NPSN: 006/082/83

Annual Report

2081/82 (2024/25)

Government of Nepal
Nepal Agricultural Research Council
National Citrus Research Program
Paripatle, Dhankuta
2025

Newly registered lemon variety ‘Paripatle Sunaulo Nibuwa’ suitable for Terai, inner Terai and rever basin area upto 800 masl

Newly registered Satsuma mandarin variety ‘Paripatle Agaute Suntala-2’ suitable for early season production up to 1000-1600 masl altitude of mid-hill region of Nepal

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National Citrus Research Program (NCRP)

Nepal Agricultural Research Council (NARC)

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FOREWORD

Citrus is a key fruit crop in Nepal, valued for both its economic and nutritional importance. Predominantly grown in the mid-hills (800–1,400 masl), it includes mandarins, sweet oranges, and acid limes, with mandarin being the most widely cultivated. Citrus farming provides a vital source of cash income for smallholder farmers, supports rural livelihoods, and contributes to household nutrition as a rich source of vitamin C. Despite this significance, productivity remains constrained by citrus decline, poor orchard management, and inadequate post-harvest practices. As a high-value horticultural crop, citrus therefore holds strategic potential for enhancing food security, income generation, and agricultural diversification in Nepal.

The National Citrus Research Program (NCRP), under the Nepal Agricultural Research Council (NARC), plays a central role in strengthening this sector. Its mandate covers the development and dissemination of improved production technologies, including high-yielding and disease-resistant varieties, integrated nutrient and pest management practices, and advanced orchard management techniques. In addition, NCRP has prioritized addressing citrus decline, improving nursery practices, and promoting effective post-harvest handling to enhance fruit quality and marketability. Through research, training, and stakeholder collaboration, NCRP contributes significantly to improving productivity, ensuring sustainability, and supporting the commercialization of citrus in Nepal.

These achievements have been made possible through the dedicated efforts of NCRP staff and the continuous support of the NARC management team, particularly the Executive Director, Directors of Planning and Coordination, Crop and Horticulture Research, and Administration. Despite limitations in human resources, NCRP has successfully met most of its planned objectives. However, long-standing vacancies in critical scientific positions-such as soil science, entomology, pathology, and plant breeding-have restricted the full utilization of available laboratory facilities at NCRP, Paripatle, Dhankuta.

This annual report is expected to serve as a useful resource for a wide range of stakeholders, including citrus farmers, researchers, students, and professionals engaged in citrus research and development. It provides updated insights and findings that may guide informed decision-making, academic inquiry, and practical field applications. The preparation of this report was further supported by the valuable contributions of Mr. Amrit Katuwal, whose assistance is sincerely acknowledged with gratitude.

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ACRONYMS

%	: Percentage
@	: At the Rate of
>	: Greater Than
2,4-D	: 2,4-Dichlorophenoxyacetic Acid
ACC	: Accession
B.S.	: Bikram Sambat
BrimA	: Brix Minus Acid
CCI	: Chlorophyll Content Index
CIRAD	: Centre of Agriculture Research for Development
cm	: Centimeter
CTV	: Citrus Tristeza Virus
CV	: Coefficient of Variation
cv.	: Cultivar
DA	: Difference in Absorbance
DAP	: Di-ammonium Phosphate
DAS	: Days After Sowing
et. al.	: et alia
FY	: Fiscal Year
FYM	: Farm Yard Manure
g	: Gram
ha	: Hectare
HLB	: Huanglongbing
i.e.	: That is
IAAS	: Institute of Agriculture and Animal Science
ICAR	: Indian Council of Agricultural Research
ICIMOD	: International Centre for Integrated Mountain Development
INGO	: International Non-Governmental Organization
INRA	: French National Institute for Agriculture Research
JICA	: Japan International Cooperation Agency
JT	: Junior Technician
JTA	: Junior Technical Assistant
K	: Potassium
Kg	: Kilogram

l	: Liter
LSD	: Least Significant Difference
m	: Meter
masl	: Meter Above Mean Sea Level
ml	: Milliliter
mm	: Millimeter
MoALD	: Ministry of Agriculture and Livestock Development
mt	: Metric Ton
mt ha^{-1}	: Metric Ton per Hectare
N	: Nitrogen
NAA	: Naphthaleneacetic acid
NARC	: Nepal Agricultural Research Council
NCRP	: National Citrus Research Program
NGO	: Non-governmental organization
NPR	: Nepalese Rupee
NS	: Non-significant
^{o}	: Degree
P	: Phosphorus
PATWG	: Provencial Agricultural Technical Working Group
PCR	: Polymerase Chain Reaction
pH	: Potential of Hydrogen
PMAMP	: Prime Minister Agriculture Modernization Project
ppm	: Parts per Million
RCBD	: Randomized Complete Block Design
TA	: Titratable acidity
TSS	: Total Soluble Solids
VCDP	: Value Chain Development Project
viz.	: Videlicet
WP	: Wettable Powder

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सुन्तलाजात फलफूल खेती नेपालको मध्य पहाड र तराईका कृषकहरुको आर्थिक अवस्थामा सुधार ल्याउने एक महत्वपूर्ण व्यावसाय हो । सुन्तलाको बढ्दो आन्तरिक तथा वाह्य बजारको कारणले यसलाई एक उच्च मूल्य भएको क्षेत्रको रुपमा पहिचान गरिएको छ । यसर्थ नेपाल सरकारले बिगत केहि वर्षदेखि सुन्तला क्षेत्रको प्रवद्र्धन र विकासको लागि उच्च प्राथमिकता दिदै आएको छ । यद्यपी विगत केहि बर्षदेखि बगैंचा ह्रासका कारण उत्पादन तथा गुणस्तरमा कमी देखिन थालेको छ । रोग र कीराको बढ्दो आक्रमण, खस्कदो माटोको उर्वराशक्ति र सिंचाइको अभाव, सीमित जातीय विविधता तथा स्वस्थ बिरुवाको अभाब जस्ता कारणले उत्पादन र उत्पादकत्वमा समस्या देखा परेको हो ।

यस परिप्रेक्ष्यमा राष्ट्रिय सुन्तला जात अनुसन्धान कार्यक्रमले राष्ट्रिय जिम्मेवारीको रुपमा यस क्षेत्रको प्रवद्र्धन गर्न उपयुक्त प्रविधि विकासको लागि अनुसन्धानका कार्यक्रमहरु सञ्चालन गर्दै आएको छ । यस कार्यक्रमले आ.व. २०८१/८२ मा जम्मा ७ वटा परियोजना अन्तर्गत ४२ ओटा अनुसन्धान क्रियाकलापहरु रहेकोमा जम्मा ४१ ओटा सम्पन्न गरेको थियो । यी कार्यक्रमहरु विशेष रुपमा जातीय अनुसन्धान, बगैचा ह्रास व्यवस्थापन र सुन्तलाजात फलफूलको रोग तथा कीरा व्यवस्थापनसँग सम्बन्धित थिए । फलफूल अनुसन्धान सम्पन्न गर्न लामो समय लाग्ने भएकोले धेरेजसो कार्यक्रमहरु नियमित संचालनमा छन् भने केहि सम्पन्न भई अपेक्षित उपलब्धिहरु हासिल भएका छन । यसरी आ.व. २०८१/८२ सम्म पुरा गरिएका क्रियाकलापहरुको उपलब्धिहरु संक्षिप्त रुपमा तल उल्लेख गरिएको छ ।

- ❖ जातीय संकलन र सम्बद्र्धन अन्तर्गत करीब १४० वटा स्थानीय र वाह्य श्रोतबाट सुन्तलाका विभिन्न जातहरु संकलन गरी कार्यक्रमको हाताभित्र फिल्ड जिन बैंकमा सम्बद्र्धन गरी राखिएको छ । यी संकलित जातहरु सुन्तला, जुनार, कागती, भोगटे, निबुवा, सुन्तलाका वर्णशंकर जातहरु तथा रुटस्टक वर्ग अन्तर्गत पर्दछन् । प्रारम्भिक अध्ययन अनुसार यी संकलित जातहरु फल लाग्ने समय, फलको गुण र बोटको बृद्धि विकास आदिको विशेषतामा निकै विविधता देखिएको छ । उपयुक्त जातको छनौट तथा विकासको लागि अझ केहि वर्ष अध्ययन गर्नुपर्ने देखिन्छ।

- सुन्तला, जुनार, कागती र टयांङगोर प्रचलनमा रहेका जातहरुको उत्पादन क्षमता कम रहेका छन । यस समस्यालाई हल गर्ने उदेश्यले विदेशबाट ल्याइएका र उपयुक्त स्थानिय जातहरुको खोजी गरी आ.व. २०६३/६४ देखि उत्पादन र उत्पादन समयको मुल्यांकन गर्दै आएको छ । प्रारम्भिक नतिजा अनुसार सुन्तलाका जातहरु जस्तैः ओकित्सुवासे, मियागावासे, नोभा, ओरोभल, मेरीसोल तथा स्थानीय जातमा खोकु स्थानीयले उत्पादनको लागि उत्साहजनक परिणाम दिएको पाइएको छ । आ.वा. २०८१/८२ मा सुन्तलाको एक जात “पारिपात्ले अगौटे सुन्तला-२” दर्ता गरियो ।
- वासिगंटन नेभल जातको जुनारले उत्पादनको लागि उत्साहजनक परिणाम दिएको छ । यो जात अन्य जातहरु भन्दा अगाडि उत्पादन गर्न सकिने देखिएको छ । यस जातलाई उन्मोचनका लागि आगामी दिनमा प्रस्ताव गर्ने क्रममा छ । अन्य जातहरुमा माल्टा ब्लड रेड, डेलिसस सिडलेस, सुकारी र धनकुटा स्थानीयको उत्पादन पनि उत्साहजनक देखिएको छ ।यसको साथै जुनारको पछौटे जातको रुपमा भ्यालेन्सिया लेटको पनि राम्रो माग भएको हुँदा छिट्टै सिफारिसको लागि अनुसन्धान कार्य अगाडी बढेको छ ।
- दस वटा कागतिका जातहरु संकलन गरी बिगत २०६३/६४ देखि पहाड तथा तराईमा परिक्षण गर्दै आएकोमा जातिय गुणको आधारमा आ.व. २०७५/७६ मा कागतीको जात तेह्रथुम स्थानीयको नामवाट पुर्वी पहाड क्षेत्रको लागि उसिफारिस गरीएको थियो भने आउने आ. व. मा औद्योगिक प्रयोजनको लागि पारिपात्ले सुनौलो निबुवालाई दर्ताको लागि प्रस्ताव तयारी गरी पेश गरिएको छ ।
- बिभिन्न उचाईमा सिट्रस सिल्लाको अनुगमन गर्दा करीब १,३०० मी भन्दा माथिको उचाईमा पनि यो कीरा देखिएको हुँदा आगामी दिनमा नर्सरी स्थापना गर्नको लागि खुल्ला क्षेत्र सुरक्षित नहुन सक्ने देखियो । त्यसकारण नर्सरी बिरुवा उत्पादन कार्य जालीधर भित्र गर्नुपर्ने देखिन्छ ।
- गत आ.व.२०८१/८२ मा करिव ९१२ जना कृषक र सरोकारवालाहरुलाई अनुसन्धान कार्यक्रमबारे जानकारी तथा प्रविधिबारे सल्लाह दिइयो ।
- कलमीको लागि सुन्तला र कागतीको माउ बोटबाट स्वस्थ सायन धनकुटा जिल्लाका नर्सरी व्यवसायीहरुलाई उपलव्ध गराइयो । त्यस्तै गरी विभिन्न जिल्लाका कृषकहरुलाई खोकु स्थानीय, बाँसखर्क स्थानीय, पारिपात्ले अगौटे सुन्तला-१ र

