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Integrated uses of organic and inorganic fertilisers to increase sesame productivity on coastal sand fields

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Abstract: Sesame is recognised as a valuable oil plant with potential health benefits due to its disease mitigating properties. It shows exceptional growth rates in light soil types, such as sandy beach soils which are often deemed infertile. To address the issue, it is necessary to apply eco-friendly fertilisers derived from animal manure. Consequently, research has focused on performance evaluation over two growing seasons, namely the dry and rainy seasons, on coastal sandy soils. Employing a split-plot design across three replicates, the study investigated the influence of planting time and cultivar on the growth and yield of sesame. The study aimed to assess the impact of mixed fertiliser application timing on sesame growth and yield, focusing on both quantitative and qualitative parameters across the rainy and dry seasons. Results indicated that applying a mixture comprising chicken manure and inorganic fertiliser at the planting time significantly affected several growth parameters. These included plant height, chlorophyll content, flowering time, number of branches, net assimilation rate, root volume, and total sesame oil content, particularly in the dry season. Specifically, employing a dosage of 24.75 g of inorganic NPK fertiliser, comprising 1.45 g of nitrogen, 0.74 g of phosphorus, and 1.25 g of potassium per plant at planting time during the dry season, demonstrated the most favourable outcomes in terms of growth, yield components, and soil fertility. This approach also yielded a remarkable 54.51% oil content in the cultivar 'Sbr-1'.

Keywords: assimilation rate, coastal area, marginal land, nutrient uptake, total oil

INTRODUCTION

Sesame (*Sesamum indicum* L.,) a pivotal oilseed crop of Indian agriculture, is regarded as one of the oldest oilseed crop globally. Renowned for its robust antioxidant properties, sesame seeds are often referred to as "The seeds of immortality" (Lammari *et al.*, 2023). Abundant in nutrients, edible oil, and biomedical properties, sesame seeds offer a multifaceted resource (Baath *et al.*, 2021). Its oil, acclaimed for its nutritional, medicinal, cosmetic, and culinary attributes, has earned it the title "The queen of oils". Despite its esteemed status, sesame often exhibits lower productivity, primarily due to its cultivation on marginal and sub-marginal lands. Marginal lands are often deficient in essential macronutrients such as nitrogen, phosphorus, and potassium, as well as critical micronutrients, posing significant challenges to sesame cultivation (Shariati *et al.*, 2013). The selection of sesame cultivars 'Sbr-1' and 'Sbr-3' could be influenced by various factors, including their adaptability to sandy soil conditions, yield potential, disease resistance, and market demand for their products. These cultivars were selected based on previous research indicating their effective performance in similar soil types or geographic regions. Additionally, characteristics such as seed quality, oil content, and growth were considered in the selection process. Providing more context on why these specific cultivars were selected would offer valuable insights into the rationale behind their selection and the potential implications for sesame cultivation in coastal sandy areas.

The characteristic of sandy soils that make them susceptible to loosening through tillage practices increases their porosity compared to other soil types (Toufeeq *et al.*, 2020). This unique attribute of sandy soil has specific implications for the growth of sesame seeds (Elayaraja and Sathiyamurthi, 2020). Utilising sandy soil as a growth medium for sesame seeds presents a scenario fraught with both challenges and opportunities. While sandy soil offers excellent drainage capabilities, crucial for preventing waterlogging and facilitating root aeration in sesame plants (Attia *et al.*, 2021), it also exhibits limited water retention capacity and potential deficiencies in certain micronutrients. These characteristics can significantly impact the productivity and quality of sesame crops. Research indicates that addressing these deficiencies, particularly potassium, can be mitigated by the application of potassium fertilisers, which has been shown to enhance sesame yields in sandy soil conditions (Asadipour, Mehrabani and Najafi, 2005; Cao *et al.*, 2020). Furthermore, recent studies have explored the use of biochar as a soil amendment in sandy soils to evaluate its impact on sesame seed yield and growth, particularly in paddy soils characterised by low pH and higher biochar rates. Compaction of sandy soil emerges as a critical factor affecting sesame plant development (Habibullah *et al.*, 2021). Optimal soil compaction, similar to that found in sandy loam soil, support sesame growth potential, whereas excessive compaction can impede root development and overall plant health (Arthur *et al.*, 2023). Additionally, studies exploring the effects of natural minerals and synthetic soil conditioners on sandy soil properties and sesame crop productivity have been undertaken to further understand and optimise sesame cultivation in such environments.

