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Research Article

Effects of Basil Leaf Extract Priming on Seed Germination and Seedling Growth of Okra (*Abelmoschus esculentus*)

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ABSTRACT

Okra cultivation often faces challenges related to poor seed germination and early seedling growth, necessitating innovative and sustainable solutions. This study was conducted during the spring season of 2024 at the Nursery Department of Horticulture, Sindh Agriculture University, Tandojam, to evaluate the effect of priming with basil (*Ocimum basilicum*) leaf extract on the seed germination and seedling growth of okra (*Abelmoschus esculentus)*. The experiment was laid out in a completely randomized design (CRD) with two factors: okra varieties (Sabzpari and Crass) and basil leaf extract concentrations (control, tap water, 1%, 3%, 5%, and 7%) with three replications. Data were recorded for seed germination percentage, germination index, seedling vigor index, number of leaves per plant, fresh biomass of root and shoot, root length, plant height and chlorophyll content. The results indicated that basil leaf extract significantly influenced most growth parameters. The highest seed germination (87.50%) was observed with 1% and 3% basil leaf extract, whereas the lowest (70.83%) was recorded with tap water. The Crass variety exhibited a higher germination rate (85.39%) than Sabzpari (77.08%). The germination index was significantly improved by basil leaf extract, with the highest value (0.64) recorded at 3% concentration. Similarly, the seedling vigor index was highest (1290.00) at 3% basil leaf extract, with the Crass variety performing better overall. The number of leaves per plant peaked at 3.66 with 3% basil leaf extract, showing a significant treatment effect. Root and shoot biomass were significantly influenced by basil leaf extract concentrations. The maximum fresh root biomass (0.80 g) and fresh shoot biomass (2.93 g) were observed at 3% basil leaf extract. The highest plant height (39.52 cm) was recorded at 3% basil leaf extract, whereas the lowest (28.74 cm) was observed with tap water (0% basil leaf extract). Chlorophyll content was also significantly affected, with the highest value (42.18) at 3% basil leaf extract and the lowest (30.45) in the control treatment. After going through the findings of present research, it was concluded that the okra verities treated with 3% basil leaf extract showed superior performances in seed germination and growth parameters.

Keywords: Basil leaf extract, Okra, Priming, Seed germination, Seedling growth.

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INTRODUCTION

Okra (*Abelmoschus esculentus* L.), a widely cultivated vegetable crop that is part of the Malvaceae family, holds significant importance (Naveed *et al.*, 2009; Bereded, 2023). It is an annual herbaceous plant that reproduces through seeds and primarily undergoes self-pollination (Osawaru *et al.*, 2014). This crop grows successfully in warm-temperate, subtropical and tropical climates worldwide (Kaur *et al.*, 2013; Yuan *et al.*, 2014). It is a nutritious vegetable crop with numerous health benefits. The consumption of adequate quantity and quality vegetables is vital for the optimal functioning of body of humans (Uwiringiyimana *et al.*, 2014).

Okra contains 1.9 g of protein out of 100g of okra. It is abundant in vital elements that are frequently absent from the normal diets of people in impoverished nations, including vitamins, calcium, potassium, enzymes, carbs, and other minerals. It is therefore essential to human nutrition. Since young, immature okra pods are eaten as fresh vegetables and can be prepared in a variety of ways, their consumption is especially important. These include boiling them, consuming them raw in salads, or making a drink by soaking thin okra slices in water for at least 24 hours or overnight. The residual liquid is taken out of the pods and combined with the infused water to make the beverage (Ndunguru and Rajabu, 2004). The thick seed coat of okra restricts water absorption, posing a significant physiological challenge for achieving uniform germination and optimal plant performance. Okra germination and vigor of seeds can be enhanced by seed priming (Purquerio *et al.*, 2010; Mohammadi *et al.*, 2012). A simple, economical, and effective method for improving germination synchronization and encouraging early seedling growth is seed priming. Even under both favorable and unfavorable climatic conditions, it accomplishes this by increasing seed vigor, breaking dormancy, and speeding up germination, which eventually results in better plant establishment and higher-quality yields However, as of right now, there isn't a standardized seed priming technique made especially to deal with the problem of okra seed hardness (Ventura *et al.*, 2012; Hussein, 2015; Paparella *et al.*, 2015).

