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Impact of Soybeans-Shallots Intercropping on Physical Quality and Antioxidant Capacity of Shallots

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ABSTRACT

This research aims to investigate the impact of various soybean varieties, combined with the application of potassium nitrate (KNO_3), on the growth, yield, bulb characteristics, and antioxidant activity of shallots (*Allium cepa*) grown in an intercropping system. The study was conducted from May to August 2025 at Tohudan, Colomadu, Karanganyar, Central Java, Indonesia, at an altitude of 105 meters above sea level. The study used a factorial randomised complete block design consisting of three soybean varieties: Biosoy, Grobogan, and Dega, and three KNO_3 concentrations (0, 3, and 6 g L^{-1}). The observed parameters included soybean growth and yield attributes: plant height, number of pods, seed weight, and 100-seed weight. Observations of shallots included growth, bulb yield, colour characteristics, and antioxidant activity (DPPH radical-scavenging capacity, %RSA). The results showed significant effects of variety, KNO_3, and their interaction on the performance of both soybeans and shallots. Biosoy exhibited the highest growth and yield attributes among the soybean varieties tested and also improved shallot bulb productivity in the intercropping system. Intercropping with Biosoy, combined with a moderate KNO_3 application (3 g L^{-1}), enhanced bulb redness (a*) and chroma, indicating greater colour intensity and market quality. The highest antioxidant activity (94.94% RSA) was observed in the Biosoy without KNO_3 treatment, whereas higher KNO_3 levels tended to reduce antioxidant potential. These findings suggest that intercropping shallots with the Biosoy soybean variety and moderate KNO_3 fertilization optimizes both agronomic productivity and functional bulb quality, offering a sustainable approach to improving land-use efficiency in limited farmland areas.

Keywords: Antioxidant; intercropping; potassium; shallot; soybean

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INTRODUCTION

In 2022, the shallot area planted amounted to 184,984 hectares. The reduction in this amount was over 3 hectares in 2023. This is despite the fact that shallots are spices that are consumed nearly every day in Indonesian cuisine (Al Rosyid & Pratiwi, 2024). More than 85% of the soybean farmers in Indonesia still practice monoculture by having one crop in a piece of land. The drawbacks of this system are that it is susceptible to pests, diseases and weeds and relies heavily on the use of pesticides to safeguard crops. The monoculture of soybean planting in Indonesia is 79%, and 21% of soybean farming is intercropping (Didorenko et al., 2021) (Central Bureau of Statistics, 2024). The dangers of land scarcity, increasing food pressure and climate change are becoming all the more complicated in agricultural problems. On the island of Java, land shortage is evident, with agricultural land being transformed to non- agricultural land at an annual rate of 12% (Durán-Sandoval et al., 2023). To effectively ensure that these issues are mitigated, intercropping has been suggested as a solution to the challenges of land use and agricultural output. Intercropping advantages include: (a) the greatest possible use of space, light, water and nutrients, (b) the reduction of pest and disease attacks, (c) a decrease of soil erosion, since the various root systems absorb water, nutrients and light, (d) an enhanced use of water, since different absorption patterns are employed, (e) increased farmer income, as different plants lessen the likelihood of crop failures, (f) increased biodiversity of agricultural land, (g) greater climate-change resilience, since different absorption patterns are used, and (h) better soil health, since more organic matter is accumulated and soil structure is improved (Toker et al., 2024).

The corn-soybean system is one of the most popular ways of applying intercropping that provides a sustainable system to smallholder farmers having limited land resources (Xu et al., 2020). Being a legume, soybean develops a symbiotic relationship with Rhizobium bacteria that help the fixation of atmospheric nitrogen, thus increasing the availability of nitrogen to the soybean crop and intercrop partners (Abd-Alla et al., 2023). Soybean is an important food product because it is a major source of vegetable protein that contains all the amino acids and is a major raw material in the tofu and tempeh industries. Consequently, it is important to develop sustainable soybean farming to propel the food self-sufficiency program in Indonesia.

