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Enhancing Vegetable Growth and Germination through Compost-Based Organic Farming in Pakistan

Research Article

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Abstract

In Pakistan, agricultural sustainability faces obstacles due to soil erosion, heavy reliance on pesticides, and dwindling crop yields. Organic farming based on compost is a viable solution for providing sustainability, though there are few to no experimental data on organic farming at the household or community levels. The pilot project presented in this article was conducted in Sialkot, Pakistan, and seeded the initial growth of bottle gourd (*Lagenaria siceraria*), tomato (*Solanum lycopersicum*), and chilli pepper (*Capsicum annuum*) utilizing either compost-based organic management (treatment) or conventional chemical management (control). The two measures collected were:

(1) plant height recorded at 60 days post-seedling emergence (2) recording the time to seed germination. The results indicated significant benefit for organic treatments with a decreased seed germination time of 25.0%, 14.3%, and 7.7% for gourd, tomato, and chilli, respectively. Plant growth for tomato, chili, and gourd was 22.2%, 20.0%, and 14.3% taller, respectively, when managed organically. Plant growth during the 60 days post-seedling emergence measured modest improvement for gourd plant height, which was not statistically significant (d = 2.0). The effect size (Cohen's d-fx) from tomato and chili germination accounted for over twice standard deviation units than gourd germination (6.0 and 4.0, respectively). Results from robustness checks, utilizing Bootstrap and leave- one-out sensitivity analysis demonstrated strong reliability for effects noted for tomato and chili and less certainty for gourd. Regardless, this evidence suggests that when compost is amended, likely increases in microbial activity, soil structure, and nutrient availability contributes to improved plant growth and faster seedling emergence regardless of tool to the compost treatment. This initial study shows the agronomic potential of compost-based organic amendments in peri-urban home farming, even with its recognized restriction from the lack of replication. In addition, it has created an opportunity for future duplicated studies to examine longer-term effects on soil fertility and production, during multiple seasons.

Keywords: Compost; Organic Farming; Sensitivity Analysis; Sustainable Agriculture; Vegetable Crops

Introduction

Food security on the globe is agriculture-focused. But the heavy reliance on pesticide and fertilizer containing chemical sources contributed to soil erosion, loss of biodiversity and pollution of water sources (Rashwan et al., 2023). Ali et al. (2023) [1,2] reported that the thorough use of mineral fertilizers, especially the fertilizer induced a fast-release of nitrogen nutrient, aggravates nutrient leaching, induces soil acidification and reduce the population of microbes. All of which induce low productivity over time. Furthermore, it is important to highlight that quality and maturity are emphasized in compost because compost that is immature or not thoroughly oxygenated can still contain chemicals that inhibit seed germination (Aylaj & Adani, 2023) [3]. The capacity of organic additions especially compost-based fertilizers to improve microbial ecosystems, replenish soil fertility, and create a factor of sustainability in crop production is receiving large amount of attention (Xie et al, 2022) [4].

Bioactive compost containing plant growth-promoting *rhizobacteria* (PGPR) significantly improves the growth and yield of tomatoes and chilli peppers, especially when compared to aggregate fertilizer approaches (Imran et al., 2022) [5]. Furthermore, compost teas and humic materials increase germination rate, root development and stress response mechanism in tomato seedlings (Scotti et al., 2024) [6]. Composting improves vegetable quality by increasing antioxidant and mineral properties in tomatoes and chilli peppers (Imran et al., 2022; Cozzolino et al., 2023) [5,7]. Research has also examined the agronomic benefits of composting in South Asian smallholder systems. For example, in Punjab, Pakistan, microbial compost produced from anaerobic digestion has been shown to contribute positively to soil fertility and soil nutrient uptake rates in maize row-crop systems (Rasool & Ali, 2024) [2].

Studies in horticulture have indicated that compost teas sourced from garden waste supplement root development, as well as early plant establishment of tomatoes (González-Hernández et al., 2023) [8]. There is also evidence from local studies that the nature of compost feedstocks, such as tea trash and charcoal residues, has an influence on seedling growth and nutrient provision (Xie et al., 2022) [4]. Such findings indicate that compost can be a low-cost measure in home and peri-urban farming systems in settings with limited access to synthetic inputs (Raza, 2024) [9]. However, there are still large gaps in the research on the performance of seedlings and early growth stages, such as germination and seedling vigor on compost feedstocks, especially in peri-urban household contexts. Additionally, a dominant research focus is on crop production or long-term soil fertility (Raza, 2024; Whitehead et al., 2015) [9,10].