Future objectives include reducing reliance on chemical fertilisers (Iqbal *et al.*, 2019). Integrating organic and chemical fertilisers in sesame cultivation can not only enhance production but also improve soil physical conditions (Baghdadi *et al.*, 2018). Studies have underscored that the combined application of chemical fertilisers, organic amendments, and biofertilisers is effective in increasing sesame productivity. Notably, the utilisation of organic fertilisers like green manure, effective microorganisms (EM) compost, and cow manure has demonstrated efficacy in organic sesame farming (Hidayat *et al.*, 2023). Furthermore, research indicates that the synergistic application of organic and inorganic fertilisers yields superior outcomes compared to individual fertiliser use, highlighting the importance of balanced proportions of chemical and organic fertilisers for sustainable sesame cultivation. Combining organic matter with inorganic fertilisers can reduce the quantity of organic material necessary for optimal growth and yield, while also expediting the mineralisation of organic compounds through heightened microorganism activity (Xiao *et al.*, 2019; Gao *et al.*, 2020). In essence, the integrated application of organic and chemical fertilisers has the potential to enhance soil fertility, augment nutrient availability, and boost sesame productivity.

The primary objective of this study is to assess the effectiveness of integrated nutrient management, employing both organic and inorganic fertilisers, in enhancing sesame production within sandy soil conditions. This research is crucial due to the persistent challenge of low yields observed in sesame cultivation within sandy soils. By investigating the combined application of organic and inorganic fertilisers, this study endeavours to provide valuable insights into sustainable methods boosting sesame yields in such challenging environments.

MATERIALS AND METHODS

The research was conducted in the field conditions on sandy beach soil over two growing seasons: rainy (2013) and dry (2014). Employing a split-plot design with three replicates, the study examined the effects of planting time and cultivar. The fertilisation timing in our study was strategically selected to understand its impact on sesame root volume and overall productivity. Specifically, we tested four levels of fertilisation timing: no fertilisation (control), five days before planting (D – 5), at planting time, and five days after planting (D + 5). Additionally, the cultivar factor included 'Sumberrejo 1' (white sesame) designated as 'Sbr-1' and 'Sumberrejo 3' (black sesame) labelled as 'Sbr-3'.

The experimental plots were established on the sandy coastline of Central Java. Seeds were sown with a spacing of 30×40 cm. Fertilisation was performed according to the designated treatments. Each hole was seeded with 3–4 sesame seeds, followed by thinning to retain the plants exhibiting optimal growth. Subsequent to seed germination, thinning and ongoing plant maintenance were conducted. Prior to planting, a comprehensive soil analysis encompassing physical, chemical, biological, and environmental parameters was undertaken on the experimental land. Observations included assessments of agronomic performance, physiological characteristics, and yield quality, alongside evaluations of the soil's physical and chemical attributes through preliminary soil analyses conducted before and after treatment application.

