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Evaluation of Fruit Growth and Development of Guava Varieties (*Psidium guajava* L.) under the Agro-climatic Conditions of Gunupur, Odisha, India

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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Abstract

Guava is an important tropical fruit crop in India valued for its nutrition and adaptability. However, its growth and fruit development vary among varieties and depend on local environmental conditions. In Gunupur, Odisha, limited information is available on suitable guava cultivars, making varietal evaluation necessary to identify better-performing types for improved growth and yield. An investigation into the growth and development of the fruits of guava (*Psidium guajava* L.) varieties was conducted during 2025–26 at the

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School of Agriculture, GIET University, Gunupur, Odisha. The study involved the evaluation of the fruit growth of four guava varieties, namely Lucknow-49 (L-49), Allahabad Safeda, Banaras Red, and KG-1, at different developmental stages of fruits under the prevailing agro-climatic conditions of the region. The Study was conducted in uniform trees of seven years old in a completely randomised design with six replications. Observations were recorded on fruit length, diameter, volume, and average weight at five distinct stages: pea, gooseberry, lime, mature, and ripening stages. The results revealed that fruit growth parameters increased progressively from the pea stage to maturity in all varieties, followed by a slight decline in weight from maturity to the ripening stage. No significant variation among varieties was observed during the early stages of development; however, significant differences emerged at later stages. L-49 and KG-1 exhibited superior fruit size and volume at maturity and ripening stages. L-49 recorded the highest fruit length (9.72 cm), diameter (9.08 cm), volume (416.05 cm^3), and weight (260.89 g) at the ripening stage. The variation among varieties was attributed to differences in physiological efficiency, source–sink relationship, and assimilate accumulation. The findings indicate that L-49 and KG-1 are better suited for cultivation under Gunupur conditions due to their superior growth performance and fruit development characteristics.

Keywords: Guava; developmental stages; growth parameters; varietal performance; Agro-climatic conditions.

1. Introduction

Guava (*Psidium guajava L.*), belonging to the family Myrtaceae, is one of the most important fruit crops widely cultivated in tropical and subtropical regions in India due to its adaptability, nutritional value, and economic significance (Fischer & Melgarejo, 2021). It is native to tropical America and was introduced to India in the early seventeenth century (Arevalo-Marín et al., 2021). This crop is the fourth most important fruit crop of India after mango, banana, and citrus. It is often referred to as the "poor man's apple" owing to its rich content of vitamin C, dietary fiber, and antioxidants (Kumari et al., 2020). India is one of the largest producers of guava, and the crop plays a vital role in ensuring nutritional security as well as providing livelihood opportunities to farmers. Guava fruits are available throughout the year and can grow in many different climates. Its ability to thrive under diverse agro-climatic conditions makes it a suitable crop for regions like Odisha, particularly in the Eastern Ghats zone. In India, it is often called the Apple of the Tropics and the Poor Man's Apple because it is affordable (Corrêa et al., 2012). Growth and development of fruits are complex physiological processes influenced by genetic, environmental, and management factors (Arevalo-Marín et al., 2021). Fruit development in guava follows a characteristic growth pattern involving successive phases of cell division, cell enlargement, and maturation, ultimately determining fruit size, weight, and quality (Van Le Van et al., 2021, Padilla-Ramirez et al., 2012, Nikhil et al., 2021). Sandhu et al. (2024) reported that genotypic differences in hormonal regulation and assimilate distribution play a crucial role in determining growth and developmental characteristics in guava. Therefore, evaluation of varietal performance under specific agro-climatic conditions is essential for identifying suitable cultivars.

Environmental factors such as temperature, rainfall, humidity, and soil conditions also play a significant role in regulating fruit growth and development. Gunupur, located in the Rayagada district of Odisha, represents a unique agro-climatic region characterised by red lateritic soils, high temperature, and moderate rainfall. These conditions are conducive to guava cultivation; however, varietal performance may vary depending on adaptability to local environmental conditions. Despite the importance of guava cultivation in this region, limited information is available on the comparative growth performance of different varieties under Gunupur conditions. In view of the above, the present investigation aims to generate useful information on varietal performance based on fruit growth parameters to help select suitable cultivars for improved productivity and profitability in the region.

