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Integrated use of plant nutrients for higher quality yield of ginger *(Zingiber officinale)* in midhills of Nepal

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Abstract

A study was carried out to assess the effectiveness of integrated plant nutrient management (IPNM) on ginger *(Zingiber officinale* Roscoe) yield and quality in two midhill sites: Bhotechaur (Sindhupalchok) and Anekot (Kavre), during 2023 and 2024, in a randomized complete block design with eight treatments combining several types of *in- situ* composts, chemical fertilizers, and micronutrients (Zn and B). Nutrient management treatments had no significant effect on final plant population (p>0.05) or rhizome yield (p>0.05) at either sites. However, notable yield differences were observed numerically. T_7 (multimix compost @ 20 tonnes/ha) produced the highest rhizome yield at both sites (24.86 tonnes/ ha at Anekot and 49.32 tonnes/ ha at Bhotechaur), while T_1 (control) and T_2 (100% NPK + Zn/B) were consistently the lowest performers. Quality parameters (crude fiber and oleoresin) were significantly influenced by treatments, though effects were highly site specific. At Anekot, T_4 (50% NPK + fine compost + Zn/B) produced the lowest crude fiber content (13.43%), while T_3 (50% NPK + coarse compost + Zn/B) yielded the highest oleoresin content (0.61%). Integrated nutrient management significantly improved ginger quality by reducing crude fiber and improving oleoresin content, despite inconsistent responses to yield across locations. For mid hill regions of Nepal, application of 50% recommended NPK combined with 10 tonnes/ha quality compost supplemented with zinc and boron is recommended for optimal quality and yield.

Key Words: Crude fiber, IPNM, Oleoresin, Rhizome, Quality, Compost, Midhills, Nepal

Ginger (*Zingiber officinale* Roscoe) is a high-value spice crop of significant economic importance in global agriculture. Apart from culinary applications, ginger is also valued for its bioactive compounds, including gingerols, shogaols, and essential oils, contributing to its widespread use in traditional medicine, pharmaceutical formulations, and functional food products (Ali *et al*., 2024). Nepal is a major global producer of ginger, ranking 4th, with a production of 3,09,533 tonnes in 2023 (FAO, 2023), thereby earning foreign exchange over 1.22 million in 2023 by exporting over 23 thousand tonnes of fresh as well as crushed/ ground ginger (MOALD, 2023). Nepal's midhill regions, ranging from 900 to 2,000 m in altitude characterized by warm and humid weather coupled with well-distributed rainfall, provide conducive agroclimatic conditions for ginger production (Joshi and Khanal, 2021).

Despite this favorable resource base and huge export potential, ginger productivity in Nepal however remains low, averaging about 12-13 tonnes/ha against a potential yield of about 24-25 tonnes/ha (Khatiwada and Yadav, 2022). One of the fundamental challenges limiting crop productivity in Nepal's midhill regions is critically low soil nutrient stocks, with widespread deficiencies in nitrogen, phosphorus, and several micronutrients (Shrestha *et al*., 2018). IPNM combining the application of organic nutrient sources with chemical fertilizers has proved highly effective in improving ginger growth, yield, soil physico-chemical properties, economic returns, and the benefit: cost ratio of ginger production (Adekiya *et al*., 2020; Yanthan *et al*., 2010). These studies emphasize the judicious combination of organic, inorganic, and biological nutrient sources in balanced combinations tailored to specific edaphic, climatic, and agronomic conditions to maintain soil fertility, improve nutrient-use efficiency, and enhance crop productivity (Kumar *et al*., 2024).

In Nepal, studies evaluating the impacts of IPNM on ginger are limited, and the previous efforts to enhance ginger productivity have often focused on singular approaches, such as the application of chemical fertilizers or organic manures in isolation. While specific nutrient recommendations exist for ginger, the practical limitations faced by Nepalese farmers, particularly regarding the unavailability and cost of chemical fertilizers, render these solutions partially effective or unsustainable. On the other hand, *in-situ* composting, which involves management of agricultural waste on the site of production, is considered an economic method of nutrient recycling, as it can reduce costs involved in collection and transportation (Muzamil

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et al., 2022). *In-situ* composting could offer significant benefits for resource-constrained smallholder farmers in Nepal's mid hills by reducing input costs while promoting sustainable agricultural practices.