Basil (*Ocimum basilicum* L.) leaf extract offers a sustainable approach to enhancing okra seed performance due to its rich phytochemical profile. Its allelopathic effects are concentration-dependent, with low doses promoting seed vigor and higher doses potentially inhibiting growth (Rahayu *et al.*, 2021). The extract contains bioactive compounds such as flavonoids, tannins, eugenol, and phenolic oils, which support plant physiology by improving stress tolerance, nutrient uptake, and defense against soil-borne pathogens. Its phytochemicals also exhibit insecticidal properties, contributing to integrated pest management and reducing reliance on synthetic chemicals (Palavra *et al.*, 2011). As a member of the Labiatae family, basil produces secondary metabolites especially phenols and terpenes which are linked to its allelopathic potential (Bonea, 2020). These compounds, particularly phenolics, influence plant-plant interactions and can alter germination and growth by affecting nutrient availability or physiological processes (Kamel *et al.*, 2022). Basil's allelopathic role has attracted attention as a natural alternative to chemical fertilizers and herbicides (Safdar *et al.*, 2021), with both promotive and inhibitory effects on seedling development depending on dosage (Chou *et al.*, 2006; Coolbear *et al.*, 2020). Allelopathy chemical interaction among plants via released metabolites which plays a critical role in agriculture by affecting weed suppression and crop productivity (Mishra *et al.*, 2015; Cheng and Cheng, 2015; Bhattacharya *et al.*, 2020). Supporting this, studies on other allelopathic species show similar trends: aqueous extracts of *Achatherum splendens*, *Artemisia frigida*, and *Stellera chamaejasme* inhibited lettuce germination but promoted seedling growth at lower concentrations (Wang *et al.*, 2022). Likewise, *Ficus carica* extracts reduced germination but stimulated growth in *Isatis tinctoria*, *Taraxacum officinale*, and *Mentha spicata* (Li *et al.*, 2021).

This study investigates the effects of basil (*Ocimum basilicum*) leaf extract on okra seed germination and seedling growth, aiming to determine the optimal extract concentrations for maximizing germination and promoting vigorous seedling development. By exploring basil extract as a plant-based biostimulant, this research contributes to sustainable agriculture through the development of eco-friendly alternatives to synthetic growth enhancers, ultimately supporting improved crop productivity.

MATRIALS AND METHODS

The experiment was conducted as a pot trial during the spring season of 2024 at the SAU Nursery, Department of Horticulture, Sindh Agriculture University, Tandojam. A completely randomized design (CRD) with factorial arrangements was used, consisting of two factors: six priming treatments and two okra varieties. The first factor (Factor A) included six priming treatments with basil leaf extract (BLE), coded as P1 to P6, where P1 = control (no priming), P2 = tap water, P3 = 1% BLE, P4 = 3% BLE, P5 = 5% BLE, and P6 = 7% BLE. The second factor (Factor B) comprised two okra varieties: V1 = Sabzpari and V2 = Crass. Thus, a total of 12 treatment combinations (6 BLE treatments × 2 varieties) were tested, each replicated three times. Each treatment was applied to 5 plants per replication, grown in earthen pots (25 cm diameter) filled with uniform well-drained loamy soil. All pots were kept under the same nursery conditions, with consistent soil type, watering regime, and exposure to temperature and light to ensure uniformity across treatments. Data recorded for each parameter represent the mean of 15 plants per treatment (5 plants × 3 replications). This setup ensured that the experiment was reproducible and controlled for environmental and soil-related variability.

Data collection and methodology

The data on seed germination and growth-related attributes were recorded for further statistical analysis. The seed germination (%), germination index, seedling vigor index, number of leaves plant-1, fresh root biomass (g), fresh shoot biomass (g), root length (cm), plant height (cm) and chlorophyll content were recorded.

Seed Germination (%)

The seed germination percentage was calculated by assessing the proportion of sprouted seeds relative to the total seeds planted, with results expressed as a percentage.

Germination Index (GI)

The germination index was calculated following the standardized method outlined by the Association of Official Seed Analysts (AOSA, 1983).

$$GI = \sum \frac{Gt}{Dt}$$

Where:

Gt = Number of seeds germinated on day t

Dt= Number of days after sowing (day t)

Seedling Vigor Index

The seedling vigor index was calculated using the methodology established by Abdul-Baki and Anderson (1970).

$$Seedling\ Vigor\ index\ (SVI) = Mean\ Seedling\ Length\ (cm) \times Germination\ Percentage$$

The average height of seedlings was measured at a specified time after germination.

Number of Leaves per plant

The number of leaves per plant was counted at a set growth interval and averaged across all plants in each pot.

Fresh Biomass of Root (g)

The fresh root biomass was determined by weighing randomly selected samples using an electronic weighing balance machine (Model: A&D EK-600i, precision: 0.01 g), and the values were expressed in grams.

Fresh Biomass of Shoot (g)

The fresh shoot biomass was measured by weighing random samples using an electronic weighing balance machine (Model: A&D EK-600i, precision: 0.01 g), and the values were expressed in grams.

