs at higher concentrations in aquaculture tanks (SÁTIRO; ZACARDI; ALMEIDA NETO, 2022; LUND, 2014).

Harvesting was conducted 57 days after transplantation, when plants had entered the initial reproductive phase. Collection at this developmental stage follows practices adopted by regional jambu producers, as the spilanthol content provides optimal flavor characteristics.

A descriptive comparative analysis of soil conditions was performed for each treatment, comparing them with the initial soil analysis results obtained from the area.

For the biometric and yield analysis, three plant groups located in the useful area of each plot were selected. The plants were transported to the laboratory, where they were cleaned and separated into roots, leaves, stems, and inflorescences. These components were processed to determine fresh weight, dry weight, dry weight percentage, yield, number of bunches per m², number of inflorescences, average fresh weight per inflorescence and length of each component.

The fresh weights of leaves (FWL), stems (FWS), roots (FWR), and inflorescences (FWI) were obtained by weighing on a digital scale, expressed in grams. After weighing the three groups from each plot, the average was calculated using Formula 1:

$$\text{FW (g)} = \frac{(\text{group1} + \text{group2} + \text{group3})}{3} \quad (1)$$

The dry weights of leaves (DWL), stems (DWS), and roots (DWR) were determined after drying the fresh matter samples in an oven at 60 °C until constant weight was achieved, with the dried material weighed on a digital scale. After weighing the three groups from each plot, the average was calculated using Formula 2:

$$\text{DW (g)} = \frac{(\text{group1} + \text{group2} + \text{group3})}{3} \quad (2)$$

The dry matter percentages of roots (DMPR), leaves (DMPL), and stems (DMPS) were obtained using Formulas 3A, 3B, and 3C, respectively.

$$\text{DMPR (\%)} = \frac{\text{DWR}}{\text{FWR}} * 100 \text{ (3A); DMPL (\%)} = \frac{\text{DWL}}{\text{FWL}} * 100 \text{ (3B): DMPS (\%)} = \frac{\text{DWS}}{\text{FWS}} * 100 \text{ (3C)} \quad (3)$$

The commercial yield (CY) without inflorescences, expressed in $g \cdot m^{-2}$, was determined considering 20 plant groups per square meter and estimated using Formula 4.

$$\mathrm{CY}\left(\frac{g}{m^2}\right) = (\mathrm{FWL} + \mathrm{FWS}) * 20 \qquad (4)$$

The number of bunches per m² (NB) was calculated by dividing the commercial yield per square meter by the standard regional market bunch weight of 300 g, according to Formula 5, with roots and inflorescences being discarded.

$$\mathrm{NB} = \frac{\mathrm{CY}.m^{-2}}{300} \qquad (5)$$

The number of inflorescences (NI) was calculated as the total number of inflorescences from all groups divided by three, following Formula 6.

$$\mathrm{NI} = \frac{(\mathrm{NI1} + \mathrm{NI2} + \mathrm{NI3})}{3} \qquad (6)$$

The average fresh weight per inflorescence (AFWI) was calculated as the ratio between total inflorescence weight and number of inflorescences according to Formula 7, expressed in grams.

$$\mathrm{AFWI}\ (g) = \frac{FWI}{NI} \qquad (7)$$

The ratio between fresh weight of leaves (FWL) and fresh weight of stems (FWS) (RLS) was calculated using Formula 8.

$$RLS = \frac{FWL}{FWS} \qquad (8)$$

The root length (RL) was determined by measuring the longest root from the plant collar to its tip, expressed in centimeters (cm), with the average of the three groups calculated using Formula 9.

$$\mathrm{RL(cm)} = \frac{(\mathrm{group1} + \mathrm{group2} + \mathrm{group3})}{3} \qquad (9)$$

Branch length (BL) was determined by measuring the longest branch from the collar to the apex, expressed in centimeters (cm), with the average of the three groups calculated using Formula 10.

$$\mathrm{BL(cm)} = \frac{(\mathrm{group1} + \mathrm{group2} + \mathrm{group3})}{3} \qquad (10)$$

The statistical analyses were performed using the SISVAR software (FERREIRA, 2019), with normality testing followed by analysis of variance (ANOVA). Means were compared using Tukey's test at 5% probability level.