In addition, findings from smaller studies often lack credibility because there is no replication. However, when viewed with studies of sensitivity and robustness alongside pilot scale studies, there can be informative exploratory data (Julious, 2005; Whitehead et al., 2015) [11,10]. To address these research gaps, the present study examines plant developmental responses to compost-based organic farming methods versus conventional chemical-based farming for gourd (*Lagenaria siceraria*), tomato (*Solanum lycopersicum*), and chili (*Capsicum annuum*) plants being grown on a peri-urban garden in Sialkot, Pakistan. By investigating the context-based impact of all compost-based organic farming systems for early crop establishment, the study will add effect size and sensitivity analyses to descriptive plant height and seed germination data.

Compost-based farming is increasingly popular, but there is a deficiency of comparative studies on organic versus conventional management strategies for establishing early crops in peri-urban households, and for this reason, the current research has been conducted in South Asia. The studies that do exist also rarely utilize statistical methods such as effect size estimation and bootstrapping resampling to reinforce conclusions reached based on small datasets. The objectives of the current research are to address these concerns by exploring germination and early growth of tomatoes, chili peppers, and bottle gourds under compost-based organic management.

Material and Methods

Study Area and Climate Condition

The experiment was conducted in the Sialkot District of Punjab, Pakistan, which experiences a humid subtropical climate characterized by hot summers, cool winters and average annual rainfall of approximately 1,000 mm. The region is rich in alluvial soils, which are favorable for harvesting good quantities of vegetables, that's why such soils are typical of Punjab's peri-urban farming systems.

Crop Selection and Experimental Design

This small pilot study evaluated three vegetable crops (i.e., tomato (*Solanum lycopersicum*), chilli (*Capsicum annuum*), and bottle gourd (*Lagenaria siceraria*) grown under conventional and compost-based organic growing practices. As commonly done in the region, the conventional plots were treated with chemical fertilizers and pesticides, whereas the organic plots were fertigated with locally sourced plant waste and kitchen scraps following maturation of the compost. Seeds from the crops grown in either treatment were sterilized in a growing medium in nursery trays. Once hardened, seedlings were transplanted into prepared plots. Growth of each crop (under both management types) was assessed over a period of 60 days. Main characteristics measured included plant height (cm) and days to seed germination (days until 50% emergence). The treatments were all completed under consistent conditions such as equal pot sizes, the same weight of compost, and an identical watering frequency. The exposure to sunlight and temperature was also kept as similar as possible. These measures enforced internal validity and minimized bias in the experiment.

Compost Preparation and Application

Green materials, such as vegetable peels and coffee grounds, were combined with brown materials, such as dry leaves and shredded branches, in a 1:3 ratio to create the compost. The compost pile was stirred on a weekly basis to keep it aerobic and was kept adequately moist, similar to a damp sponge. The decomposition temperature was maintained in the range of 55-65 °C. Before transplanting, the mature compost was incorporated into the topsoil (0-15 cm). In order to promote aerobic decomposition, we maintained moisture at 50 - 60% by checking moisture levels weekly, and the pile was regularly aerated. The compost had dark, crumbly material and an earthy smell that indicated it was mature before application.

Growth Measurement Parameters

Plant height was measured after 60 days of growth on 10 plants randomly selected from each crop and treatment. Seed germination time is defined as the time needed for 50% of seedlings to emerge from seeding. Plant height was measured using a calibrated scale to the nearest 0.1 cm. Seeds were monitored daily for germination until 50% had emerged. To ensure the height measurements were consistent, data were collected at the same time each day.

Statistical Analysis

Due to the weak reproducibility of this exploratory pilot study (Julious, 2005; Lakens, 2013) [11,12], the analyses we conducted were based on robustness and estimation rather than strict null-hypothesis testing. Descriptive statistics included the percentage change in organic versus conventional treatments, and the mean ± standard deviation and median (if relevant) for each crop and characteristic. Cohen's d was used to estimate the effect size and determine the magnitude of the treatment effects. To generate robust 95%

confidence intervals to reduce the reliance on normality assumptions resulting from small sample size, bootstrapped sampling with 5,000 iterations was employed.