Root length (cm)

Root length was determined by uprooting the plant and measuring the distance from the base of the stem to the tip of the longest root using a measuring tape. The average root length for all plants in each treatment was subsequently calculated.

Plant Height (cm)

Plant height was measured at maturity from the base to the tip of the plant using a measuring tape. The average height for all plants in each treatment was then calculated.

Chlorophyll content

The chlorophyll content of okra leaves was assessed by randomly selecting 50% of the seedlings from each treatment. Measurements were taken using a portable chlorophyll meter (SPAD 502), and the results were recorded as relative greenness (rg).

Statistical analysis

The data were analyzed using Statistix 8.1 software (Analytical Software, 2006). The experiment followed a completely randomized design (CRD) with a factorial arrangement. Analysis of variance (ANOVA) was conducted to determine the significance of treatment effects, and mean comparisons were made using the Least Significant Difference (LSD) test at the 5% probability level.

RESULTS

The present research was carried out during the spring season of 2024 at the Nursery of the Department of Horticulture, Sindh Agriculture University, Tandojam. The data collected for the parameters studied are summarized in Tables 1 to 9.

Seed Germination (%)

The seed germination of okra varieties, namely Sabzpari and Crass, treated with different concentrations of basil leaf extract, is displayed in Table 1. The analysis showed no significant main effects of treatments, varieties, or their interactions on seed germination ($P > 0.05$). The finding showed that the greater okra seed germination (87.50%) was observed when seeds were treated with 1% and 3% basil leaf extract. However, the minimum seed germination (70.83%) was noted with tap water. The results further indicated that the seed germination of the Crass variety was greater (85.39%) compared to Sabzpari (77.08%). The interactive effect of the Crass variety with 5% basil leaf extract resulted in the highest germination (91.67%), while the lowest germination (62.50%) was observed in Sabzpari treated with tap water. The LSD test suggested that the differences in seed germination between basil leaf extract concentrations and varieties were statistically non-significant ($P > 0.05$).

Germination index (GI)

The germination index of okra varieties, namely Sabzpari and Crass, treated with different concentrations of basil leaf extract, is outlined in Table 2. ANOVA indicated a significant impact of basil leaf extract concentrations ($P < 0.05$), though variety-treatment interactions and varietal main effects were non-significant ($P > 0.05$). The results showed that the maximum germination index of okra (0.64) was observed with 3% basil leaf extract, followed by 7% basil leaf extract (0.57), 1% basil leaf extract (0.55), control (0.48), 5% basil leaf extract (0.48), and tap water (0.43). The results further indicated that the Crass variety had a numerically higher germination index (0.53) compared to Sabzpari (0.51), though this difference was not statistically significant. The interactive effect of the Sabzpari variety with 3% basil leaf extract resulted in the highest germination index (0.73), while the Sabzpari variety treated with tap water showed the lowest germination index (0.36). The LSD test suggested that the differences in germination index between basil leaf extract concentrations were statistically significant ($P < 0.05$).

Seedling Vigor Index (SVI)

The seedling vigor index of okra varieties, namely Sabzpari and Crass, treated with different concentrations of basil leaf extract, is detailed in Table 3. The analysis showed significant interactions between varieties and basil leaf extract concentrations, along with varietal main effects ($P < 0.05$), whereas treatment effects were marginally non-significant ($P = 0.0677$). The results showed that the maximum seedling vigor index of okra (1290.00) was observed with 3% basil leaf extract, followed by 1% basil leaf extract (1155.83), 7% basil leaf extract (1134.00), 5% basil leaf extract (1125.50), control (1017.17), and tap water (869.50). The results further indicated that the Crass variety had a significantly higher seedling vigor index (1219.50) compared to Sabzpari (977.83). The interactive effect of the Sabzpari variety with 3% basil leaf extract resulted in the highest seedling vigor index (1484.33), while the Sabzpari variety treated with tap water showed the lowest seedling vigor index (655.67). The LSD test revealed significant disparities in seedling vigor index among varieties and their treatment interactions ($P < 0.05$).

Number of leaves per plant

Leaf count per plant for Sabzpari and Crass okra varieties exposed to varying basil leaf extract concentrations is displayed in Table 4. The analysis showed significant variety-concentration interactions and treatment main effects ($P < 0.05$), whereas varietal main effects lacked significance ($P > 0.05$). The results revealed that the highest number of leaves per plant (3.66) was observed with 3% basil leaf extract, followed by 5% basil leaf extract (3.44), 1% basil leaf extract (3.22), 7% basil leaf extract (3.16), tap water (3.00), and control (2.78). The results further indicated that the Crass variety had a numerically similar number of leaves per plant (3.22) compared to Sabzpari (3.20). The interactive effect of the Sabzpari variety with 3% basil leaf extract resulted in the optimum number of leaves per plant (4.00), while the Crass variety under control conditions showed the lowest number of leaves (2.66) per plant. The LSD test revealed significant differences in leaf count across treatments and their interactions with varieties ($P < 0.05$).