कागतीका बिभिन्न जातहरु जस्तै सुनकागती-१, सुनकागती-२ र तेह्रथुम स्थानीयका कलमी बिरुवाहरु वितरण गरियो ।

- गत आ.व. २०८१/८२ मा कृषकहरुलाई सुन्तला, कागती, जुनार तथा अन्य प्रजाति गरि जम्मा २१,४४९ कलमी विरुवा बिक्रि-वितरण गरिएको थियो ।
- यस कार्यक्रमको आ.व. २०८१/८२ को लागि विनियोजित वजेट रु ३,६१,३९,४०० थियो जस मध्ये चालु कार्यक्रमको लागि जम्मा रू २,७७,१७,५६७ विनियोजन गरिएको थियो । बार्षिक आम्दानी रु ४५,८६,७३८ थियो जुन खासगरी बिरुवा तथा ताजाफल बिक्रिवाट प्राप्त भएको थियो भने केही रकम प्रशासनिक बिधिबाट समेत प्राप्त भयो ।
- बिशेष परियोजना अन्तर्गत "पहाडी काष्ठफल तथा फलफूल विकास आयोजनामा" सुन्तलाजातका फलफूलमा विकास चरणको बिशेषता अध्ययन अन्तर्गत विभिन्न जातहरुमा जातीय दर्ताको लागि फूल फूलेदेखि फल टिप्दासम्मको अवस्थाको आकडा संकलन गरिएको थियो । यसको साथै सुन्तलाजात फलफूलका बेर्ना उत्पादन गर्ने कार्य समेत भएको थियो । यस आयोजना अन्तर्गत १० लाख, ३० हजार रुपैया विनियोजन गरिएको थियो ।

Executive Summary

Citrus production is an important agriculture sub-sector which helps raise economic standard of the Nepalese farmers in mid hills and terai plains. Citrus sector has been recognized as the high value commodity having high demand in domestic as well as international market. Thus, the government of Nepal has kept citrus sector under high priority for its growth and development in the country. However, lower productivity with low quality of production has been evident from past few years. This condition is attributed to increasing invasion of various insects, diseases, nutritional deficiency, moisture stress, limited choice of varieties and inadequate sources for quality planting materials. National Citrus Research Program (NCRP) with the national mandate of developing appropriate technologies has been conducting research programs for improving condition of the citrus enterprises in Nepal. During the fiscal year 2081/82, a total of 41 activities out of 42 activities under 7 research projects were accomplished by the program. Particularly, these research projects comprised of varietal research, citrus decline management, and management of diseases and insect pest of citrus. Most of the activities were continuation of those from last year, while some of them were concluded with worthwhile outputs that are summarized below.

- A field gene bank was maintained with a total of 140 different citrus germplasms which were collected from local and exotic sources in past periods. These conserved germplasm includes mandarin orange, sweet orange, acid lime, lemon, grapefruit, tangor, tangelo, and different rootstock species. A distinct variation with respect to flowering, fruiting behavior, fruit traits and morphological characteristics has been observed. Further selection is necessary to screen the promising varieties based on economic traits.
- As the existing cultivars of mandarin, sweet orange, acid lime, and tangor had low yield, the exotic cultivars inclusive of elite local cultivars have been introduced and evaluated since 2063/64. The preliminary performances of varietal evaluation of mandarin revealed some exotic genotypes such as 'Okitsuwase', 'Miyagawase', 'Oraval', 'Page', and 'Marisol' are promising with early maturity and high fruit yield. During the FY 2081/82, Satsuma mandarin genotype 'Paripatle Agaute Suntala-2' was registed and recommend for cultivation in mid-hill region of Nepal.
- 'Washington Navel', a variety of sweet orange had been performing more excellent in terms of higher fruit yield than those of other varieties. This genotype was noted to be suitable for early-season production. This genotype is in the process of being proposed for variety release. Similarly, other genotypes viz., 'Malta Blood Red', 'Delicious Seedless', 'Succari' and 'Dhankuta Local' had shown good fruit yield characteristics. 'Valencia Late' of sweet orange variety has been found as a popular

variety for late season production in mid-hill region of Nepal. Therefore, multilocation trial has been started for the purpose of registration.

- Ten elite acid lime genotypes collected locally have been evaluated since 2063/64 in Terai and mid-hills of Nepal. Three acid lime varieties: 'Sunkagati-1', 'Sunkagati-2', 'Tehrathum Local' were registered in the past seven years for upland condition of Terai, inner Terai, foothills and mid-hill areas. For the coming year, proposal of one variety of lemon 'Paripatle Golden Lemon' has been prepared and submitted for the registration.
- During monitoring of Asian citrus psylla at different altitudes, the pest was recorded at an elevation of 1,300 masl. Therefore, it is not safe to establish citrus nurseries in open conditions at this altitude. Nursery owners are advised to produce saplings under protected structures with insect nets.
- During the fiscal year 2081/82, technical counseling was given to 912 farmers and other stakeholders regarding the research programs and technologies developed in the citrus sector.
- The scion source from the mother plant of mandarin and acid lime varieties was provided to the nearby nursery entrepreneurs. Likewise, grafted saplings of 'Khoku Local' mandarin, 'Paripatle Agaute-1' and three varieties of acid lime viz. 'Sunkagati-1', 'Sunkagati-2' and 'Terhathum Local' were provided to the farmers in different districts.
- In the fiscal year 2081/82 a total of 21,449 grafted saplings of mandarin, sweet orange, and acid lime were sold to farmers.
- The total annual budget approved for the program was NPR 3,61,39,400, out of which operational budget consisted of NPR 2,77,17,567 to execute the research and production programs. The total revenue collected in the FY 2081/82 was NPR 45,86,738 which was primarily from selling of saplings and fresh fruits, however small amount was contributed by administrative method.
- To investigate the phenology of citrus crops with the objective of varietal registration, a special project 'NAFHA' was initiated at the National Citrus Research Program (NCRP), Paripatle, Dhankuta. The phenological study focused primarily on mandarin, sweet orange, and acid lime. In addition to phenological observations, sapling production was also undertaken for these citrus species. For the implementation of project activities, a budget of NPR NPR 10,30,000 was allocated to NCRP, Paripatle, Dhankuta, during the FY 2081/82.

1 WORKING CONTEXT

Citrus fruits hold a significant place in Nepal's agricultural sector, thanks to the country's favorable geography and climate. With the growing interest among the younger generation in commercial agricultural enterprises, citrus farming has the potential to become a profitable venture, contributing to the national economy.

Nepal is recognized for producing high-quality mandarins and sweet oranges. The mid-hill districts, located at altitudes between 800 and 1,400 masl, offer ideal sub-tropical climates for citrus cultivation, as do other regions across the country with favorable agro-climatic conditions. Citrus thrives in areas with deep sandy loam soil and a soil pH between 4.5 and 6.5. In recent years, citrus is being cultivated in 69 districts, however commercially, it is cultivated in 60 districts of Nepal.

Table 1. Area, production, and productivity of citrus fruits during the FY 2008/09 to 2023/24 in Nepal

Year	Total area (ha)	Productive area (ha)	Production (mt)	Productivity (mt ha^{-1})
2008/09	32,322	22,482	2,53,766	11.29
2009/10	33,898	22,903	2,59,191	11.30
2010/11	35,578	23,609	2,63,710	11.20
2011/12	37,565	24,089	2,40,793	10.00
2012/13	36,975	23,645	2,16,188	9.14
2013/14	38,988	25,497	2,24,357	8.80
2014/15	39,035	25,261	2,22,790	8.82
2015/16	40,554	24,854	2,18,447	8.82
2016/17	46,328	26,759	2,39,773	8.96
2017/18	44,424	25,946	2,45,176	9.44
2018/19	46,411	28,406	2,71,908	9.57
2019/20	46,715	27,339	2,74,140	10.03
2020/21	50,235	32,188	3,11,188	9.76
2021/22	49,306	32,417	3,06,149	9.47
2022/23	49,469	33,829	317,494	9.39
2023/24	48,329	34,271	318,939	9.31

Source: MoALD (2025)

The data presented in Table 1 reveal a dynamic trend in citrus cultivation in Nepal over the fiscal years 2008/09 to 2081/82, characterized by a steady expansion of cultivated area, moderate growth in production, and a fluctuating but overall declining trend in productivity.

The total citrus area exhibited a consistent increasing trend from 32,322 ha in 2008/09 to a peak of 50,235 ha in 2020/21. This represents a substantial expansion of nearly 55%, reflecting increased interest of farmers in citrus cultivation, likely driven by favorable market demand, government promotion programs, and suitability of mid-hill agro-ecologies for citrus production. However, after 2020/21, a slight contraction in total area was observed, declining to 48,329 ha by 2081/82, which may be associated with orchard senescence, land-use changes, or emerging production constraints such as pests, diseases, and climate variability.

Similarly, productive area increased from 22,482 ha in 2008/09 to 34,271 ha in 2081/82, indicating gradual maturation of orchards and expansion of bearing plants. Notably, the productive area growth was relatively slower than total area expansion during the early years, suggesting a lag phase between orchard establishment and fruit-bearing stage. In recent years, however, the gap between total and productive area has narrowed, implying improved orchard management and a higher proportion of bearing trees.

Citrus production showed an overall increasing trend despite periodic fluctuations. Production rose from 253,766 mt in 2008/09 to 318,939 mt in 2081/82, with notable dips during 2011/12 to 2015/16. The decline during this period (reaching as low as 216,188 mt in 2012/13) could be attributed to adverse climatic conditions, incidence of diseases such as citrus greening, and poor orchard management practices. Subsequently, production recovered steadily, surpassing 300,000 mt after 2020/21, which may reflect improved management practices, expansion of productive orchards, and possibly better input use.

In contrast to area and production, productivity (yield per hectare) exhibited a declining trend over the study period. Productivity was highest at 11.30 mt ha^{-1} in 2009/10 but declined sharply to 8.80 mt ha^{-1} in 2013/14. Although there was a partial recovery in subsequent years, productivity remained relatively low, stabilizing around 9.31 mt ha^{-1} in 2081/82. This decline in productivity despite increased area and production suggests that expansion has been largely area-driven rather than efficiency-driven. Factors such as aging orchards, poor-quality planting materials, inadequate nutrient and water management, pest and disease pressures, and limited adoption of improved technologies likely contributed to reduced yield performance.

The data presented in Table 2 provide a comprehensive overview of the distribution of area, production, and productivity among major citrus fruits in Nepal during the fiscal year 2081/82, highlighting significant variation across species in terms of their contribution and performance.