RESULTS AND DISCUSSION

Descriptive comparative analysis of the soil after plant harvest in the respective treatments as compared to the pre-treatment soil analysis

By analyzing the soil condition (Table 5) at the end of the experiment after the application of treatments and plant harvest, compared to the soil analysis carried out before treatment application, it is possible to observe a slight increase in pH in all treatments, even in the one where only irrigation was applied during the cultivation period. The treatment with effluent use, although it had a pH of 7.0, had less influence on the increase in soil pH. The pH of the biofertilizer and some of its components tend to raise the pH as they are added to the soil (BRASIL; CRAVO; VIEGAS, 2020).

The carbon and organic matter contents also increased, with some treatments showing a doubling in value. The highest values were obtained in the well water and 100% biofertilizer concentration treatments.

The increase in carbon and organic matter contents may be related to the decomposition of plant parts that were growing in the area and were fragmented during weeding, plowing, and harrowing operations. These fragments remained incorporated and decomposed in the soil during the field research. In treatments with higher biomass production, there was also greater consumption, reducing accumulation in the soil. A characteristic of Amazonian soils is the rapid decomposition of organic matter (PRIMAVESI, 2016).

With the use of biofertilizer, small amounts of components were also supplied. However, in the most productive treatments, the levels were lower after the experiment ended, indicating that the plants and microorganisms added to the soil also consumed them (SOUZA et al., 2015).

The initial low fertility value of the soil also contributed to the results, as soils with continuous use of organic matter especially those following organic farming principles respond differently to biofertilizer application since it complements what is already present in the soil (MOURA et al., 2020).

Nitrogen levels remained unchanged, regardless of the treatment applied. Regarding phosphorus, the values remained similar to the initial levels in treatments with well water, effluent use, and 25% diluted biofertilizer. From 50% diluted biofertilizer onward, the values increased significantly, exceeding 600% in the 100% biofertilizer treatment. A similar trend occurred with potassium.

The nitrogen added in fertilization was used by both plants and microorganisms, with the unused fraction lost through volatilization or, after irrigation, leached into deeper soil layers due to the nutrient's solubility characteristics (BRASIL; CRAVO; VIEGAS, 2020). Phosphorus was likely partially fixed in the soil and rendered unavailable to plants, considering the soil's initial chemical properties that promote this effect. However, it is expected that, with continued biofertilizer use in the area, some phosphorus would become available again to plants (RODRIGUES et al., 2014; MOURA et al., 2020).

Table 5. Soil analysis results after plant harvest for the applied treatments in a fertilization experiment on jambu plants (*A. oleracea* (L.) R.K. Jansen).

Treatment	pH	C	OM	N	P	K	Na
	H_2O	g/kg	g/kg	%	mg. dm^{-3}		
T1	5.02	7.02	12.12	0.07	2.94	16.07	5.12
T2	4.91	6.25	10.79	0.06	2.56	15.39	4.75
T3	5.23	5.92	10.20	0.06	2.41	17.10	21.93
T4	5.53	5.72	9.86	0.06	4.29	22.91	42.40
T5	5.74	6.75	11.64	0.06	8.06	25.99	57.75
T6	5.79	8.43	14.54	0.06	18.90	83.79	53.0

Treatment	Al	Ca	Ca+Mg	H+Al	Total CEC	Effective CEC	Base Saturation (V)	Effective Saturation (m)
	$cmol_c/dm^3$						%	
T1	0.56	0.65	0.88	5.03	5.97	1.50	15.81	37.25
T2	0.58	0.53	0.87	4.99	5.92	1.51	15.72	38.41
T3	0.47	0.68	0.95	4.39	5.48	1.56	19.89	30.14
T4	0.26	0.80	1.35	4.05	5.64	1.85	28.23	14.03
T5	0.07	1.05	2.03	3.68	6.02	2.42	38.98	2.90
T6	0.04	1.25	2.91	3.19	6.54	3.40	51.28	1.18

Treatment	Fe	Zn	Cu	Mn
	mg/kg			
T1	408.93	1.0	0.41	10.77
T2	311.36	0.63	0.32	9.80
T3	331.14	0.43	0.28	7.35
T4	397.97	0.73	0.33	9.04
T5	360.24	0.51	0.35	7.57
T6	295.67	0.83	0.33	9.04

T1 - well water (control); T2 - aquaculture effluent; T3 - 25% biofertilizer; T4 - 50% biofertilizer; T5 - 75% biofertilizer; T6 - 100% biofertilizer.

