**Enhancing Tomato Yield and Stress Resilience through Grafting: A Study in Kalahandi District of Odisha, India**

ABSTRACT

In this study attempt has been made to evaluate the performance of grafted tomato SAHOO variety in comparison to non-grafted tomato (NGT) and local tomato (LT) varieties under rainfed conditions in Kalahandi district, Odisha, during the Kharif 2024 season. The experiment was carried out as a part of the NICRA project to enhance climate resilient tomato cultivation under water stress and changing climatic situations of the region. The results revealed that the grafted tomato plants exhibited superior growth, yield, and stress tolerance compared to non-grafted and local tomato varieties. The grafted plants resulted in increased plant height, greater fruit weight, and higher overall yield (215.8 kg/ha) compared to NGT (178.6 kg/ha) and LT (158.7 kg/ha) varieties. Additionally, grafted tomatoes had a longer active fruiting period of 45 days as compared to 30 days for NGT, and lower wilting incidence of 4 seedlings vs. 76 plants wilting in NGT, highlighting enhanced drought and disease resistance. The grafting technique also resulted in higher seedling establishment, survival rates, and resilience under environmental stress, expected to offer a promising solution for tomato cultivation in water-stress areas. Economically, grafted tomatoes bear higher market value due to better fruit quality, higher yield, and reduced losses, making grafted tomato cultivation technology a cost-effective strategy for farmers despite initial grafting expenses. This technology has efficacy of grafting as a sustainable, climate-smart agricultural practice in rainfed areas like Kalahandi District. The findings of the study supports the broader adoption of grafting technology in tomato to improve tomato productivity and farm profitability in rainfed, drought-prone regions.

**Keywords:** Grafting, Stress Resilience, Tomato, fruit quality, higher yield

**Introduction**

Vegetables constitute to be a vital component of human nutrition, supplying crucial dietary nutrients, vitamins, minerals, bioactive compounds, and fibers essential for a healthy body functioning (Axelle et al., 2018; Singh, 2020). Among these vegetable foods, tomato (*Solanum lycopersicum*) stands out not only as a kitchen ingredient but also as a significant source of nutrition (Bhowmic *et al*., 2012; Toor *et al*., 2005). Though tomato is technically a fruit in botanical terms, it is a widely used food item containing impressive amounts of beta-carotene (which converts to vitamin A), vitamin C, the powerful antioxidant lycopene, and the other various beneficial plant bio-compounds that help protect our body against diseases (Bhowmic *et al*., 2012). Tomato is widely used in different cooking methods—eaten raw, cooked, or as an ingredient in numerous delicious dishes worldwide and this versatile use of tomato has made it India's second most important vegetable crop economically, with only potato ranking higher in production volume and market value (Gulati *et al*., 2022).

Tomato plants bear particular sensitivity to their growing environment, especially changing temperature conditions (Tania *et al*., 2022). While somewhat adaptable, they perform best within a specific temperature range of 21-24°C. Though they can survive in temperatures from 10°C to 30°C, their productivity decreases as growing temperature move away from the ideal range. Extended exposure of tomato plants to temperatures below 12°C or above 32°C (Tania *et al*., 2022) significantly disrupts plant processes, including photosynthesis, flower development, and nutrient movement—resulting in poor fruit formation, lower harvests, and reduced quality. The exposure of tomato plants to cold stress do have significant difference in the physiology of plants with similar production status (Tania et al., 2022). Other weather factors like light intensity, humidity levels, and rainfall patterns also affect important plant development stages, pigment formation, taste compound development, and overall plant growth stages in tomato crops (Jędrszczyk et al., 2016; Song et al., 2022; Angmo et al., 2021). Tomato plants prefer moderate rainfall distribution, as too little or too much water can lead to problems such as blossom-end rot, fruit cracking, and increased vulnerability to diseases.