Evidence on the combined effects of *in-situ* composting, chemical fertilizers, and micronutrients in the midhills of Nepal is limited, particularly regarding their impact on both yield and quality parameters. Therefore, experiment was conducted to evaluate the effects of IPNM by combining *in-situ* compost with chemical fertilizers and micronutrients on yield and quality at two distinct midhill locations, representing Bhotechaur (Sindhupalchok) and Anekot (Kavre) of Bagmati province, Nepal.

MATERIALS AND METHODS

Experimental design

Field experiments were conducted during 2023 and 2024 at two midhill locations in Nepal, viz. Bhotechaur, Sindhupalchok (1380 masl) and Anekot, Kavre, (1255 masl), both known for their favorable conditions for ginger production. The experiments were conducted using the native ginger landrace, widely grown and well-adapted to these mid-hill environments. The soil parameters of the experimental sites were: 4.68 pH, 2.05 % organic matter , 0.20% total N , 20 .0 kgha^{-1} P_2O_5 and 221.82 kgha^{-1} K_2O at Bhotechaur (Sindhupalchok). Whereas at Anekot (Kavre), these properties were observed as: 5.8 pH, 2.70 % organic matter, 0.13% total N, 29.7 kgha^{-1} P_2O_5, and 125.38 kgha^{-1} K_2O. As many as eight IPNM-treatments with three replications at each site were tested under randomized complete block designs. Each plot measured 9 m^2, accommodating 100 ginger plants with a spacing of 30 cm × 30 cm apart. Standard agronomic practices for ginger cultivation were followed uniformly across all treatments.

Treatments formulations

Compost formulation: Three different quality compost formulations were prepared at the National Commercial Crop Research Centre as part of IPNM:

i. Quality compost (Fine-C1), prepared by thoroughly mixing 800 kg fresh cow dung, 50 kg mustard cake, and 150 kg wood ash. The mixture was finely ground, sieved, and well packaged before use.

ii. Quality compost (Course-C2), prepared in two layers. Layer 1 consisted of 150 kg of *Sesbania bispinosa* (green biomass), 10 kg of sawdust, 50 kg of wood ash, 50 kg of cow dung, and 10 kg of mustard cake. Layer 2 consisted of 10 kg of sawdust, 150 kg of cow dung, 10 kg of mustard cake, 1 drum of paddy husk and 100 kg of wood ash.

iii. Quality compost (Multimix-C3), formulated by mixing 100 kg each of cow dung, Sesbania green leaves, and Tithonia, along with 30 kg mustard cake, 50 kg wood ash, and 10 kg sawdust to enhance nutrient diversity and microbial activity.

Fertilizer sources

Chemical nutrient supplementation was provided using standard chemical fertilizers. Urea and Diammonium phosphate (DAP) served as sources of nitrogen (N) and phosphorus (P_2O_5), and muriate of potash (MOP) was used for potassium (K_2O). The required micronutrients were supplied through zinc carbonate (Zn-52%) and boric acid (B-17.5%).

Treatment combinations

The experiment included eight treatment combinations integrating chemical fertilizers, 3 compost types, and micronutrients (Zn and B) as : T_1(control as no input),T_2 (recommended dose of NPK at 100:50:75 kgha^{-1} + Zn at 5 kgha^{-1}), T_3 (NPK at 50:25:37.5 kgha^{-1} + Zn/B at 5 kgha^{-1} + coarse compost at 10 tonsha^{-1}), T_4 (NPK at 50:25:37.5 kgha^{-1} + Zn/B at 5 kgha^{-1} + fine compost at 10.0 tonsha^{-1}) ,T_5 (quality compost–1 as fine at 20.0 tonsha^{-1}), T_6 (quality compost–2 a Coarse at 20.0 tonsha^{-1}),T_7 (quality compost–3 as multimix at 20.0 tonsha^{-1}) , and T_8 (fine, coarse, and multimix compost at10.0 tons ha^{-1} each + Zn/B at 5 kg ha^{-1}).

Data collection and analysis

Observations were recorded on plant population, yield, and quality parameters of ginger (crude fiber and Oleoresin content), following standard procedures. Data were collected from selected plants from each plot to ensure representative sampling. At harvest, data on fresh rhizome weight per plant, rhizome yield per plot and total rhizome yield (tonsha^{-1}) were recorded.

For quality parameters, representative rhizome samples were analyzed for oleoresin and crude fiber content at the National Food Research Centre, Khumaltar, Lalitpur. Crude fiber content was estimated by acid-alkali digestion and oleoresin by high-performance liquid chromatography (FSSAI, 2016).