As for potassium, part of its accumulation in the soil may be related to the presence of sodium, as it interferes with the absorption of other cations. The use of biofertilizer strongly influenced sodium accumulation in the soil, reaching high levels in all treatments with biofertilizer. Chloride levels were likely also elevated, considering that the probable source of sodium in the biofertilizer was salted food waste from the kitchen where the biodigester was installed. Manure, the primary raw material for the biodigester, is not a significant sodium source (SOUZA et al., 2015; BRASIL; CRAVO; VIEGAS, 2020).

Calcium and Ca + Mg values increased with higher biofertilizer concentrations, tripling at the highest concentration. Similarly, CEC (Cation Exchange Capacity) and base saturation (V%) values increased, with V% reaching 51.28 at the highest biofertilizer concentration. The H+Al value decreased with increasing biofertilizer concentration, creating favorable conditions for cultivation. The increase in product concentration also led to higher magnesium accumulation in the soil, resulting from the biofertilizer's composition, which was richer in magnesium compared to calcium, a condition not reported in other studies. Like potassium, calcium and magnesium absorption may also be impaired by sodium presence in the solution (TAIZ et al., 2017).

Regarding micronutrients, iron concentration decreased but remained high. Zinc levels decreased, while copper and manganese levels increased. The presented values did not act as toxic substances affecting jambu behavior, as they remained within the low-to-medium range after the cultivation period (BRASIL; CRAVO; VIEGAS, 2020).

The results demonstrate residual accumulation of various nutrients in the soil as biofertilizer concentration increased, while well water and aquaculture effluent had minimal influence on the evaluated soil characteristics. However, medium-term attention is needed, as residual nutrient accumulation whether from aquaculture effluent or biofertilizer may, after successive crops, render the soil limiting for plant development, requiring fallow periods or other measures to reduce excess nutrients (SOUZA et al., 2015; BRASIL; CRAVO; VIEGAS, 2020).

Biometrics

The treatment with 75% biofertilizer concentration achieved the highest values for fresh leaf mass, stem mass, and the sum of these parameters. On the other hand, the values obtained for the same characteristics in the control treatment and with aquaculture effluent resulted in low plant growth (Table 6).

According to Carvalho, Souza and Oliveira (2022), groundwater generally has little interference in the fertilization of plants cultivated in soil. In liquid cultivation systems, such as aquaponics and hydroponics, the effects can be much more significant, as they may interfere with the balance of the nutrient solution (SAMPAIO et al., 2022).

Table 6. Fresh weight production (g/group) of leaves (FWL), stems (FWS), leaves + stems (FWLS), roots (FWR), and inflorescences (FWI) of jambu plants (*A. oleracea* (L.) R.K. Jansen) fertilized with different biofertilizer concentrations and aquaculture effluent.

	FWL	FWS	FWLS	FWR	FWI
	----------	----------	g	----------	----------
T1	14.13 d	6.29 d	20.30 d	6.21 c	2.52 c
T2	24.84 d	9.92 d	34.80 d	10.76 c	2.26 c
T3	111.83 c	95.53 c	207.38 c	41.14 a	30.19 a
T4	143.87 b	164.50 ab	308.37 b	35.91 a	31.04 a
T5	195.06 a	188.27 a	383.33 a	36.28 a	20.32 ab
T6	148.30 b	135.39 cd	283.68 b	25.57 b	6.56 bc
CV (%)	6.14	19.09	11.42	13.10	41.91

T1 - well water (control); T2 - aquaculture effluent; T3 - 25% biofertilizer; T4 - 50% biofertilizer; T5 - 75% biofertilizer; T6 - 100% biofertilizer. Means followed by the same letter do not differ significantly from each other according to Tukey's test at 5% probability level.