 The Indian food security and nutrition is highly pivoted by the cultivation and production of tomato which has a great stake in the socioeconomic status of millions of farm families (Asgarian et al., 2016; Moola et al., 2021). Across India, tomato cultivation spans approximately 864,000 hectares in various growing regions with a total production of 20.42 million tonnes fruit tomatoes with an average yield of 23.6 tonnes/ha (PIB, India, 2022-23). The crop is grown throughout the country—in southern states like Karnataka, Andhra Pradesh, Telengana and Tamil Nadu, eastern regions including Odisha and West Bengal, western areas such as Maharashtra and Gujarat, and northern zones extending to the plains and foothills of Uttar Pradesh and Himachal Pradesh. During 2020-21, tomato production in Odisha had covered an area of 91.01 thousand hectares with a total production of 1312.07 thousand tonnes, and a productivity of 14.42 tonnes per hectare (ICAR, 2020-21). Though Odisha stands as third for production and productivity of tomato in India, the per hectare yield of tomato is quite disappointing when compared with the national productivity being lower than international standards of quality maintenance. This yield and quality gap in tomato results from various biotic and abiotic stress encountered by tomato crop during entire cropping period such as insect pests and soil-borne diseases, particularly bacterial wilt and heat stress, cold stress, waterlogging or heavy rain as being major limiting factors (Pandey et al., 2022).

The causative agent of bacterial wilt, *Ralstonia solanacearum*, a soil borne bacterium represents one of the most destructive and difficult-to-manage plant pathogens affecting tomatoes and related crops globally (Wang *et al*., 2023; Phiri *et al*., 2024). This bacterium presents a great diversity and infects numerous plants from more than 50 plant families. It infects entering through root wounds or openings and rapidly multiplies in the plant's water-conducting xylem vessels, and there produces substances that blocks water transport systems inside the plant. This blockage prevents water and nutrients from moving through the plant, causing characteristic wilting that quickly progresses from initial drooping to complete tissue death. The pathogen thrives particularly in conditions combining warm soil (28-35°C) with high humidity—exactly the conditions found across much of Odisha and similar tropical regions (Su et al., 2020; Álvarez et al., 2022; Wang et al., 2023). Since the current breeding efforts have developed partially resistant tomato varieties and still these tomato varieties are not commercially viable as they show poorer performance in terms of yield, fruit consistency, storage life, and taste qualities compared to commercial hybrid varieties, the farmers lack to get a good bacterial wilt resistant-varieties in the market.

The grafting technology in tomato cultivation offers a promising solution to overcome the limitations of conventional disease management strategies (Flores et al., 2010; Bahadur and Anant, 2024). This technique combines vegetative tissues from two different plants: a commercially valuable upper portion (scion) chosen for superior fruit qualities and market appeal, attached to a root system (rootstock) selected specifically for its resistance to soil-based stresses (Alqardaeai et al., 2024). This approach has become increasingly popular in Europe, Japan, Korea, and North America as an environmentally friendly alternative to chemical soil treatments for managing persistent soil-borne diseases while maintaining high production quality. In India, research institutions like Kerala Agricultural University's Agricultural Research Station have successfully developed methods for grafting commercial tomato hybrids onto *Solanum torvum* (turkey berry) rootstocks—chosen for their strong resistance to bacterial wilt, root-knot nematodes, and other soil-borne diseases (Karthiga et al., 2023). Beyond disease resistance, grafted plants often show improved capabilities, including better water and nutrient use, increased production and movement of plant hormones, enhanced photosynthesis, and greater tolerance to environmental stresses like salt, drought, and temperature extremes (Razi et al., 2024).

Kalahandi district in Odisha represents a unique agricultural environment dominated by rain-fed farming systems, where tomato growers face various biotic and abiotic challenges from unpredictable rainfall patterns and prevalent soil-borne diseases. In this context, grafting technology in tomato brings potentially transformative benefits for small and marginal farmers by addressing multiple production challenges simultaneously. However, a thorough systematic scientific evaluation of performance of grafted tomatoes under these specific rainfed growing situations has not been achieved yet. This investigation thus intends to have a systematic assessment and compare various growth indicators, plant responses, yield components, and stress-tolerance factors between grafted and regular tomato plants under the rainfed growing situations of typical climatic zone of Kalahandi district. The findings from this investigation will bring important scientific relevance into the adaptability and efficacy of tomato grafting technology which may enable for recommending evidence-based cultivation technologies for expanding tomato productivity, stability, and profitability in water-limited farming systems.

