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Performance of acid lime varieties on rough lemon under *Hasta bahar* season in Vidarbha region of Maharashtra

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ABSTRACT

An experiment was conducted to evaluate the performance of nine acid lime varieties budded on Rough lemon in high clay soil during the *Hasta bahar* season. The varieties were planted in 2015 at 6 × 3 m on raised bed at the ICAR-Central Citrus Research Institute in Nagpur, Maharashtra, and assessed for growth, yield, quality, pest incidence and citrus canker infection from 2019 to 2023. Significant variations were observed in growth characteristics, with PKM-1 showing the highest canopy volume (36.44 m^3) and yield per plant (21.11 kg/plant and 11.72 t/ha), followed by NRCC-8 (18.41 kg/plant and 10.22 t/ha). PKM-1 also recorded the highest fruit quality traits, such as fruit weight (64.15 g), and total soluble solids (7.76°Brix). While pest and disease incidence varied across varieties, NRCC acid lime -7 [7.23 percent disease intensity (PDI)] and PKM-1 (8.25 PDI) demonstrated better tolerance to citrus canker. However, no variety exhibited complete tolerance to pests or diseases. The results suggest that rootstock Rough lemon plays a crucial role in improving growth and yield, particularly in high-clay soils. Based on the findings PKM-1 (11.72 t/ha), NRCC acid lime-8 (10.22 t/ha) and NRCC acid lime-7 (9.37 t/ha) are recommended for optimal productivity in the Vidarbha region.

Key words: Citrus canker, fruit quality, rootstock, yield, pests.

INTRODUCTION

Acid lime (*Citrus aurantifolia* Swingle) is the third most important commercial citrus species in India, after mandarin and sweet orange. Due to its lower production costs relative to mandarins and sweet oranges, combined with superior shelf life and high market demand, the area under acid lime cultivation is steadily expanding each year. As of 2023-24, acid lime was cultivated on approximately 0.32 million hectares, yielding 3.83 million metric tons with a productivity of 12.02 t/ha (MoAFW, 15). The fruits are rich in vitamins, particularly vitamin C, as well as minerals, and are primarily consumed as fresh juice or pickles. The demand for fresh acid lime is high throughout the year, with a peak in summer. Market preferences favour fruits with large size, high juice content, and few seeds, as these traits command premium prices (Ghosh *et al*., 8). Acid lime typically blooms three times per year, with major flowering periods during *Ambia bahar* (January-February) and *Mrig bahar* (June-July), and a minor flowering period in *Hasta bahar* (September-October) (Deshmukh *et al*., 6). *Ambia bahar* and *Mrig bahar* fruits are harvested during the rainy and winter seasons, respectively, and generally fetch lower market prices. In contrast, *Hasta bahar* fruits, which are harvested during the summer, receive higher prices.

Rootstocks play a crucial role in citrus production by shortening the juvenile phase, providing an extensive root system, particularly in clay soils, and enhancing the vigour of the scion. Mandarins and sweet oranges are primarily propagated through budding using Rough lemon (*Citrus jambhiri* Lush) and Rangpur lime (*Citrus limonia* Osbeck) rootstocks, respectively (Sonkar *et al*., 19). In contrast, acid lime (*Citrus aurantiifolia* Swingle) is traditionally cultivated from seedlings across India. However, the high clay content characteristic of black cotton soils severely restricts root proliferation, leading to suboptimal nutrient uptake, reduced biomass accumulation, and a shortened economic lifespan of acid lime orchards. The integration of compatible rootstocks is imperative for ensuring sustainable acid lime cultivation, particularly in edaphic conditions with high clay content. Despite the critical role of rootstocks in modulating growth, productivity, and stress resilience, there is a paucity of systematic research on the performance of acid lime grafted onto different rootstocks under Indian conditions. Among the various rootstocks evaluated in India, Rough Lemon has demonstrated broad adaptability, robust

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root system development, and the ability to confer enhanced vegetative vigour and drought tolerance to the scion.