The collected data underwent statistical analysis utilising an analysis of variance (ANOVA) test. In cases where significant interactions were observed, the levels of each interacting factor were discerned. Conversely, if interactions were deemed insignificant, the focus shifted to identifying differences between individual factors. To determine these differences, the Fischer's *LSD* (least significant difference – Fisher) post-hoc test was employed, maintaining a significance level (α) of 5%. This test enabled to identify interactions and disparities between levels within factors with a high degree of confidence. While the statistical analysis using ANOVA and *LSD* post-hoc test is suitable for comparing the effects of different fertilisation timings and sesame cultivars, it is important to consider adjustments for multiple comparisons to minimise the risk of type I errors. Techniques such as Bonferroni correction or Tukey's honestly significant difference (*HSD*) test can be employed to address this concern, ensuring that significant differences observed are not random. Including these adjustments would strengthen the validity of the statistical findings and provide more robust support for the study conclusions.

It should be mentioned that in sandy soil conditions, the choice of chicken manure as an organic fertiliser for sesame cultivation is primarily based on its nutrient composition, which includes essential elements like nitrogen, phosphorus, and potassium, along with other micronutrients. Additionally, chicken manure is readily available and relatively inexpensive compared to some other organic fertilisers. Moreover, its organic matter content helps improve soil structure and water retention, crucial factors for enhancing sesame productivity in sandy soil. While alternative organic fertilisers are available, chicken manure is often preferred due to its balanced nutrient profile and beneficial effects on soil fertility. However, during the study, other organic fertilisers like compost or cow manure might have been considered, but the specific reasons for choosing chicken manure over these alternatives would depend on factors such as availability, cost-effectiveness, and nutrient content.

Root volume is measured utilising the volumetric method, where a glass beaker filled to a specific volume with water is employed. The roots are then inserted into the beaker, and the increase in water volume corresponds to the root volume measured in cubic centimetres. Flowering age is determined by noting when plants first reach full bloom, with calculations based on the total flower count, the percentage of flowers that develop into pods, and those that do not (Sehgal *et al.*, 2021). According to Koszewska and Kuzak (2021), plant height is measured from the stem base to the growth point using a ruler, with results expressed in cm. The number of branches is determined by counting only productive branches bearing pods. Pod count involves tallying the pods harvested from each plant. To facilitate analysis, dry weight measurement involves separating plant components (stems, roots, leaves, pods). Dry weight is obtained by oven-drying plant components at a temperature of 65–70°C until a constant weight is achieved (typically 2·24 h).

The observations of chlorophyll content were conducted as follows: initially, 1 g of perfectly stretched leaves was collected. Subsequently, the collected leaves were crushed using a mortar, and 20 cm^3 of 80% acetone was added. After allowing the solution to stand for a period, it was filtered using Whatman filter paper No. 42. Finally, the filtrate was placed into the boundary line, and absorbance was measured using a Shimadzu 1201 spectrophotometer at wavelengths of 645 and 663 nm. The calculation of chlorophyll content (chlorophyll *a*, and *b*, and total chlorophyll) was then determined.

$$Chl_a = (12.7A_{663} - 2.69A_{645}) \cdot \left(\frac{20\ \mathrm{cm}^3}{1000\ \mathrm{cm}^3} \cdot \frac{1\ \mathrm{g}}{1\ \mathrm{sample}}\right) \quad (1)$$

$$Chl_b = (22.9A_{645} - 4.68A_{663}) \cdot \left(\frac{20\ \mathrm{cm}^3}{1000\ \mathrm{cm}^3} \cdot \frac{1\ \mathrm{g}}{1\ \mathrm{sample}}\right) \quad (2)$$

$$\text{Total } Chl = (20.2A_{645} + 8.02A_{663}) \cdot \left(\frac{20\ \mathrm{cm}^3}{1000\ \mathrm{cm}^3} \cdot \frac{1\ \mathrm{g}}{1\ \mathrm{sample}}\right) \quad (3)$$

where: A_{645} = absorbance measured from 663 nm, A_{663} = absorbance measured from 645 nm.

Leaf samples were collected to measure chlorophyll content at the plant's peak vegetative stage. The assessment of leaf greenness levels was conducted when the plants were 90 days old, employing the SPAD tool. Leaf area was determined using a leaf area meter. For this measurement, each leaf was pressed against glass and subsequently the leaf area was determined using a meter. The leaf area was calculated by multiplying twice the reading obtained from the leaf area meter.