**MATERIALS AND METHODS**

**EXPERIMENTAL SITE**

The field experiment was carried out during the Kharif 2024 at Bagpur village, Narla Block, Kalahandi district, Odisha, as part of an ongoing study under NICRA project for improving tomato cultivation under existing stress conditions of this area. The experimental site is located in the Western Undulating Zone of Odisha at 20.10°N latitude and 83.39°E longitude, with an elevation of 285 meters above mean sea level (MSL). The region falls under the south-west monsoon receiving uneven rainfall with high variability. The experimental field consisted of medium-low land with a loam (silty) soil texture, known for its moderate water-holding capacity, making it particularly suitable for the study.

**CLIMATIC CONDITION**

The research location at Bagpur village, Narla Block, Kalahandi district, Odisha is characterized by a sub-humid tropical climate effecting three distinct seasonal phases: an arid, hot summer; a cool winter; and a pronounced monsoon interval. The southwest monsoon, critical for agricultural yields, initiates in mid-June and continues until early October, contributing 80-90% of yearly precipitation totals. The area receives 1330.5 mm average annual rainfall, with occasional precipitation events during summer and winter periods. Nevertheless, the uneven rainfall distribution requires judicious water resource management, particularly for moisture-sensitive crops like tomato that respond poorly to extended dry intervals.

Throughout the study period, despite receiving nearly typical precipitation, supplementary irrigation was applied during critical growth phases to alleviate water deficit stress and facilitate proper plant growth. Considering vulnerability of tomato to inadequate moisture availability especially during blooming and fruiting stages, sustaining sufficient soil water content proved fundamental for optimizing fruit production and high quantum of harvest.

The temperature profile of the region exhibits elevated summer heat levels varying from 35°C to 43°C, while winter temperatures goes down below 20°C. These temperature variations significantly affect tomato cultivation, as intense heat can compromise flower formation, diminish pollen effectiveness, and trigger premature fruit dropping. Likewise, extended cold exposure may hinder vegetative progression and compromise fruit attributes. Atmospheric relative humidity remained above 85% during morning time frames in the wet season, with daily fluctuations influencing water loss rates and pathogen proliferation. The elevated humidity combined with periodic rainfall heightened vulnerability to fungal infections, requiring appropriate and timely disease control interventions to counteract outbreaks of early blight, late blight, and bacterial wilt pathogens.

Weather measurements during the experimental period were systematically observed and documented at the Regional Research and Technology Transfer Station (RRTTS) Observatory in Bhawanipatna. These atmospheric conditions, characteristic of the climatic patterns of this area, established a standard experimental system for assessing the adaptability and relative performances of grafted tomato variety SAHOO (GT), non-grafted tomato variety SAHOO (NGT) and local tomato (normal) (LT) seedlings under rain-fed cultivation circumstances.

Table 1. Average variations in temperature, humidity, rainfall, rainy day and BSH for critical months in Kalahandi District of Odisha

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Month** | **Temperature (oC)** | **Humidity (%)** | **Rainfall (mm)** | **Rainy day****(Nos.)** | **BSH****(Hrs.)** |
| **Min.** | **Max.** | **Max.** | **Min.** |   |   |  |
| **June** | 26.9 | 37.9 | 63.3 | 57.4 | 131 | 6 | 2.3 |
| **July** | 24.7 | 31.1 | 83.4 | 84.1 | 296.2 | 16 | 0.7 |
| **August** | 24.4 | 31.7 | 84.8 | 82.4 | 354.6 | 21 | 1.6 |
| **September** | 24.3 | 31.9 | 80.5 | 80.8 | 193.6 | 12 | 3.0 |
| **October** | 23.0 | 32.6 | 75.5 | 72.8 | 17.2 | 2 | 5.1 |
| **November** | 15.3 | 29.4 | 74.9 | 64.1 | 0 | 0 | 5.2 |
| **Mean**  | **23.1** | **32.4** | **77** | **73.6** | **165.4** | **57 (Total)** | **2.9** |

The SAHOO variety of tomato is known for its high yield potential and adaptability to diverse climatic conditions, making it a suitable choice of vegetable growers of rainfed areas in Kalahandi. By using grafted tomato seedlings, this study aimed to compare the advantages of enhanced root vigor, improved nutrient uptake, and better resistance to environmental stress in grafted plants versus normal seedlings.