According to Saraiva and Preto (2023), the composition of aquaculture effluent depends on various factors, including fish concentration and species, their feed, and the effluent's retention time in ponds. This effluent can be recommended for use in fertigation systems and aquaponics. In the present study, however, the nutrient composition of the effluent did not contribute to jambu production.

Conversely, jambu cultivation showed a positive response to biofertilizer application as a nutrient source, producing higher fresh shoot biomass than in several other studies with this species (SAMPAIO et al., 2019). The results indicate that, considering the characteristics of the biofertilizer used, higher concentrations than typically recommended in literature may be advantageous (MOURA et al., 2020). The findings also suggest that chemical fertilizers can be omitted, as organic fertilization alone proved sufficient to meet the species' nutritional requirements, even when using soil with poor chemical characteristics (PRIMAVESI, 2016).

The biofertilizer used in this study contained high concentrations of most elements. Its pH was slightly alkaline, a common characteristic of anaerobically produced biofertilizers (SANTOS et al., 2014).

Recommended dilution rates vary considerably across studies. Some research establishes dilution based on the nutrient with the highest concentration and crop requirements, though most recommendations suggest 20% to 50% as the standard dilution range. Compared to concentrations recommended for hydroponic systems, the biofertilizer used in this study contained significantly higher nutrient concentrations, particularly nitrogen (SANTOS et al., 2014; PEREIRA et al., 2021).

The 100% biofertilizer concentration limited plant growth, potentially due to salinity or toxic nutrient concentrations. Supporting this observation, soil analysis from this treatment showed elevated levels of various elements, particularly potassium. High potassium concentrations can increase salinity and interfere with cation absorption. Primavesi (2016) notes that excessive salinity and nutrient levels can restrict normal crop development and impair production.

Regarding root fresh weight and inflorescence characteristics, treatments with 25% to 75% biofertilizer concentrations outperformed the effluent, control, and 100% concentration treatments.

The inflorescence yield was lower than values reported by Oliveira and Inecco (2015) in organically fertilized cultivation. Early harvest during the initial reproductive phase, 67-day cycle, significantly reduced inflorescence production compared to studies with delayed harvests. This is because jambu exhibits continuous flowering from the onset of reproduction, with yields increasing as this phase progresses (GUSMÃO; GUSMÃO, 2013; SAMPAIO et al., 2022).

The 100% concentration impaired root and inflorescence development, mirroring the reduced shoot fresh weight yield, likely due to the same factors.

According to Taiz et al. (2017), among abiotic factors affecting plant metabolism, mineral nutrient supply plays a crucial role, and both excess and deficiency can alter metabolic pathways, ultimately affecting biomass production and secondary metabolites. The authors note that limited nitrogen and calcium availability strongly impacts root system development, while potassium deficiency reduces inflorescence production. Research on nutrient deficiency in jambu plants demonstrated that calcium and nitrogen directly influence root system development and inflorescence yield in this species (SAMPAIO et al., 2019).

Brasil, Cravo and Viegas (2020) highlight nitrogen's mobility in soil, making it susceptible to various loss pathways. These losses are exacerbated with biofertilizer use, where nitrogen is readily available and vulnerable to depletion. As nitrogen primarily drives fresh biomass accumulation (SAMPAIO et al., 2022), its limitation in certain treatments (e.g., effluent) likely constrained plant growth.

Table 7 shows dry weight trends paralleling fresh weight results: control and effluent treatments consistently yielded the lowest values. Biofertilizer treatments produced the most significant results, with leaf (DWL) and stem (DWS) dry weights exceeding other treatments by over 90%. Root dry weight (DWR) differences were less pronounced, though the 25% treatment outperformed the others.

Table 7. Dry matter production (DW) of leaves (DWL), stems (DWS), and roots (DWR) of jambu plants (*Acmella oleracea* (L.) R.K. Jansen) grown with different biofertilizer concentrations and aquaculture effluent fertilization.