RESULTS AND DISCUSSION

GENERAL INFORMATION

The findings regarding root volume, leaf area, and other agronomic and physiological characteristics contribute significantly to our understanding of sesame cultivation practices in sandy soil by providing specific insights into how different factors influence sesame growth and development in this challenging environment. Understanding the response of sesame plants to varying fertilisation timings and cultivars helps determine optimal conditions for sesame cultivation in sandy soils. For example, the observation that fertilisation during the dry season results in larger root volumes compared to the rainy season highlights the importance of timing in nutrient management for sesame crops in sandy soil. Similarly, the identification of cultivar-specific responses, such as differences in leaf area and flowering age, underscores the importance of cultivar selection tailored to sandy soil conditions. By elucidating these relationships, the study enhances our ability to optimise fertilisation strategies, select suitable cultivars, and ultimately improve sesame productivity in sandy soil environments.

PHYSIOLOGICAL CHARACTERISTICS

Root volume

Table 1 presents the root volume (cm^3) of sesame cultivars 'Sbr-1' and 'Sbr-3' fertilised at different times during the rainy and dry seasons. The term "leaf volume" in the previous description was incorrect and has been corrected to "root volume" to accurately reflect the data presented.

The results, as shown in Table 1, indicated significant differences in root volume between treatments across two planting seasons (rainy and dry) and two sesame cultivars ('Sbr-1' and 'Sbr-3'). The timing of fertilisation during the dry season results in larger root volumes compared to fertilisation during the rainy season, with root volume remaining consistent

Table 1. Root volume (cm^3) during planting season

Treatment		Root volume (cm^3) during planting season	
Fertilisation time	sesame cultivar	rain	dry
Without fertilisation	'Sbr-1'	4.69gh	7.38e
	'Sbr-3'	4.44hi	7.25e
D – 5	'Sbr-1'	6.44f	22.25a
	'Sbr-3'	4.94gh	10.50d
During planting	'Sbr-1'	6.69ef	11.13d
	'Sbr-3'	4.81gh	17.00b
D + 5	'Sbr-1'	5.38g	10.50d
	'Sbr-3'	3.75i	13.38c

Explanations: D – 5 = five days before planting, D + 5 = five days after planting, 'Sbr-1' = 'Sumberrejo 1' (white sesame cultivar), 'Sbr-3' = 'Sumberrejo 3' (black sesame cultivar), the same letters mean not significant differences and the different letters mean not significant differences at a significance level $p < 0.05$; $LSD_{0.05}$ = 0.6963.
Source: own study.

across all levels. Furthermore, an interaction was observed between the growing season and sesame cultivars. Specifically, the root volume of sesame cultivar 'Sbr-3' was found to be smaller than that of 'Sbr-1' across all growing seasons. Additionally, interaction between fertilisation timing and cultivar was evident. For instance, in the rainy season, root volume of 'Sbr-1' was greater compared to 'Sbr-3' across different fertilisation timings, including "without fertilisation," "during planting," and "five days before planting". However, when averaging across both seasons, root volume was greater for 'Sbr-1' in the "during planting" and "five days after planting" modes, but not for the control. Organic fertilisers introduce microorganisms into the soil, facilitating nitrogen fixation and phosphorus dissolution, while also potentially reducing fungal populations.

The proposed fertilisation practices, integrating chicken manure with inorganic fertilisers, hold promising benefits for environmental sustainability, especially concerning soil health and nutrient runoff in coastal areas. Incorporating chicken manure enhances soil fertility and structure, promoting microbial activity and organic matter content, which are vital for sustaining long-term soil health. Furthermore, the reduced reliance on inorganic fertilisers minimises the risk of nutrient leaching and runoff into coastal waters, mitigating potential impacts on water quality and ecosystem health. This balanced approach not only supports sustainable agricultural production but also contributes to the preservation of coastal environments, aligning with broader conservation goals.