**Data Collection and Analysis**

**Growth Parameters**

The plant height measurements at different growth stages indicated that grafted tomato plants exhibited superior vegetative growth as compared to non-grafted SAHOO tomato variety and local tomato variety. At 30 DAT (Days After Transplanting), the plant height for grafted tomatoes was 42.75 cm, slightly higher than the non-grafted tomato variety (42.10 cm) and local tomato variety. By 45 DAT, the difference became more pronounced, with grafted plants reaching 63.75 cm compared to 62.50 cm in non-grafted tomato plants. The growth advantage continued at 60 DAT and 90 DAT, where grafted plants attained 89.2 cm and 119 cm, respectively, while the non-grafted SAHOO tomato plants measured 88.5 cm and 115 cm. This suggests that grafting positively influenced plant vigor and biomass accumulation, likely due to improved root system efficiency and nutrient uptake.

**Yield Attributes**

**Fruit Weight:** The average fruit weight was significantly higher in grafted plants (98 gm) compared to NGT plants (71.30 gm), indicating better fruit development and size uniformity.

**Average Fruit Yield per Plant:** Grafted tomato (GT) plants yielded 6.5 kg per plant, while non-grafted tomato (NGT) plants produced only 4.2 kg, demonstrating a substantial increase in productivity.

**Average Fruit Yield per Hectare:** The GT plants achieved a yield of 215.8 kg/ha, whereas NGT plants recorded 178.6 kg/ha, confirming that grafting enhances yield potential under rainfed conditions.

**Active Fruiting Period**: The GT plants recorded an average active fruiting period of 45 days as compared to 30 days of active fruiting period of 30 days and that of 32 days for local tomato plants. This parameter emphasizes that grafting of tomato has added advantage for increased yield by increase of active fruiting period.

**Stress Tolerance Indicators**

**Seedling Establishment and Survival:** Out of 500 transplanted seedlings, 497 grafted seedlings established successfully, compared to 461 in the non-grafted tomato group.

**Wilting Percentage:** Grafted plants showed significantly lower wilting incidence (only 4 seedlings affected) compared to NGT plants (76 seedlings affected), indicating superior drought and disease resistance.

**Survival Rate:** The final number of seedlings that survived was higher in grafted tomato plants (493) than in the non-grafted (385), highlighting improved resilience to environmental stress.

Table 2 Variation in plant heights (in cms) of grafted tomato, Non-grafted SAHOO tomato and local variety at different durations

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Sl. No., | Particulars | 30DAT | 45DAT | 60DAT | 90DAT |
| 1 | Grafted | 42.75 | 63.75 | 89.2 | 119.00 |
| 2 | Non-grafted | 42.10 | 62.50 | 88.50 | 115.00 |
| 3 | Local Tomato | 40.80 | 61.75 | 83.90 | 105.80 |

Table 3 Variations in the plant growth and yield parameters of grafted tomato (GT), non-grafted tomato (NGT) and local tomato (LT) plants

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Sl. No. | Parameter of study | Unit of parameter | GT | NGT | LT | SD | SEM | CD |
| 1 | No. of seedings transplanted | No. | 500 | 500 | 500 | - | - | - |
| 2 | No. of seedlings established | No. | 497 | 461 | 402 | 10.86 | 3.02 | 6.12 |
| 3 | Nos. of will affected seedlings | No. | 4 | 76 | 85 | 0.99 | 0.27 | 0.55 |
| 4 | No. of seedlings survived  | No. | 493 | 385 | 317 | 1.57 | 0.44 | 0.89 |
| 5 | Fruit weight | G | 98 | 81.30 | 74.8 | 0.86 | 0.239 | 0.485 |
| 6 | Active fruiting period | Days | 45 | 30 | 32 | 1.39 | 0.39 | 0.79 |
| 7 | Average fruit yield/plant | Kg | 6.5 | 4.2 | 3.5 | 0.36 | 0.100 | 0.203 |
| 8 | Average fruit yield per hectare | Quintal | 215.8 | 178.6 | 158.7 | 7.39 | 2.04 | 4.14 |

