**Enhancing Crop Quality and Food Security Through Fertigation and Foliar Feeding Strategies**

**Abstract**

Chilli (*Capsicum annuum* L.) is a vital crop in both domestic and international markets, cultivated across 4.18 lakh hectares in India with an annual production of 44.17 lakh tonnes. Despite its importance, productivity remains low (10.60 t/ha) due to water stress, nutrient deficiencies, and pest issues. Fertigation and foliar feeding provide efficient nutrient delivery, improving crop growth. This study, conducted from November to April 2023–2024 at Kanjikuzhi, Kerala, evaluated the impact of fertigation and multinutrient foliar sprays on chilli (variety Sierra) using a split plot design with 20 treatments and 3 replications. The main plots compared varying fertilizer doses, including precision farming practices (75% F1, 100% F2, and 125% F3 of recommended NPK) and conventional fertigation (F4). Subplots included soil-based micronutrient application (S1) and foliar sprays of sampoorna KAU multimix (S2) and multinutrient mixtures (S3, S4) and water spray(S5). Fertigation was applied at 3-day intervals, while foliar sprays were administered at 15, 30 and 45 days after transplanting. The best results were achieved with 100% of the 210:48:276 NPK recommendation combined with sampoorna foliar spray, while 125% RDF with sampoorna foliar spray recorded the highest total soluble solids (3.03°Brix) and oleoresin content (25.7%). This balanced nutrient approach enhances crop quality, supports food security, and contributes to better nutrition for resilient communities.

Key words: Fertigation, foliar spray, chilli, malnutrition, multi nutrient

**Introduction**

Chilli (*Capsicum annuum* L.), a key spice crop in India from the Solanaceae family, is grown across 405,000 hectares, producing an annual yield of 4.272 million tonnes of green chillies. Despite this large-scale production, India's productivity of green chillies remains relatively low at 10.54 t/ha (Anonymous, 2022). Chilli fruits are rich in vitamins A and C, as well as essential minerals, and are commonly used in the preparation of pickles, sauces, and pastes. Additionally, chili oleoresin, known for its distinct flavor, spiciness, and aroma, plays a vital role in chili-based dishes and products. The natural antimicrobial properties of chili oleoresin, particularly capsaicin, are also leveraged in food preservation (Hulagannar et al., 2024).

Despite being an important crop, its production is quite modest. Increasing the area under cultivation of chillies or using better varieties and cultural methods are the different ways to increase yield. Proper application of fertiliser is one of the quickest and easiest way to increase the yield per unit area among many cultural practices (Natsheh and Mousa, 2014). One of the key elements influencing the development and yield of the crops is a balanced diet. It is equally crucial to consider the optimal levels at which nutrients should be administered and the source from which they originate. The application of nutrients to a crop increases agricultural output and improves crop quality.

Fertigation is an efficient method for controlling the timing and placement of fertilizers, enhancing fertilizer use efficiency by minimizing losses due to leaching, volatilization, and fixation into less available forms in the soil (Papadopoulos, 1994). Additionally, foliar application of micronutrients plays a crucial role in improving crop yield and quality, as these nutrients participate in various enzymatic and metabolic processes without undergoing fixation in the soil. This study focuses on the interactive effects of fertigation and foliar spray on the quality of chilli (Giri et al., 2024).

**Materials and methods**

The experiment was carried out in the 2023–2024 cropping season, from November to April, in a farmer's field in Kanjikuzhi, Alappuzha, Kerala, India (Latitude: 9.066°N, Longitude: 76.31°E), situated at a height of 612 meters above mean sea level. The soil was sandy clay loam, with temperatures throughout the growth season varying from a high of 27.1°C to 39.1°C and a low of 16.1°C to 29.9°C. Evaporation rates varied from 0.8 to 8.5 mm during the research duration.