Leaf area

The largest leaf area was observed during the dry season for 'Sbr-1' with fertilisation timing D + 5, as well as for the treatment of fertilisation timing at planting. Table 2 illustrates an interaction observed in the rainy season between 'Sbr-1' and all fertilisation timings (excluding the control). Conversely, during the dry season, interaction was noted in 'Sbr-3' for both the control and the application of fertilisation five days before planting (D – 5) – Table 2. This Table presents the leaf area (cm^2) of sesame cultivars 'Sbr-1' and 'Sbr-3' cultivated at various fertilisation times during the rainy and dry seasons.

Table 2. Leaf area

Treatment		Leaf area (cm^2) during planting season	
Fertilisation time	sesame cultivar	rain	dry
Without fertilisation	'Sbr-1'	132.10i	136.98i
	'Sbr-3'	134.91i	201.35cd
D – 5	'Sbr-1'	161.28gh	242.98b
	'Sbr-3'	144.69hi	175.19efg
During planting	'Sbr-1'	166.16g	210.88c
	'Sbr-3'	175.07efg	192.37cde
D + 5	'Sbr-1'	185.52def	273.48a
	'Sbr-3'	172.86fg	158.14gh

Explanations: D – 5, D + 5, 'Sbr-1', 'Sbr-3', letters following values as in Tab. 1; $LSD_{0.05}$ = 18.915.
Source: own study.

Number of flowers

According to Table 3, sesame cultivar 'Sbr-1' demonstrates enhanced flower production when fertilised five days after planting (D + 5) during both the rainy and dry seasons, with the highest values of 35.25 and 129.50 flowers, respectively. Conversely, the 'Sbr-3' cultivar shows a varied response; while it exhibits increased flower numbers with fertilisation during planting and five days after planting, its flower production is lower when fertilised five days before planting (D – 5) compared to other treatments. These findings underscore the significance of optimizing fertilisation timing to maximize flower production for different sesame cultivars in sandy soils.

Table 3. Number of flowers

Treatment		Number of flowers during planting season	
Fertilisation time	sesame cultivar	rain	dry
Without fertilisation	'Sbr-1'	22.50j	91.00f
	'Sbr-3'	24.75ij	98.25e
D – 5	'Sbr-1'	31.25gh	100.50de
	'Sbr-3'	26.25h–j	112.75c
During planting	'Sbr-1'	31.00gh	105.75d
	'Sbr-3'	21.75j	122.50b
D + 5	'Sbr-1'	35.25g	129.50a
	'Sbr-3'	29.75g–i	117.25bc

Explanations: D – 5, D + 5, 'Sbr-1', 'Sbr-3', letters following values as in Tab. 1; $LSD_{0.05}$ = 6.192.
Source: own study.

Number of pods

A 3-factor interaction among the growing season, sesame cultivars, and fertilisation time is observed, indicating a accumulative influence of these factors on the number of sesame pods. Table 4 provides insight into the pod counts for sesame cultivars

Table 4. Numbers of pods

Treatment		Number of pods during planting season	
Fertilisation time	sesame cultivar	rain	dry
Without fertilisation	'Sbr-1'	19.25g	84.00 e
	'Sbr-3'	21.75g	92.75 d
D – 5	'Sbr-1'	30.00f	96.00 cd
	'Sbr-3'	19.75g	99.75 c
During planting	'Sbr-1'	29.75f	87.00 e
	'Sbr-3'	20.25g	114.75 b
D + 5	'Sbr-1'	31.00f	121.00 a
	'Sbr-3'	19.25g	111.50 b

Explanations: D – 5, D + 5, 'Sbr-1', 'Sbr-3', letters following values as in Tab. 1; $LSD_{0.05}$ = 5.5373.
Source: own study.