Mandarin orange emerged as the dominant citrus crop, occupying the largest share of both total area (28,790 ha) and productive area (20,215 ha), and contributing 194,565 mt to total production. This accounts for more than 60% of the total citrus area and production, underscoring its economic and cultural importance in Nepal's mid-hill regions. Despite its dominance, the productivity of mandarin (9.62 mt ha^{-1}) was only slightly above the national average (9.31 mt ha^{-1}), suggesting scope for improvement through better orchard management, rejuvenation of senile orchards, and disease control, particularly against citrus decline. Sweet orange ranked second in terms of production (45,641 mt) but demonstrated the highest productivity (10.70 mt ha^{-1}) among all citrus crops. This indicates relatively better yield efficiency and possibly improved management practices or favorable agro-climatic adaptation in areas where it is cultivated. The comparatively lower area (6,099 ha) suggests that sweet orange has strong potential for horizontal expansion as well as vertical productivity enhancement.

Acid lime occupied a substantial area (9,898 ha) and contributed 55,807 mt of production, making it the second-largest crop in terms of area after mandarin. However, its productivity (7.86 mt ha^{-1}) was considerably lower than the national average, indicating inefficiencies in production. Similar trends were observed for lemon, which recorded a productivity of 7.85 mt ha^{-1}. The lower yields in these acid citrus crops may be attributed to suboptimal management practices, inferior planting materials, or higher susceptibility to biotic and abiotic stresses.

The category of "other citrus crops" showed a relatively small area (1,437 ha) but a productive area (1,668 ha) slightly exceeding total area, which may indicate inconsistencies in data reporting or inclusion of orchards reaching bearing stage during the reporting period. Productivity in this group (9.42 mt ha^{-1}) was close to the national average, suggesting moderate performance.

The data presented in the table 2 provide a comprehensive overview of the area, production, and productivity of major citrus fruits, revealing clear differences among species in terms of their contribution to the overall citrus sector.

Mandarin orange occupies the largest share of citrus cultivation, with a total area of 28,790 ha and a productive area of 20,215 ha, contributing 194,565 mt to the total production. This dominance indicates its adaptability to diverse agro-ecological conditions and strong market preference. However, its productivity (9.62 mt ha^{-1}) is slightly above the national average (9.31 mt ha^{-1}) but lower than that of sweet orange. This suggests that despite its extensive cultivation, there is scope for improving yield through better orchard management practices, including nutrient management, pest control, and rejuvenation of old orchards.

Sweet orange, although cultivated on a much smaller area (6,099 ha), exhibits the highest productivity (10.70 mt ha^{-1}) among all citrus crops. With a production of 45,641 mt from 4,267 ha of productive area, it demonstrates superior yield efficiency. This higher productivity may be attributed to improved varieties, better orchard management, or favorable growing conditions in specific regions. The relatively high yield indicates that expanding sweet orange cultivation could be a viable strategy for increasing overall citrus production.

Acid lime and lemon together represent a moderate share of the citrus sector. Acid lime covers 9,898 ha with a productivity of 7.86 mt ha^{-1}, while lemon occupies 2,105 ha with a productivity of 7.85 mt ha^{-1}. Both crops show relatively lower productivity compared to mandarin and sweet orange, which may reflect limitations such as suboptimal management practices, pest and disease pressure, or less favorable growing environments. Despite this, acid lime contributes significantly to total production (55,807 mt), highlighting its importance in local markets and year-round demand.

The category of “other citrus crops” shows a smaller cultivation area (1,437 ha) but a relatively higher productivity (9.42 mt ha^{-1}), exceeding the national average. This suggests that certain minor or emerging citrus species may have high yield potential and could be promoted to diversify the citrus industry.

At the aggregate level, the total citrus area is 48,329 ha, with 34,271 ha under productive cultivation, producing 318,939 mt at an average productivity of 9.31 mt ha^{-1}. The gap between total area and productive area indicates the presence of immature orchards or unproductive plantations, which may temporarily reduce overall efficiency. Enhancing the proportion of productive orchards and improving management practices could significantly increase national citrus productivity.

Overall, the data suggest that while mandarin orange dominates in terms of area and production, sweet orange leads in productivity. The relatively lower yields of acid lime and lemon highlight the need for targeted interventions, including improved varieties, better agronomic practices, and integrated pest management. Increasing productivity across all citrus crops, along with strategic expansion of high-yielding species, could substantially enhance the citrus sector’s contribution to agricultural income and food security.

Table 2. Total area, productive area, production, and productivity of major citrus fruits during 2023/24 in Nepal

Major citrus fruits	Total area (ha)	Productive area (ha)	Total production (mt)	Productivity (mt ha^{-1})
Mandarin orange	28,790	20,215	194,565	9.62
Sweet orange	6,099	4,267	45,641	10.70
Acid lime	9,898	7,103	55,807	7.86
Lemon	2,105	1,519	11,929	7.85
Other citrus crop	1,437	1,668	10,996	9.42
Grand Total	**48,329**	**34,271**	**318,939**	**9.31**

Source: MoALD (2025)

Table 3 shows the provincial-level distribution of citrus crops in Nepal during 2081/82 reveals marked spatial variation in area, production, and productivity, reflecting differences in agro-climatic suitability, management practices, and crop specialization across provinces. For mandarin, which is the dominant citrus species, Gandaki Pradesh accounts for the largest cultivated area (8,114 ha) and production (54,412 mt), with a relatively high productivity of 10.60 mt ha^{-1}. Similarly, Lumbini Pradesh and Karnali Pradesh also exhibit high productivity levels (10.60 and 10.19 mt ha^{-1}, respectively), indicating favorable growing conditions and effective orchard management. Notably, Sudurpashchim Pradesh records the highest mandarin productivity (11.76 mt ha^{-1}) despite having a relatively smaller area, suggesting highly efficient production systems. In contrast, Koshi Pradesh shows comparatively lower productivity (7.52 mt ha^{-1}), which may be attributed to suboptimal management, older orchards, or environmental constraints. Madhesh Pradesh reports no mandarin cultivation, likely due to its unfavorable tropical lowland climate for this crop.

In the case of sweet orange, Bagmati Pradesh dominates both in area (3,439 ha) and production (26,854 mt), and also achieves the highest productivity (11.91 mt ha^{-1}). This highlights its comparative advantage in sweet orange cultivation, possibly due to suitable mid-hill climates and better orchard management practices. Sudurpashchim Pradesh also performs well, with a high yield of 11.05 mt ha^{-1}. Conversely, Koshi Pradesh records the lowest productivity (6.47 mt ha^{-1}), indicating potential yield gaps. As with mandarin, sweet orange is absent in Madhesh Pradesh, reinforcing the limited suitability of this region for certain citrus species.

Acid lime shows a wider distribution across provinces, including Madhesh Pradesh, reflecting its adaptability to warmer climates. Lumbini Pradesh stands out with the highest productivity (9.40 mt ha^{-1}) and substantial production (14,537 mt), indicating favorable agro-ecological conditions and management. Gandaki Pradesh and Sudurpashchim Pradesh also demonstrate relatively good productivity (8.55 and 8.60 mt ha^{-1}, respectively). In contrast, lower yields in Karnali Pradesh (6.70 mt ha^{-1}) and Koshi Pradesh (6.79 mt ha^{-1}) may be due to climatic limitations or less intensive management practices.

For lemon, Gandaki Pradesh records the highest productivity (9.34 mt ha^{-1}), followed by Sudurpashchim Pradesh (8.17 mt ha^{-1}) and Bagmati Pradesh (8.07 mt ha^{-1}). These provinces appear to provide optimal conditions for lemon cultivation. On the other hand, Karnali Pradesh shows the lowest productivity (4.75 mt ha^{-1}), suggesting significant constraints such as harsh climatic conditions or poor orchard management. Lemon cultivation is also absent in Madhesh Pradesh. The “other citrus” category, although limited in area, shows relatively high productivity in Gandaki Pradesh (10.38 mt ha^{-1}) and Bagmati Pradesh (10.10 mt ha^{-1}), indicating the potential of minor citrus species in these regions. However, lower productivity in Sudurpashchim Pradesh and Lumbini Pradesh suggests variability in performance depending on species and management.

Overall, the data clearly indicate that mid-hill provinces such as Gandaki Pradesh and Bagmati Pradesh consistently achieve higher productivity across multiple citrus species, highlighting their comparative advantage for citrus cultivation. In contrast, lower productivity in provinces like Koshi Pradesh and Karnali Pradesh points to the need for improved orchard management, rejuvenation of senile orchards, and adoption of improved varieties. The absence of several citrus crops in Madhesh Pradesh underscores the importance of agro-climatic suitability in determining crop distribution.

Table 3. Total area, total productive area, total production, and productivity of different citrus species in the different provinces of Nepal during 2023/24

Province	Crop	Area (ha)	Productive Area (ha)	Production (mt)	Yield (mt ha^{-1})
Koshi Pradesh	Mandarin	6,765	5,043	37,936	7.52
Madhesh Pradesh		-	-	-	-
Bagmati Pradesh		4,358	3,162	28,773	9.10
Gandaki Pradesh		8,114	5,131	54,412	10.60
Lumbini Pradesh		3,979	3,361	35,618	10.60
Karnali Pradesh		3,859	2,254	22,959	10.19
Sudurpashchim Pradesh		1,715	1,264	14,868	11.76
Total	**Mandarin**	**28790**	**20,215**	**194,565**	**9.62**
Koshi Pradesh	Sweet orange	644	547	3538	6.47
Madhesh Pradesh		-	-	-	-
Bagmati Pradesh		3,439	2,255	26,854	11.91
Gandaki Pradesh		128	82	706	8.66
Lumbini Pradesh		587	394	3,842	9.75
Karnali Pradesh		189	117	1,065	9.10
Sudurpashchim Pradesh		1,112	872	9,637	11.05
Total	**Sweet orange**	**6,099**	**4,267**	**45,641**	**10.70**
Koshi Pradesh	Acid Lime	3,106	2,608	17,721	6.79
Madhesh Pradesh		98	75	504	6.72
Bagmati Pradesh		1,793	1439	11,300	7.85
Gandaki Pradesh		1415	674	5,762	8.55
Lumbini Pradesh		2,203	1,546	14,537	9.40
Karnali Pradesh		607	295	1,978	6.70
Sudurpashchim Pradesh		676	466	4,007	8.60
Total	**Acid Lime**	**9,898**	**7,103**	**55,807**	**7.86**
Koshi Pradesh	Lemon	138	107	718	6.71
Madhesh Pradesh		-	-	-	-
Bagmati Pradesh		612	435	3511	8.07
Gandaki Pradesh		442	322	3006	9.34
Lumbini Pradesh		213	166	1066	6.42
Karnali Pradesh		191	107	508	4.75
Sudurpashchim Pradesh		509	382	3120	8.17
Total	**Lemon**	**2,105**	**1,519**	**11,929**	**7.85**
Koshi Pradesh	Others	281	229	1,824	7.97
Madhesh Pradesh		-	-	-	-
Bagmati Pradesh		531	430	4,343	10.10

Province	Crop	Area (ha)	Productive Area (ha)	Production (mt)	Yield (mt ha^{-1})
Gandaki Pradesh		394	355	3,680	10.38
Lumbini Pradesh		93	64	496	7.75
Karnali Pradesh		16	7	55	7.90
Sudurpashchim Pradesh		122	83	597	7.20
Total	**Others**	**1,437**	**1,168**	**10,996**	**9.42**

Source: MoALD (2025)

Domestic citrus production in Nepal satisfies only a small proportion of the national demand, even during the peak harvesting season. As a result, fresh and processed citrus fruits worth hundreds of millions of rupees are imported annually. This highlights the significant potential for expanding and commercializing the citrus sector in Nepal, particularly for import substitution and export promotion.