	DWL	DWS	DWR
	----------g----------		
T1	0.74 c	0.64 c	0.61 c
T2	1.06 c	0.76 c	0.79 c
T3	25.87 b	23.30 ab	2.18 a
T4	25.84 b	24.32 a	1.48 b
T5	29.97 a	24.60 a	1.04 bc
T6	23.28 b	19.45 b	0.84 c
CV (%)	8.34	11.85	17.65

T1 - well water (control); T2 - aquaculture effluent; T3 - 25% biofertilizer; T4 - 50% biofertilizer; T5 - 75% biofertilizer; T6 - 100% biofertilizer. Means followed by the same letter do not differ significantly from each other according to Tukey's test at 5% probability level.

Regarding the percentage of dry matter relative to fresh weight (Table 8), it is observed that the control and effluent treatments significantly affected biomass accumulation, particularly in foliage, with values more than four times lower than that of the 25% biofertilizer treatment. Increasing the biofertilizer concentration also reduced dry matter content in foliage compared to the 25% treatment, with the highest biofertilizer concentration producing only half the dry matter percentage of the latter. For stems, only the 25% biofertilizer treatment showed notable results, with values approximately 50% higher than those found in the other treatments.

Table 8. Dry matter percentage relative to fresh weight of jambu plants (*A. oleracea* (L.) R.K. Jansen) grown with different biofertilizer concentrations and aquaculture effluent fertilization.

	DMPL	DMPS	DMPR
	---------- % ----------		
T1	5.32 d	10.52 cd	10.51 a
T2	4.21 d	7.86 d	7.51 b
T3	23.28 a	24.63 a	5.37 c
T4	17.94 b	14.88 b	4.09 cd
T5	15.36 b	13.16 bc	2.87 de
T6	11.58 c	14.49 b	2.39 e
CV (%)	8.34	12.19	10.95

T1 - well water (control); T2 - aquaculture effluent; T3 - 25% biofertilizer; T4 - 50% biofertilizer; T5 - 75% biofertilizer; T6 - 100% biofertilizer. Means followed by the same letter do not differ significantly from each other according to Tukey's test at 5% probability level.

According to Taiz et al. (2017) and Brasil, Cravo and Viegas (2020), soil nutrient availability significantly influences dry matter accumulation in plants, as various nutrients participate in metabolic processes that directly affect biomass production. The control and effluent treatments failed to provide sufficient nutrients to support metabolic activity conducive to dry matter accumulation, despite yielding low fresh weight values. In contrast, treatments with higher nutrient availability achieved greater fresh weight values, though the dilution effects in larger shoot areas - combined with strong sink competition from inflorescences - prevented proportional dry matter increases compared to the 25% biofertilizer treatment.

The percentage values obtained align with most studies evaluating dry matter in jambu plants (HOMMA et al., 2011; SAMPAIO et al., 2019), including those with longer field periods. However, Borges et al. (2016) reported substantially lower values (4-6%) for both organic and chemical fertilization systems.

Dry matter accumulation has several implications for jambu utilization. When comparing values obtained for foliage and stems, plants with similar values for both components and satisfactory growth likely had not reached full maturity, meaning most stems remained tender and nearly entirely usable for culinary purposes. As dry matter concentration in stems increases, it may indicate increasing fiber content, typically leading to the discard of hardened portions during food preparation (HOMMA et al., 2011; GUSMÃO; GUSMÃO, 2013).

Furthermore, increased dry matter concentration is expected to enhance the production of secondary metabolites, particularly spilanthol - a compound of significant industrial interest. This represents a major advantage for commercial applications while maintaining the crop's culinary acceptability (TAIZ et al., 2017; BORGES et al., 2021).

Regarding root dry matter percentage, water and aquaculture effluent treatments showed greater accumulation, whereas biofertilizer application reduced dry matter content in roots. This suggests nutritional deficiency conditions may limit root system renewal, resulting in a higher proportion of older roots remaining in the soil (TAIZ et al., 2017; SAMPAIO et al., 2019).