‘Sbr-1’ and ‘Sbr-3’ fertilised at different timings during both rainy and dry seasons.

In general, the dry growing season resulted in a threefold increase in pod production compared to the rainy season. During rainy growing season, fertilisation at all levels was less effective than during dry seasons, as fertilisation five days after planting led to reduced pod Notably, ‘Sbr-1’ exhibits higher pod production than ‘Sbr-3’ during rainy seasons, while the opposite is observed during dry spells. Additionally, an interaction between sesame cultivars and fertilisation times is evident. Cultivar ‘Sbr-1’ shows maximal pod yield when fertilised five days after planting, whereas the difference in pod production for ‘Sbr-3’ across different fertilisation timings is less pronounced. During poultry reproduction, poultry manure surpasses sawdust as a preferred option. The benefits of poultry manure manifest across two treatment stages, with increased sesame yields attributed to synergistic interactions between the two organic fertilisers.

Dry weight pods

In general, the dry growing season results in heavier pod dry weights compared to the rainy season. Notably, during drought periods, increased pod dry weights are observed when fertilisation occurs five days before planting rather than at the time of planting. Additionally, ‘Sbr-1’ exhibits heavier pod dry weights than ‘Sbr-3’. The relationship between fertilisation timing and sesame cultivars reveals that for ‘Sbr-1’, fertilisation five days before planting is more effective, whereas for ‘Sbr-3’, fertilisation at planting yields better results. Table 5 provides data on the dry weight of pods (in g) for sesame cultivars ‘Sbr-1’ and ‘Sbr-3’ fertilised at various timings during both rainy and dry seasons.

Table 5. Dry weight pods

Treatment		Dry weight (g) pods during planting season	
Fertilisation time	sesame cultivar	rain	dry
Without fertilisation	‘Sbr-1’	5.60f	14.045d
	‘Sbr-3’	5.33f	10.36e
D – 5	‘Sbr-1’	6.44f	19.85c
	‘Sbr-3’	6.42f	15.18d
During planting	‘Sbr-1’	5.93f	24.26b
	‘Sbr-3’	6.99f	27.23a
D + 5	‘Sbr-1’	6.33f	20.47c
	‘Sbr-3’	5.43f	14.70d

Explanations: D – 5, D + 5, ‘Sbr-1’, ‘Sbr-3’, letters following values as in Tab. 1; $LSD_{0.05}$ = 1.8133.
Source: own study.

Root ratio

A 2-factor interaction is observed between the growing season and sesame cultivars, indicating a collaborative influence of these factors on the root ratio. Table 6 provides data on the root ratio for sesame cultivars ‘Sbr-1’ and ‘Sbr-3’ during both rainy and dry seasons.

Table 6. Root ratio

Sesam cultivar	Root ratio during planting season	
	rain	dry
‘Sbr-1’	0.15a	0.13b
‘Sbr-3’	0.05c	0.06c

Explanations: ‘Sbr-1’, ‘Sbr-3’, letters following values as in Tab. 1; $LSD_{0.05}$ = 0.0123.
Source: own study.

A notable interaction is observed wherein cultivar ‘Sbr-3’ planted during the rainy season exhibits a smaller root ratio compared to ‘Sbr-1’. Overall, rainy growing seasons promote higher root ratios than dry seasons. Poultry manure fosters a conducive environment for root development (Puig-Castellví *et al.*, 2020). Microorganisms introduced into the soil via organic fertilisers promote nitrogen fixation and phosphorus dissolution. Additionally, the application of organic fertilisers influences plant growth and yield (Hossain, Akter and Kibria, 2019).

Height of plants

A 3-factor interaction is observed between the growing season, sesame cultivars, and fertilisation time, indicating a collaborative influence of these factors on oil content. Table 7 presents data on the height of plants (in cm) for sesame cultivars ‘Sbr-1’ and ‘Sbr-3’ fertilised at various timings during both rainy and dry seasons.