All statistical analyses were performed with software R (version 4.3.1) using the packages tidyverse, ggplot2, agricolae, and patchwork. Treatment effects were tested by ANOVA, and mean separation was carried out using Fisher's LSD at $\alpha = 0.05$.

RESULTS AND DISCUSSION

Effect on yield and yield- attributing characters

Plant population: Nutrient management treatments had no significant effect on final plant population of ginger, either within individual sites (Figs. 2 and 3) or data pooled across sites (Fig. 1). In the pooled analysis, the experimental site had a highly significant effect on plant population ($p<0.001$), whereas treatment ($p=0.551$) and the treatment x site interaction ($p=0.481$) were not significant. This indicated that plant establishment and survival were mainly influenced by site-specific conditions rather than nutrient management treatments. At Anekot (Site A), treatment effects on the final plant population were statistically non-significant ($p= 0.289$), despite the numerical differences among treatments (Fig. 2). However, effect of replication was significant ($p=0.025$) suggesting the presence of within-site variability influencing plant survival. Similarly, at Bhotechaur (Site B), no significant treatment effect ($p=0.972$) was observed on final plant population (Fig. 3). When the data were averaged across two sites, treatment effects remained non-significant ($p=0.709$) (Fig. 4). Across treatments, the average plant population ranged from ~54 plants (T_2, 100% NPK + Zn/B) to ~61 plants (T_7, multi-mix compost at 20.0 tonsha^{-1}), with all treatments belonging to a single statistical group, confirming the absence of treatment-induced differences. In summary, final plant population was largely independent of nutrient management treatments, with plant survival primarily governed by site-specific factors, indicating that the establishment of ginger and its survival were largely independent of nutrient source under the conditions of this study. The observed reductions in final plant stand from the initial 100 plants per plot are likely attributable to environmental conditions and biotic or abiotic stresses, rather than treatment effects.

Response on yield : The interaction effect between treatment and site was non-significant ($p=0.937$). There was no significant effect of treatments on yield at individual sites, and this response was consistent across both locations (Figs. 2 and 3). This indicates that, at either site, yield remained statistically similar across all treatments. At Anekot (Site A), the treatment effects on yield were not significant ($p=0.20$) (Fig. 2). This indicated that variation among replications contributed to differences in yield. While at Bhotechaur (Site B), no significant differences among treatments ($p=0.20$) were observed (Fig. 3). Treatment as T_7 (multi-mix compost at 20 tonsha^{-1}) had the highest yield at both sites (24.86