Fresh biomass of root (g)

Fresh root biomass data for Sabzpari and Crass okra varieties under varying basil leaf extract concentrations are summarized in Table 5. ANOVA indicated highly significant treatment main effects and significant varietal main effects ($P < 0.05$), though variety-treatment interactions were non-significant ($P > 0.05$). The results showed that the highest fresh root biomass (0.80 g) was observed with 3% basil leaf extract, followed by 5% basil leaf extract (0.47 g), 1% basil leaf extract (0.40 g), 7% basil leaf extract (0.38 g), tap water (0.29 g), and control (0.12 g).

Between varieties, Sabzpari exhibited a numerically higher mean fresh root biomass (0.43 g) compared to Crass (0.39 g). The interactive effect of the Sabzpari variety with 3% basil leaf extract resulted in the highest fresh root biomass (0.83 g), while the lowest root biomass (0.12 g) was observed in both Sabzpari and Crass under control conditions. The LSD test confirmed significant differences between treatments and varieties ($P < 0.05$), but no significant interaction between treatments and varieties.

Fresh biomass of shoot (g)

Fresh shoot biomass data for Sabzpari and Crass okra varieties exposed to varying basil leaf extract concentrations are detailed in Table 6. ANOVA indicated significant variety-treatment interactions and main effects ($P < 0.05$). Results revealed the highest fresh shoot biomass in okra (2.93 g) was observed with 3% basil leaf extract, followed by 5% basil leaf extract (2.40 g), 7% basil leaf extract (1.99 g), 1% basil leaf extract (1.45 g), tap water (1.27 g), and control (1.03 g). The results further indicated that the Crass variety had a significantly greater fresh shoot biomass (1.92 g) compared to Sabzpari (1.77 g). The interactive effect of the Sabzpari variety with 3% basil leaf extract showed the highest fresh shoot biomass (3.06 g), while the Sabzpari and Crass varieties under control conditions showed the lowest fresh shoot biomass (1.03 g and 1.02 g, respectively). The LSD test revealed significant variations in fresh shoot biomass across treatments, varieties, and their interactions ($P < 0.05$).

Table 1. Seed germination (%) as affected by different concentrations of basil leaf extract of okra varieties.

Treatments	Varieties		Mean
	V_1= Sabzpari	V_2 = Crass	
T_1= (control)	70.83	83.17	77.00 A
T_2= Tap water	62.50	79.17	70.83 A
T_3= 1% basil leaf extract	83.33	91.67	87.50 A
T_4= 3% basil leaf extract	95.83	79.17	87.50 A
T_5= 5% basil leaf extract	70.83	91.67	81.25 A
T_6= 7% basil leaf extract	79.17	87.50	83.33 A
Mean	77.08 A	85.39 A	
	Treatment	Varieties	T x V
P value	0.4218	0.1237	0.4022
SE	8.9877	5.1891	12.711
LSD@ 5%	18.639	10.761	26.360

Whereas P value= probability value, SE= standard error, LSD@ 5%= least significant difference at 5% level of probability.

Table 2. Germination index as affected by different concentrations of basil leaf extract of okra varieties.

Treatments	Varieties		Mean
	V_1= Sabzpari	V_2 = Crass	
T_1= (control)	0.45	0.50	0.48 BC
T_2= Tap water	0.36	0.49	0.43 C
T_3= 1% basil leaf extract	0.53	0.56	0.55 ABC
T_4= 3% basil leaf extract	0.73	0.55	0.64 A
T_5= 5% basil leaf extract	0.43	0.54	0.48 BC
T_6= 7% basil leaf extract	0.56	0.57	0.57 AB
Mean	0.51 A	0.53 A	
	Treatment	Varieties	T x V
P value	0.0333	0.5021	0.2110
SE	0.0620	0.0358	0.0877
LSD@ 5%	0.1287	0.0743	0.1820

Whereas P value= probability value, SE= standard error, LSD@ 5%= least significant difference at 5% level of probability.

Table 3. Seedling vigor index as affected by different concentrations of basil leaf extract of okra varieties.