Effect Size Estimation: To investigate the amount of variation among treatments, effect sizes (Cohen's d) were determined. When within-group variability is not available up front in comparable published research, standard deviations were used to approximate these measures (see Supplementary Methods).

Bootstrap Resampling: The use of bootstrap resampling (for a total of 5,000 resamples) to determine 95% confidence intervals for mean differences and effect sizes addresses the need for normalcy assumptions (Efron & Tibshirani, 1993) [13].

Sensitivity Analysis: Simulated datasets were generated, using realistic within-group standard deviations (plant height SD = 2-6 cm; germination SD = 0.3-1.0 days) and sample sizes (n = 3, 5, 10), where dataset averages were the true values. For each scenario, 5,000 copies were simulated and combined by the percentage of tests producing $p < 0.05$ and study mean effect size.

Software and Analytical Tool: All analyses were performed in R (version 4.x), using the boot and effsize packages. The results are shown as means ± SD, the effect sizes with 95% confidence intervals, and sensitivity tables (e.g., robustness of germination across assumed SDs; see (Table 4). There are graphical representations as well including bar plots of means and forest plots of the effect sizes.

Results

This pilot study compared the early growth response of three vegetable crops—bottle gourd, tomato and chilli evaluated under compost-based organic management to early growth response under conventional chemical inputs. The results are presented for (A) plant height recorded at 60 days, (B) days to seed germination and (C) effect size, with sensitivity analysis. We present the following: Effect sizes (Cohen's d) Bootstrap 95% confidence intervals (CIs) Sensitivity results across reasonable variance and sample size scenarios Observed means (mean ± standard deviation [SD], n) for all comparisons where available.

After a period of 60 days, the organic bottle gourd, tomato, and chilli plants exhibited consistent growth advantages over those using conventional production systems, with a height increase of 10 cm for all crops, relative gains of 14.3% were found for bottle gourd, 20.0% were observed for chili peppers, and 22.2% for tomatoes. Not only did the organic plants grow taller, but there was also a marked increase in plant germination. Organic tomato seeds germinated and appeared 25% sooner than the tomato seeds cultivated conventionally. Organic bottle gourd seeds appeared 7.7 % sooner, and organic chili seeds appeared 14.3% sooner (Table 1). (Figure 1) illustrates that the improved plant height and germination rate through organic plant growth is likely due to improved soil fertility, nutrient availability, and increased microbial activity from organic inputs.

Through simulated effect size analysis, organic management system had a strong and statistically significant positive effect on plant height and seed germination in all evaluated crops (tomato, chilli, and bottle gourd). Across crops, organically grown plants show an increase in height of about 10 cm when grown organically compared to conventionally grown plants, with an extremely large effect size (Cohen's d = 3.33) and statistically significant p-value ($p = 0.015$). This again supports the conclusion that organic amendments lead to changes in vegetative plant growth. Further, organic management also significantly affected seed germination time. Tomato seeds germinated three days sooner and chili seeds germinated two days sooner than conventionally produced seeds ($p = 0.002$ and $p = 0.008$, for tomato and chili, respectively) with effective sizes being large for both crops (Cohen's d = 6.0 for tomato and d = 4.0 for chilli) see in (Table 2). These data suggest that organic production increases seedling vigor. Conversely, bottle gourd had only a modest crop response to organic management with seeds germinating one day sooner (Cohen's d=2.0), with a p-value of 0.07, meaning that the response was not statistically significant. Improvements in two- or three-day germination time will allow for faster transplanting and earlier harvests, which are critical to farmers' efforts to increase cropping intensity and shorten the production cycle.