Therefore, the present study was undertaken to evaluate the growth performance and yield potential of nine acid lime varieties budded onto Rough lemon rootstock during the *Hasta bahar* flowering season in the Vidarbha region of Maharashtra. This investigation aims to generate empirical data to facilitate rootstock-based recommendations for optimizing acid lime production in high-clay soil conditions.

MATERIALS AND METHODS

The study was conducted at ICAR-Central Citrus Research Institute in Nagpur, Maharashtra, India. Nine acid lime varieties budded onto Rough lemon rootstock were used in this study (Table 1). These varieties were planted on raised beds (6 feet wide × 1.5 feet height) at a spacing of 6 × 3 m. The texture of the soil was: sand 26.4%, silt 20.9% and clay 52.7%. The soil chemical properties were: pH 7.82, and EC 0.41 dS/m. The available soil N, P, and K_2O contents were 216.13, 21.83, and 849.92 kg/ha, respectively. One-year-old, uniform-sized, disease-free plants of these varieties were planted in 2015. During the first year, 200:50:50 g N, P, K per plant and 1 kg of vermicompost were applied and the dose was doubled and tripled in the second and third year, respectively. Two kilograms of vermicompost and 800:200:200 g of N, P, and K were applied to each plant starting in the fourth year.

Canopy volume (m^3) was calculated using the formula [(tree spread × tree height) × 0.85] (Castle, 3). Ten fruits were randomly selected from each replicate for analysis, and the average was calculated. Fruit weight (g) was measured using an electronic balance, while fruit length (mm) and diameter (mm) were measured using a Vernier caliper. The juice percentage was calculated using the following formula: [(juice weight (g)/ fruit weight (g)) × 100]. Total soluble solids (TSS) were measured with a handheld refractometer and expressed as °Brix. Titratable acidity (TA) was determined using the procedure by AOAC (1). Fruit yield data were recorded on a per tree basis (kg/tree) and per area basis (t/ha). The data were collected during 2019-20 to 2022-23 and pooled mean data were used for analysis.

In a 1:2.5 (w/v) aqueous solution, the pH and EC of the soil were determined. Available N, P, and K (Subbiah and Asija, 22; Watanabe and Olsen, 23; Merwin and Peech, 14) were ascertained from the 0–15 cm soil depth. The incidence of psylla (population/5 cm twig), citrus leaf miner (% infestation), thrips (population/ 5-10 cm twig tapping), mites (population/ leaf), lemon butterfly (population/ plant), and blackfly (population/ leaf) were recorded on four twigs (15-20 cm length) from all the directions at fortnight intervals during the study period, and the average was recorded. Based on a 0–5 scale, the bacterial canker was calculated (where 0 represents free, 1 represents 1 to 10%, 2 represents 11 to 25%, 3 represents 26 to 50%, 4 represents 51 to 75%, and 5 represents 76 to 100% infected leaf areas) (Krishna and Nema, 11) and the percent disease intensity (PDI) was calculated based on the formula given by Das and Singh (5):

$$PDI = \frac{\text{Sum of all numerical ratings}}{\text{No of leaves assessed} \times \text{Maximum disease grade}} \times 100$$

The randomized block design with three replicates was used in this study. To identify significant differences among the varieties, pooled data on growth, yield, quality, pest, and canker intensity were analyzed statistically by analysis of variance (ANOVA) using the statistical package WASP 2.0.

RESULTS AND DISCUSSION

The importance of using suitable citrus rootstocks is well understood (Dubey and Sharma, 7) and it

Table 1. Citrus varieties used in the study.