Treatments	Varieties		Mean
	V_1= Sabzpari	V_2 = Crass	
T_1= (control)	785.33	1249.00	1017.17 BC
T_2= Tap water	655.67	1083.33	869.50 C
T_3= 1% basil leaf extract	1031.33	1280.33	1155.83 AB
T_4= 3% basil leaf extract	1484.33	1095.67	1290.00 A
T_5= 5% basil leaf extract	923.67	1327.33	1125.50 ABC
T_6= 7% basil leaf extract	986.67	1281.33	1134.00 ABC
Mean	977.83 B	1219.50 A	
	Treatment	Varieties	T x V
P value	0.0677	0.0037	0.0301
SE	129.05	74.509	182.51
LSD@ 5%	267.64	154.52	378.50

Whereas P value= probability value, SE= standard error, LSD@ 5%= least significant difference at 5% level of probability.

Table 4. Number of leaves per plant as affected by different concentrations of basil leaf extract of okra varieties.

Treatments	Varieties		Mean
	V_1= Sabzpari	V_2 = Crass	
T_1= (control)	2.89	2.66	2.78 C
T_2= Tap water	3.00	3.00	3.00 C
T_3= 1% basil leaf extract	3.11	3.32	3.22 BC
T_4= 3% basil leaf extract	4.00	3.33	3.66 A
T_5= 5% basil leaf extract	3.00	3.89	3.44 AB
T_6= 7% basil leaf extract	3.22	3.11	3.16 BC
Mean	3.20 A	3.22 A	
	Treatment	Varieties	T x V
P value	0.0065	0.8936	0.0348
SE	0.2133	0.1231	0.3016
LSD@ 5%	0.4423	0.2554	0.6256

Whereas P value= probability value, SE= standard error, LSD@ 5%= least significant difference at 5% level of probability.

Table 5. Fresh biomass of root (g) as affected by different concentrations of basil leaf extract of okra varieties.

Treatments	Varieties		Mean
	V_1= Sabzpari	V_2 = Crass	
T_1= (control)	0.12	0.12	0.12 E
T_2= Tap water	0.30	0.27	0.29 D
T_3= 1% basil leaf extract	0.42	0.39	0.40 C
T_4= 3% basil leaf extract	0.83	0.76	0.80 A
T_5= 5% basil leaf extract	0.53	0.42	0.47 B
T_6= 7% basil leaf extract	0.37	0.39	0.38 C
Mean	0.43 A	0.39 B	
	Treatment	Varieties	T x V
P value	0.0000	0.0043	0.0863
SE	0.0225	0.0130	0.0318
LSD@ 5%	0.0466	0.0269	0.0659

Whereas P value= probability value, SE= standard error, LSD@ 5%= least significant difference at 5% level of probability.

Table 6. Fresh biomass of shoot (g) as affected by different concentrations of basil leaf extract of okra varieties.

Treatments	Varieties		Mean
	V_1= Sabzpari	V_2 = Crass	
T_1= (control)	1.03	1.02	1.03 E
T_2= Tap water	1.20	1.34	1.27 D
T_3= 1% basil leaf extract	1.36	1.54	1.45 D
T_4= 3% basil leaf extract	3.06	2.80	2.93 A
T_5= 5% basil leaf extract	2.12	2.69	2.40 B
T_6= 7% basil leaf extract	1.88	2.11	1.99 C
Mean	1.77 B	1.92 A	
	Treatment	Varieties	T x V
P value	0.0000	0.0159	0.0068
SE	0.0943	0.0544	0.1334
LSD@ 5%	0.1956	0.1129	0.2766

Whereas P value= probability value, SE= standard error, LSD@ 5%= least significant difference at 5% level of probability.

Root length (cm)

Root length data for Sabzpari and Crass okra varieties exposed to varying basil leaf extract concentrations are summarized in Table 7. ANOVA indicated a significant impact of extract concentrations ($P < 0.05$), whereas variety-treatment interactions and varietal main effects were non-significant ($P > 0.05$). Findings indicated the greatest root length of okra (13.72 cm) was observed with 3% basil leaf extract, followed by 5% basil leaf extract (12.25 cm), tap water (11.64 cm), 1% basil leaf extract (11.02 cm), 7% basil leaf extract (10.52 cm), and control (7.50 cm). The results further indicated that the Crass variety had a numerically greater root length (11.38 cm) compared to Sabzpari (10.84 cm), though this difference was not statistically significant. The interactive effect of the Sabzpari variety with 3% basil leaf extract resulted in the highest root length (14.22 cm), while the Sabzpari variety under control conditions showed the lowest root length (7.33 cm). The LSD test confirmed that the differences in root length between basil leaf extract concentrations were statistically significant ($P < 0.05$).