The required nitrogen for the shallots (*Allium cepa var. aggregatum L.*) growth may be provided by the soybean root nodules. The spacing usually applied in intercropping systems is the soybean spacing of 40 x 30 cm between the rows of the soybeans, with the shallots in between the rows of the soybean to allow maximum land utilisation. Shallots are an extremely popular product in Indonesia, and can be used both as a spice in the kitchen and as a component of traditional medicine (Yofananda et al., 2021). Shallots contain bioactive compounds like quercetin, flavonoids, saponins, tannins, glycosides, polyphenols and alkaloids. Shallots even contribute to their antioxidant, antibacterial, antiviral, antidiabetic, and anti-inflammatory properties (Anggarani & Amalia, 2022). Sustainable production of shallots is, however, limited by environmental conditions, particularly water availability, as optimum production is achieved during dry seasons with adequate irrigation.

Shallots can also be used to provide bioactive compounds; besides, they can be used to facilitate intercropping systems as they have the capacity to reduce pests that attack soybean plants. The intercropping of soybean with corn, oil palm and cassava has been investigated before (Xu et al., 2020; Wagino et al., 2024); but only a few studies have investigated soybean-shallot intercropping. Therefore, the research proposal will test the influence of intercultural sowing of soybean and shallot to the treatment of nitrate fertiliser on the physical and antioxidant qualities of shallots.

MATERIALS AND METHODS

Materials and Experimental Site

This experiment was conducted at the Tohudan experimental site, Colomadu, Karanganyar Regency, Central Java, Indonesia (105 m above sea level) between May and August 2025. The mean temperature was 29-32 °C, and the total area of the experiment was around 300-400 m². This study used three types of soybean, which included Biosoy, Grobogan and Dega. Shallot bulbs were planted between the rows of the soybean. Basal fertilisers were applied using chicken manure and NPK fertiliser (15:15:15), and potassium nitrate (KNO_3) was used as a treatment fertiliser.

Experimental Design

The study was set up using a randomised complete block design (RCBD). With a factorial treatment structure and three replications. The type of soybean (Biosoy = B, Grobogan = G, and Dega = D) was the first factor, and the dosage of KNO_3: K0 (0 g per plant), K1 (7.5 g per plant) and K2 (15 g per plant) was the second one. There were nine treatments that were applied: Biosoy + no Potassium; Biosoy + Potassium 7.5 g per plant; Biosoy + Potassium 15 g per plant. Grobogan - does not contain Potassium; Grobogan Potassium 7.5 g/plant; Grobogan + Potassium 15 g/plant. Dega × - potassium; Dega + Potassium 7.5 g/plant; Potassium 15 g/plant (Table 1).

Table 1
Treatment Codes

Treatment	Without Potassium Nitrate	Potassium Nitrate7.5 g per Plant	Potassium Nitrate 15 g per Plant
Biosoy variety	BK0	BK1	BK2
Grobogan variety	GK0	GK1	GK2
Dega variety	DK0	DK1	DK2

Experimental Procedure

Land preparation consisted of ploughing and weeding, and later 20 t ha^{-1} of chicken manure and 50 t ha^{-1} of NPK (15:15:15) fertiliser. The spacing of the soybean was 40 x 20 cm with two seeds per hole, with a depth of 3cm. Each plot had 28 soybean plants and was 120 x 120 cm. The transplantation of shallot bulbs between soybean rows was done after 25 days of soybean planting at a spacing of 40 cm with 18 shallot plants per plot. The treatments were 30 and 40 days of planting, where KNO_3 was used in two equal doses. Crop management activities like irrigation, weeding, pest and disease control were performed on a need basis. The soybeans were harvested 83-85 days after planting.

Growth and Yield Parameters

The measurements of the soybeans were the number of pods per plant, weight of each plant, weight of each plot, number of seeds per plant, weight of each plant and weight of 100 seeds. The observations were made of shallots in terms of height of the plants, the number of bulbs per cluster, weight of fresh bulbs per cluster, weight of dry bulbs per cluster and the diameter of the bulb.

Colour Analysis

The colour of the shallot bulbs was measured with the help of a chromameter on the basis of the CIELAB system. Measurements were made of the brightness (L*), the red-green axis (a*) and the yellow-blue axis (b*). Chroma (C*), hue angle (h°), and total colour variation (ΔE) were calculated. This was measured three times, and the values are reported as the standard deviation and the mean.