Variety	Released from	Year of release
NRCC-7	ICAR-Central Citrus Research Institute, Nagpur, Maharashtra	2014
NRCC-8	ICAR-Central Citrus Research Institute, Nagpur, Maharashtra	2014
Vikram	Vasantrao Naik Marathwada Krishi Vidyapeeth, Parbhani, Maharashtra	1994
Pramalini	Vasantrao Naik Marathwada Krishi Vidyapeeth, Parbhani, Maharashtra	1994
Balaji	Citrus Research Station, Dr Y.S.R. Horticultural University, Tirupati, Andhra Pradesh	2006
PKM-1	Horticultural College and Research Institute, TNAU, Periyakulam, Tamil Nadu	1990
Phule Sharbati	Mahatma Phule Krishi Vidyapeeth, Rahuri, Maharashtra	2008
Sai Sharbati	Mahatma Phule Krishi Vidyapeeth, Rahuri, Maharashtra	1994
PDKV Bahar	Dr Panjabrao Deshmukh Krishi Vidyapeeth, Akola, Maharashtra	2017

influences the growth of scion. Rootstocks influence several physiological and morphological traits, including plant height, canopy development, nutrient uptake efficiency, and tolerance to biotic and abiotic stresses. Table 2 showed significant variations in the growth of different varieties. The data on the growth parameters of nine acid lime varieties budded onto Rough lemon rootstock revealed that the plant height and canopy volume varied from 3.24 to 3.98 m and from 19.33 to 36.44 m^3, respectively. Among the different varieties evaluated, PKM-1 had the highest canopy volume (36.44 m^3), followed by NRCC acid lime-8 (30.6 m^3). These variations in growth characteristics can be attributed to multiple factors, including the genetic potential of the varieties, environmental conditions such as soil properties and climate, and the physiological effects of the rootstock. In citrus, differential growth responses due to rootstock selection have been widely reported across various species. Studies have shown that rootstock-related differences significantly influence growth traits in mandarin (Sau *et al.*, 16), sweet orange (Singh *et al.*, 18), acid lime (Sonkar *et al*., 20) and lemon (Dubey and Sharma, 7). Additionally, interactions between the rootstock and scion can modify tree architecture, fruit-bearing patterns, and overall orchard productivity, making rootstock selection a key determinant in optimizing citrus cultivation.

Significant differences in yield were observed among the varieties, both in terms of yield per plant and yield per unit area (Table 2). Over the years, yield has gradually increased for all the varieties. Among the varieties, PKM-1 recorded the highest yield (21.11 kg/plant), followed by NRCC Acid lime-8 (10.22 kg/ plant). Similarly, for yield per unit area, PKM-1 achieved the highest yield at 11.72 t/ha, with NRCC Acid lime-8 following at an average of 10.22 t/ha. These results suggest that inherent genetic differences among the varieties contribute to variations in yield-related traits. In addition to genetic factors, variations in yield can be attributed to differences in canopy architecture, photosynthetic efficiency, soil fertility, water availability, and climatic adaptability also influence yield performance. Moreover, the role of rootstock in plant productivity is critical, as rootstocks significantly affect vigour, nutrient uptake, water-use efficiency, and overall stress tolerance, ultimately impacting yield potential (Sharma *et al*., 17). Several citrus studies have also demonstrated that rootstocks can enhance nutrient uptake and influence the hormonal balance, thereby potentially increasing yield (Araujo *et al*., 2; Grace *et al*., 10; Sau *et al*., 16).

Table 2. Growth performance of nine acid lime varieties budded on Rough lemon.

Variety	Plant height (m)	Canopy volume (m^3)	Yield (kg/ plant)	Yield (t/ha)
Pramalini	3.55	24.20	12.63	7.01
PKM-1	3.98	36.44	21.11	11.72
Vikram	3.83	30.04	13.00	7.21
Phule Sharbati	3.46	27.48	13.84	7.68
Sai Sharbati	3.53	26.29	13.18	7.32
PDKV Bahar	3.64	26.13	13.91	7.72
Balaji	3.36	19.33	12.35	6.85
NRCC acid lime -7	3.24	21.23	16.89	9.37
NRCC acid lime -8	3.79	30.60	18.41	10.22
CV(%)	5.59	1.27	1.70	2.80
SE (d)	0.08	1.71	1.02	0.57
CD@5%	NS	0.60	0.45	0.41