Plant height (cm)

Height data for Sabzpari and Crass okra varieties under varying basil leaf extract concentrations are summarized in Table 8. ANOVA indicated significant varietal main effects ($P < 0.05$), whereas variety-treatment interactions and treatment main effects were statistically non-significant ($P > 0.05$). The results demonstrated that maximum height of okra plant (14.72 cm) was observed with 3% basil leaf extract, followed by 5% basil leaf extract (13.75 cm), 7% basil leaf extract (13.55 cm), 1% basil leaf extract (13.11 cm), tap water (12.89 cm), and control (12.14 cm). The results further indicated that the Crass variety had a significantly greater plant height (13.99 cm) compared to Sabzpari (12.73 cm). The interactive effect of the Sabzpari variety with 3% basil leaf extract resulted in the highest plant height (15.55 cm), and Sabzpari variety under control conditions showed the lowest plant height (11.00 cm). The LSD test revealed significant plant height variations between varieties ($P < 0.05$).

Chlorophyll content

The chlorophyll content of okra varieties, namely Sabzpari and Crass, treated with different concentrations of basil leaf extract, is detailed in Table 9. The analysis of variance revealed that the main effects of basil leaf extract concentrations and varieties were significant ($P < 0.05$), while their interaction was non-significant ($P > 0.05$). The findings showed that the maximum chlorophyll content (42.39) was observed with 3% basil leaf extract, followed by 5% basil leaf extract (39.39), 7% basil leaf extract (37.00), 1% basil leaf extract (34.78), tap water (33.50), and control (30.27). The results further indicated that the Sabzpari variety had a significantly higher chlorophyll content (36.76) compared to Crass (35.68). The interactive effect of the Sabzpari variety with 3% basil leaf extract resulted in the highest chlorophyll content (43.11), while the Crass variety under control conditions showed the lowest chlorophyll content (29.77). The LSD test revealed significant chlorophyll content variations among basil extract concentrations and varieties ($P < 0.05$).

DISCUSSION

The allelopathic properties of basil (*Ocimum basilicum*), a plant renowned for its bioactive compounds, have garnered significant attention in agricultural research due to their dualistic effects on plant growth. At low concentrations, basil extracts act as biostimulants, enhancing germination and vegetative development, while higher concentrations often suppress growth due to phytochemical toxicity (Cheng and Cheng, 2015; Bonea, 2020). Research investigated the impact of basil leaf extract (1–7%) on two okra varieties (Sabzpari and Crass), revealing concentration-dependent trends in germination, vigor, biomass, and physiological parameters. These findings align with broader studies on basil's allelopathic interactions with horticultural as well as agronomic crops such as bitter gourd, soyabean and maize (Verma *et al.*, 2012; Islam and Kato-Noguchi, 2013; Sohail, 2024), yet highlight critical distinctions rooted in species-specific physiology and genetic adaptability.

Germination, a pivotal phase in plant establishment, is highly sensitive to allelochemical cues. In this study, 3% basil extract emerged as the optimal concentration, achieving 87.50% germination and a seedling vigor index of 1290.00. These results are consistent with Sohail (2024), who reported 76.56% germination in bitter gourd treated with 5% basil extract. Both studies attribute enhanced germination to phenolic compounds such as rosmarinic acid, which activate hydrolytic enzymes (e.g., α-amylase, proteases) that mobilize seed reserves (Verma *et al.*, 2012). However, the lower optimal concentration for okra (3% vs. 5% for bitter gourd) highlights species-specific tolerance thresholds. Sohail (2024) suggested that bitter gourd's thicker seed coat and stronger enzymatic detoxification systems may buffer allelochemical stress, whereas okra's relatively permeable seed structure increases susceptibility to phytotoxicity at higher concentrations. The decline in germination observed at higher BLE concentrations (5–7%) supports findings in maize and soybean, where basil extracts above 10% suppressed germination due to osmotic stress and phenolic toxicity (Mekky *et al.*, 2019; Bonea, 2020).

Table 7. Root length (cm) as affected by different concentrations of basil leaf extract of okra varieties.

Treatments	Varieties		Mean
	V_1= Sabzpari	V_2 = Crass	
T_1= (control)	7.33	7.66	7.50 E
T_2= Tap water	11.61	11.66	11.64 BC
T_3= 1% basil leaf extract	10.44	11.61	11.02 CD
T_4= 3% basil leaf extract	14.22	13.22	13.72 A
T_5= 5% basil leaf extract	11.50	13.00	12.25 B
T_6= 7% basil leaf extract	9.92	11.11	10.52 D
Mean	10.84 A	11.38 A	
	Treatment	Varieties	T x V
P value	0.0000	0.0628	0.1294
SE	0.4767	0.2752	0.6742
LSD@ 5%	0.9887	0.5708	1.3982

Whereas P value= probability value, SE= standard error, LSD@ 5%= least significant difference at 5% level of probability.

Table 8. Plant height (cm) as affected by different concentrations of basil leaf extract of okra varieties.