Most citrus growers in the country are smallholder farmers with limited landholdings, low investment capacity, and minimal ability to bear risks. These constraints often lead to inadequate crop management practices, especially since citrus cultivation requires relatively high external inputs, technical skills, and proper orchard management. Consequently, essential cultural practices such as manuring, training and pruning, and effective pest and disease management are often neglected. This has resulted in the gradual decline of many citrus orchards across the country.

In addition, farmers generally lack access to certified, disease-free planting materials. This has contributed to the widespread incidence of major diseases such as *Phytophthora* root rot, Citrus greening, Citrus canker, and *Citrus tristeza virus*, which severely affect orchard health and productivity. Furthermore, the lack of varietal diversity limits the harvesting period, concentrating production within a short seasonal window.

Due to these challenges, Nepal continues to rely heavily on imports of citrus fruits such as mandarin, sweet orange, acid lime, and other with annual imports equals to 1.62 billion Rupees (MoALD, 2025). Poor fruit quality—caused by pest and disease damage, inadequate orchard management, and physical injuries during harvesting and transportation—further constrains the country's potential for export. Addressing these issues through improved management practices, access to quality planting materials, and diversification of varieties will be essential for strengthening Nepal's citrus industry.

These contexts bring about too many areas of research and development to be carried out, ranging from variety improvement, tree health management, integrated soil management, plant protection, postharvest handling, processing, and marketing. Eventually the sector could be transformed into commercial and export industry producing quality fruits in sizeable volume.

2 INTRODUCTION

2.1 Background

Citrus plays a crucial role in Nepal's horticultural sector and is an important source of income for rural households. The country's diverse geography and suitable climate allow citrus cultivation to thrive, particularly in the mid-hill regions between 800 and 1,400 meters above sea level, stretching from eastern to western Nepal. Recognizing its economic value, the Government of Nepal has identified citrus as a priority crop with strong potential for income generation, employment creation, import substitution, and export promotion.

In acknowledgment of this importance, the Government of Nepal established the Citrus Research Station in 1961 (2018 B.S.). Later, in 2000 (2057 B.S.), it was upgraded to the National Citrus Research Program under the Nepal Agricultural Research Council. The program is mandated to conduct research on citrus crops, generate technologies, and produce and distribute quality planting materials. The research station is located at Paripatle, Dhankuta-10, in Dhankuta District, at an elevation ranging from 900 to 1,390 meters above mean sea level, covering about 20 hectares of southeast-facing land. It is situated approximately 8 km northwest of the district headquarters.

The research farm consists of terraced land primarily used for production orchards of major citrus species such as mandarin, sweet orange, and acid lime. It also houses a field gene bank that conserves both local and exotic citrus germplasm, along with dedicated plots for varietal evaluation. The Program maintains seven screen houses to preserve mother plants of promising varieties, including mandarin, sweet orange, Kinnow, and acid lime. Additionally, a separate 3-hectare nursery block is used for plant propagation and related research. Supporting infrastructure includes a tissue culture laboratory, agronomy lab, cellar storage facilities, irrigation canals, and ponds. Despite resource limitations, the Program actively focuses on varietal improvement, crop and nursery management, citrus decline mitigation, pest control, tissue culture-based propagation, high-density planting systems, and post-harvest management studies.

2.2 Goal

- ❖ Contribute to increasing the productivity and quality of citrus fruit through the use of modern technologies.

2.3 Purpose

- Increase economy and living standard of farmers through commercialization of citrus sector through technology advancement

2.4 Objectives

- To conduct research on variety, husbandry management, postharvest, disease/pest control, nursery, tissue culture and genetic resource conservation and utilization
- To coordinate with various research and development line agencies for collaborative citrus research and development programs
- To establish linkage with national and international citrus research organizations
- To prioritize research areas in the country
- To document and maintain information on citrus research and development
- To provide technical supports and services to citrus stakeholders

2.5 Strategies

- Conduct participatory, holistic and systematic research and studies on citrus fruit crops
- Prioritize research areas and policy formulation based on problems and demands in citrus sector
- Variety improvement and selection for extended harvesting season
- Enhancing production and productivity by generating technologies
- In-vitro technology for healthy propagation
- Conservation and improvement of citrus genetic resources
- Technologies advancement on citrus-based farming system
- Marketing and export promotion of citrus industry
- Ensuring effective dissemination and adoption of developed technologies
- Coordination and collaboration with line agencies including farmers' communities

2.6 Responsibilities

- Identify problems and needs of citrus sector for setting up the research areas
- Develop appropriate technologies on different aspects of citrus fruit crops
- Genetic resources conservation and utilization
- Mother plant maintenance and nursery plant production

- Out-scaling of technologies for wider impact
- Coordinate with other national and international organizations for collaborative research and studies
- Publications and documentation
- Provide technical and consultancy services to the clients

2.7 Prioritized research for forthcoming years

- Integrated approach to combat citrus decline
- Integrated nutrient management in citrus
- Breeding new varieties for early and late maturity period
- Breeding for addressing the problem of HLB, CTV, and root rot
- Biological pest and disease control
- Cost effective and eco-friendly production technologies
- Postharvest processing and value addition
- *In-vitro* technology for healthy propagation
- Citrus based farming system
- Marketing and export business
- Socio-economic studies

2.8 Infrastructure and resources

The National Citrus Research Program (NCRP), initially established in 1961 (2018 B.S.) as the Citrus Research Station, was brought under the Nepal Agricultural Research Council in 2000 (2057 B.S.). It is mandated to develop and disseminate technologies for citrus crops at the national level. The Program occupies about 20 hectares of land, including forested and marginal areas.

A large portion of the farm's production area is devoted to mandarin cv. 'Khoku Local' and sweet orange cv. 'Dhankuta Local', which are widely cultivated and locally important varieties. In addition, five distinct research blocks have been established to study different citrus groups, including mandarin, sweet orange, acid lime, rootstocks, and hybrid mandarins. The Program also maintains a field gene bank for in-situ conservation of diverse citrus germplasm. Furthermore, a separate block is dedicated to the demonstration of released acid lime varieties and other promising selections. The farm includes a specialized nursery area of approximately two hectares, which supports both propagation and research activities. This facility comprises seven screen houses, a hi-tech nursery unit, and more than 40 nursery beds containing mother plants of various citrus species. Research activities are further supported by a well-equipped tissue culture laboratory, a general laboratory building, and two glasshouses. To ensure reliable irrigation, several ponds are distributed across the farm, along with a 700-meter pipeline-based canal system that facilitates efficient water supply.

2.9 Organization structure and human resources

A total of 37 positions have been approved for the operation of the National Citrus Research Program at Paripatle, Dhankuta. However, only 7 of these positions are currently filled, indicating a substantial gap in human resources. As a result, the Program is functioning under severe staff shortages, which may significantly constrain its research, development, and extension activities (Figure 1).

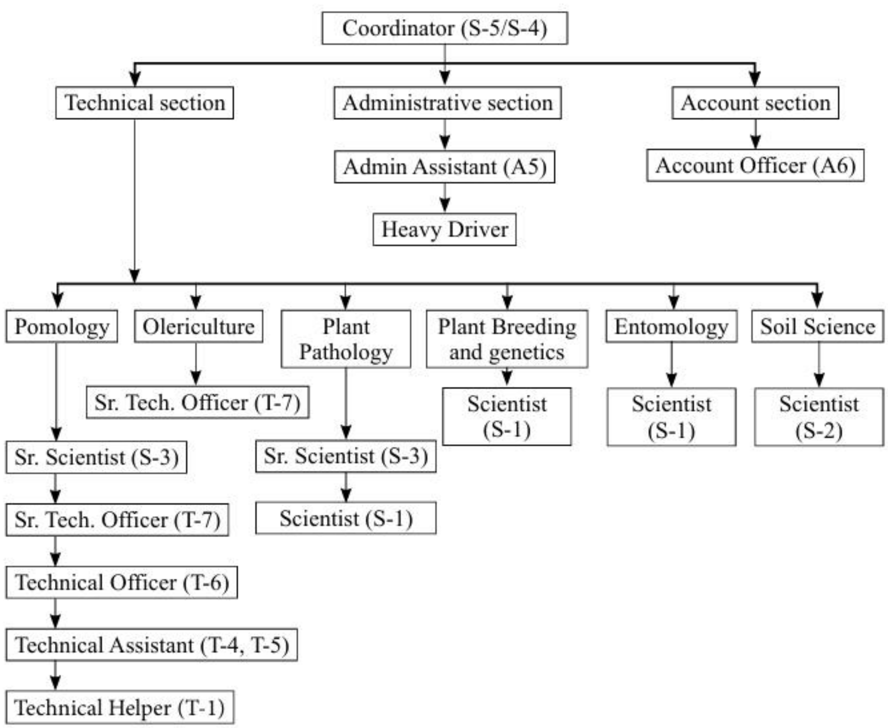

Figure 1. Organogram of the National Citrus Research Program, Paripatle, Dhankuta, Nepal

3 RESEARCH HIGHLIGHTS

3.1 Varietal evaluation

Citrus varieties currently grown in Nepal are generally characterized by low yield potential and a relatively short harvesting window. Despite the country's rich genetic diversity in citrus species, most commonly cultivated varieties of mandarin, sweet orange, and acid lime mature within a narrow period, typically from October to January. This concentration of production creates seasonal gluts and highlights the need for alternative varieties that can extend the harvesting period. To address this limitation, the National Citrus Research Program (NCRP), Paripatle, Dhankuta has introduced a range of exotic citrus varieties alongside selected elite local cultivars over the years. These genotypes have been systematically evaluated in recent years to assess their adaptability, yield potential, and fruit quality, with the aim of identifying suitable varieties for different agro-climatic regions of Nepal.

3.1.1 Mandarin

Mandarin (*Citrus reticulata* Blanco) is a high potential fruit crop in Nepal. It is widely grown throughout the mid hills across the country. In Nepal, almost all mandarin varieties are of local origin that are specific to the location and vary each other. These varieties are characterized as declining yield potential and short production period within same season. Therefore, mandarin production is confined to three to four months leading to shortage for the rest of the year. A huge amount is being imported to make the national demand during other periods of the year.

Thus, NCRP has continued the study on variety introduction and selection to determine appropriate varieties instead of local varieties to expand the production period. In this line, variety selection and evaluation has been continued and 22 varieties introduced from abroad and local sources have been evaluated since 2063/64.

Fruit physical parameters and yield attributing characteristics of mandarin orange

The present study revealed significant variation among mandarin genotypes for fruit physical characteristics and yield parameters, as indicated by highly significant F-test values ($P<0.001$) for all traits (Table 4). This highlights the strong genetic influence on fruit morphology, seed content, and productivity, suggesting ample scope for selection and varietal improvement under Nepalese conditions.