Table 3 showed that the significant differences among the varieties in terms of fruit quality traits. PKM-1 recorded the maximum average fruit weight (64.15 g), fruit length (62.17 mm), fruit diameter (50.44 mm) followed by Phule Sharbati (59.27 g and 46.21 mm) in fruit weight and fruit diameter and Paramlini in fruit length (51.27 mm). Balaji and NRCC acid lime-7 recorded the lowest fruit weight (46.29 and 46.95 g, respectively). Pramalini and PKM-1 recorded the least seeds per fruit (6.36 and 6.40 seeds per fruit). Phule Sharbati recorded the highest juice content (44.03%) while NRCC acid lime-8 (35.94%), PKM-1 (37.06%), Balaji (37.10%) and NRCC acid lime-7 (37.64%) recorded the lowest juice content. TSS and acidity are two important parameters in citrus that determine their quality. In this study, PKM-1 had the highest TSS content (7.76°Brix) while PDKV Bahar (7.17%) had the highest acidity. The minimum rind thickness was recorded for NRCC acid lime-8 (1.76 mm). Phule Sharbati and Balaji recorded the maximum vitamin C content (25.73 and 25.17 mg/100 mg). Variation in quality attributes among the varieties might be due to inherent genetics and soil and climatic factors of locality. In acid lime, variation in quality parameters among the varieties was earlier reported by Lakshmi *et al*. (12). Further, previous studies reported that the rootstocks also have profound influence on quality traits of the mandarin (Gora *et al*., 9), sweet orange (Singh *et al*., 18) and acid lime (Sonkar *et al*., 20).

The findings presented in Figure 1 indicate significant variations in pest incidence across all cultivars. The incidence of citrus leaf miner (CLM) was lowest in PKM-1 (17.14%), NRCC Acid lime-7 (17.33%), and Balaji (18.57%). Similarly, psylla

Table 3. Quality traits of acid lime varieties budded on Rough lemon .

Variety	Fruit weight (g)	Fruit length (mm)	Fruit diameter (mm)	No. of seed	TSS (°Brix)	Juice content (%)	Acidity (%)	Rind thickness (mm)	Vit. C (mg/100 mg)
Pramalini	55.40	51.27	45.89	6.36	7.35	42.83	6.46	1.84	24.89
PKM-1	64.15	62.17	50.44	6.40	7.76	37.06	7.04	2.27	24.66
Phule Sharbati	59.27	49.92	46.21	9.94	7.16	44.03	6.15	1.99	25.73
Sai Sharbati	56.15	48.75	45.77	7.57	7.44	43.01	6.30	1.94	23.21
Vikram	49.60	46.84	43.36	7.78	7.13	41.00	7.10	1.87	23.02
PDKV Bahar	55.21	45.85	45.58	8.80	7.23	43.03	7.17	1.91	23.50
Balaji	46.29	43.90	42.81	5.14	7.24	37.10	6.36	1.91	25.17
NRCC acid lime-7	46.95	43.32	42.67	8.51	6.98	37.64	6.18	1.87	23.51
NRCC acid lime-8	48.84	43.68	44.95	7.17	7.12	35.94	6.32	1.76	24.33
CV (%)	0.71	0.84	0.84	1.64	0.25	0.63	2.89	6.58	0.17
SE(d)	2.01	1.96	0.79	0.48	0.08	1.07	0.14	0.05	0.318
CD @ 5%	0.66	0.70	0.66	0.21	0.03	0.44	0.33	0.22	0.07