2. Materials and Methods

The present investigation was conducted during the year 2025–26 at the orchard of the School of Agriculture, GIET University, Gunupur, located in the Rayagada district of Odisha, India. The experimental site lies in the Eastern Ghats region at an altitude of approximately 83 m above mean sea level, with geographical coordinates of 19°03′14″ N latitude and 83°49′21″ E longitude. The climate of the region is humid tropical, characterized by hot summers and mild winters. The maximum temperature during summer reaches up to 40–42°C, while in winter it drops to 10–12°C. The area receives an average annual rainfall of 1200–1400 mm, most of which is

concentrated during the southwest monsoon period from June to September. The soil at the experimental site is red lateritic, with a sandy loam to loam texture, ensuring good drainage. Soil analysis indicated a pH of 7.3 and an electrical conductivity (EC) of 0.3 dS m^{-1}, indicating non-saline conditions. Investigations were conducted on four guava varieties (L-49, Allahabad Safeda, Banaras Red, and KG-1) of seven-year-old plants with six replications. Observations on different growth and yield parameters were recorded.

Sampling Procedures and Data Collection: From each replicated tree, a total of six fruits per variety per developmental stage were randomly selected for observations. The selected fruits were uniform in size and free from visible damage, insect infestation, or disease. Fruits were tagged at the pea stage to ensure consistent identification throughout the growth and development period. Observations were recorded on fruit length, diameter, volume, and average weight at five distinct developmental stages: pea stage, gooseberry stage, lime stage, mature stage, and ripening stage.

Measurement Techniques: Fruit length was measured using a digital vernier calliper (accurate to 0.01 cm) from the basal end (where the fruit is attached to the twig) to the distal end. Fruit diameter was measured in two perpendicular directions at the widest point of the fruit using the same calliper, and the mean value was recorded. Fruit volume was determined using the water displacement method, wherein each fruit was immersed in a graduated cylinder filled with water, and the volume displaced was recorded in cubic centimetres (cc or cm^3). Average fruit weight was determined by weighing individual fruits using a digital electronic balance (accurate to 0.01 g). All measurements were recorded in triplicate for each selected fruit to ensure accuracy and minimize measurement errors.

2.1 Statistical Design

Statistical analysis of the data was done using the analysis of variance (ANOVA) method suggested by Sir Ronald A Fisher. The data collected from each parameter across varieties and developmental stages were analysed using a completely randomised design (CRD).

3. Results and Discussion

Data on growth parameters of guava fruits at different developmental stages, including fruit length, diameter, volume, and average weight, were recorded at the pea, gooseberry, lime, mature, and ripening stages across four guava varieties (L-49, Allahabad Safeda, Banaras Red, and KG-1) were recorded. The results are furnished in Tables 1 to 4.

The length of fruits increased steadily from the pea stage to the ripe stage in all varieties, indicating a continuous growth pattern. The varieties did not differ significantly at the pea, gooseberry, and lime stages; however, significant differences were observed at the mature stage, with non-significant differences among varieties. Similarly, at the lime stage, fruit length ranged across ripening stages. At the pea stage, fruit length ranged from 1.20 cm in Allahabad Safeda to 1.30 cm in L-49, Banaras Red, and KG-1, with all varieties being statistically at par. At the gooseberry stage, the fruit length varied from 3.82 cm in Banaras Red and KG-1 to 3.88 cm in Allahabad Safeda, from 5.35 cm in Banaras Red and KG-1 to 5.55 cm in Allahabad Safeda, with all varieties being statistically at par.