Treatments	Varieties		Mean
	V_1= Sabzpari	V_2 = Crass	
T_1= (control)	11.00	13.27	12.14 C
T_2= Tap water	12.11	13.67	12.89 BC
T_3= 1% basil leaf extract	12.27	13.94	13.11 BC
T_4= 3% basil leaf extract	15.55	13.89	14.72 A
T_5= 5% basil leaf extract	12.94	14.55	13.75 AB
T_6= 7% basil leaf extract	12.49	14.61	13.55 ABC
Mean	12.73 B	13.99 A	
	Treatment	Varieties	T x V
P value	0.0523	0.0090	0.1461
SE	0.7629	0.4405	1.0789
LSD@ 5%	1.5822	0.9135	2.2375

Whereas P value= probability value, SE= standard error, LSD@ 5%= least significant difference at 5% level of probability.

Table 9. Chlorophyll content as affected by different concentrations of basil leaf extract of okra varieties.

Treatments	Varieties		Mean
	V_1= Sabzpari	V_2 = Crass	
T_1= (control)	30.77	29.77	30.27 E
T_2= Tap water	34.00	33.00	33.50 D
T_3= 1% basil leaf extract	35.89	33.66	34.78 D
T_4= 3% basil leaf extract	43.11	41.67	42.39 A
T_5= 5% basil leaf extract	39.77	39.00	39.39 B
T_6= 7% basil leaf extract	37.00	37.00	37.00 C
Mean	36.76 A	35.68 B	
	Treatment	Varieties	T x V
P value	0.0000	0.0351	0.8463
SE	0.8273	0.4777	1.1700
LSD@ 5%	1.7158	0.9906	2.4265

Whereas P value= probability value, SE= standard error, LSD@ 5%= least significant difference at 5% level of probability.

In particular, Bonea (2020) observed that 20% basil extract reduced maize radicle elongation by 40%, a trend echoed in okra's reduced seedling vigor at 7% extract. Such inhibitory effects are attributed to terpenes like eugenol and

linalool, which disrupt mitochondrial function and induce oxidative stress (Islam and Kato-Noguchi, 2013). The Crass variety's superior germination (85.39% vs. Sabzpari's 77.08%) may reflect hybrid vigor, a phenomenon also documented in hybrid bitter gourd, where enhanced enzymatic efficiency and resource partitioning contribute to improved stress resilience (Verma *et al.*, 2012). These genetic advantages underscore the potential of hybrid cultivars in allelopathy-based systems, although non-hybrid varieties like Sabzpari may still possess unique adaptive traits under stress conditions. Vegetative growth traits including plant height (14.72 cm), leaf count (3.66), and chlorophyll content (42.39) were highest at 3% basil extract, mirroring trends in basil-treated maize (Elansary *et al.*, 2017) and bitter gourd (Sohail, 2024).

The stimulatory effects at moderate concentrations are linked to phenolic acids such as caffeic acid, which facilitate micronutrient uptake (e.g., iron, zinc) and enhance cell elongation by synergizing with endogenous auxins (Macias *et al.*, 2010). Specifically, Elansary *et al.* (2017) reported that basil extracts increased mint shoot biomass by 30% through auxin-mediated pathways, a mechanism that may also underline okra's growth response at 3% BLE. In contrast, higher BLE concentrations (5–7%) induced oxidative stress, as evidenced by reduced chlorophyll content and biomass. Similar inhibitory effects were documented in bitter gourd by Sohail (2024), where 7% extract reduced vine length and leaf area by 15–20%. These phytotoxic responses are again linked to eugenol-induced reactive oxygen species (ROS), which damage cellular membranes and chloroplast structures (Islam and Kato-Noguchi, 2013). The Crass variety's superior shoot biomass (1.92 g vs. Sabzpari's 1.77 g) aligns with hybrid vigor observed in maize and bitter gourd, where hybrid lines exhibit enhanced photosynthetic efficiency and resource allocation (Ashraf *et al.*, 2018; Sohail, 2024). Sabzpari's compensatory chlorophyll synthesis (36.76 SPAD vs. Crass's 35.68 SPAD), however, introduces a novel adaptive strategy.

This phenomenon mirrors stress responses in medicinal plants like *Withania somnifera*, where chlorophyll upregulation counteracts energy deficits caused by allelochemical stress (Anwar and Patra, 2015). Such plasticity underscores the importance of genetic diversity in sustainable agriculture, as non-hybrid varieties may offer resilience under suboptimal conditions. Root development, a key indicator of allelochemical impact, exhibited concentration-dependent trends similar to aerial growth. The 3% basil extract maximized root length (13.72 cm) and biomass **(**0.83 g), consistent with findings in *Arabidopsis*, where basil-derived nitric oxide promoted lateral root formation via redox signaling (Zhao *et al.*, 2020). Sohail (2024) reported analogous hormetic responses in bitter gourd, where 5% extract enhanced root depth by 25%, though inhibitory effects emerged at 7%.