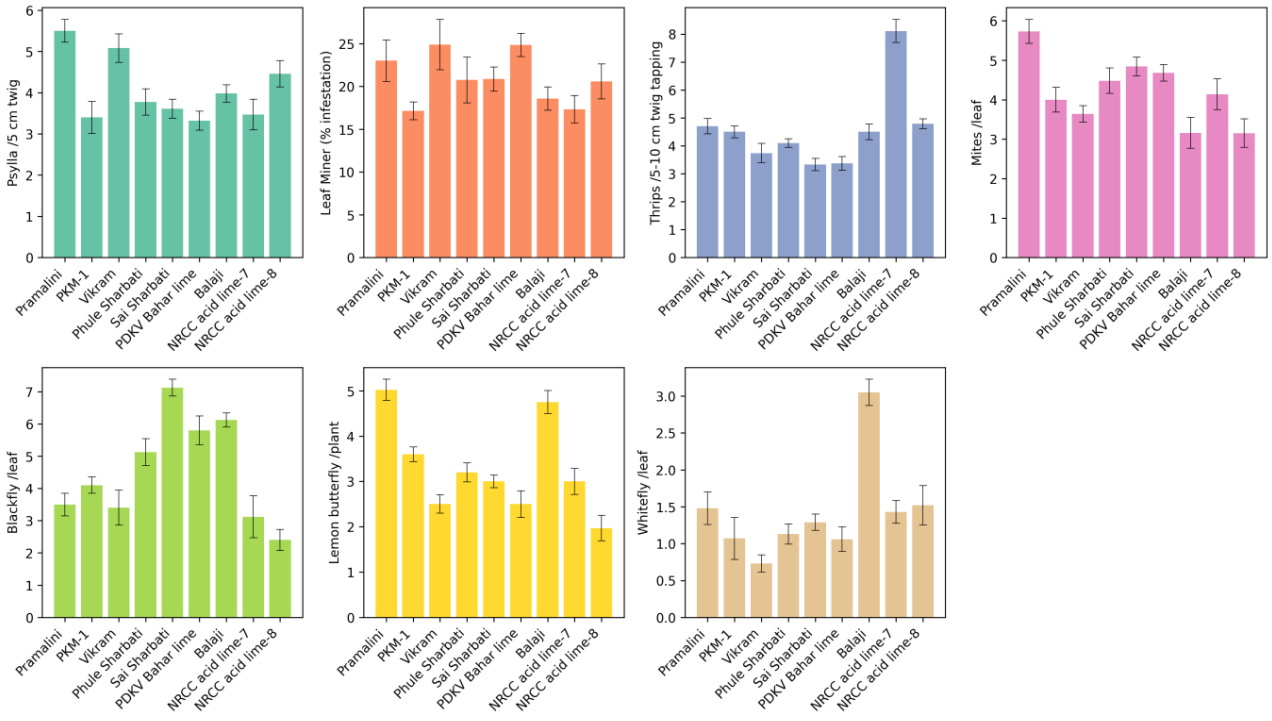

Fig. 1. Insect pests and mite incidence in acid lime varieties.

infestation was lowest in PDKV Bahar Lime (3.32/ twig), NRCC Acid lime-7 (3.47/ twig), and PKM-1 (3.40/ twig). Sai Sharbati recorded the lowest thrips incidence (3.33 per 5–10 cm twig tapping), followed by PDKV Bahar lime (3.37 per 5–10 cm twig tapping). The lowest mite population was observed in NRCC Acid lime-8 (3.15/ leaf) and Balaji (3.16/leaf). The blackfly population was minimal in NRCC Acid lime-8 (2.40/leaf) and NRCC acid lime-7 (3.12/leaf). The lowest whitefly population was recorded in Vikram (0.73/leaf) and PDKV Bahar lime (1.06/leaf). The lemon butterfly population was lowest in NRCC Acid lime-8 (1.97/plant), followed by Vikram and PDKV Bahar lime (2.50/plant). Although significant differences were observed in pest and mite infestation levels across cultivars, the degree of variation was relatively low. Similar findings have been reported for