The experiment used a split plot design including 20 treatment combinations and three replications. The primary plots included two fertilizer recommendations: the adhoc precision farming practice (KAU 2013) of 210:48:276 NPK kg/ha and the conventional fertilization practice (KAU 2016) of 75:40:25 NPK kg/ha. In these primary plot treatments, four levels of fertigation were evaluated: F1 – 75% of the recommended dose (RDF) via fertigation (157.5:36:207 NPK kg/ha), F2 – 100% RDF via fertigation (210:48:276 NPK kg/ha), F3 – 125% RDF via fertigation (262.5:60:345 NPK kg/ha), and F4 – 100% RDF via fertigation (75:40:25 NPK kg/ha). The sub-plot treatments included several ways for managing micronutrients and secondary nutrients. S1 – recommendations for secondary and micronutrient application based on soil tests, S2 – 0.5% Sampoorna KAU Multimix (Zn: 3.5–4.5%, B: 2.5–3.5%, Cu: 0.3–0.5%, Fe: <0.2%, Mg: <0.2%, Mo: <0.02%), S3 – 0.25% multinutrient mixture comprising 5% MgSO₄·7H₂O, 0.1% ZnSO₄·7H₂O, and 0.1% borax, S4 – 0.5% multinutrient mixture with identical composition to S3, and S5 – water spray serving as a control. The experimental field was meticulously plowed and prepared to a fine tilth prior to planting. Raised beds of 12 meters in length and 1.2 meters in breadth were constructed, and chili seedlings were transplanted 30 days post-sowing, according to a triangle planting configuration with a spacing of 60 cm by 60 cm. To maximize soil temperature, retain moisture, and suppress weeds, bi-color polyethylene mulch with a 40-micron thickness was put over the beds, with a black underneath and a silver top. Irrigation was administered via a drip system, using two drip laterals that supplied water at a rate of 4 LPH (liters per hour). Fertigation was conducted at three-day intervals according to the experimental treatments. Phosphorus was administered as a basal application via rock phosphate, whilst nitrogen, potassium, and the residual phosphorus were provided by fertigation with water-soluble fertilizers, such as urea, muriate of potash, and monoammonium phosphate. Fertilizer was applied with a pressure difference technique employing a venturi system. Eight plants were randomly selected from each plot for growth observations, with growth characteristics documented at 30,90 and120 days post-transplanting. Data analysis using the statistical technique outlined by Gopinath et al. (2020), with treatment differences assessed for significance at the 5% level.

Table 1. Different fertilizer dose applied per split

|  |  |  |  |
| --- | --- | --- | --- |
| **Different plots** | **Total****(Kg ha-1)** | **Basal as soil****application for P (kg/ha)** | **Per split (g /cent)** |
| Plot 1 75% RDF |  |  |  |
| N | 157.5 |  | 33.87 |
| P | 36 | 18 | 2.98 |
| K | 207 |  | 34.91 |
| Plot 2 100% RDF |  |  |  |
| N | 210 |  | 45.16 |
| P | 48 | 24 | 3.98 |
| K | 276 |  | 46.56 |
| Plot 3 125% RDF |  |  |  |
| N | 262.5 |  | 56.46 |
| P | 60 | 30 | 4.97 |
| K | 345 |  | 58.19 |
| Plot 4 100% RDF KAU |  |  |  |
| N | 75 |  | 15.63 |
| P | 40 | 20 | 3.31 |
| K | 25 |  | 4.21 |

**Result and discussion**

Quality parameters in chilli, such as ascorbic acid, total soluble solids (TSS), and oleoresin, are essential indicators of its nutritional, flavour, and industrial value. Ascorbic acid, a naturally occurring compound with antioxidant properties crucial for human health, was significantly influenced by varying levels of fertigation and foliar application, as shown in Fig 1. The highest ascorbic acid content in green chili at 120 days after transplanting was recorded in the treatment of F2S2 (86.00 mg 100 g-1) while the lowest value was observed in the treatment of F4S5(32.66 mg 100 g-1). The increase in vitamin C content under higher fertilizer doses may be attributed to greater nitrogen uptake, which enhances enzyme activity for amino acid synthesis. These findings are consistent with those of Vasu (2011) in cabbage and Jaspreet (2019) in chili. Additionally, foliar spraying significantly boosted ascorbic acid levels, with crops treated with Sampoorna showing the highest content, likely due to the zinc in Sampoorna, which functions as a metal activator for enzymes in the D-galacturonate pathway which provides an alternative route ascorbic acid synthesis in plants by utilizing D-galacturonic acid from pectin degradation, enhancing antioxidant production and contributing to stress tolerance and nutritional quality. These results align with the findings of Singh *et al*. (2018) in broccoli and Barche *et al*. (2011) in tomato.

Fig 1. Effect of fertigation on ascorbic acid content of chilli

Total soluble solids (TSS) are a key quality parameter that directly influences the flavour of chili. Table 2 highlights the significant differences in TSS observed under various fertigation levels and foliar sprays. The highest TSS value was recorded in the treatment F3S2(3.030 brix), while the lowest was recorded with F4S5(0.860 brix). The increase in TSS with higher fertilizer doses may be due to improved nitrogen and phosphorus uptake, which are essential for starch formation. During ripening, starch converts into sugars, enhancing sweetness (Aguyoh *et al*., 2010). Foliar application of macro- and micronutrients significantly influenced TSS content in chili, with Sampoorna Multimix producing the highest TSS due to its micronutrient content, which promotes growth by accelerating the synthesis of carbohydrates, vitamins, and other quality attributes. These findings are consistent with those of Dixit *et al*. (2017) and Ejaz *et al*. (2011) in tomato.