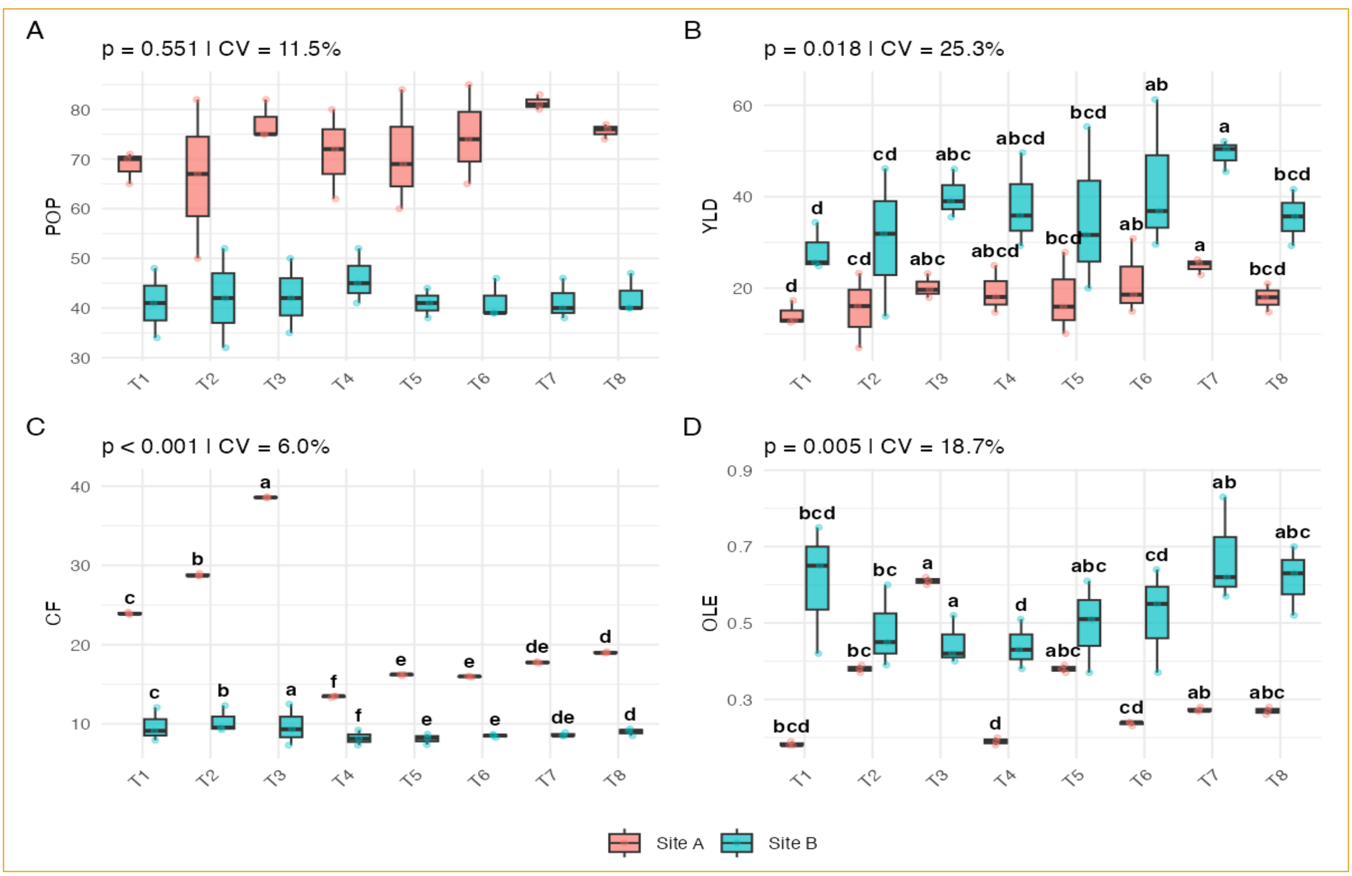

Fig. 1: Pooled analysis of treatment effects on plant population (A), yield (B), crude fiber content (C), and oleoresin content (D) across two locations using a combined RCBD model with site and treatment interaction terms. Colors indicate sites. Boxplots and points show replicate-level variation within each site. LSD group letters are based on the pooled treatment effect when significant (α = 0.05).

tons ha^{-1} at A and 49.32 tons ha^{-1} at B). These observations aligned with the established principle that when humus and organic matter are available, ginger grows well and has a favorable relationship with yield (Divyashree *et al.*, 2022). Similarly, Srinivasan *et al.* (2018) stated INM reduced nitrogen losses via nitrification, leaching, volatilization, and N_2O emissions while improving inorganic nutrient use efficiency, leading to higher rhizome yield. Treatments T_1 (control, 14.25 tonsha^{-1}A, 28.28 tonsha^{-1}) and T_2 (100% NPK + Zn/B, 15.44 t/ha-A, 30.63 t/ha-B) were consistently the lowest performers. Although, the effects of treatments on the yield were statistically non-significant, the use of organic fertilizers such as multi-mix compost and the integrated use of organic and chemical fertilizers demonstrated higher rhizome yield over chemical fertilizers alone.

The enhanced performance of organic nutrients was attributed to improved soil structure, slow release of nutrients, and water retention (Abdou *et al.*, 2023), which enhanced the rhizome growth. Amala *et al.* (2023) also reported optimal performance achieved even at reduced (50%) RDF levels. These results also agreed with Noor *et al.* (2008), who reported that integrated use of zinc and boron along with recommended doses of NPK, produced significantly higher ginger yield. Similarly, Shaikh *et al.* (2010) also documented that the recommended dose of fertilizer combined with farmyard manure favorably influenced the yield and uptake of nutrients of ginger.

Collectively, the data from Anekot and Bhotechaur confirm that the combined effect of organic and inorganic fertilizers in INM strategies is a useful approach to acquire higher yield. These results demonstrate two viable paths toward the sustainable intensification of ginger production, one fully organic and one integrated. From a sustainability perspective, the success of treatments incorporating reduced chemical fertilizers (50% NPK) demonstrated the potential for minimizing synthetic input use while maintaining high productivity, as indicated by the finding that integrated nutrient management systems produced higher values for a variety of economic factors in comparison to organic and conventional nutrient management (Divyashree *et al.*, 2022).