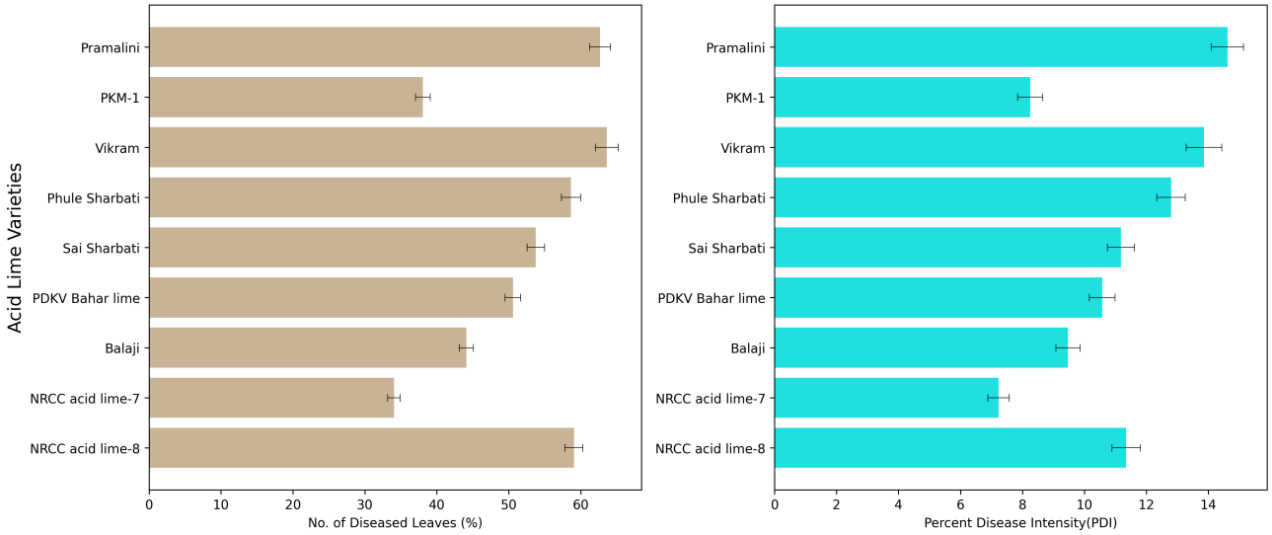

Fig. 2. Reaction of acid lime varieties to citrus canker.

varying levels of insect pest incidence in different acid lime clones (Sreedevi and Rajulu, 21).

Xanthomonas citri ssp. *citri* poses a significant threat to acid lime cultivation in India (Das, 4). The severity of the infection varied among varieties, with the number of affected leaves ranging from 34.04 to 63.63% and the percent disease intensity (PDI) from 7.23 to 14.62% (Fig. 2). NRCC acid lime-7 demonstrated the lowest infection rate, with 34.04% diseased leaves and a PDI of 7.23. Conversely, Vikram (63.63% disease infection and 13.86 PDI), and Pramalini (62.68% disease infection and 14.62 PDI) varieties displayed the highest number of infected leaves and PDI values. Balaji has been reported as canker-tolerant in Andhra Pradesh and Telangana states of India. In our study, Balaji also had a lower incidence of PDI (9.47), although slightly higher than NRCC acid lime-7 and PKM-1. An infestation of citrus leaf miners (CLM) increases the risk of citrus canker (Das, 4). In the present study, a lower level of CLM population was observed in Balaji and NRCC acid lime-7, which may explain the lower canker infestation in these varieties. The findings indicated that all varieties exhibited symptoms, with none showing resistance or tolerance to the disease. The variable reaction to citrus canker in different varieties of acid lime might be due to the genetics of the varieties. A similar kind of variable reaction to canker in acid lime clones was observed by Mahawer *et al*. (13).

In conclusion, nine acid lime varieties budded onto Rough lemon planted in high clay soil were evaluated for performance during *Hasta bahar* season. When budded onto Rough lemon, PKM-1, NRCC acid lime-7 and NRCC acid lime-8 outperformed other varieties in growth and yield in clay soils of Vidarbha region. Although variations in pest resistance and canker infection were observed among the varieties, no variety demonstrated complete tolerance. These findings highlight the importance of rootstock and selection of varieties for optimal acid lime production in Vidarbha regions.

AUTHORS' CONTRIBUTION

Conceptualization and designing of experiment (RKS, MSL); Implementing experiment (RKS, MSL, AT, AM); Data collection and analysis (RKS, AT, AKD, NM, GTB, AG, AK, JK, SC); Preparation of manuscript (AT, RKS).

DECLARATION

The authors have no competing interests.

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