Antioxidant Activity (DPPH Assay)

The 2, 2-diphenyl-1-picryl-hydrazine (DPPH) test was used to measure antioxidant capacity. The DPPH solution was made 0.1 mM in methanol, and the necessary concentration of shallot extract was added to the solution. This solution was then left in the dark at room temperature, and after 30 minutes, the absorbance of the solution was measured at 517 nm on the UV-Vis spectrophotometer. The scavenging activity percentage (RSA) was determined, and the IC_{50} was determined by regression analysis in the case of a series of extract concentrations.

Statistical Analysis

Analysis of variance (ANOVA) was used to analyse all variables use SPSS software. The comparison of the treatment means was done using the Duncan Multiple Range Test (DMRT) at a significance level of 5%.

RESULTS AND DISCUSSION

Soybean Performance

The performance of soybean varieties in terms of yield was highly affected by the use of KNO_3 (Table 2). Biosoy recorded a higher number of pods, weight of the pod and seed per plant than Grobogan and Dega. This difference could be attributed to the genetic difference in uptake potential and assimilate partitioning. The use of potassium nitrate enhanced pod filling, weight of 100 seeds and productivity. This is consistent with Torabian et al., (2021) who noted that potassium plays a vital role in the photosynthetic process, enzyme activation, and assimilate transport. The stimulating activity of KNO_3 may also be attributed to the enhancement of nitrogen assimilation, since nitrate is a biogenic compound and a signal which triggers protein synthesis (Soujanya et al., 2024). Similar findings were reported by Menalled et al., (2021), who found that as the uptake capacity increased, so did seed yield. These results indicate that diversity is important, and equal K fertilisation is significant for maximising soybean yield. The best outcomes for the Biosoy soybean variety were achieved with the application of 7.5 g of K fertiliser.

The use of Biosoy as an intercrop and the application of KNO_3 resulted in a significant enhancement in the growth and yield parameters (plant height, number of bulbs, fresh and dry bulb weight) of shallot (Table 2). Allium plants need potassium as it controls carbohydrate metabolism, sulfur assimilation, and water balance (Farghly et al., 2021). The increase in the size and weight of the bulb during fertilisation with KNO_3 is similar to other reports such as Etana et al. (2019), which propose that the application of K leads to an increase in dry matter in garlic and onions. The microenvironment of shallots is favourable when Biosoy is grown with them, compared with Grobogan and Dega, leading to denser

Table 2
Growth and yield of soybeans in different varieties and KNO_3 treatments

Treatments	Plant Height (cm)	Pods per Plant	Seed Weight per Plant (g)	100-seed Weight (g)
Biosoy + KNO3 0 g	32.11^{b}	18.2^{b}	12.8^{b}	15.6^{a}
Biosoy + KNO3 7.5 g	44.29^{a}	22.5^{a}	16.9^{a}	15.8^{a}
Biosoy + KNO3 15 g	48.04^{a}	21.8^{a}	17.4^{a}	15.9^{a}
Grobogan + KNO3 0 g	23.75^{c}	14.3^{c}	9.6^{c}	14.3^{b}
Grobogan + KNO3 7.5 g	25.24^{c}	15.1^{c}	10.2^{c}	14.5^{b}
Grobogan + KNO3 15 g	37.53^{b}	17.4^{b}	13.7^{b}	14.8^{b}
Dega + KNO3 0 g	19.22^{c}	12.1^{c}	8.3^{c}	13.5^{c}
Dega + KNO3 7.5 g	25.14^{c}	13.8^{c}	9.1^{c}	13.9^{c}
Dega + KNO3 15 g	42.05^{ab}	16.2^{b}	12.4^{b}	14.1^{c}

Note. Data represent mean values (n = 3). Distinct superscript letters in the same column denote statistically significant differences (DMRT, $p \leq 0.05$)