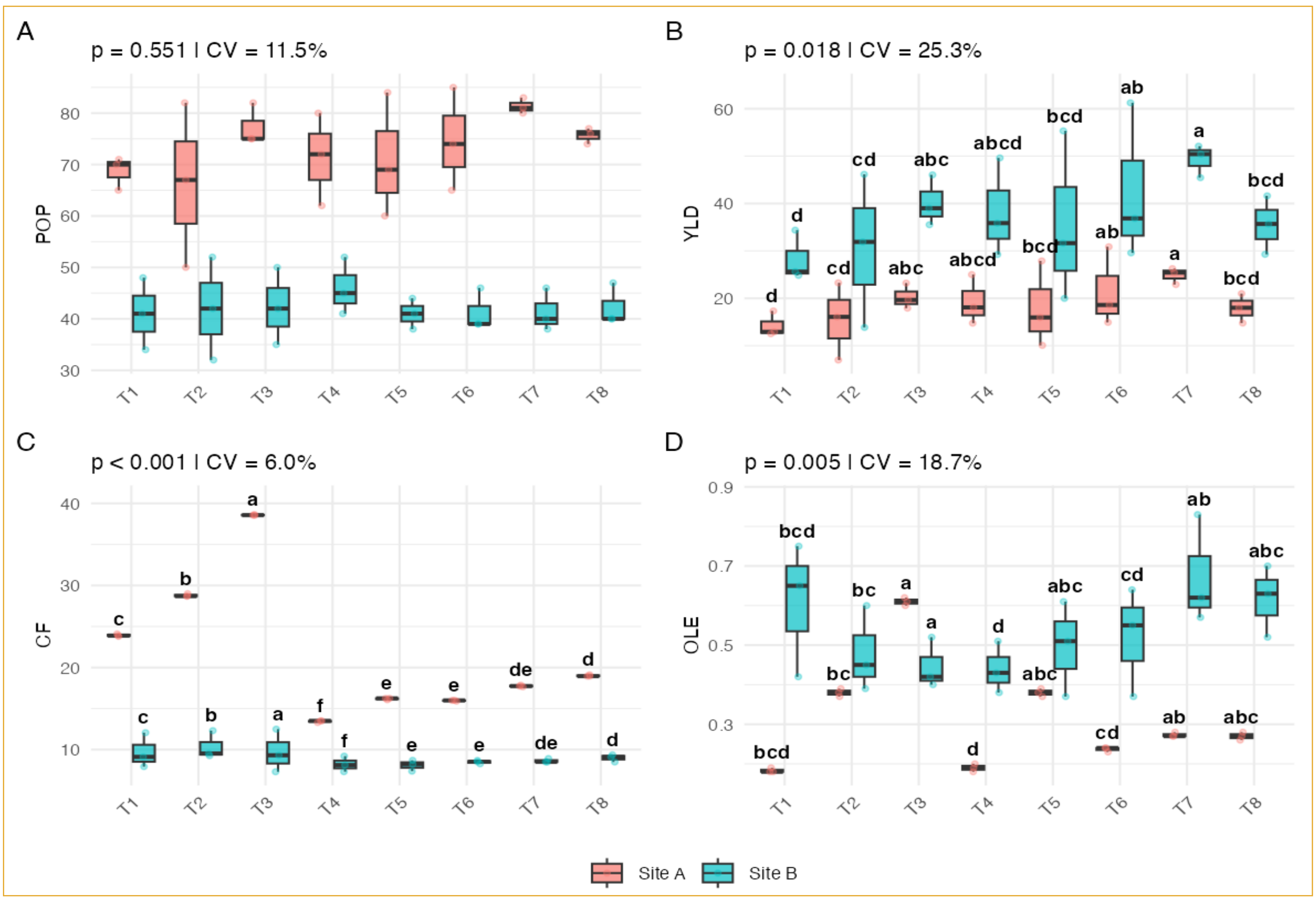

Fig. 2: Treatment effects on plant population (A), yield (B), crude fiber content (C) and oleoresin content (D) at Anekot, Sindhupalchok (Site A). Boxplots, jitter points, and whiskers show replicate variability within treatments. Letters above treatments indicate significant differences based on the LSD test at α=0.05 when the treatment effect was significant.