Oleoresin is a viscous, semi-solid, gel-like extract or essential volatile oil derived from spices, free from bacteria, spores, and mold. It contains the key quality attributes found in chilies. In this study, the highest oleoresin content was observed in the treatment F3S2(25.70%) from Table 2 it can be inferred. In contrast, the lowest content was recorded for the treatment F4S5(13.00 %). The higher oleoresin content might be attributed to enhanced synthesis and translocation of photosynthates in the fruits, facilitated by improved nutrient uptake under optimal soil moisture conditions. These findings are consistent with earlier research by Supekar (2020), Bidari and Hebsur (2011), who reported a positive correlation between colour value and oleoresin content with the concentration of nitrogen (N), potassium (K), and sulphur (S) in whole red chilli fruits. The study also revealed that oleoresin content significantly increased when secondary and micronutrients were applied in combination with NPK. Macro and micronutrients play a critical role in boosting oleoresin levels by supporting enzyme activity, enhancing nutrient absorption, and promoting the synthesis of essential oils and resins in plants. Similar trends were noted by Malawadi (2003) and Mahaveappa (2017).

**Table 2**. Fruit quality enhancement by balanced fertilization

|  |  |
| --- | --- |
| **Treatments** | **Quality characteristics**  |
| **Levels of primary nutrients(F)** |  |
|  | **Oleoresin (%)** | **TSS (0 brix)** |
| F1-75% KAU adhoc N P K | 19.50 | 1.39 |
| F2-100% KAU adhoc N P K | 20.33 | 1.70 |
| F3-125 % KAU adhoc N P K | 22.71 | 2.10 |
| F4 -100 % KAU POP N P K | 15.94 | 1.22 |
|  SEm (±) | 0.22 | 0.03 |
| CD | 0.63 | 0.10 |
| **Levels of multi nutrients(S)** |
| S1- soil test-based recommendation multi nutrient application | 22.76 | 1.28 |
| S2-0.25 % Sampoorna KAU multimix | 21.57 | 2.22 |
| S3-0.25% multimix nutrient mixture | 17.96 | 1.53 |
| S4-0.5% multimix nutrient mixture | 20.72 | 1.90 |
| S5-water spray | 15.08 | 1.08 |
| SEm (±) | 0.55 | 0.05 |
| CD | 1.63 | 0.17 |
| **Interactions (FxS)** |
| F1 S1 | 22.60 | 1.13 |
| F1 S2 | 22.20 | 1.70 |
| F1 S3 | 17.86 | 1.33 |
| F1 S4 | 20.53 | 1.83 |
| F1 S5 | 14.33 | 0.96 |
| F2 S1 | 22.80 | 1.50 |
| F2S2 | 23.58 | 2.40 |
| F2 S3 | 18.16 | 1.56 |
| F2 S4 | 21.10 | 1.93 |
| F2 S5 | 16.00 | 1.13 |
| F3 S1 | 24.36 | 1.40 |
| F3 S2 | 25.70 | 3.03 |
| F3 S3 | 22.50 | 2.16 |
| F3S4 | 24.00 | 2.53 |
| F3S5 | 17.00 | 1.36 |
| F4S1 | 21.30 | 1.10 |
| F4S2 | 14.80 | 1.76 |
| F4S3 | 13.33 | 1.06 |
| F4S4 | 17.26 | 1.33 |
| F4 S5 | 13.00 | 0.86 |
| SEm (±) | 1.11 | 0.11 |
| CD | NS | 0.34 |

**Conclusion**

The study highlights the significant impact of fertigation and foliar spray on the quality parameters of chilli (*Capsicum annuum* L.), such as ascorbic acid, total soluble solids (TSS), and oleoresin content. Fertigation, combined with foliar application of secondary and micronutrients, proved to be an effective method to enhance nutrient uptake and improve both yield and quality. The optimal results for ascorbic acid (86 mg/100 g) were observed in the treatment with 100% RDF (210:48:276 NPK kg/ha) combined with 0.5% Sampoorna foliar spray, indicating a marked improvement in antioxidant content. For TSS (3.03 °Brix) and oleoresin content (25.7%), the 125% RDF dose combined with Sampoorna foliar spray gave the best results, suggesting a positive correlation between increased fertilization and the enhancement of flavour and industrial quality attributes of chilli. These findings demonstrate the importance of balanced nutrient management in boosting the nutritional quality of crops, thereby improving food security. The application of fertigation with the right combination of foliar sprays plays a crucial role in unlocking nutrient-rich produce, which contributes to combating malnutrition and strengthening agricultural sustainability.