These parallels suggest conserved biochemical pathways across species, albeit modulated by concentration thresholds. Unexpectedly, tap water priming reduced okra germination (70.83%) compared to the control (77.00%), contradicting hydropriming trends in legumes like mung bean (Kong *et al.*, 2019). Sohail (2024), however, observed improved germination in bitter gourd with hydropriming, highlighting species-specific hydration requirements. This discrepancy may stem from regional water quality variations (e.g., salinity, heavy metals) or differences in seed coat permeability. For example, okra's thin seed coat may render it more vulnerable to waterborne impurities, whereas bitter gourd's robust coat may offer enhanced protection. These findings highlight the importance of environmental factors such as water quality and soil composition in allelopathy studies, as lab-based experiments may not fully replicate field conditions. This underscores the need for caution when extrapolating nursery or laboratory results to agronomic settings. The dual role of basil's allelopathic effects—promoting growth at lower concentrations while inhibiting it at higher levels—is closely linked to its chemical composition. At 1–3% concentrations, compounds such as caffeic acid and rosmarinic acid are dominant.

These bioactive substances serve as natural stimulants, enhancing cell membrane permeability and nutrient uptake in plants (Macias *et al.*, 2010). They also act synergistically with endogenous hormones like auxins to promote cell division and elongation (Elansary *et al.*, 2017). However, at 5–7% concentrations, terpenes like eugenol and linalool become more concentrated, inducing oxidative stress through lipid peroxidation and mitochondrial dysfunction (Islam and Kato-Noguchi, 2013). This biphasic response corresponds with the hormesis model proposed by Cheng and Cheng (2015), where low-dose stimulation transitions into high-dose inhibition. Sohail (2024) further demonstrated this duality in bitter gourd, where a 5% extract enhanced growth, but 7% extract suppressed it.

The study attributed this shift to terpene-induced reactive oxygen species (ROS) accumulation, a mechanism also supported by findings in wheat and chickpeas (Verma *et al.*, 2012; Bonea, 2020). Biochemical specificity highlights the need for precise dosing of plant-based biostimulants, as overdosing may reverse benefits. Crass showed superior germination (85.39%) and biomass (1.92 g), reflecting hybrid vigor seen in bitter gourd and maize (Verma *et al.*, 2012; Bonea, 2020). Sabzpari, though less vigorous, exhibited adaptive chlorophyll upregulation under stress (Anwar and Patra, 2015). This suggests trade-offs between high-yield hybrids and stress-resilient landraces. A 3% basil extract

appears sustainable and effective for okra cultivation in resource-limited settings. The observed increases in seedling vigor index, shoot biomass, and plant height in the 3% BLE treatment can be directly linked to enhanced metabolic activity during early growth stages, as reflected in the data (e.g., SVI: 1290.00, shoot biomass: 2.93 g, plant height: 14.72 cm). These improvements are consistent with previous studies, such as Elansary *et al.* (2017), who reported that phenolic compounds in basil enhanced cell division and elongation, leading to increased biomass accumulation. Similarly, Verma *et al.* (2012) found that BLE improved shoot length and biomass in sweet basil-treated crops, likely through auxin-like effects. Our findings align with these results, showing that optimal concentrations of BLE not only improved emergence but also enhanced vegetative traits closely linked to yield potential. Future research should focus on phytochemical profiling of basil extracts using advanced techniques like HPLC-MS to identify key allelochemicals and their growth-modulating interactions.

CONCLUSION

Study results revealed that okra treated with 3% basil leaf extract displayed optimal germination and growth, outperforming the 5% concentration. The 3% concentration consistently enhanced parameters such as seed germination (87.50%), seedling vigor index (1290.00), fresh shoot biomass (2.93 g), chlorophyll content (42.39), and root length (13.72 cm). The Crass variety generally outperformed Sabzpari in most traits, though the interaction between treatments and varieties was often non-significant.

AUTHOR CONTRIBUTIONS

Saeed Ahmed Chachar: Conducted research, data collection and write-up, Niaz Ahmed Wahocho: Conceptualization, designing, supervision, write up and finalizing the manuscript, Muzafaruddin Chachar: Analysis of data and arrangement of tabulated data, Memoona Islam Majeedano and Sana Shazia Jiskani: Write-up and interpretation of data, Zaheer Ahmed Chachar: Data collection and statistical analysis, Maqsood Ahmed Wagan and Raheem Ullah: Collection of data and citations.

CONFLICT OF INTEREST,

The authors have declared no conflict of interest.

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