Fruit weight and size attributes

Fruit weight varied significantly among genotypes, ranging from 72.70 g (‘Nules’) to 124.00 g (‘Khoku Local’), with a grand mean of 98.29 g. Larger fruits were observed in ‘Khoku Local’, ‘Pongan’ (123.00 g), and ‘Fortune’ (118.00 g), indicating their superiority in terms of individual fruit size. Similarly, fruit diameter followed a comparable trend, with ‘Khoku Local’ (65.80 mm) and ‘Satsuma Mino’ (67.80 mm) producing larger fruits than the overall mean (59.49 mm). The positive association between fruit weight and diameter suggests that genotypes with larger fruit size contribute to enhanced market preference due to better visual appeal and consumer acceptance.

However, higher fruit size did not necessarily translate into higher yield. For instance, ‘Fortune’ and ‘Pongan’, despite producing heavier fruits, recorded relatively low yields (19.10 and 13.60 mt ha^{-1}, respectively), indicating that yield is more dependent on fruit number rather than individual fruit weight.

Peel thickness

Peel thickness ranged from 1.57 mm (‘Fortune’) to 2.50 mm (‘Satsumawase’), with a mean of 1.95 mm. Genotypes such as ‘Satsumawase’, ‘Sikkime Suntala’ (2.38 mm), and ‘Kara’ (2.24 mm) exhibited thicker peels, which may confer better resistance to mechanical damage and longer shelf life. In contrast, thinner peel observed in Fortune may enhance consumer preference due to ease of peeling, though it may reduce postharvest durability. The relatively low coefficient of variation (7.55%) suggests moderate environmental influence on this trait.

Number of segments per fruit

The number of segments per fruit showed limited variation (9.14 to 11.60), with a mean of 10.39. ‘Satsuma Okitsu’ recorded the highest number of segments (11.60), followed by ‘Avana’ and ‘Kara’ (11.20 each). Since segment number is a genetically stable trait with low variability (CV=4.42%), it may serve as a reliable descriptor for genotype identification rather than a major yield determinant.

Seed content

A wide variation in seed number was observed, ranging from near seedless types such as ‘Paripatle Agaute-2’ (0.16), ‘Satsuma Okitsu’ (0.28), and ‘Satsuma Mino’ (0.36), to highly seeded genotypes like ‘Kara’ (13.80) and ‘Khoku Local’ (13.60). The relatively high coefficient of variation (16.39%) indicates considerable diversity for this trait.

Seedlessness is a highly desirable trait for fresh consumption. In this regard, ‘Paripatle Agaute-2’ and ‘Satsuma’ group genotypes demonstrated clear superiority. However, many of these low-seeded genotypes exhibited moderate to low yields, suggesting a potential trade-off between seedlessness and productivity.

Number of fruits per tree and yield

The number of fruits per tree varied widely, from 102 (‘Nova’) to 964 (‘Sikkime Suntala’), with a high coefficient of variation (49.62%), indicating strong environmental and management influence. ‘Sikkime Suntala’ produced an exceptionally high number of fruits per tree (964), which directly translated into the highest yield (103.00 mt ha^{-1}), far exceeding the grand mean (30.54 mt ha^{-1}).

Similarly, ‘Commune’ (616 fruits/tree) and ‘Avana’ (555 fruits/tree) also recorded high yields (49.90 and 42.10 mt ha^{-1}, respectively), reinforcing the strong positive relationship between fruit number and overall yield. In contrast, genotypes such as ‘Marisol’, ‘Page’, and ‘Nova’ produced fewer fruits per tree and consequently recorded lower yields (11.50, 11.10, and 12.00 mt ha^{-1}, respectively).

Interestingly, genotypes with moderate fruit size but higher fruit numbers (e.g., ‘Commune’ and ‘Avana’) outperformed those with larger fruits but fewer numbers (e.g., ‘Fortune’ and ‘Pongan’). This indicates that yield in mandarin is predominantly governed by fruit load rather than individual fruit size.

Overall performance and implications

Among the evaluated genotypes, ‘Sikkime Suntala’ emerged as the most promising genotype due to its exceptionally high fruit number and yield. ‘Commune’ and ‘Avana’ also demonstrated superior performance with balanced fruit size and higher productivity. Conversely, genotypes such as ‘Marisol’, ‘Page’, and ‘Nova’ were inferior in terms of yield despite acceptable fruit quality traits.

Seedless and low-seeded genotypes like Paripatle ‘Agaute-2’ and ‘Satsuma’ types showed potential for niche markets, although their relatively lower yields may limit their commercial adoption unless compensated by premium pricing.

The high coefficients of variation observed for yield and number of fruits per tree suggest that these traits are highly influenced by environmental conditions and management practices. Therefore, further multi-location trials are necessary to validate the stability and adaptability of these genotypes.

Table 4. Fruit physical parameters and yield attributing characteristics of mandarin genotypes at NCRP, Paripatle, Dhankuta during 2081/82

Genotype	Fruit weight (g)	Fruit diameter (mm)	Peel thickness (mm)	Nos. of Segments fruit^{1}	Nos. of seeds fruit^{-1}	Number of fruits tree^{-1}	Yield (mt ha^{-1})
Avana	73.90	53.50	1.68	11.20	8.46	555.00	42.10
Banskharka Local	96.60	58.20	1.90	9.28	12.00	311.00	33.40
Commune	75.90	52.40	1.89	10.20	5.28	616.00	49.90
Dancy	98.20	58.80	1.69	9.88	11.80	229.00	24.90
Fortune	118.00	61.70	1.57	10.60	9.24	163.00	19.10
Kara	116.00	63.40	2.24	11.20	13.80	287.00	37.70
Khoku Local	124.00	65.80	2.05	10.50	13.60	302.00	38.90
Marisol	89.70	56.80	1.90	9.34	2.24	124.00	11.50
Paripatle Agaute-2	98.70	60.40	1.82	11.00	0.16	200.00	20.00
Nova	110.00	60.40	1.72	10.60	10.40	102.00	12.00
Nules	72.70	53.50	1.70	9.14	10.10	401.00	34.30
Paripatle Agaute-1	90.50	57.80	2.14	11.10	0.64	194.00	18.20
Oroval	93.00	56.50	1.88	10.10	3.20	296.00	28.70
Page	88.30	55.00	1.70	10.30	11.60	125.00	11.10
Pongan	123.00	64.50	2.00	10.50	12.40	103.00	13.60
Satsuma Mino	98.70	67.80	2.03	11.10	0.36	193.00	21.10
Satsuma Okitsu	102.00	61.70	1.86	11.60	0.28	267.00	27.60
Satsuma URSS	93.80	60.30	2.40	10.50	2.84	241.00	23.30
Satsumawase	103.00	61.60	2.50	10.30	1.20	350.00	40.30
Sikkime Suntala	99.10	59.70	2.38	9.28	10.40	964.00	103.00
Grand mean	**98.29**	**59.49**	**1.95**	**10.39**	**6.99**	**301.13**	**30.54**
LSD (P<0.05)	12.23	3.74	1.86	0.58	1.44	188.22	18.86
F-test	***	***	***	***	***	***	***
CV (%)	9.88	4.99	7.55	4.42	16.39	49.62	49.01

Juice content (%)

Juice content varied significantly from 38.00% (‘Khoku Local’) to 60.50% (‘Paripatle Agaute-1’), with a grand mean of 49.78%. Genotypes such as ‘Paripatle Agaute-1’ (60.50%), ‘Paripatle Agaute-2’ (58.60%), and ‘Satsumawase’ (57.70%) exhibited superior juice recovery, making them highly suitable for both fresh consumption and processing purposes. High Juice content is a desirable trait, particularly for commercial juice extraction industries.

Conversely, genotypes like ‘Khoku Local’ (38.00%), ‘Banskharka Local’ (38.30%), and ‘Sikkime Suntala’ (38.40%) recorded lower juice percentages, which may limit their suitability for processing despite their potential advantages in other traits such as yield. The relatively low coefficient of variation (6.72%) suggests that Juice content is a relatively stable trait with limited environmental influence.

Total soluble solids (TSS)

TSS, an indicator of sweetness, ranged from 7.44% (‘Satsumawase’) to 12.20% (‘Kara’), with a mean of 10.07%. High TSS values were recorded in ‘Kara’ (12.20%), ‘Banskharka Local’ (12.00%), and ‘Sikkime Suntala’ (12.00%), indicating superior sweetness and better flavor quality.

In contrast, lower TSS values observed in ‘Satsumawase’ (7.44%), ‘Satsuma URSS’ (7.68%), and ‘Paripatle Agaute’ genotypes (8.06%) suggest comparatively less sweet, which may affect consumer acceptance in fresh markets. However, these genotypes may still be suitable for processing or for consumers preferring mild sweetness. The low CV (3.52%) indicates high reliability and genetic control over this trait.

Titratable acidity (TA)

Titratable acidity ranged from 0.69% (‘Pongan’) to 1.60% (‘Kara’), with a mean of 1.05%. Higher acidity levels were observed in ‘Kara’ (1.60%), ‘Fortune’ (1.36%), ‘Avana’ (1.34%), and ‘Sikkime Suntala’ (1.31%), contributing to a stronger sour taste. In contrast, genotypes like ‘Pongan’ (0.69%), ‘Nules’ (0.79%), and ‘Commune’ (0.80%) exhibited lower acidity, resulting in a sweeter taste perception when combined with moderate TSS.

The balance between TSS and TA is crucial in determining fruit flavor quality. Genotypes such as ‘Commune’ (TSS: 10.20%, TA: 0.80%) and ‘Dancy’ (TSS: 9.92%, TA: 0.80%) likely offer a favorable sugar-acid balance, enhancing palatability. The moderate CV (13.67%) indicates some environmental influence on acidity.

Difference in absorbance (DA)

The DA value, an indicator of chlorophyll degradation and fruit maturity, showed considerable variation (0.02 to 1.29), with a mean of 0.37. Higher DA values were observed in 'Paripatle Agaute-1' (1.29), 'Paripatle Agaute-2' (1.11), and 'Satsuma Okitsu' (1.03), indicating advanced maturity and faster degreening.

In contrast, 'Khoku Local' (0.02), 'Sikkime Suntala' (0.04), and 'Fortune' (0.05) exhibited very low DA values, suggesting delayed ripening or retention of green coloration. The high CV (33.64%) indicates that DA value is strongly influenced by environmental conditions and may vary across locations and seasons.

Chlorophyll content index (CCI)

CCI values ranged widely from -0.94 ('Satsuma Okitsu') to 16.30 ('Oroval'), with a mean of 8.75. Higher CCI values indicate better peel coloration (deep orange), which is a critical market quality attribute. Genotypes such as 'Oroval' (16.30), 'Commune' (15.20), and 'Nova' (13.20) exhibited superior peel coloration, making them more attractive for fresh market sales.

Negative or low CCI values, as observed in 'Satsuma Okitsu' (-0.94) and 'Paripatle Agaute-1' (0.10), indicate poor coloration or greenish peel, which may reduce market appeal despite acceptable internal quality. The moderate CV (10.58%) suggests a balance between genetic and environmental influence.

Overall quality assessment

The results indicate that no single genotype excelled in all quality parameters, highlighting the need for balanced selection based on end-use. 'Paripatle Agaute-1' and 'Paripatle Agaute-2' were superior in Juice content and maturity indices but had lower TSS, indicating moderate sweetness. 'Kara' stood out for high TSS and acidity, suggesting a strong flavor profile but potentially excessive sourness.