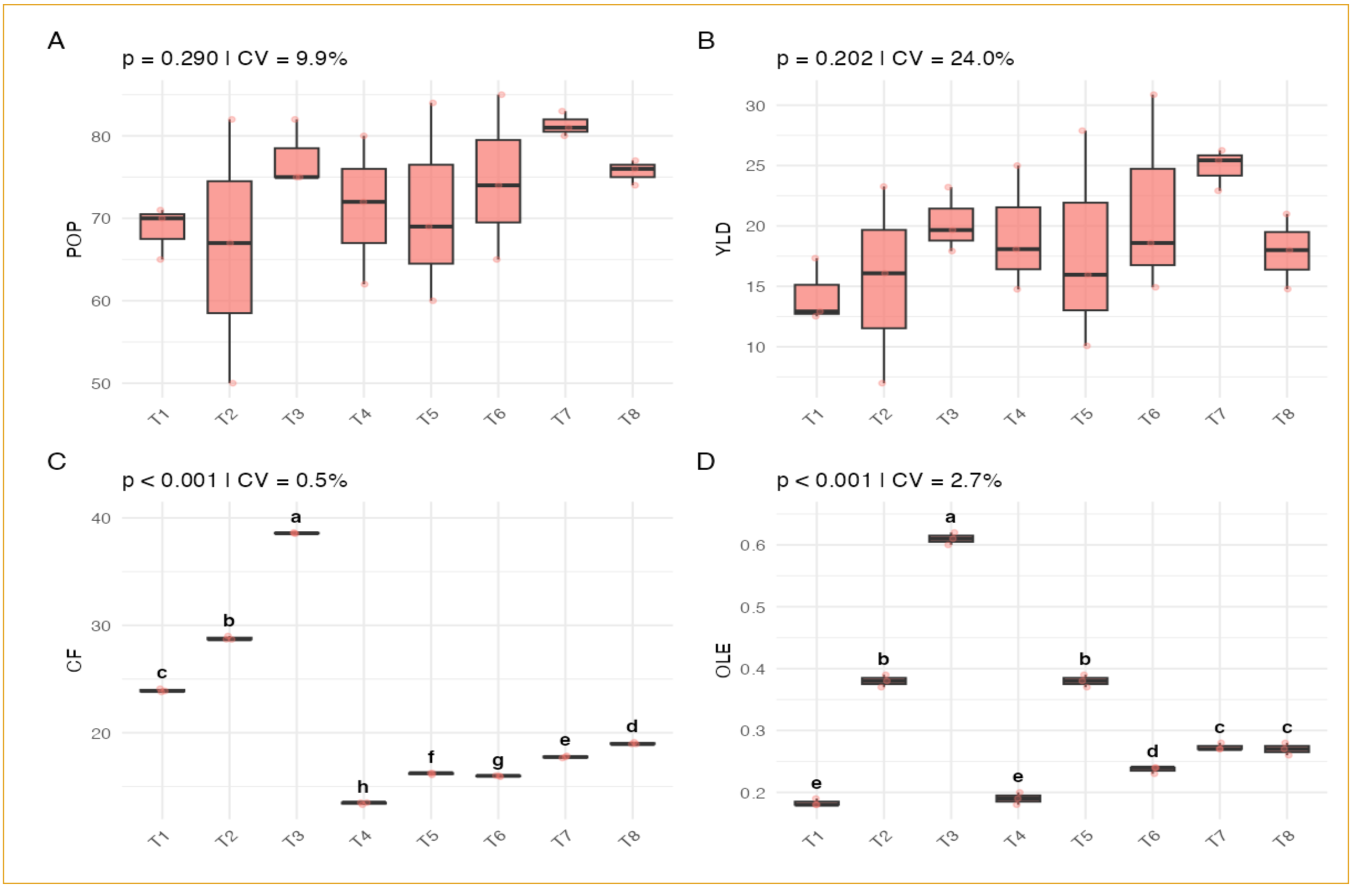

Fig. 3: Treatment effects on plant population (A), yield (B), crude fiber content (C) and oleoresin content (D) at Bhotechaur, Sindhupalchok (Site B).