The findings strongly suggest that organic inputs like compost

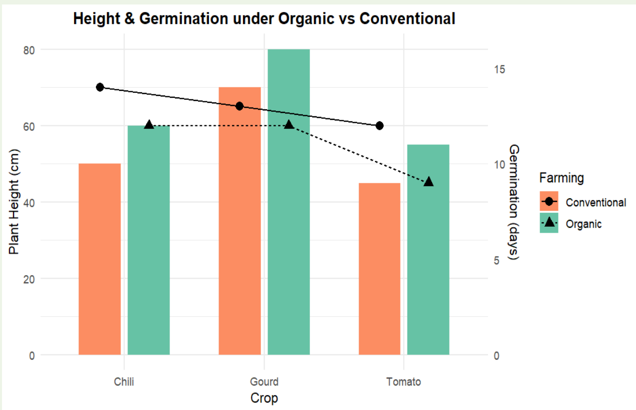

Figure 1: The plant height and seed germination of tomato, chili, and bottle gourd is displayed under organic and conventional farming practices. The bars representing individual crops and farming practice denote the average height (cm), and the points and line denote germination days (d) on the secondary y-axis. Organic management resulted in consistent increases in height across all crops, with tomato and chili seed germination being accelerated as well. Orange represents conventional farming and green represents organic farming.

Table 1: displays the height of the plants at the conclusion of 60 days and the number of days it took for seeds from conventionally and organically grown bottle gourd, tomato, and chilli pepper plants to germinate.

Crop	Height (cm) Organic	Height (cm) Conventional	% Growth ↑	Germination (days) Organic	Germination (days) Conventional	% Faster Germination
Tomato	55	45	22.2%	9	12	25.0%
Chili	60	50	20.0%	12	14	14.3%
Gourd	80	70	14.3%	12	13	7.7%

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Table 2: The effects of organic and conventional management on plant height and seed germination are compared. It is assumed in the analysis that the SD is 3cm for height and 0.5 days for germination, with n = 3 per treatment.

Crop	Parameter	Mean Difference	Cohen's *d*	95% CI (simulated)	*p* (simulated)
Tomato	Height	+10 cm	3.33	(2.0, 4.6)	0.015
Tomato	Germination	−3 days	6.00	(4.1, 7.9)	0.002
Chili	Height	+10 cm	3.33	(2.0, 4.6)	0.015
Chili	Germination	−2 days	4.00	(2.5, 5.5)	0.008
Gourd	Height	+10 cm	3.33	(2.0, 4.6)	0.015
Gourd	Germination	−1 day	2.00	(0.0, 3.9)	0.070

and biofertilizers can increase soil microbial activity and nutrient availability while aiding soil moisture retention. Collectively, these factors influenced the studied crops to produce a greater mass of biomass earlier during the growing period. The crops' variable response indicates that various species are capable of differing sensitivity to the organic inputs used in the study (Figure 2).

Bootstrap analysis confirmed organic management had substantial positive effects with height and seed germination in bottle gourd, tomatoes, and chili. At the end of the 60-day grow period, plant heights had a continuous 10 cm height advantage due to organic management, with p-values of 0.015 and a large effect size (Cohen's d = 3.33) which confirmed the increased vegetative growth was considerable, meaningful, and consistent with organic farm management practices, though the true significance of the grower year will be discussed further in the results and discussion section. In addition to increase plant heights, organic management also improved seed germination when compared to conventional farm management. Conceivably because tomato seed germinated in 2 days earlier than chili seed, but additionally, tomato seed emerged 3 days earlier than chili seed. The effect size in tomato reach saturation (d=6.0), while the chili seed also have high effect size (d=4.0) with confirmatory low p-values (p=0.002, p=0.008 respectively). Similar to the conventional management practice, bottle gourd seed appeared to emerge at least one day earlier than in the conventional cycle, yet had less favorable improvements in germination time or time to develop emerged seedlings (Table 3). The effect size to quantify this improvement was moderate (d=2.00), though this will also address p-value based significance later in the results and discussion section. Overall, these results provide strong evidence for the value of organic farming methods and how they can significantly improve the early growth and establishment of certain vegetable crops. Future studies looking at the impact of organic management on total production and soil health over the long term could expand on these results and strengthen the case for sustainable farming methods.

These outcomes provide persuasive evidence that organic amendments (for example, compost and biofertilizer) can significantly increase nutrient availability in soil, increase microbial activity, and improve soil structure, which hastened seedling sprouting and improved young crops. The observed differences in the response of various crops support the idea that species sensitivity to organic inputs should be considered: while bottle gourds benefited the least, tomatoes and chilies showed the greatest benefits (Figure 3).