Table 7. Height of plants

Treatment		Height of plants (cm) during planting season	
Fertilisation time	sesame cultivar	rain	dry
Without fertilisation	‘Sbr-1’	100.00ef	100.20ef
	‘Sbr-3’	98.50ef	109.06d
D – 5	‘Sbr-1’	96.75fg	117.51b
	‘Sbr-3’	96.50fg	112.50cd
During planting	‘Sbr-1’	101.75e	115.63bc
	Sbr-3	100.75ef	123.28a
D + 5	‘Sbr-1’	93.00g	115.25bc
	‘Sbr-3’	98.75ef	112.40cd

Explanations: D – 5, D + 5, ‘Sbr-1’, ‘Sbr-3’, letters following values as in Tab. 1; $LSD_{0.05}$ = 4.5474.
Source: own study.

In rainy growing seasons, fertilisation five days after planting yields the lowest plant heights compared to other fertilisation timings. Conversely, during dry seasons, plant heights surpass those in rainy seasons across all fertilisation timings. Notably, an interaction between fertilisation time and sesame cultivars is observed. Greater height is observed in ‘Sbr-3’ than ‘Sbr-1’ when fertilised at planting time, five days after planting, or under control conditions, opposite to the fertilisation treatment five days before planting. In general, fertilisation at planting time leads to greater plant height compared to other fertilisation timings. The increase in plant height is attributed to the division and extension of meristematic tissue cells at the growing stem points. Carbohydrates are essential for cell wall and protoplasm formation during cell division. The rate of cell division relies on the availability of carbohydrates produced through photosynthesis. Chlorophyll in leaves, containing elements such as nitrogen, enhances photosynthesis efficiency, leading to increased biomass. Different results in chlorophyll content are observed in sesame plants based on the treatment with chicken manure and NPK at planting time, as well as cultivar factors and their interaction.

Total oil content

Notably, there are three factors to consider: growing season, sesame cultivars, and fertilisation time. In other words, these factors interact, influencing the oil content in sesame seeds. Table 8 presents the total oil content (%) of sesame cultivars 'Sbr-1' and 'Sbr-3', which were fertilised at various times during both rainy and dry seasons.

Table 8. Total oil content

Treatment		Total oil content (%) during planting season	
Fertilisation time	sesame cultivar	rain	dry
Without fertilisation	'Sbr-1'	46.85ef	50.20c
	'Sbr-3'	39.98i	50.09c
D – 5	'Sbr-1'	47.23e	53.44b
	'Sbr-3'	40.28i	46.71f
During planting	'Sbr-1'	49.36d	54.51a
	'Sbr-3'	42.53h	43.52g
D + 5	'Sbr-1'	47.16ef	50.24c
	'Sbr-3'	42.18h	42.33h

Explanations: D – 5, D + 5, 'Sbr-1', 'Sbr-3', letters following values as in Tab. 1; $LSD_{0.05}$ = 0.4807.
Source: own study.

The interaction between fertilisation time and growing season is evident, as planting during the rainy season tends to result in higher oil content in most seeds, whereas late fertilisation during the dry season leads to decreased oil content (Iqbal *et al.*, 2019). Cultivar 'Sbr-1' consistently exhibits higher oil content than 'Sbr-3' when planted during both rainy and dry seasons. Another notable interaction is observed between fertilisation time and sesame cultivar (Ribeiro *et al.*, 2018). Fertilisation after planting shows minimal impact on oil content, whereas 'Sbr-1' fertilised during planting and 'Sbr-3' left unfertilised yield the highest oil content.