'Commune' emerged as a well-balanced genotype, combining high Juice content (48.20%), moderate TSS (10.20%), low acidity (0.80%), and excellent peel coloration (CCI: 15.20), making it suitable for both fresh consumption and market appeal.

Similarly, 'Dancy' and 'Oroval' also demonstrated desirable combinations of internal quality and external appearance.

In contrast, 'Sikkime Suntala', despite being the highest yielder (as observed in the previous table), exhibited moderate Juice content, high acidity, and only moderate coloration, indicating a trade-off between yield and fruit quality.

Table 5. Physicochemical properties of mandarin orange genotypes at NCRP, Paripatle, Dhankuta during 2081/82

Genotype	Juice (%)	TSS (%)	TA (%)	DA value	CCI value
Avana	45.90	11.30	1.34	0.22	8.14
Banskharka Local	38.30	12.00	1.21	0.09	10.50
Commune	48.20	10.20	0.80	0.27	15.20
Dancy	53.10	9.92	0.80	0.18	12.10
Fortune	55.80	10.10	1.36	0.05	9.86
Kara	54.60	12.20	1.60	0.48	10.50
Khoku Local	38.00	11.30	1.06	0.02	10.50
Marisol	52.80	10.00	0.81	0.11	12.70
Paripatle Agaute -2	58.60	8.06	1.16	1.11	1.78
Nova	45.20	10.70	0.80	0.09	13.20
Nules	45.50	11.60	0.79	0.17	9.68
Paripatle Agaute-1	60.50	8.06	0.90	1.29	0.10
Oroval	50.40	10.20	0.89	0.29	16.30
Page	50.10	11.20	1.22	0.05	12.40
Pongan	39.50	10.70	0.69	0.27	7.13
Satsuma Mino	53.70	8.16	1.03	0.56	2.89
Satsuma Okitsu	53.50	8.47	0.91	1.03	-0.94
Satsuma URSS	55.80	7.68	1.15	0.53	5.67
Satsumawase	57.70	7.44	1.20	0.55	6.19
Sikkime Suntala	38.40	12.00	1.31	0.04	11.20
Grand mean	**49.78**	**10.07**	**1.05**	**0.37**	**8.75**
LSD (P<0.05)	4.21	0.45	0.18	0.16	1.17
F-test	***	***	***	***	***
CV (%)	6.72	3.52	13.67	33.64	10.58

3.1.2 Sweet orange

Sweet orange (*Citrus sinensis* Osbeck) ranks as the second most important citrus fruit in Nepal, following mandarin in both production and economic significance. It is cultivated primarily in several mid-hill districts across the country, with major production areas including Dhankuta, Khotang, Sindhuli, Parbat, Palpa, and Dadeldhura. These regions provide suitable agro-climatic conditions that support the successful cultivation and commercial viability of sweet orange.

The harvesting time of present local varieties remains only two months during December-January and beyond this period, Nepal imports fresh sweet orange fruit as well as processed fruit juice throughout the year. Thus, NCRP has focused on variety selection of this species, so that there will be varietal diversity for expanding the fruit harvesting period beyond normal season, especially for early and late harvesting seasons. With this objective varietal evaluation of sweet orange including 17 exotic and local varieties has been continued since 2064/65. The performance of the sweet orange genotypes being evaluated in NCRP, Paripatle are described as follows.

Fruit characteristics and yield of different genotypes of sweet oranges

Fruit characteristics and yield attributes like individual fruit weight, individual fruit diameter, fruit rind thickness, fruit rind weight, number of seed per fruit, number of fruits per tree and fruit yield per hectare were statistically different due to the effects of different genotypes of sweet oranges (Table 6)

The evaluation of sweet orange genotypes revealed highly significant differences ($P < 0.001$) for all studied traits, including fruit physical characteristics, seed content, and yield. This indicates substantial genetic variability among genotypes, offering considerable potential for selection and improvement under Nepalese agro-climatic conditions.

Fruit weight and size parameters

Fruit weight exhibited wide variation, ranging from 121.00 g (‘Valencia Late’) to 227.00 g (‘Washington Navel’), with a grand mean of 161.64 g. Genotypes such as ‘Washington Navel’ (227.00 g), ‘Lane Late’ (204.00 g), and ‘Salustiana’ (195.00 g) produced significantly larger fruits, indicating their superiority in fruit size attributes. This was further supported by higher fruit diameter and height values, where ‘Washington Navel’ (74.00 mm diameter; 75.70 mm height) and ‘Lane Late’ (73.80 mm diameter; 71.80 mm height) recorded the largest fruits.

Conversely, smaller fruits were observed in ‘Valencia Late’ (121.00 g) and ‘Pineapple’ (123.00 g), although these genotypes compensated with higher fruit numbers per tree. The relatively low coefficients of variation for fruit diameter (4.84%) and height (5.79%) suggest that fruit size is predominantly under genetic control with minimal environmental influence.

Peel thickness

Peel thickness ranged from 2.66 mm (‘Vanelle’) to 3.99 mm (‘Lane Late’), with an overall mean of 3.50 mm. Thicker peels were recorded in ‘Lane Late’ (3.99 mm), ‘LueGim Gong’ (3.93 mm), and ‘Succari’ (3.83 mm), which may contribute to improved shelf life and resistance to mechanical damage during handling and transport. In contrast, thinner peel in ‘Vanelle’ (2.66 mm) and ‘Valencia Late’ (2.95 mm) may enhance consumer acceptability due to ease of peeling but could reduce storability. The moderate CV (6.81%) indicates limited environmental influence on peel thickness, suggesting its reliability as a varietal trait.

Seed content

A highly significant variation in seed number per fruit was observed, ranging from near seedless types such as ‘Cara Cara Navel’ (0.36), ‘Salustiana’ (0.36), and ‘Washington Navel’ (0.48), to highly seeded genotypes like ‘Succari’ (16.60), ‘Malta Blood Red’ (13.80), and ‘LueGim Gong’ (9.84). The high coefficient of variation (32.45%) indicates considerable diversity and environmental influence on this trait.

Seedlessness is a desirable attribute for fresh consumption. In this regard, navel types (‘Cara Cara Navel’ and ‘Washington Navel’) and ‘Salustiana’ are particularly promising. However, these genotypes did not always correspond with the highest yields, indicating a possible trade-off between seedlessness and productivity.

Number of fruits per tree and yield

The number of fruits per tree showed extreme variability, ranging from 65.80 (‘Succari’) to 635.00 (‘Tamango’), with a very high CV (65.43%), reflecting strong environmental and management influences.

'Tamango' recorded an exceptionally high number of fruits per tree (635.00), which translated into the highest yield (84.40 mt ha^{-1}), far exceeding the grand mean (30.70 mt ha^{-1}). Similarly, 'Salustiana' (258.00 fruits tree^{-1}) and 'Valencia Late' (296.00 fruits tree^{-1}) produced high yields of 53.40 mt ha^{-1} and 38.50 mt ha^{-1}, respectively.

In contrast, genotypes such as 'Cara Cara Navel' (81.80 fruits/tree) and 'LueGim Gong' (83.20 fruits/tree) produced lower yields (15.70 and 12.50 mt ha^{-1}, respectively), despite having relatively larger fruit size. This clearly indicates that yield is more strongly influenced by fruit number per tree than by individual fruit weight.

Relationship between fruit size and yield

An inverse relationship between fruit size and fruit number was evident. Genotypes producing larger fruits, such as 'Washington Navel' and 'Lane Late', tended to have fewer fruits per tree, resulting in moderate yields. Conversely, genotypes with smaller fruits, such as 'Tamango' and 'Valencia Late', produced higher fruit numbers and consequently higher yields.

This trade-off suggests that assimilate partitioning plays a crucial role in determining fruit size and number, where increased fruit load may limit individual fruit growth due to competition for photosynthates.

Overall performance and implications

Among the evaluated genotypes, 'Tamango' emerged as the most promising due to its exceptionally high fruit number and yield. 'Salustiana' also demonstrated superior performance by combining relatively large fruit size, low seed content, and high yield, making it an excellent candidate for both fresh consumption and commercial cultivation.

'Washington Navel' and 'Cara Cara Navel', despite producing large and seedless fruits, exhibited moderate to low yields, indicating their suitability for premium markets rather than bulk production. Conversely, 'Succari' and 'LueGim Gong' performed poorly in terms of yield and are less suitable for commercial cultivation under the tested conditions.

The high coefficients of variation for fruit number and yield suggest that these traits are strongly influenced by environmental factors and orchard management practices, necessitating further multi-location and multi-season evaluation for stability assessment.

Table 6. Fruit characteristics of different sweet orange genotypes at NCRP, Paripatle, Dhankuta during 2081/82

Genotype	Fruit weight (g)	Fruit diameter (mm)	Fruit height (mm)	Peel thickness (mm)	No. of seeds $fruit^{-1}$	No. of fruit $tree^{-1}$	Yield (mt ha^{-1})
Cara Cara Navel	177.00	68.20	68.70	3.62	0.36	81.80	15.70
Delicious Seedless	161.00	66.00	72.60	3.34	1.38	212.00	36.90
Dhankuta Local	151.00	67.80	65.30	3.45	7.92	225.00	35.60
Hamlin	145.00	64.60	65.70	3.30	4.04	100.00	15.60
Lane Late	204.00	73.80	71.80	3.99	0.92	118.00	22.10
LueGim Gong	143.00	65.20	65.50	3.93	9.84	83.20	12.50
Malta Blood red	173.00	70.40	68.00	3.76	13.80	142.00	25.90
Pineapple	123.00	61.40	62.00	3.47	1.56	217.00	28.40
Salustiana	195.00	71.50	73.60	3.72	0.36	258.00	53.40
Succari	150.00	65.60	65.70	3.83	16.60	65.80	10.80
Tamango	136.00	61.80	66.30	3.31	1.40	635.00	84.40
Valencia Late	121.00	61.00	61.90	2.95	4.36	296.00	38.50
Vanelle	157.00	64.40	70.70	2.66	8.98	79.20	12.70
Washington Navel	227.00	74.00	75.70	3.59	0.48	158.00	37.30
Grand Mean	**161.64**	**66.83**	**68.11**	**3.5**	**5.15**	**190.77**	**30.7**
LSD ($P<0.05$)	28.38	4.11	5	0.3	2.12	158.42	25.11
F-test	***	***	***	***	***	***	***
CV (%)	13.83	4.84	5.79	6.81	32.45	65.43	64.43

Physicochemical properties of different genotypes of sweet orange

Physicochemical properties of sweet orange like juice quantity, TSS, TA and DA meter reading and CCI were found significantly different at harvest among the genotypes (Table 7). DA meter is a device that measures the decline in chlorophyll content immediately below the skin during ripening. Likewise, CCI has been computed using an automatic computer vision system (spectrophotometer CM-700d). In the citrus industry CCI is used to determine the harvesting date or to decide if citrus fruits should undergo a degreening treatment. DA meter reading and CCI measurement are non-destructive method of citrus maturity/skin color measurement.