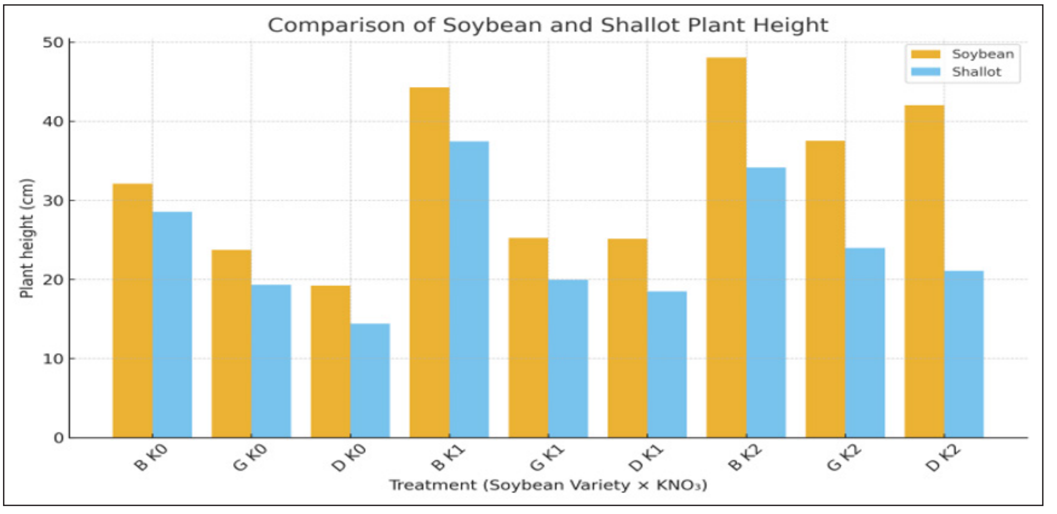

Figure 1. Height of soybean and shallot plants in different varieties and KNO_3 treatments (*B K0: Biosoy + KNO_3 0 g per plant; G K0: Grobogan + KNO_3 0 g per plant; D K0: Dega + KNO_3 0 g per plant; B K1: Biosoy + KNO_3 7.5 g per plant; G K1: Grobogan + KNO_3 7.5 g per plant; D K1: Dega + KNO_3 7.5 g per plant; B K2: Biosoy + KNO_3 15 g per plant; G K2: Grobogan + KNO_3 15 g per plant; D K2: Dega + KNO_3 15 g per plant)

canopies. Intercropping relies on the interspecific complementarity in light capturing and the efficacy of nutrient use (Yang et al., 2023). Moderate application of KNO_3 (K1); middle concentrations were the best, and the balance of nutrients to grow bulbs and reach their quality should be taken into account (Toker et al., 2024).

The height of the soybean plants was always greater than that of shallots, and thus the shade was different among the varieties (Figure 1). The competitive advantage of taller soybean plants reduced the height of shallots in Grobogan and Dega, and Biosoy allowed relatively good growth of shallots. Competitive advantage of a crop is the ability of a commodity or agricultural product to compete and out-compete other analogous products in the market. This is done by cost efficiency, distinctive characteristics (taste or nutrition) and even resistance to pests. Intercropping systems are known to have vertical asymmetry. Interception of light has been particularly essential in plants that need light (Allium plants) (Alam et al., 2019). Low levels of light suppress photosynthetic activities and the growth of carbohydrates, thereby preventing the growth of the bulbs. The same has been observed in the context of cereal legume intercropping where canopy structure plays a considerable role in compatibility and productivity across the system (Brooker et al., 2015; Soujanya et al., 2024). Such findings imply the significance of planting soybean varieties that do not grow a vigorous canopy when planted with shallots (Table 3).

In addition to the productivity of individual crops, the other parameter of intercropping that is crucial is the land equivalent ratio (LER), which is the efficiency of land use relative to the sole crop. The yield patterns used in this study, though, did not provide the actual LER,

Table 3
Growth and yield of shallots in the intercropping treatment of soybeans and KNO_3