Regarding shoot yield (leaves + stems) - the primary plant parts used for culinary purposes and consequently crucial for both consumption and grower income estimation, Table 9 shows that the 75% biofertilizer concentration treatment was the most productive. It yielded approximately 20% more than both the 50% dilution and the 100% concentration treatments. Control group plants and those receiving only aquaculture effluent produced less than 1000 g per square meter of cultivation.

Table 9. Yield of leaves+stems (g·m^{-2} and bunch·m^{-2}), fresh weight of leaves/fresh weight of stems ratio (FWL/FWS), number of inflorescences per group (NI) and average fresh weight of inflorescence (AFWI) in jambu plants (*A. oleracea* (L.) R.K. Jansen) grown under different biofertilizer concentrations and aquaculture effluent fertilization.

	Yield g.m^{-2}	Yield bunch.m^{-2}	FWL/FWS	NI	AFWI g. inflores^{-1}
T1	405.9 c	1.35 c	2.30 a	1.35 d	0.32 ab
T2	696.8 c	2.32 c	2.64 a	2.32 d	0.17 a
T3	4147.6 b	13.82 b	1.18 b	13.82 c	0.56 c
T4	6167.4 b	20.56 ab	0.89 b	20.56 b	0.43 bc
T5	7666.5 a	25.56 a	1.04 b	25.56 a	0.34 ab
T6	5673.4 b	18.91 b	1.12 b	18.91 b	0.25 ab
CV %	11.42	11.42	26.77	33.85	28.02

T1 - well water (control); T2 - aquaculture effluent; T3 - 25% biofertilizer; T4 - 50% biofertilizer; T5 - 75% biofertilizer; T6 - 100% biofertilizer. Means followed by the same letter do not differ significantly from each other according to Tukey's test at 5% probability level.

The most commonly reported yield benchmark in research studies is approximately 4,000 g·m^{-2} for cultivation beds, whether using chemical fertilizers, hydroponic systems, or organic methods (SAMPAIO et al., 2022). Reports from farming areas also indicate lower yield levels (HOMMA et al., 2011; GUSMÃO; GUSMÃO, 2013).

Considering that the standard commercial unit for culinary jambu is the bunch (maço), conversion to this measure shows that the most productive treatment (75% biofertilizer) yielded 25 bunches per square meter a figure significantly higher than the typical yield of 16 bunches/m² reported for cultivated areas (HOMMA et al., 2011; GUSMÃO; GUSMÃO, 2013). Other studies have documented lower yield, further demonstrating the positive effects of biofertilizer on plant development (RODRIGUES et al., 2014; ARAÚJO et al., 2021).

These results reinforce the assertion that organic cultivation principles can yield outcomes far superior to conventional and hydroponic systems. They also highlight the viability of biofertilizers as a means to enhance soil nutritional properties, comparable to other recommended organic inputs (PRIMAVESI, 2016; SARAIVA; PRETO, 2023; MOURA et al., 2020).

Auriglietti, Paula Junior and Michellon (2024) emphasize that access to technical guidance is one of the main factors influencing the achievement of high yield rates in family farming units practicing organic agriculture, as the different techniques for producing organic fertilizers require specific instructions. In this context, the adoption of on-farm biofertilizer production and its use for soil fertilization can provide excellent results in yield improvement through relatively simple technology (PRIMAVESI, 2016; MOURA et al., 2020).

Table 9 also presents the leaf-to-stem mass ratio. No significant differences were observed among biofertilizer treatments, with ratios remaining close to 1.0. In contrast, treatments without biofertilizer showed twice this ratio value. This condition may represent a stress adaptation strategy in non-biofertilized plants, as leaves contain the primary structures for photosynthesis and energy production (TAIZ et al., 2017). While a higher leaf proportion might theoretically enhance bunch quality, the low yield in non-biofertilizer treatments negated this potential advantage.