The analysis of internal fruit quality parameters in sweet orange genotypes revealed significant to highly significant variation among genotypes. The F-test indicated highly significant differences ($P < 0.001$) for Total soluble solids(TSS), Titratable acidity (TA), Difference in absorbance (DA value), and Chlorophyll content index (CCI), while juice percentage showed significant variation at $P < 0.05$. This suggests that most quality attributes are strongly governed by genetic factors, although Juice content appears to be comparatively more influenced by environmental conditions, as reflected by its higher coefficient of variation (25.66%) (Table 7).

Juice content (%)

Juice content ranged from 25.20% ('Washington Navel') to 45.70% ('Dhankuta Local'), with a grand mean of 31.94%. 'Dhankuta Local' exhibited significantly higher Juice content (45.70%), followed by 'Valencia Late '(38.00%) and 'Tamango' (35.80%), indicating their suitability for juice extraction and processing purposes.

In contrast, genotypes such as 'Washington Navel' (25.20%), 'Salustiana' (25.70%), and 'Pineapple' (26.40%) recorded lower juice percentages, which may reduce their efficiency for processing despite their potential advantages in fruit size or yield. The relatively high variability (CV = 25.66%) suggests that Juice content is influenced by both genotype and environmental factors.

Total soluble solids (TSS)

TSS values ranged from 9.67% ('Delicious Seedless') to 12.60% ('Succari'), with an overall mean of 11.06%. Higher TSS was recorded in 'Succari' (12.60%), 'Pineapple' (11.60%), 'Lane Late' (11.60%), and 'Tamango' (11.60%), indicating superior in sweetness and enhanced flavor quality.

Lower TSS values in 'Delicious Seedless' (9.67%) and 'LueGim Gong' (9.85%) suggest relatively less sweetness, which may affect fresh consumption preference. The very low CV (2.20%) indicates that TSS is a stable trait with strong genetic control.

Titratable acidity (TA)

Titratable acidity varied from 0.74% ('Washington Navel') to 1.66% ('Tamango'), with a mean of 1.31%. Genotypes such as 'Tamango' (1.66%), 'Malta Blood Red' (1.59%), and 'LueGim Gong' (1.56%) exhibited higher acidity, contributing to a stronger sour taste. In contrast, ‘Washington Navel’ (0.74%) and ‘Delicious Seedless’ (1.06%) showed lower acidity, indicating a milder taste profile.

The balance between TSS and TA is crucial in determining overall fruit flavor. Genotypes like ‘Succari’ (TSS: 12.60%, TA: 1.10%) and ‘Pineapple’ (TSS: 11.60%, TA: 1.34%) likely provide a favorable sugar-acid balance, enhancing palatability. The moderate CV (8.70%) suggests some environmental influence on acidity.

Difference in absorbance (DA Value)

The DA value, reflecting chlorophyll degradation and fruit maturity, ranged from 0.00 to 0.14, with a mean of 0.03. ‘Washington Navel’ recorded the highest DA value (0.14), followed by ‘Lane Late’ (0.09) and ‘LueGim Gong’ (0.07), indicating relatively advanced maturity and better degreening.

Most genotypes exhibited very low DA values (0.00–0.01), suggesting delayed or limited chlorophyll degradation at the time of observation. The extremely high CV (122.03%) indicates that DA value is highly variable and strongly influenced by environmental conditions, harvest stage, and measurement sensitivity.

Chlorophyll content index (CCI)

CCI values ranged from 6.52 (‘Washington Navel’) to 11.70 (‘Pineapple’), with a mean of 9.00. Higher CCI values were recorded in ‘Pineapple’ (11.70), ‘Dhankuta Local’ (11.00), and ‘Cara Cara Navel’ (10.50), indicating better peel coloration and enhanced market appeal.

Lower CCI values in ‘Washington Navel’ (6.52), ‘Vanelle’ (7.32), and ‘Lane Late ‘(7.86) suggest comparatively poorer coloration, which may affect consumer preference in fresh markets. The moderate CV (9.74%) indicates a combined influence of genotype and environment on peel color development.

Overall quality assessment

The results demonstrate that no single genotype excelled across all quality parameters, highlighting the importance of genotype selection based on intended use. ‘Dhankuta Local’ emerged as a promising genotype for juice production due to its high Juice content and acceptable TSS. ‘Succari’ showed superior sweetness (highest TSS) with moderate acidity, making it suitable for fresh consumption.

'Tamango', which was previously identified as the highest-yielding genotype, also exhibited relatively high Juice content and TSS but had the highest acidity, which may affect taste preference unless balanced properly. 'Pineapple' and 'Lane Late' showed good combinations of TSS and CCI, indicating both internal and external quality appeal.

Table 7. Physicochemical properties of different sweet orange genotypes at NCRP, Paripatle, Dhankuta in 2081/82

Genotype	Juice %	TSS %	TA %	DA value	CCI value
Cara Cara Navel	29.30	11.40	1.17	0.01	10.50
Delicious Seedless	32.00	9.67	1.06	0.00	9.70
Dhankuta Local	45.70	11.20	1.45	0.01	11.00
Hamlin	29.60	10.40	1.16	0.00	9.11
Lane Late	30.60	11.60	1.52	0.09	7.86
LueGim Gong	30.80	9.85	1.56	0.07	8.03
Malta Blood red	31.00	11.30	1.59	0.01	9.43
Pineapple	26.40	11.60	1.34	0.00	11.70
Salustiana	25.70	11.00	1.45	0.01	8.15
Succari	32.90	12.60	1.10	0.04	9.32
Tamango	35.80	11.60	1.66	0.01	9.46
Valencia Late	38.00	10.70	1.30	0.00	7.90
Vanelle	34.30	11.50	1.18	0.01	7.32
Washington Navel	25.20	10.40	0.74	0.14	6.52
Grand mean	**31.94**	**11.06**	**1.31**	**0.03**	**9**
LSD (P<0.05)	10.4	0.31	0.14	0.04	1.11
F-test	*	***	***	***	***
CV (%)	25.66	2.2	8.7	122.03	9.74

3.1.3 Acid lime

Acid lime (*Citrus aurantifolia* Swingle) is an important fruit crop of commercial value, ranking third after mandarin and sweet orange in Nepal. Traditionally, acid lime cultivation was limited to range of 800-1400 masl in mid hill districts with production of small volume and confined to short time duration (September-November). Due to the changes in feeding habit and being more conscious about health benefits (Vitamin C) of acid lime consumption, the demand of the fruit has increased dramatically. As the domestic production is far below to meet the demand, Nepal imports more than 90% of fresh lime fruit in the country every year. Moreover, the cultivation practice is attributed to marginal land with poor yielding varieties. Similarly, the potential of cultivating range could be much wider from 125 to 1400 masl in Nepal. After the release of two acid lime varieties viz. ʹSunkagati-1ʹ and ʹSunkagati-2ʹ for terai region in 2072 B.S., the cultivation area of acid lime has increased significantly. These two varieties are becoming popular among acid lime cultivating farmers in Terai region of Nepal. At the same time, ʹTerhathum Localʹ is famous for mid-hill region.

Fruit characteristics and yield of different genotypes of sweet oranges

Fruit characteristics and yield attributes like individual fruit weight, fruit diameter and peel thickness were statistically different whereas number of seeds/fruit, number of fruits/tree, and fruit yield/ hectare were not significantly different due to the effect of different genotypes of sweet orange (Table 8).

The evaluation of acid lime genotypes revealed significant to highly significant variation for all studied traits, indicating substantial genetic diversity among the genotypes. The F-test showed highly significant differences ($P < 0.001$) for most traits, while the number of fruits per tree was significant at $P<0.01$, suggesting relatively greater environmental influence on this parameter compared to others.

Fruit weight and size attributes

Fruit weight varied significantly among genotypes, ranging from 27.20 g (‘IAAS Acc#71’ (5)) to 92.40 g (‘Paripatle Sunaulo Nibuwa’), with a grand mean of 42.48 g. ‘Paripatle Sunaulo Nibuwa’ distinctly outperformed all other genotypes, producing exceptionally larger fruits, followed by ‘Kaptangunj Lamo’ (53.30 g) and ‘Tehrathum Local’ (48.50 g). The corresponding increase in fruit diameter, with ‘Paripatle Sunaulo Nibuwa’ (53.80 mm) and ‘Madrasi Kagati’ (43.10 mm) showing higher values compared to the mean (40.92 mm), further supports the superiority of these genotypes in fruit size.

The relatively low coefficients of variation for fruit diameter (1.92%) and moderate for fruit weight (9.35%) indicate that these traits are largely under genetic control with limited environmental influence. Larger fruit size is generally desirable for market preference; however, it may not always correlate positively with yield.

Peel thickness and peel weight

Peel thickness ranged from 1.54 mm (‘Banarasi Kagati’) to 3.24 mm (‘Kaptangunj Lamo’), with a mean of 1.91 mm. Genotypes such as ‘Kaptangunj Lamo’ (3.24 mm) and

'Belepur' (2.31 mm) had thicker peels, which may enhance resistance to mechanical injury and improve shelf life. Conversely, thinner peel in 'Banarasi Kagati' (1.54 mm) and 'Sundarpur' (1.58 mm) may be advantageous for juice extraction and consumer preference.

Peel weight showed a similar trend, with the highest value in 'Paripatle Sunaulo Nibuwa' (50.80 g), followed by 'Kaptangunj Lamo' (34.30 g), indicating a strong association between fruit size and peel weight. The low CV (6.33%) for peel weight suggests high reliability of this trait.

Seed content

The number of seeds per fruit varied from 4.70 ('Paripatle Sunaulo Nibuwa') to 12.50 ('IAAS Acc#71' (5)), with a mean of 8.93. Genotypes such as 'Paripatle Sunaulo Nibuwa' (4.70), 'Tehrathum Local' (6.87), and 'Madrasi Kagati' (7.40) exhibited lower seed content, which is a desirable trait for fresh consumption and processing.

In contrast, 'IAAS Acc#71' (5) (12.50) and 'Banarasi Kagati' (11.20) showed higher seed numbers, which may reduce consumer preference. The relatively higher CV (17.74%) indicates notable variability and environmental influence on this trait.

Number of fruits per tree and yield

The number of fruits per tree ranged from 63.00 ('Banarasi Kagati') to 129.00 ('IAAS Acc#01' (25)), with a mean of 95.62. 'IAAS Acc#01' (25) produced the highest number of fruits per tree (129.00), followed by 'Kaptangunj Golo' and 'Madrasi Kagati' (113.00 each). However, the variation in fruit number was only significant at $P < 0.01$, and the moderate CV (17.41%) suggests a considerable influence of environmental and management factors.

Yield ranged from 1.93 mt ha^{-1} (IAAS Acc#71 (5)) to 9.27 mt ha^{-1} ('Paripatle Sunaulo Nibuwa'), with a mean of 4.25 mt ha^{-1}. 'Paripatle Sunaulo Nibuwa' was markedly superior in yield (9.27 mt ha^{-1}), followed by 'Tehrathum Local' (5.93 mt ha^{-1}) and 'Madrasi Kagati' (5.45 mt ha^{-1}). The high yield of 'Paripatle Sunaulo Nibuwa' can be attributed to its significantly larger fruit size combined with a moderate number of fruits per tree.

Interestingly, genotypes such as 'IAAS Acc#01' (25), despite having the highest number of fruits per tree, did not achieve the highest yield (4.69 mt ha^{-1}), indicating that fruit size plays a crucial role alongside fruit number in determining total yield in acid lime.