Table 1. Mean length (cm) of fruits at different developmental stages

Variety	Pea stage	Gooseberry stage	Lime stage	Mature stage	Ripe stage
L-49	1.30	3.85	5.52	8.13[b]	9.72[a]
Allahabad Safeda	1.20	3.88	5.55	8.15[b]	8.98[c]
Banaras Red	1.30	3.82	5.35	8.45[a]	8.95[c]
KG-1	1.30	3.82	5.35	9.05[a]	9.55[b]
CV (%)	6.54	4.12	3.75	2.31	1.81
CD (p=0.05)	NS	NS	NS	0.27	0.24

At the mature stage, the fruit length ranged from 8.13 cm in L-49 to 9.05 cm in KG-1. Among the varieties, KG-1 recorded the significantly highest fruit length, followed by Banaras Red (8.45 cm), and they were at par; whereas Allahabad Safeda (8.15 cm) and L-49 (8.13 cm) were at par and recorded significantly lower fruit length. At the ripening stage, fruit length ranged from 8.95 cm in Banaras Red to 9.72 cm in L-49. The fruit

length of L-49 (9.72 cm) and KG-1 (9.55 cm) were at par and recorded significantly higher fruit length than Allahabad Safeda (8.98 cm), while Banaras Red recorded the lowest fruit length significantly.

Table 2. Mean diameter (cm) of fruit at different developmental stages

Variety	Pea stage	Gooseberry stage	Lime stage	Mature stage	Ripe stage
L-49	1.07	2.97	4.88	7.52[b]	9.08[a]
Allahabad Safeda	1.01	3.10	4.88	7.53[b]	8.48[c]
Banaras Red	1.10	3.00	4.80	7.75[b]	8.40[c]
KG-1	1.06	3.00	4.85	8.25[a]	8.75[b]
CV (%)	6.61	4.88	4.35	3.17	2.11
CD (p=0.05)	NS	NS	NS	0.34	0.26

Table 3. Mean volume (cm³) of fruits at different developmental stages

Variety	Pea stage	Gooseberry stage	Lime stage	Mature stage	Ripe stage
L-49	0.77[a]	17.75	72.07	347.05[a]	416.05[a]
Allahabad Safeda	0.66[b]	19.67	69.15	264.10[c]	338.83[c]
Banaras Red	0.86[a]	18.07	64.67	266.10[c]	331.20[c]
KG-1	0.79[a]	18.07	66.10	323.28[b]	382.97[b]
CV (%)	17.13	13.43	8.69	6.33	5.76
CD (p=0.05)	0.18	NS	NS	26.55	29.57

Table 4. Average weight (g) of fruits at different developmental stages

Variety	Pea stage	Gooseberry stage	Lime stage	Mature stage	Ripe stage
L-49	0.75[a]	17.00	70.98[a]	293.79[a]	260.89[a]
Allahabad Safeda	0.66[b]	18.93	66.93[a]	203.40[b]	201.29[b]
Banaras Red	0.85[a]	17.43	61.45[b]	200.56[b]	199.96[b]
KG-1	0.76[a]	17.55	64.20[a]	235.36[b]	224.49[b]
CV (%)	14.39	13.45	9.04	9.19	9.35
CD (p=0.05)	0.15	NS	8.33	29.99	28.98

The uniformity in fruit length during early stages might be due to the dominance of the cell division phase, where growth remains relatively similar across varieties under the prevailing climatic conditions of Gunupur. The variation observed during later stages might be attributed to increased cell enlargement and elongation, along with higher accumulation of photosynthates and water, which contribute to fruit growth. This pattern in L-49 and KG-1 suggests a more efficient source–sink relationship and higher metabolic activity, resulting in greater fruit elongation. Additionally, the warm temperature and favorable humidity conditions of Gunupur during fruit development likely enhanced cell expansion processes, leading to greater differentiation in fruit length among varieties at later stages (Shubham et al., 2026). Similar observations were reported by Singh et al. (2015), who noted that fruit growth in guava is relatively slow during early stages and accelerates during later stages due to cell enlargement, resulting in variation in fruit size parameters such as length among different genotypes. Bose et al. (2012), who noted that guava fruit development typically follows a double sigmoid growth curve. They emphasized that while the first phase is dominated by cell division, the subsequent rapid increase in fruit dimensions during the mature stage is primarily a result of cell enlargement and the development of intercellular spaces (Vani et al., 2024).