Effect on quality parameters

Crude fiber content : The crude fiber content of rhizomes was significantly influenced by the treatment, but this effect was dependent on the experimental site, as indicated by a highly significant treatment x site interaction ($p < 2 \times 10^{-16}$). At Site A, the treatments had a strong and significant effect on the crude fiber content ($p<0.001$), showing that the treatments greatly affected fiber content of the ginger rhizomes (Fig. 2). Lowest fiber contents (13.43%), a desirable quality trait, was observed in T_4 (50% NPK + fine compost + Zn/B) followed by treatment T_6 (coarse compost only) of 15.97%, T_5 (fine compost only) of 16.19% and T_7 (multi-mix compost only) of 17.75%. Treatment T_3 (50% NPK + coarse compost + Zn/B) resulted in the highest crude fiber content of 38.58% which is undesirable ginger quality. In contrast, no significant differences among treatments were detected at Site B (p=0.373) (Fig. 3). Treatment T_4 numerically produced one of the lowest crude fiber values (8.21%), although differences among treatments were not statistically significant. These outcomes aligned with independent reports confirming that the fiber content was significantly reduced in organic nutrient management system (Divyashree *et al.*, 2022). When averaged across both sites, the overall treatment ranking was dominated by the strong response observed at Site A (Fig. 4). Treatment T_4 consistently yielded the lowest mean crude fiber content (10.82%), while T_3 promoted the highest fiber accumulation (24.14%). This aligns with findings from Li *et al.* (2021) who reported that balanced nutrition reduces lignification and improves tissue quality through optimized carbohydrate partitioning. In summary, while the expression of treatment effects on crude fiber was highly site-specific, the use of integrated nutrient sources along with micronutrients emerged as the best and most effective treatment for minimizing crude fiber content, a key quality trait for ginger. This suggested that the combined application of compost with reduced NPK and micronutrients created optimal conditions for secondary metabolite synthesis, potentially through enhanced phosphorus availability and microbial symbiosis as stated by (Abdou *et al.*, 2023).

Oleoresin content: Oleoresin content of ginger rhizomes was significantly influenced by treatment, but this effect was strongly dependent on the experimental