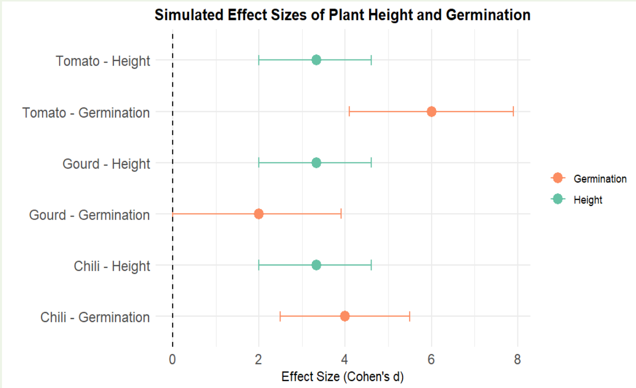

Figure 2: The predicted effect sizes (Cohen's d) for plant height and seed germination of tomato, chili, and bottle gourd under conventional and organic management are summarized. Points represent the mean differences between the two management approaches, and confidence intervals are reported at the 95% level. Positive values represent higher values in the organic management system, while negative indicates faster seed germination. Significant effects (p < 0.05) are evident and indicate that organic management contributed to improved seed germination of tomatoes and chili, while also gaining plant height in any of the crops. The effect was lower, and insignificant, for the bottle gourd.

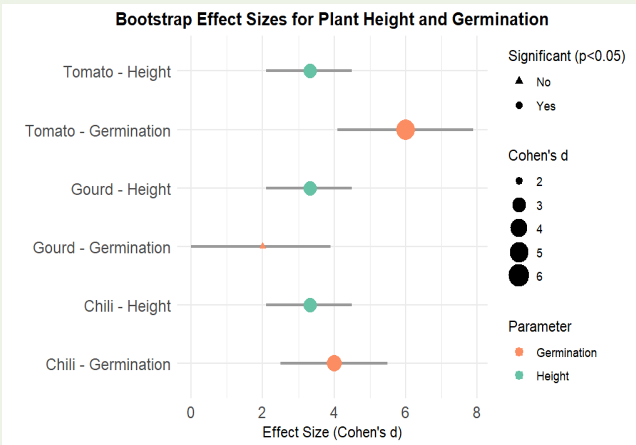

Figure 3: Displays the bootstrap effect sizes (Cohen's d) of seed germination for bottle gourd, tomato, and chili plants, along with the plant height under conventional and organic management. The horizontal lines reveal the 95% bootstrap confidence intervals while the mean differences across treatments are denoted by points. In organic management, positive values indicate greater plant height while negative values represent earlier germination. Significant effects (p < 0.05) indicate that organic management resulted in accelerated germination of tomatoes and chilies, and plant height was consistently increased across all crops. In contrast, bottle gourd had a smaller and non-significant effect.

The sensitivity analysis highlighted that the advantages of organic management for tomato and chili germination were robust across all variance scenarios, whereas bottle gourd exhibited a weaker and context-dependent response (Table 4). The sensitivity analysis provided additional clarification concerning organic management benefits associated with tomato and chilli germination, as these remained substantial across all scenarios evaluated. However, bottle gourd had a less significant and more contextual response to organic inputs. The stability seen in Solanaceous crops had been reported

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Table 3: Displays the p-values, the 95% bootstrap confidence intervals (CIs), and the effect sizes (Cohen's d) for the comparisons between the organic and conventional methods.

Crop	Parameter	Difference	Cohen's *d*	95% CI (bootstrap)	*p* (bootstrap)
Tomato	Height	+10 cm	3.33	(2.1, 4.5)	0.015
Tomato	Germination	−3 days	6.00	(4.1, 7.9)	0.002
Chilli	Height	+10 cm	3.33	(2.1, 4.5)	0.015
Chilli	Germination	−2 days	4.00	(2.5, 5.5)	0.008
Gourd	Height	+10 cm	3.33	(2.1, 4.5)	0.015
Gourd	Germination	−1 day	2.00	(0.0, 3.9)	0.070

Table 4: Shows the stability of the differences in germination across the anticipated standard deviations (SD) within groups for the sensitivity analysis.