The diameter of fruits increased steadily from the pea stage to the ripening stage of all varieties, reflecting normal fruit growth behaviour. The varieties did not differ significantly at the pea, gooseberry, and lime stages, whereas significant differences were observed at the mature and ripening stages. At the pea stage, fruit diameter ranged from 1.01 cm in Allahabad Safeda to 1.10 cm in Banaras Red, with all varieties being statistically at par. At the gooseberry stage, fruit diameter varied from 2.97 cm in L-49 to 3.10 cm in Allahabad Safeda, with non-significant differences among varieties. At the lime stage, fruit diameter ranged from 4.80 cm in Banaras Red to 4.88 cm in L-49 and Allahabad Safeda, with all varieties being statistically at par. At the mature stage, fruit diameter ranged from 7.52 cm in L-49 to 8.25 cm in KG-1. Among the varieties, KG-1 recorded the

significantly highest fruit diameter, whereas Banaras Red (7.75 cm), Allahabad Safeda (7.53 cm), and L-49 (7.52 cm) were statistically at par and recorded lower fruit diameter. At the ripening stage, fruit diameter ranged from 8.40 cm in Banaras Red to 9.08 cm in L-49. L-49 recorded the significantly highest fruit diameter, followed by KG-1 (8.75 cm), whereas Allahabad Safeda (8.48 cm) and Banaras Red (8.40 cm) were at par and recorded significantly lower fruit diameter.

The relatively uniform fruit diameter during early stages might be due to the dominance of the cell division phase, where radial growth remains similar across varieties under the prevailing climatic conditions of Gunupur. However, the subsequent divergence at later growth intervals underscores the role of genetic architecture in governing source-sink efficiency and hormonal dynamics (Ghosh et al., 2022). This dramatic increase in fruit diameter toward full physiological maturity reflects accelerated carbohydrate accumulation and cell expansion, which are maximized under optimal agroclimatic parameters (Shubham et al., 2026; Srivastava et al., 2025). The variation observed during later stages might be attributed to cell enlargement and radial expansion, along with increased accumulation of water and photosynthates, which contribute to fruit thickening. This variation in L-49 and KG-1 suggests a more efficient source–sink relationship and higher metabolic activity, leading to greater fruit diameter. Additionally, favorable temperature and humidity conditions in Gunupur during fruit development may have enhanced cell expansion and tissue differentiation, resulting in increased fruit girth in certain varieties. Similar observations were reported by Singh et al. (2015), who noted that fruit growth in guava during later stages is mainly governed by cell enlargement and assimilate accumulation, leading to variation in fruit size parameters such as diameter among different genotypes.

The volume of fruit increased steadily from the pea stage to the ripe stage in all varieties. Significant differences were observed at the pea, mature, and ripening stages, whereas the varieties did not differ significantly at the gooseberry and lime stages. At the pea stage, fruit volume ranged from 0.66 cc in Allahabad Safeda to 0.86 cc in Banaras Red. Banaras Red recorded significantly higher fruit volume than Allahabad Safeda, while KG-1 (0.79 cc) and L-49 (0.77 cc) were statistically at par with each other. At the gooseberry stage, fruit volume varied from 17.75 cc in L-49 to 19.67 cc in Allahabad Safeda, with non-significant differences among varieties. At the lime stage, fruit volume ranged from 64.67 cc in Banaras Red to 72.07 cc in L-49, with all varieties showing no statistical variation. At the mature stage, fruit volume ranged from 264.10 cc in Allahabad Safeda to 347.05 cc in L-49. L-49 (347.05 cc) and KG-1 (323.28 cc) were at par and recorded significantly higher fruit volume than Banaras Red (266.10 cc) and Allahabad Safeda (264.10 cc), which were also statistically at par. At the ripening stage, fruit volume ranged from 331.20 cc in Banaras Red to 416.05 cc in L-49. L-49 recorded the significantly highest fruit volume, followed by KG-1 (382.97 cc), whereas Allahabad Safeda (338.83 cc) and Banaras Red (331.20 cc) were at par and recorded significantly lower fruit volume.