Treatments	Plant Height (cm)	Bulbs per Hill	Fresh Bulb Weight (g)	Dry Bulb Weight (g)	Bulb Diameter (mm)	Moisture Content (%)
Biosoy + KNO3 0 g	28.57^{b}	4.8^{b}	19.6^{b}	12.3^{b}	24.8^{a}	82.1^{a}
Biosoy + KNO3 7.5 g	37.47^{a}	6.2^{a}	25.7^{a}	15.6^{a}	25.4^{a}	82.4^{a}
Biosoy + KNO3 15 g	34.14^{a}	6.0^{a}	26.2^{a}	16.1^{a}	25.6^{a}	82.3^{a}
Grobogan + KNO3 0 g	19.35^{c}	3.5^{c}	14.2^{c}	8.9^{c}	23.1^{b}	81.2^{ab}
Grobogan + KNO3 7.5 g	19.98^{c}	3.7^{c}	15.1^{c}	9.2^{c}	23.4^{b}	81.0^{ab}
Grobogan + KNO3 15 g	23.99^{bc}	4.3^{bc}	17.8^{b}	10.4^{bc}	23.9^{b}	81.5^{ab}
Dega + KNO3 0 g	14.40^{d}	2.8^{c}	12.4^{c}	7.2^{c}	22.6^{b}	80.4^{b}
Dega + KNO3 7.5 g	18.48^{cd}	3.4^{c}	13.6^{c}	8.1^{c}	22.8^{b}	80.7^{b}
Dega + KNO3 15 g	21.10^{c}	3.9^{c}	15.9^{bc}	9.8^{bc}	23.2^{b}	81.1^{b}

Note. Data represent mean values ($n = 3$). Distinct superscript letters in the same column denote statistically significant differences (DMRT, $p \leq 0.05$)

but there is a possibility of higher efficiency in land use, especially when using the Biosoy x K1 combination. It has been emphasised in the prior literature that LER values more than 1 mean that intercropping systems are better than monocropping systems (Bhattacharya, 2019; Maclaren et al., 2023). Therefore, implementing LER analysis in future studies will strengthen the ecological and economic justification for soybean-shallot intercropping.

The observed poor growth of shallot in Grobogan and Dega might be attributed to the canopy covering of the shallot canopy that limits the amount of photosynthetically active radiation (PAR) to the canopy. Photosynthesis rate, carbon assimilation and the increase of the bulb are limited directly by the decrease of PAR. Biosoy with less competitive canopy architecture allows more light to penetrate, hence allowing shallot to grow. Similar mechanisms have been reported in other systems, and canopy structure is a key factor in establishing intercrop compatibility and productivity in cereal-legume systems (Major et al., 2022).

Colour Attributes of Shallot Bulbs

Colour attributes (L*, a*, b*, chroma, and hue angle) were very much affected by variety and addition of KNO_3 application (Table 4). Intercropping biosoy with moderate KNO_3 (K1) resulted in higher redness (a*) and chroma, which is a measure of pigment strength. Potassium enhances anthocyanins and flavonoids due to an increase in the level of carbohydrates and stabilisation of pigment production (Vincent-Caboud et al., 2019; Yan et al., 2025). The alterations in the hue angles indicate the alterations in the pigment composition, particularly anthocyanins and quercetin derivatives, which constitute the

Table 4
Colour attributes of shallot bulbs under soybean and KNO_3 intercropping treatments

Treatment	L* (Mean ± SD)	A* (Mean ± SD)	B* (Mean ± SD)
Biosoy + KNO3 0 g	49.26 ± 4.06	28.62 ± 4.74	−13.97 ± 1.47
Biosoy + KNO3 7.5 g	42.59 ± 7.73	34.25 ± 3.25	−15.05 ± 0.46
Biosoy + KNO3 15 g	47.79 ± 4.35	29.16 ± 6.23	−12.86 ± 1.48
Grobogan + KNO3 0 g	53.46 ± 4.05	25.06 ± 3.53	−12.66 ± 1.63
Grobogan + KNO3 7.5 g	53.47 ± 0.89	19.20 ± 1.09	−10.41 ± 0.71
Grobogan + KNO3 15 g	34.88 ± 0.46	37.14 ± 1.33	−15.30 ± 0.42
Dega + KNO3 0 g	46.60 ± 1.07	26.98 ± 2.64	−12.77 ± 0.77
Dega + KNO3 7.5 g	38.67 ± 3.89	33.78 ± 0.65	−13.98 ± 0.45
Dega + KNO3 15 g	46.47 ± 3.67	32.89 ± 5.98	−15.00 ± 0.16