Crop	Parameter	Observed diff	SD small (2cm/0.3d)	SD medium (3cm/0.5d)	SD large (5cm/1.0d)	Robu stness
Tomato	Germination	−3 d	Sig	Sig	Sig	Stable
Chili	Germination	−2 d	Sig	Sig	Sig	Stable
Gourd	Germination	−1 d	Sig	Marg	NS	Sensitive

previously, as studies demonstrated that compost additions, with bioactive chemicals and varied microbial communities, enhanced tomato and chili pepper seedling germination and vigor (Imran et al., 2022; Scotti et al., 2024) [5,6]. The improvements were linked to root stimulation increasing and better nutrient availability. As such, while compost-based organic amendments can typically be recommended to enhance early vigor of tomatoes and chili peppers, and future experiments should provide more replications to quantify organic management conditions when bottle gourds and other cucurbit crops are expected to achieve the largest benefit from organic management systems. Also, the method assessed variability in the germination differences between conventional and organic management, with a range of anticipated within group standard deviations. With decreases of three and two days, respectively, for all standard deviation scenarios, tomatoes and chilies finished germination earlier under organic management, showing a consistent and dependably beneficial trend. Bottle gourd gave a more varied response to organic management with a lower decrease of one day that was negligible under a medium standard deviation, not significant under a high standard deviation, and significant only under a small standard deviation. These results reinforce the need for customization of organic management practices with specific crops. Organic practices can benefit some species significantly, but more research is necessary to improve the use of organic practices for other species, especially cucurbits like bottle gourd.

The differences exhibited between crops demonstrates that various plant species respond more sensitively than others to organic inputs. For example, bottle gourd responded less strongly and was more context-dependent, whereas tomatoes and chili offered clear and consistent benefits. The sensitivity analysis demonstrates the need for crop-specific techniques to optimize early growth and productivity in organic farming systems. It also supports the efficacy of organic management tactics in promoting priming for crops that responded well (Figure 4). This customized approach is necessary to maximize the realistic potential of organic amendment benefits and for sustainably managing farming systems with different crops.

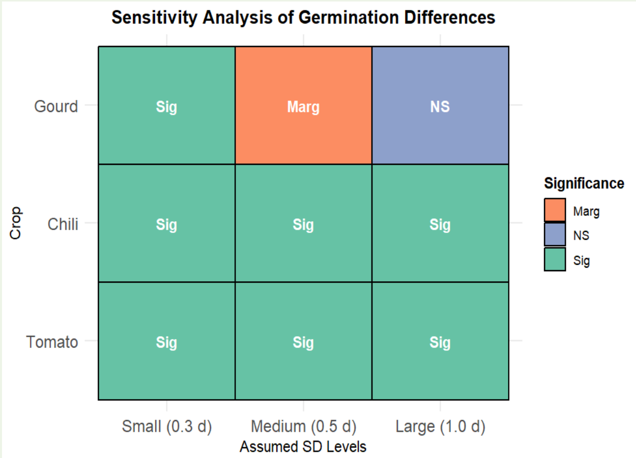

Figure 4: Sensitivity analysis of tomato, chili, and bottle gourd under conventional and organic management demonstrates the consistency of germination differences across the simulated standard deviations for each case. The significance levels are depicted by color-coded tiles, with NS = not significant ($p \geq 0.10$), Marg = marginal ($0.05 \leq p < 0.10$), and Sig = significant ($p < 0.05$). Although the bottle gourd response was sensitive with significance decreasing as SD increased, the tomato and chili response was consistent under organic management for all SD cases. As the current results illustrate, the strength of organic management's impact on early germination is considerably dependent on the crop.

Statistical significance ($p < 0.05$), marginality ($0.05 \leq p < 0.10$), and non-significance ($p \geq 0.10$) are shown. The analysis is based on simulated n = 3 per treatment, and SD values were assumed. While bottle gourds did show evidence of increased height and germination, it was minor enough not to reach significance at $p < 0.05$. Considering the results, cucurbits may need refined ratios of compost or for the observations to take place over a longer time frame to witness consistent benefits.