Fruit volume increased steadily from the pea stage to the ripening stage in all guava varieties, reflecting continuous fruit growth and development. The differences among varieties were relatively less evident during the early stages, whereas distinct variations appeared as the fruits progressed towards maturity and ripening. At the mature stage, KG-1 and Banaras Red exhibited comparatively higher fruit volume, while at the ripening stage, L-49 recorded the maximum fruit volume, followed by KG-1. This indicates that varietal differences in fruit volume become more pronounced during the later stages of fruit development. Similar findings were reported by Singh et al. (2015), who described that fruit growth in guava follows a characteristic pattern in which early stages are dominated by cell division, while later stages are governed by rapid cell enlargement, tissue expansion, and accumulation of assimilates. They further reported that fruit volume is largely determined during the enlargement phase and varies among genotypes due to differences in physiological efficiency, assimilate partitioning, and environmental response, leading to significant variation in fruit size parameters during advanced stages of development.

The average weight of fresh fruits increased steadily from the pea stage to the mature stage, and then slightly decreased at the ripe stage. Significant differences were observed at the pea, lime, mature, and ripening stages, whereas the varieties did not differ significantly at the gooseberry stage. At the pea stage, average fruit weight ranged from 0.66 g in Allahabad Safeda to 0.85 g in Banaras Red. Banaras Red recorded significantly higher fruit weight than Allahabad Safeda, while KG-1 (0.76 g) and L-49 (0.75 g) were statistically at par with both. At the gooseberry stage, average fruit weight varied from 17.00 g in L-49 to 18.93 g in Allahabad Safeda, with non-significant differences among varieties.

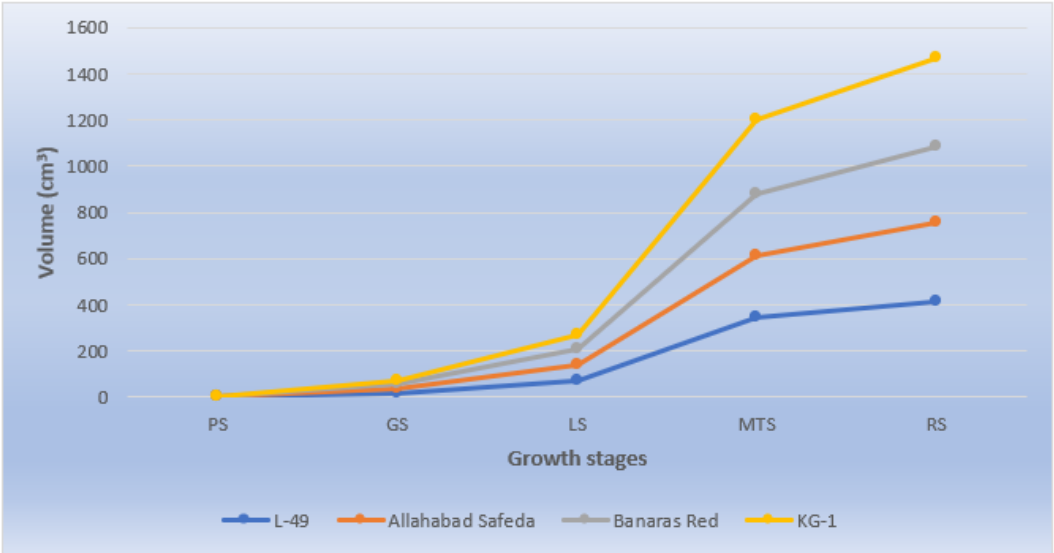

Fig. 1. Volume of fruit at different developmental stages

(Note: PS- Pea stage, GS- Gooseberry stage, LS- Lime stage, MTS- Mature stage, RS- Ripe stage)