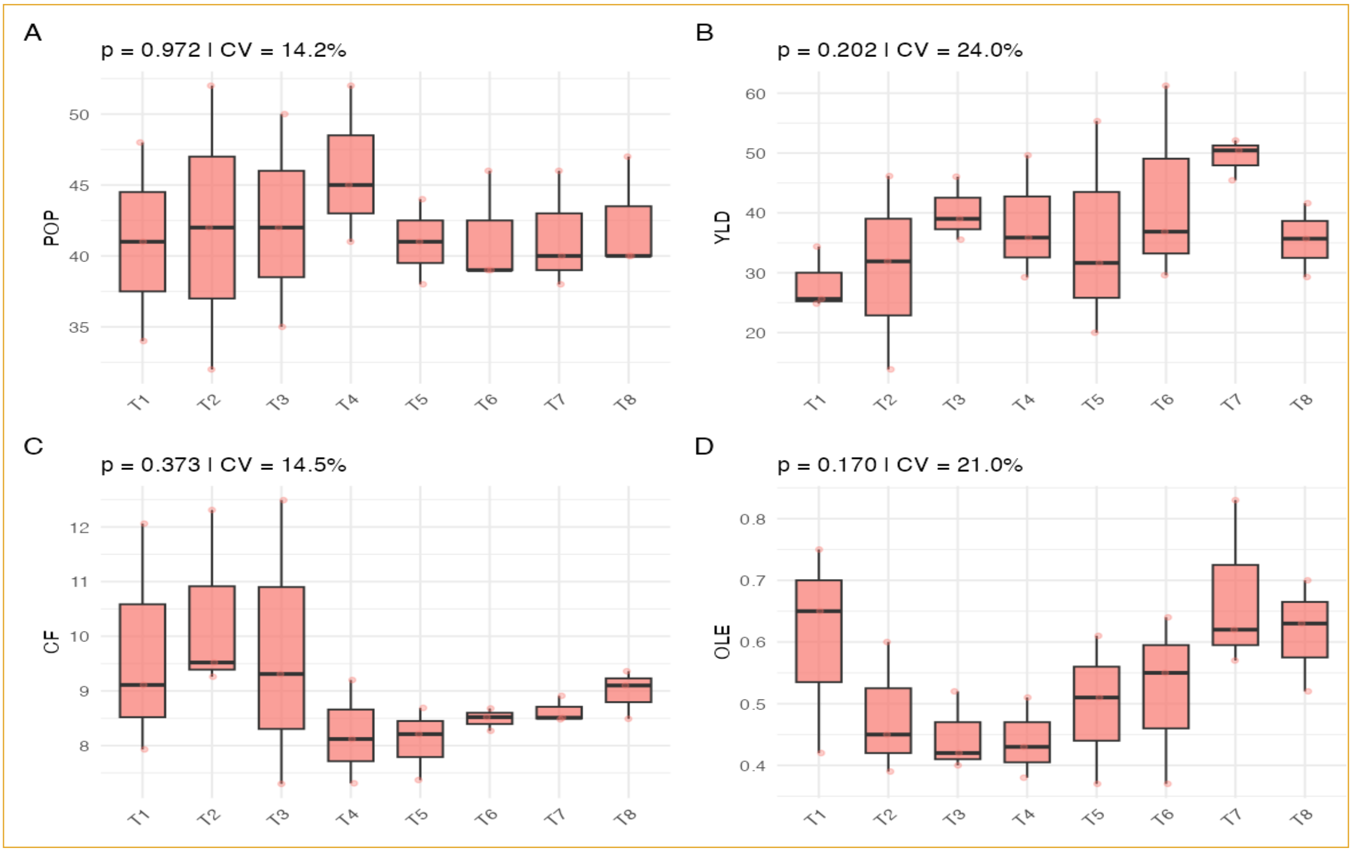

Fig. 4. Treatment performance averaged across Site A and Site B for plant population (A), yield (B), crude fiber content (C), and oleoresin content (D). Boxplots summarize the replicate variation of averaged values. Significance groupings (LSD, α = 0.05) are shown where applicable.

site, as indicated by a highly significant treatment × site interaction ($p = 8.68 \times 10^{-6}$) (Fig. 1). At Site A, treatment effects were extremely significant ($p<2 \times 10^{-16}$), with very high experimental precision (CV = 2.73%), indicating strong treatment differentiation (Fig. 2). Treatment T_3 (50% NPK + coarse compost + Zn/B) produced the highest oleoresin content (0.61), followed by T_2 (0.380%) and T_5 (0.380%), whereas T_1 and T_4 recorded the lowest values (0.183% and 0.190% each). In contrast, no significant differences were observed at Site B (p=0.170) (Fig. 3). Here, treatment T7 numerically recorded the highest oleoresin (0.67), while T_3, the top performer at Site A, recorded a comparatively lower oleoresin content at Site B (0.447%). These findings align with past reports that although the essential oil content was relatively higher in INM in comparison to conventional and organic nutrient management, there was very little variation in oleoresin and fiber contents among the different treatments (Srinivasan *et al.*, 2018).

When averaged across both sites, overall treatment means were heavily influenced by the strong response at Site A (Fig. 4). Treatment T_3 emerged as the top performer (0.530%), maintaining the highest overall average, while T_4 remained the lowest (0.320%), consistently producing the lowest oleoresin. The stronger response across all measured parameters at Bhotechaur suggests a highly responsive and biologically active soil environment. These observations aligned with the understanding that beneficial rhizosphere microorganisms can boost plant growth via multiple regulatory biochemical pathways, including manipulating the plant hormonal signaling, preventing pathogenic microbial strains and increasing the bioavailability of nutrients (Bargaz *et al.*, 2018). According to Sidhu and Shekon (2000), improvements in crop quality under integrated nutrient management arise from balanced macro and micronutrient supply and enhanced soil physicochemical and biological conditions that promote root proliferation and nutrient utilization.

CONCLUSION

The results clearly demonstrated that IPNM, combining compost, chemical fertilizers, and micronutrients, significantly influenced ginger quality attributes at both experimental sites, indicating that nutrient source and its balance play a decisive role in determining ginger quality. For yield responses, treatments incorporating organic and inorganic nutrient sources consistently outperformed the control and the treatment with only chemical sources across both sites, reflecting the benefits of nutrient integration. The mid hills of Nepal, having similar edaphic and biophysical conditions like Bhotechaur and Anekot, are suggested to use 50% of the recommended NPK dose plus 10 $tonsha^{-1}$ quality enhanced compost with Zn and B supplements as a soil application for better quality and yield of ginger rhizome. Additionally, farmers opting for organic farming are advised to apply quality enhanced compost at least 20 $tonsha^{-1}$ to obtain a better rhizome yield.

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