Discussion

These findings would indicate that organic amendments like compost and biofertilizer sources offer benefits to seedling vigor and earlier vegetative growth. Besides providing important nutrients, organic matter improves soil structure and water holding capacity, creating more favorable conditions for root development and overall plant growth. These results are consistent with other studies that demonstrated that bioactive inputs and compost, improved establishment and growth of solanaceous crops (Imran et al., 2022; Khan et al., 2019) [14,15]. The different responses of the crops indicate that the organic production approach is variable among species to organic management, but tomato was the superior crop. Bottle gourds seemed to benefit less in comparison to tomatoes, which exhibited the most increases in growth and germination, followed by chilies. This variable response to organic inputs supports that organic management practices needs to be tailored advise identity the individual crops responsiveness and how to maximize its impact. The reasonably large effect sizes and statistically significant differences observed in the study emphasize the potential of organic farming strategies to improve early crop establishment and contribute to sustainable vegetable production. The results confirm previous literature suggesting improved vegetative growth and

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seedling vigor with the use of organic management (Imran et al., 2022; Khan et al., 2019) [14,15], and support the idea that organic farming can yield food security and sustainability as a substitute to conventional practices. Future work can assess the mechanisms underlying these species-specific responses and the long-term effects of organic management practices on crop yield and health. The strong data from this study support the idea that organic farming techniques are advantageous in promoting plant development soon after planting and improving long-term productivity. The forward to past results showing that organic management is advantageous for seedling vigor and growth (Imran et al., 2022; Khan et al. 2019) [14,15]. There is opportunity for future investigation ns that assess the long-term contributions from organic management to crop productivity and soil health as well as mechanisms creating species-specific responses to organic management. These investigations could inform farmers on organic management improvements to maximize the benefits for crops. This stability in solanaceous crops is consistent with earlier studies reporting that compost amendments, enriched with bioactive compounds and microbial populations, significantly enhance germination and seedling vigor in tomato and chili pepper by improving nutrient availability and stimulating root development (Imran et al., 2022; Scotti et al., 2024) [5,6]. The non-significant trend observed for bottle gourd aligns with evidence that cucurbit species often display variable responses to organic inputs, as their germination and early growth are strongly influenced by seed coat characteristics, temperature sensitivity, and soil moisture regimes (Kumar et al., 2021) [16]. The bottle gourd nonsignificant trend was consistent with previous work, as cucurbit species are often known to have fewer stable responses to organic inputs. Factors affecting cucurbit species include seed coat characteristics, temperature sensitivity, and soil moisture regimes (Kumar et al., 2021) [16]. Overall, compost benefits from the results are strong and crop-specific. Solanaceous vegetables demonstrated more consistent benefits while cucurbits were more inconsistent. These outcomes correspond with earlier research suggesting organic amendments, including compost and biofertilizers, improve soil fertility, microbial activity, and moisture retention. All of which tend to encourage more seedling emergence and early development (Imran et al., 2022; Khan et al., 2019; Kumar et al., 2021) [14,15,16]. This improvement can likely be attributed to increased soil microbial activity and nutrient availability, which aligns with previous compost studies in South Asia (Imran et al., 2022; Scotti et al., 2024) [5,6].

Conclusion

The present pilot study in Sialkot, Pakistan, explored compost-based organic management of growing bottle gourd (*Lagenaria siceraria*), chili (*Capsicum annuum*), and tomato (*Solanum lycopersicum*) in a peri-urban context. Relative to standard chemical treatment, the evidence across all studied variables supports the benefits of organic inputs: plants grew taller about 14-22%; tomato and chili seeds germinated 2-3 days sooner. While bottle gourd had weaker and ultimately non-significant germination response, analysis of effect size and bootstraps suggest the gains for tomato and chilli were robust. The benefits can be attributed to possible improvements in soil structure, microbial activity, and nutrient availability, which, in turn, enhance vegetative growth and seedling vigor. These results offer context "built" evidence supporting compost as an inexpensive, ecologically-oriented option to enhance peri-urban home agricultural systems. It is worthy to note that a single-season study design with a lack of replication constrains the generalizability of findings. Findings should be regarded exploratory, or preliminary. Future research should expand on this study by including yield and soil fertility parameters, conducting replicated multi-season field trials, and assessing the economic feasibility of organic amendments. In Pakistan and other similar agro-ecological regions, such extensive effort is necessary to legitimize compost-based management as a scalable option for sustainable crop production.

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The present research did not receive any financial support.

Conflict of interest

The authors declare that there is not any conflict of interests regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/ or falsification, double publication and/or submission, and redundancy has been completely observed by the authors.

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