At the lime stage, average fruit weight ranged from 61.45 g in Banaras Red to 70.98 g in L-49. L-49 recorded significantly higher fruit weight than Banaras Red, whereas Allahabad Safeda (66.93 g) and KG-1 (64.20 g) were statistically at par with both. At the mature stage, average fruit weight ranged from 200.56 g in Banaras Red to 293.79 g in L-49. L-49 recorded the significantly highest fruit weight, followed by KG-1 (235.36 g), whereas Allahabad Safeda (203.40 g) and Banaras Red (200.56 g) were at par and recorded significantly lower fruit weight. At the ripening stage, average fruit weight ranged from 199.96 g in Banaras Red to 260.89 g in L-49. L-49 recorded the significantly highest fruit weight, whereas KG-1 (224.49 g), Allahabad Safeda (201.29 g), and Banaras Red (199.96 g) were statistically at par and recorded lower fruit weight.

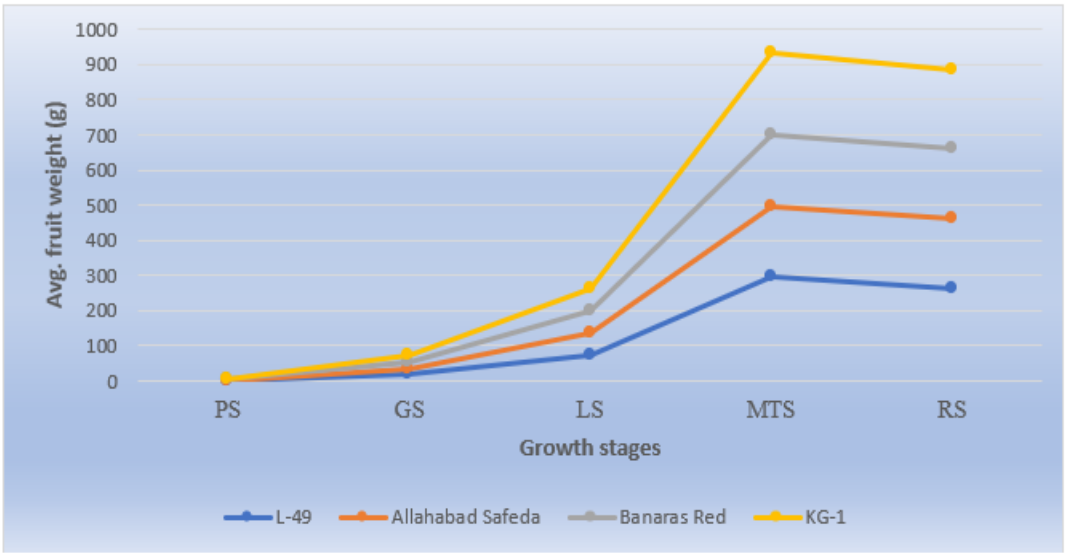

Fig. 2. Average Weight of fruit at different developmental stages

(Note: PS- Pea stage, GS- Gooseberry stage, LS- Lime stage, MTS- Mature stage, RS- Ripe stage)

The average fruit weight increased progressively from the pea stage to the ripening stage in all guava varieties, indicating continuous accumulation of biomass during fruit development. The differences among varieties were relatively small during the early stages, whereas clear variation became evident during the later stages.