**Result and Discussion**

The data was analysed for standard deviation (SD), standard errors of means (SEM) and critical difference (CD) to examine their distribution and quality of experiment. In Table 3 the SD, SEM and CD for eight studied parameters of grafted tomato plants has been represented. From this it is evident that there is no significant deviations between replications of the trial and the results of this analysis could be carried out for results and discussion. The grafted tomato plants performed significantly better than non grafted tomato SAHOO seedlings in terms of growth, yield, stress tolerance, and economic efficiency, endorsing this grafting technology in tomato as a potential alternative for sustainable tomato cultivation under rainfed conditions. In terms of growth performance, grafted plants exhibited greater plant vigor and total biomass accumulation compared to their non-grafted counterparts. At 30 days after transplanting (DAT), the height of grafted tomato plants was 42.75 cm, slightly exceeding that of NGT plants (42.10 cm), suggesting an early-stage advantage in vegetative growth. As the plants matured, the difference in plant height became more pronounced, with grafted plants reaching 63.75 cm at 45 DAT, compared to 62.50 cm in non-grafted SAHOO tomato plants. By 60 DAT, this trend continued, with grafted plants measuring 89.2 cm, while NGT plants reached 88.5 cm, indicating a consistent growth advantage. The plant height recorded at 90 DAT showed that grafted tomato plants attained 119 cm, whereas NGT and local tomato plants measured 115 cm and 105.80 cm respectively, reinforcing the notion that grafted plants had a better ability to sustain growth under rainfed conditions. This improved growth performance can be attributed to the enhanced root system efficiency of grafted plants, which allowed for better water and nutrient absorption, particularly in the moisture-stress conditions of Kalahandi district. Additionally, the reduced incidence of wilting in grafted plants suggests that these plants were able to maintain cellular turgor pressure and physiological stability more effectively than control plants, making them more adaptable to drought stress.

While evaluating yield performance, it was found that grafted tomato plants exhibited a significant advantage over normal seedlings of high yielding and local varieties. One of the key indicators of improved yield potential was fruit weight, which was 98 grams per fruit in grafted plants, compared to 81.30 and 74.8 grams in NGT and LT plants. This 37.5% increase in fruit weight over NGT plants suggests that the grafted plants not only produced larger fruits but also had an enhanced ability to accumulate biomass in the reproductive phase. Additionally, the average fruit yield per plant was 6.5 kg in grafted plants, whereas it was only 4.2 kg in non-grafted SAHOO tomato plants, demonstrating a significant improvement in productivity per plant. When extrapolated to per hectare yield, grafted plants recorded 215.8 quintals/ha, which is 20.8% higher than the NGT group (178.6 quintals/ha) whereas the yield of local varieties was 158.70 quintals per hactare. The substantial increase in overall plot yield can be ascertained to the robust root system of grafted plants, which allowed for better nutrient and water uptake, reducing the physiological stress commonly experienced by non-grafted plants under rainfed conditions. The ability of grafted plants to sustain higher yields under inadequate moisture conditions further underscores the role of grafting in enhancing crop resilience and productivity.

Another crucial aspect of the study was the evaluation of drought tolerance and stress response, particularly in terms of seedling establishment, survival rate, and resistance to wilting. Out of 500 seedlings transplanted, 497 grafted seedlings successfully established, compared to only 461 in the NGT group, indicating that grafted plants had better initial adaptation after transplanting. More importantly, the wilting incidence was significantly lower in grafted plants, with only 4 seedlings affected, whereas 76 seedlings in the non grafted SAHOO tomato group showed signs of wilting, representing a substantial difference in stress resistance. This highlights the ability of grafted plants to maintain better hydration and resist environmental stress factors, such as soil-borne pathogens and moisture fluctuations, which are common challenges in rainfed agriculture. The total number of surviving seedlings further confirms this trend, with 493 plants successfully surviving in the grafted tomato group, compared to only 385 plants in the NGT group, reflecting a significantly higher survival rate in grafted plants. This improved survival rate can be attributed to the stronger and more extensive root system in grafted plants, which likely facilitated deeper water extraction and nutrient uptake, enabling them to withstand periods of low soil moisture more effectively than non-grafted plants. These findings reinforce the importance of grafting in increasing drought tolerance, as it reduces seedling mortality and enhances plant robustness in challenging agro-climatic conditions.