**Note*. Data represent mean values (n = 3). Distinct superscript letters in the same column denote statistically significant differences (DMRT, $p \leq 0.05$)

Figure 2. Harvested shallot samples from an intercropping system with soybean

major part of shallot bulb colour (Zhang et al., 2018). The accumulation of pigments can also be significantly affected by environmental and nutritional parameters; one of them is potassium, which may enhance the stability of anthocyanins and inhibit oxidative breakdown (Hasanuzzaman et al., 2018). Since the colour of the bulb directly depends on consumer preference and marketability, K supply in intercropping systems is important in enhancing quality (Figure 2).

Other Allium species have been reported to have similar patterns. Fertilisation with potassium and nitrogen increases the size and yield of bulbs in shallots and garlic and has a tendency to decrease the quantity of flavonoids and antioxidant potential (Chernukha et al., 2022). The results of this experiment confirm that shallots also act similarly, which implies the need to take fertilisation strategies into account to have the most commercial traits and health-promoting properties.

Antioxidant Activity

The effects of the soybean variety, the dosage of potassium nitrate and the interactions between them on the antioxidant activity of shallot bulbs (percentage reduction in soybean activity, a.k.a. percent reduce activity, or percent RSA) were significant. Biosoy showed by far the best antioxidant activity in zero KNO_3 (Biosoy × K0), meaning that there was a good natural genetic ability to produce phenolic and flavonoid compounds. Recent reports testify that genotypic variation is a powerful regulator of the antioxidant potential in Allium crops due to variation of quercetin, flavonols, sulfur-based compounds, and secondary metabolites (Yang et al., 2023).

It was also observed that there was an evident decreasing tendency as KNO_3 content of all varieties increased. This pattern is consistent with new findings that increased nitrogen levels tend to lower phenolic levels by the carbon-nitrogen trade-off process, in which plants use more carbon in growth-related processes instead of secondary metabolism (Supriyadi et al., 2020). High levels of nitrates increase vegetative biomass and water content, and in this case, the dilution effect decreases the phytochemicals to unit dry mass ratio (Olsovska et al., 2024).

The results of the current study agree with the observations of other Allium species, in which over-fertilisation reduces the level of flavonoids and antioxidant ability (Hasanuzzaman et al., 2018). On the other hand, moderate or even lower nutrient intakes are likely to increase stress-responsive biosynthesis in phenolic pathways, increasing the antioxidant activity (Ninkuu et al., 2025). In this way, the elevated antioxidant activity of Biosoy (B) in the absence of potassium and B K1 (KNO_3 7.5 g) would probably indicate the presence of weak stresses on the nutrients that cause the synthesis of protective secondary metabolites.

The varietal differences were also involved. Biosoy could sustain a good amount of antioxidants in shallots in contrast to Grobogan and Dega. This aligns with the fact that various intercropping partners develop diverse below-ground interactions (root exudates, N fixation, rhizosphere signalling), which are capable of controlling biosynthesis of companion crop secondary metabolites (Brooker et al., 2015). Both intercropping of the legumes with high N fixation and high N fixation increase the amount of nitrogen available in the soil but also produce competition or facilitation effects that change the metabolic allocation in shallots.

Regarding the functional food, the present results underline that the antioxidant content of shallots is extremely sensitive to fertilisation methods. The antioxidant activity was found to be relatively high in moderate KNO_3 (7.5 g), though the highest values were always at zero KNO_3 (Figure 3). This pattern is similar to the latest reviews that suggest a possibility to increase the phytochemical density of vegetables by reducing excessive fertilisation (Olsovska et al., 2024). Therefore, KNO_3 inputs have to be maximised to achieve the yield as well as to maintain the nutritional and functional characteristics of shallot bulbs.