Srivastava and Narasimhan (1967) also observed that fruit weight and size of guava followed a general pattern of steady increase until maturity, across seeded and seedless guava cultivars, with the most rapid growth occurring between 45 to 90 days after fruit set (Jagga et al., 2026). At the mature stage, KG-1 exhibited relatively higher fruit weight, while at the ripening stage, L-49 recorded the maximum fruit weight, followed by KG-1. This suggests that varietal differences in fruit weight become more pronounced as the fruit approaches full maturity. The relatively uniform fruit weight during early stages might be due to the predominance of the cell division phase, where dry matter accumulation is limited and similar across varieties under the prevailing climatic conditions of Gunupur. A study reported by Van Le Van (2021) showed significant length and diameter increases between 2-12 weeks, peaking by week 14 (approximately 98 days after anthesis), marking physiological maturity in the case of guava. Significant variation was observed among genotypes and across stages for all traits, with the highest values occurring at the physiological maturity (PM) stage. The variation observed during later stages might be attributed to the rapid accumulation of photosynthates, water, and metabolites, leading to increased fruit mass. This variation in L-49 and KG-1 suggests a more efficient source–sink relationship, higher photosynthetic activity, and better assimilate partitioning, resulting in greater fruit weight. Additionally, the favorable climatic conditions of Gunupur, particularly temperature and humidity, might have enhanced metabolic activity and translocation of assimilates to developing fruits, thereby contributing to increased fruit weight in certain varieties. Similar findings were reported by Singh et al. (2015), who explained that fruit weight in guava is largely determined during the later stages of development due to increased accumulation of assimilates and water within the fruit. They further noted that genotypic differences in physiological efficiency, source–sink relationship, and metabolic activity lead to variation in fruit weight among varieties, particularly during the maturation and ripening phases. Gomasta et al. (2024) highlighted that higher ambient temperatures during the fruit growth period accelerate metabolic enzyme activities, such as acid invertase, which increases the osmotic potential of fruit cells, leading to greater water uptake and fruit expansion.

4. Limitations of the Study

This study has several important limitations that warrant careful consideration when interpreting and applying the findings. First, the investigation was conducted only at a single location (Gunupur, Rayagada) during a single season (2025–26), which limits the representativeness of the results to other agroclimatic zones and seasons. Varietal performance may differ substantially under different environmental conditions, soil types, and management practices in other regions. Second, the study was restricted to four guava varieties, and the findings may not be applicable to other available commercial varieties or local cultivars not included in this investigation. Third, the study was conducted on seven-year-old trees exclusively, and fruit growth and development patterns may vary significantly with tree age, vigor, and historical management. Fourth, observations were made during a single growing season only; replication across multiple seasons would strengthen the validity and reliability of the conclusions by accounting for annual variations in weather and phenological patterns. Fifth, factors such as rootstock type, tree spacing, pruning history, and cumulative soil management effects, which may influence fruit development characteristics, were not specifically documented or controlled as independent variables. Finally, the study focused only on physical parameters of fruit growth (length, diameter, volume, and weight) and did not encompass biochemical quality attributes such as sugar content, acidity, vitamin C levels, or organoleptic characteristics, which are important for overall fruit quality assessment. These limitations suggest that future research should involve multi-location trials across diverse agroclimatic zones, evaluation over multiple consecutive seasons, inclusion of more varieties, use of trees of varying ages, and consideration of additional environmental, genetic, and management variables to enhance the generalizability and broader applicability of findings for comprehensive horticultural recommendations and policy development.

5. Summary and Conclusions

The present investigation clearly demonstrated that significant variation exists among guava varieties with respect to growth and development parameters under Gunupur agro-climatic conditions. All varieties exhibited a progressive increase in fruit length, diameter, volume, and weight from the pea stage to the mature stage, followed by a slight decline in weight at the ripening stage. However, varietal differences became more pronounced during the later stages of fruit development. Among the varieties studied, L-49 and KG-1 exhibited superior performance in terms of fruit size, volume, and weight, particularly at the mature and ripening stages. L-49 recorded the highest values for most of the growth parameters, indicating its higher physiological

efficiency and better assimilation and accumulation capacity. The enhanced performance of these varieties may be attributed to a more efficient source–sink relationship, higher metabolic activity, and better adaptability to the prevailing environmental conditions of Gunupur. The study highlights that fruit growth in guava is largely governed by genetic factors along with environmental influences such as temperature, humidity, and soil conditions. Based on the findings, L-49 and KG-1 can be recommended for cultivation in the Gunupur region for achieving better growth performance and higher productivity. The results of this study will be useful for varietal selection and improving guava production under similar agro-climatic conditions.

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Disclaimer (Artificial Intelligence)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

Competing Interests

Authors have declared that no competing interests exist.

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