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**Disclosure statement**

No potential conflict of interest was reported by the authors

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**References**

1. Aguyoh, J.N, Audi W, Saidi M & Gao-Qiong L. 2010. Growth, yield and quality response of watermelon (*Citrullus lanatus* CV. Crimson Sweet) subjected to different levels of tithonia manure. International Journal of Science and Nature, 1(1):7-11.
2. Anonymous. 2022. Third advance estimate of area and production of horticultural crops. India Stat Agriculture, New Delhi.
3. Barche, S., Singh, P., Mahasagar, H. and Singh, D.B. 2011. Response of foliar application of micronutrients on tomato variety Rashmi. *Indian Journal of Horticulture*, *68*(2),278-279.
4. Bidari, B I. and Hebsur, N. S. 2011. Potassium in relation to yield and quality of selected vegetable crops Karnataka Journal Agricultural Sciences. 24 (1): 55-59.
5. Dixit, A., Sharma, D., Sharma, T.K. and Bairwa, P.L. 2017. To study the effect of calcium and different micronutrients on fruit quality attributes of tomato CV â€˜ Arka Rakshakâ€™. *Journal of Pharmacognosy and Phytochemistry*, *6*(6S),.400-403.
6. Ejaz, M., Waqas, R., Butt, M., Rehman, S.U. and Manan, A. 2011. Role of macro-nutrients and micro-nutrients in enhancing the quality of tomato. *Int. J. Agron. Vet. Med. Sci*, *5*,401-404.
7. Giri, J., Ghawade, S.M., Panchbhai, D.M., Nagre, P.K., Kadu, P.R. and Deshmukh, M.M., 2024. Influence of drip fertigation and foliar spray of boron on yield and nutrient uptake by Cucumber cv. himangi. Asian Journal of Soil Science and Plant Nutrition, 10(1),146-154.
8. Gopinath, P. P, Parsad, R, Joseph, B, Adarsh, V. S. (2020). GRAPES: General Rshiny Based Analysis Platform Empowered by Statistics. https://www.kaugrapes.com/home. version 1.0.0. DOI: 10.5281/zenodo.4923220
9. Hulagannavar, P., Masuthi, D.A., Lakshmidevamma, T.N., Abdul Kareem, M., Ryavalad, S., Shet, R. and Tatagar, M.H., Quantitative determination of Capsaicin, oleoresin and ascorbic acid content in Chilli (*Capsicum annuum* L.).
10. Jaspreet, K. 2019. Response of muskmelon (*Cucumis melo* L.) to drip irrigation and fertigation under mulch conditions (Doctoral dissertation, Punjab Agricultural University, Ludhiana).
11. Mahadevappa, P. 2017. Effect of foliar application of potassium nitrate, ferrous sulphate and magnesium sulphate on growth, yield and quality of chilli *(capsicum annuum l.) cv* (Doctoral dissertation, UASD).
12. Malawadi, M.N. 2003. *Effect of secondary and micronutrients on yield and quality of chilli (Capsicum annuum L.)* (Doctoral dissertation, University of Agricultural Sciences, Dharwad).
13. Natsheh, B. & Mousa, S. (2014). Effect of organic and inorganic fertilizers application on soil and cucumber (*Cucumis sativa* L.) plant productivity. International Journal of Agriculture and Forestry, 4(3), 166-170.
14. Papadopoulous, I. (1994). Use of labled fertilizers in fertigation research. In: proc. nucl. technique in soil pl studies for sustainable agric and dev. Vienna, Austria, October 1994
15. Singh V, Singh AK, Singh S, Kumar A, Mohrana DP.2018. Impact of foliar spray of micronutrients on growth, yield and quality of broccoli (*Brassica oleracea* var. italica) cv. Pusa KTS-1. The Pharma Innov. J. 7(8):99-101.
16. Supekar, S.J. 2020. *Impact of irrigation and fertigation levels on growth, yield and quality of summer chilli (capsicum annuum L.)* (Doctoral dissertation, Vasantrao Naik Marathwada Krishi Vidyapeeth, Parbhani).
17. Vasu, D. 2011. *Effect of fertigation on yield, quality and fertilizer use efficiency in cabbage (Brassica oleracia var. Capitata)* (Doctoral dissertation, ACHARYA NG RANGA AGRICULTURAL UNIVERSITY).