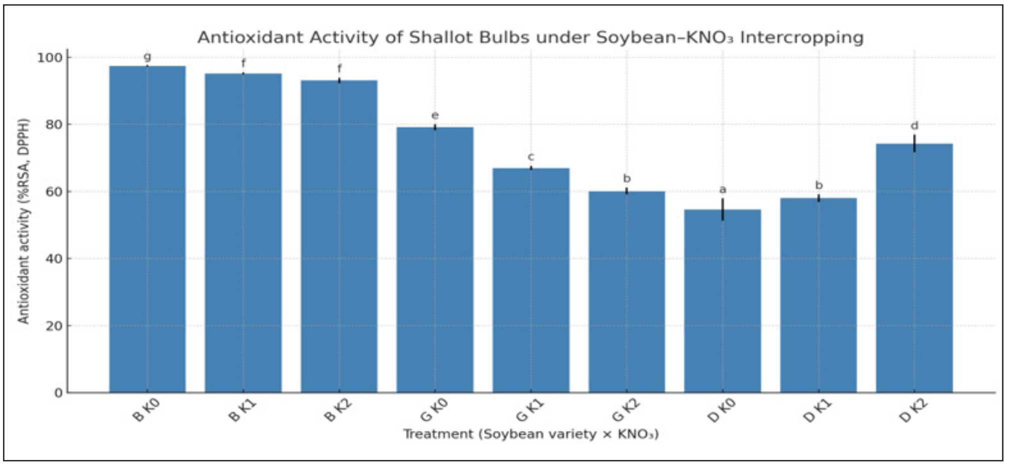

Figure 3. Antioxidant activity (%RSA, DPPH assay) of shallot bulbs grown under soybean-KNO_3 intercropping treatments. Values are presented as mean ± SD (n = 4). Different letters above the bars signify statistically significant differences based on Duncan's Multiple Range Test at $p \leq 0.05$. Antioxidant activity in shallots is driven by flavonoids, phenolics, and sulfur-containing compounds and is strongly influenced by genotype and nutrient availability

Overall, these results confirm. Letters above the bars indicate the statistically significant differences on the basis of Duncan Multiple Range Test, p 0.05. The moderate fertilisation by using Biosoy soybean and moderate KNO_3 is a viable method to regulate the yield-to-quality of functional and moderate functional quality, and minimal fertilisation adds to the antioxidant potential further. This agroecological feedback correlates with modern ideas of sustainable intensification, in which the mutual optimisation of nutrient efficiency and functional food properties is attained (Yofananda et al., 2021).

CONCLUSION

This study shows that the yield and quality of soybean in intercropping with shallot are very much reliant on the soybean variety and the quantity of KNO_3 to be applied. Biosoy could exhibit consistent good performance in soybean and grow a canopy structure that increased light penetration and consequently the growth of shallots and yield of the bulbs. The interactions between variety and fertilisers had a strong impact on bulb colour, and the moderate KNO_3 had a positive effect on pigment intensity in combination with Biosoy. Bioactivity was also not the same across the variety × fertiliser interactions, with more KNO_3 in Biosoy and Grobogan and less in Dega, showing that varieties react differently to biochemical reactions. In general, soybean-shallot intercropping increased the efficiency of the land, crop yield, and the nutritional value of shallots, and Biosoy + moderate KNO_3 (K1) was the best agronomic combination. The findings highlight the necessity of integrating appropriate variety selection and equalising nutrient management in the attainment of sustainable intensification, improved crop quality and improved resiliency in smallholder systems.

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CONFLICTS OF INTEREST

The authors state that they have no conflicts of interest.

HIGHLIGHTS

- Intercropping soybeans with shallots significantly increases the yield and quality of the tubers.
- Biosoy variety combined with moderate KNO_3 is producing the best agronomic performance and quality.
- The antioxidant activity of shallot bulbs decreased with increasing KNO_3 supply, indicating a trade-off between yield and phytochemical content.

AUTHOR CONTRIBUTIONS

Conceptualisation	:	Sumarmi
Methodology	:	Sumarmi, Avisema Sigit Saputro, Fadilah Husnun
Formal analysis	:	Sumarmi, Avisema Sigit Saputro
Investigation	:	Sumarmi; Edy Listanto
Writing - original draft preparation	:	Sumarmi, Avisema Sigit Saputro, Fadilah Husnun
Writing - review and editing	:	Sumarmi, Fadilah Husnun; Edy Listanto
Supervision	:	Sumarmi, Edy Listanto

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