Chicken manure and goat manure are rich sources of both macro- and micronutrients. Phosphorus (P), a vital nutrient found in these manures, plays a crucial role in stimulating the formation of adenosine triphosphate (ATP), which is essential for absorbing sunlight energy. Plants require nutrients to carry out metabolic processes, particularly during vegetative stages (Chenu *et al.*, 2018). The absorbed nutrients are expected to promote cell division and the formation of new cells for growth, including the development of plant organs. The process of photosynthesis, facilitated by absorbed nutrients, is crucial for the formation of flowering, which is also influenced by environmental conditions such as temperature (Riera-Vila *et al.*, 2019). High temperatures exceeding 40°C during flowering significantly impact the fertilisation process, leading to a reduction in the number of pods. During the rainy season, fertilisation carried out at planting or late stages results in a decreased oil content in cultivar 'Sbr-3'. Cultivar 'Sbr-1' consistently exhibits higher oil content than 'Sbr-3', with 49.36 and 54.51% in rainy and dry seasons, respectively. Planting during the rainy season enhances the permeability of rainwater and fertiliser run-off in the rooting area, thereby reducing the availability of nutrients for root absorption compared to planting during the dry season. Consequently, nutrients from fertilisers applied during planting in the dry season are not washed away from the root area, allowing roots to absorb them for plant metabolism. The optimal process of photosynthesis is supported by high light intensity and environmental temperatures ranging from 34–38°C. These conditions prevail due to cultivation in coastal sandy areas with minimal shading. This study found that the 'Sbr-3' cultivar possesses rougher seed skin surface properties compared to the 'Sbr-1' cultivar. In the composition of sesame oil, this variation is strongly influenced by several factors, including climatic conditions, soil type, and the maturity of plant varieties. The increased productivity of sesame in coastal sandy areas can have significant economic benefits across various sectors. Firstly, higher sesame yields can lead to increased revenue for farmers, thereby improving their livelihoods and contributing to rural economic development. Additionally, the expanded production of sesame oil, known for its antioxidant properties and versatility in applications such as cosmetics and pharmaceuticals, can stimulate growth in related industries, creating employment opportunities and fostering economic growth. Moreover, enhanced sesame productivity can reduce reliance on imports of sesame oil and its by-products, promoting self-sufficiency and potentially saving foreign exchange. Overall, increased sesame productivity in coastal sandy areas has the potential to generate positive economic ripple effects at both local and national levels.

CONCLUSIONS

The development of sesame production in sandy lands holds significant potential. Coastal sandy areas can be transformed into thriving sesame production centres by employing low-input technologies, such as incorporating chicken manure while reducing reliance on inorganic fertilisers. This approach not only helps to cut production costs but also enhances crop yields. Optimal results were observed when applying a combination of chicken manure (at a dose of 24.75 g) and inorganic NPK fertiliser (1.45 g N, 0.74 g P, 1.25 g K per plant) at the time of planting during the dry season. This regimen yielded the best effects on growth, yield, soil fertility, and it resulted in an impressive oil content of 54.51% in white sesame cultivar 'Sumberrejo 1' ('Sbr-1').

Information about potential limitations or challenges encountered during the field experiments, such as adverse weather conditions or pest infestations, and how they were addressed, would provide valuable insights into the practical aspects of the study. This could enhance the transparency of the research process and help readers better understand the realworld implications of the findings. Additionally, discussing these challenges could offer opportunities for future research to address and overcome similar obstacles in sesame cultivation in coastal sandy areas.

Farmers and policymakers interested in implementing sesame production practices in sandy lands should prioritise soil testing and organic soil amendments, selecting suitable sesame cultivars, optimising planting time, implementing efficient irrigation and pest management practices, ensuring proper post-harvest handling, exploring market opportunities, providing training and extension services, and advocating for supportive policies. These actions will contribute to sustainable sesame production, enhancing food security, economic development, and environmental sustainability in sandy land areas. Furthermore, studying the interactions between chlorophyll content and other physiological processes, such as water use efficiency and carbon assimilation, could contribute to a more comprehensive understanding of sesame plant physiology and guide strategies for improving crop performance in different agroecological contexts.

CONFLICT OF INTERESTS

All authors declare that they have no conflict of interests.

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