Another factor contributing to the preservation of qualitative characteristics was the similar dry matter accumulation in both plant segments, indicating tender stems suitable for culinary use. This condition was favored by the harvest timing during early reproductive phase - a period of rapid vegetative growth and high nutrient demand, without significant leaf senescence (ARAÚJO et al., 2021; SAMPAIO et al., 2022).

Regarding inflorescence number, the more diluted biofertilizer treatments promoted initial production, while non -biofertilized treatments produced almost no floral heads (Table 9). The average inflorescence mass, which indicates size or developmental stage, revealed that the heaviest inflorescences occurred in the 25% biofertilizer treatment, with similar values in the 50% concentration treatment.

Inflorescence presence characterizes a specific plant developmental phase that may occur on schedule or be advanced/delayed by environmental effects (TAIZ et al., 2017). In this study, harvesting occurred at identical early flowering stages across all treatments - a standard practice among jambu growers for culinary purposes.

Higher nutrient concentration treatments maintained prolonged vegetative growth with vigorous branch sinks, consequently reducing flowering intensity at the predetermined harvest time. This dilution effect typically occurs during excessive vegetative growth (TAIZ et al., 2017). Other studies have reported higher values (BORGES et al., 2016; RODRIGUES et al., 2014). An alternative explanation involves intensified plant competition in high-nutrient treatments, where canopy self-shading may have triggered compensatory photosynthetic area expansion, subsequently altering hormonal balance and photoassimilate allocation for flowering induction (TAIZ et al., 2017).

For culinary purposes, inflorescences are considered non-essential by consumers and are often discarded during food preparation (HOMMA et al., 2011; GUSMÃO; GUSMÃO, 2013). However, as spilanthol extraction becomes increasingly sought after, its concentration shows direct correlation with flowering stage and intensity (RODRIGUES et al., 2014). This necessitates careful consideration between prioritizing early production versus potentially increasing secondary metabolite yields through extended field cultivation.

Regarding nutrient content, the effluent showed insufficient concentrations to meet crop nutritional requirements, explaining its limited production enhancement. While Saraiva and Preto (2023) suggest aquaculture effluent can replace nutrient solutions in hydroponic formulations, potassium and magnesium levels require adjustment. Comparative analysis reveals that the effluent used in this study contained substantially lower nutrient concentrations than standard hydroponic solutions for leafy crops (LUND, 2014). The high C/N ratio primarily resulted from low nitrogen content - a nutrient typically more abundant in fish farming systems (SÁTIRO; ZACARDI; ALMEIDA NETO, 2022; LUND, 2014).

Branch length was enhanced by biofertilizer application, though growth was reduced at the 100% concentration compared to the control and effluent treatments, which exceeded 39 cm in length (Table 10). The results from non-biofertilized treatments confirm restricted plant growth, with branch elongation contributing significantly to overall plant biomass. *A. oleracea* typically exhibits reduced or ceased branch development as plants progress through reproductive stages. Additionally, light competition between plants may have induced etiolation in more vigorous treatments (TAIZ et al., 2017).

Table 10. Branch length (BL) and root length (RL) in jambu plants (*A. oleracea* (L.) R.K. Jansen) cultivated with different biofertilizer concentrations and aquaculture effluent.

	BL	RL
	cm	
T1	16.68 d	9.59 b
T2	19.06 d	10.51 ab
T3	45.78 bc	13.26 a
T4	53.65 a	12.52 a
T5	53.12 a	12.52 a
T6	39.7 bc	11.79 ab
CV %	13.56	16.45

T1 - well water (control); T2 - aquaculture effluent; T3 - 25% biofertilizer; T4 - 50% biofertilizer; T5 - 75% biofertilizer; T6 - 100% biofertilizer. Means followed by the same letter do not differ significantly from each other according to Tukey's test at 5% probability level.

Treatments with higher aboveground yield, where plants were less affected by stress conditions, produced longer roots, enabling greater soil exploration due to increased interplant competition.

CONCLUSIONS

Under the conditions in which the research was conducted, it can be concluded that the aquaculture effluent used did not contribute to improving the production characteristics of jambu. The 100% biofertilizer concentration negatively affected jambu production traits. The 75% biofertilizer concentration provided the best results in jambu yield.

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