From an economic viability perspective, the benefits of grafted tomato cultivation extend beyond improved yield and stress resilience, offering higher profitability for farmers despite the initial costs associated with grafting. One of the major economic advantages is the higher fruit yield per hectare, which directly translates into increased market returns. Given that grafted plants produced 20.8% more yield per hectare than non grafted SAHOO tomato plants, farmers cultivating grafted tomatoes under rainfed conditions can expect a substantial increase in income. Additionally, the larger and more uniform fruit size in grafted plants enhances their market value, as consumers and traders often prefer tomatoes with better visual appeal and weight consistency. Furthermore, the higher survival rate of grafted tomato seedlings (98.6%) compared to non grafted normal seedlings (77%) means that farmers experience fewer losses during the transplanting phase, reducing the need for replanting and ensuring a more stable and productive crop stand. The most significant observation was that the active fruiting period is significantly greater (50%) than the non grafted SAHOO tomato plant group which justifies the grafting of tomato for high yield and increased duration of fruiting period and it may help in high revenue income during off season periods of tomato cultivation. Although grafting requires additional labor and technical expertise, the long-term benefits far outweigh the initial investment, making it a cost-effective solution for improving tomato productivity in rainfed regions. The economic returns from higher yields, better fruit quality, and reduced losses due to wilting and disease position grafting as a viable strategy for enhancing farm profitability and sustainability in water-limited environments.

When compared with past studies on tomato grafting, the results of this study find well alignment with existing research investigations and simultaneously validated the high efficiency of grafted tomato with respect to growth, yield and stress tolerance. Several studies have demonstrated that grafting tomatoes onto stress-tolerant rootstocks significantly enhances drought resistance, nutrient uptake efficiency, and overall plant health, leading to higher yields even under challenging environmental conditions (Yang et al., 2022; Suresh and Muneer, 2025; Hui et al., 2024). The observed increase in plant height, survival rate, and fruit weight in this study is consistent with findings from similar research conducted in different agro-climatic regions, where grafting has been shown to enhance root vigor and reduce disease susceptibility (Singh et al., 2020; Razi et al., 2024). Furthermore, studies focusing on economic feasibility have indicated that the additional cost of grafting is justified by the higher market returns, particularly in areas where drought stress and soil-borne diseases limit tomato productivity. The findings of this study reinforce the practical benefits of grafting as a climate-smart agricultural technique, supporting its wider adoption among farmers seeking sustainable and profitable cultivation practices under rainfed conditions (Pankaj et al., 2024; Sawargaonkar et al., 2025).

**Conclusion:**

The findings of this study clearly demonstrate that grafted tomato plants outperformed normal seedlings in all key parameters, including growth performance, yield, drought tolerance, and economic viability. The significant increase in plant height, fruit weight, and overall yield highlights the efficacy of grafting in enhancing tomato productivity, particularly in water-stress environments. The superior stress tolerance and lower wilting incidence in grafted tomato plants further emphasize the potential of grafting as an effective strategy for mitigating environmental stress factors. Additionally, the economic benefits associated with higher yields and improved fruit quality make grafting a viable investment for farmers, ensuring higher profitability and sustainability. By aligning with previous research findings, this study provides compelling evidence for the adoption of grafting technology as a practical solution for enhancing tomato production in rainfed regions like Kalahandi. Given the growing challenges of climate change and water scarcity, promoting grafted tomato cultivation could play a crucial role in securing food security and improving livelihoods for farmers in drought-prone areas.

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