Relationship between yield components

Unlike mandarin and sweet orange, where yield is primarily driven by fruit number, the present study suggests that yield in acid lime is influenced by a combination of fruit size and fruit number. 'Paripatle Sunaulo Nibuwa', with both high fruit weight and moderate fruit number, achieved the highest yield. Conversely, 'IAAS Acc#71' (5), with small fruit size and lower fruit number, recorded the lowest yield. This indicates that balanced assimilate partitioning between fruit size and number is essential for maximizing productivity in acid lime.

Overall performance and implications

Among the evaluated genotypes, 'Paripatle Sunaulo Nibuwa' emerged as the most promising due to its superior fruit weight, lower seed content, and highest yield. 'Madrasi Kagati' and 'Tehrathum Local' also demonstrated good performance, combining moderate fruit size, lower seed content, and higher yields.

Genotypes such as 'IAAS Acc#01' (25) and 'Kaptangunj Golo' showed potential due to higher fruit numbers but may require improvement in fruit size to enhance overall productivity. On the other hand, IAAS Acc#71 (5) and 'Banarasi Kagati' were inferior in both yield and quality traits.

The moderate to high coefficients of variation for yield and fruit number indicate that these traits are influenced by environmental conditions, suggesting the need for multi-location trials to assess stability and adaptability.

Table 8. Fruit characteristics and yield parameters of different acid lime genotypes at NCRP, Paripatle, Dhankuta in 2081/82

Genotype	Fruit weight (g)	Fruit diameter (mm)	Peel thickness (mm)	Peel wight (g)	Nos. of seed fruit^{-1}	No. of fruit tree^{-1}	Yield (mt ha^{-1})
Banarasi Kagati	38.90	40.60	1.54	17.80	11.20	63.00	2.50
Belepur	33.10	38.50	2.31	16.40	9.33	86.30	2.81
IAAS Acc #101(17)	35.10	39.50	1.59	16.50	8.13	88.70	3.20
IAAS Acc #101(2)	37.30	38.90	1.81	17.50	9.67	107.00	4.10
IAAS Acc #101(3)	32.70	38.30	1.58	15.30	10.10	86.50	2.72
IAAS Acc#01(25)	36.40	39.00	1.77	17.10	8.63	129.00	4.69
IAAS Acc#71 (5)	27.20	36.30	2.08	13.60	12.50	66.00	1.93
Kaptangunj Golo	39.30	40.70	1.84	19.90	9.83	113.00	4.41
Kaptangunj Lamo	53.30	42.60	3.24	34.30	9.07	76.30	4.35
Khursani Bari Local	37.20	39.80	1.89	19.10	9.33	99.30	4.12
Madrasi Kagati	46.30	43.10	1.84	24.00	7.40	113.00	5.45
Paripatle Sunaulo Nibuwa	92.40	53.80	2.02	50.80	4.70	99.70	9.27
Sundarpur	37.00	39.30	1.58	18.20	8.37	100.00	4.00
Tehrathum Local	48.50	42.40	1.64	24.80	6.87	111.00	5.93
Grand Mean	**42.48**	**40.92**	**1.91**	**21.81**	**8.93**	**95.62**	**4.25**
LSD (P<0.05)	6.67	1.32	0.25	2.32	2.66	27.93	1.35
F-test	***	***	***	***	***	**	***
CV (%)	9.35	1.92	7.65	6.33	17.74	17.41	18.87

The evaluation of biochemical quality parameters in acid lime genotypes revealed significant to highly significant differences among genotypes. The F-test indicated highly significant variation (P<0.001) for Juice content, Total soluble solids(TSS), Difference in absorbance (DA value), and Chlorophyll content index (CCI), while

Titratable acidity (TA) was significant at P<0.01. This reflects considerable genetic variability governing internal fruit quality traits, which are crucial for both fresh consumption and processing (Table 9).

Juice content (%)

Juice content varied significantly from 24.50% (‘Kaptangunj Lamo’) to 49.50% (‘IAAS Acc #101’ (17)), with a grand mean of 43.14%. Genotypes such as ‘IAAS Acc #101’ (17) (49.50%), ‘Banarasi Kagati’ (48.40%), ‘IAAS Acc#01’ (25) (48.10%), and ‘Tehrathum Local’ (47.30%) exhibited higher juice recovery, making them suitable for juice extraction and commercial processing.

In contrast, ‘Kaptangunj Lamo’ (24.50%) and ‘Paripatle Sunaulo Nibuwa’ (33.00%) recorded comparatively lower Juice content. Notably, ‘Paripatle Sunaulo Nibuwa’, despite being the highest-yielding genotype in the previous table, showed relatively low juice percentage, indicating a trade-off between yield and juice recovery. The low CV (6.59%) suggests that Juice content is a relatively stable trait with strong genetic control.

Total soluble solids (TSS)

TSS ranged from 7.12% (‘Sundarpur’) to 8.31% (‘Kaptangunj Lamo’), with a mean of 7.71%. Higher TSS values were observed in ‘Kaptangunj Lamo’ (8.31%), ‘Tehrathum Local’ (8.20%), ‘Kaptangunj Golo’ (8.06%), and ‘IAAS Acc #101’ (3) (8.10%), indicating relatively higher soluble sugars and improved flavor intensity.

Lower TSS values in ‘Sundarpur’ (7.12%), ‘IAAS Acc#71’ (5) (7.32%), and ‘IAAS Acc#01’ (25) (7.35%) suggest comparatively less sweetness. However, in acid lime, TSS is less influential than acidity in determining overall taste. The low CV (3.50%) confirms that TSS is a stable and genetically controlled trait.

Titratable acidity (TA)

Titratable acidity showed moderate variation, ranging from 6.74% (‘Kaptangunj Lamo’) to 7.88% (‘Kaptangang Golo’), with a mean of 7.23%. High acidity levels were recorded in ‘Kaptangang Golo’ (7.88%), ‘Banarasi Kagati’ (7.72%), and ‘IAAS Acc #101’ (3) (7.55%), which is a desirable characteristic in acid lime, as it determines the characteristic sour taste and suitability for culinary uses.

Lower acidity was observed in ‘Kaptangunj Lamo’ (6.74%), ‘Paripatle Sunaulo Nibuwa’ (6.83%), and ‘IAAS Acc#71’ (5) (6.94%), which may result in comparatively milder sourness. The relatively low CV (4.17%) indicates limited environmental influence and strong genetic control over acidity.

Difference in absorbance (DA Value)

The DA value ranged from 0.34 (‘Paripatle Sunaulo Nibuwa’) to 0.99 (‘Madrasi Kagati’), with a mean of 0.72. Higher DA values were recorded in ‘Madrasi Kagati’ (0.99), ‘IAAS Acc #101’ (2) (0.93), and ‘IAAS Acc#71’ (5) (0.92), indicating more advanced chlorophyll degradation and maturity.

Lower DA values in ‘Paripatle Sunaulo Nibuwa’ (0.34) and ‘Kaptangunj Golo’ (0.49) suggest relatively delayed maturity or slower degreening. The moderate CV (16.92%) indicates that DA value is influenced by both genetic and environmental factors.

Chlorophyll content index (CCI)

CCI values showed wide variability, ranging from -1.15 (‘Madrasi Kagati’) to 1.61 (‘Paripatle Sunaulo Nibuwa’), with a mean of 0.42. Higher CCI values, as observed in Paripatle Sunaulo Nibuwa (1.61), ‘Kaptangunj Golo’ (1.11), and Sundarpur (1.04), indicate relatively better peel coloration.

Negative or low CCI values, such as in ‘Madrasi Kagati’ (-1.15) and ‘Khursani Bari Local’ (-0.21), indicate poor coloration or retention of greenish peel, which is typical in acid lime and may not necessarily reduce market acceptability, as green color is often preferred in lime markets. The extremely high CV (95.13%) suggests that CCI is highly variable and strongly influenced by environmental conditions.

Overall quality assessment

The results indicate that no single genotype excelled in all quality parameters, highlighting the importance of selecting genotypes based on specific end-use requirements. ‘IAAS Acc #101’ (17), ‘Banarasi Kagati’, and ‘Tehrathum Local’ were superior in Juice content and acceptable acidity, making them suitable for juice extraction and fresh use.

‘Kaptangunj Golo’and ‘Tehrathum Local’ demonstrated a desirable combination of higher TSS and acidity, contributing to a strong flavor profile. ‘Madrasi Kagati’ showed advanced maturity (high DA value) but poor peel coloration (negative CCI), which may limit its visual appeal.

'Paripatle Sunaulo Nibuwa', although identified earlier as the highest-yielding genotype, showed lower Juice content and acidity but better peel coloration, indicating that it may be more suitable for yield-oriented production rather than processing quality.

Table 9. Physicochemical properties of different acid lime genotypes at NCRP, Paripatle, Dhankuta during 2081/82

Genotype	Juice (%)	TSS (%)	TA (%)	DA value	CCI value
Banarasi Kagati	48.40	7.60	7.72	0.53	0.16
Belepur	42.60	7.53	7.44	0.71	0.47
IAAS Acc #101(17)	49.50	7.83	7.46	0.73	0.34
IAAS Acc #101(2)	42.80	7.41	6.95	0.93	0.58
IAAS Acc #101(3)	44.00	8.10	7.55	0.77	0.11
IAAS Acc#01(25)	48.10	7.35	7.10	0.79	0.30
IAAS Acc#71 (5)	42.50	7.32	6.94	0.92	0.01
Kaptangang Golo	42.70	8.06	7.88	0.49	1.11
Kaptangunj Lamo	24.50	8.31	6.74	0.79	0.75
Khursani Bari Local	46.80	7.44	6.97	0.87	-0.21
Madrasi Kagati	46.20	7.84	7.27	0.99	-1.15
Panta -1	33.00	7.83	6.83	0.34	1.61
Sundarpur	45.50	7.12	7.04	0.59	1.04
Tehrathum Local	47.30	8.20	7.34	0.64	0.73
Grand mean	**43.14**	**7.71**	**7.23**	**0.72**	**0.42**
LSD (P<0.05)	4.77	0.45	0.51	0.2	0.67
F-test	***	***	**	***	***
CV (%)	6.59	3.50	4.17	16.92	95.13

3.1.4 Grapefruit, tangor, and tangelo

Fruit physical characteristics

Fruit weight varied widely among the genotypes, with the highest recorded in 'Reed' grapefruit (498.24 g), followed by 'Shamber' (293.03 g) and 'Henderson' (208.96 g), whereas the lowest fruit weight was observed in 'Murcott' tangor (82.52 g). Similarly, fruit diameter and height followed a comparable trend, with 'Reed' showing the largest fruit size (105.03 mm diameter and 103.73 mm height), indicating its superior fruit development potential. These findings suggest that grapefruit genotypes, particularly 'Reed', tend to produce larger fruits compared to tangelo and tangor genotypes, which generally exhibited smaller fruit size (Table 10).

Peel thickness also showed considerable variation among genotypes. The thickest peel was recorded in 'Reed' (8.64 mm), which was substantially higher than all other genotypes, while the thinnest peel was observed in 'Murcott' (1.76 mm). Thick peel in 'Reed' may be associated with better postharvest handling and storage potential, whereas thinner peel in tangor genotypes may be advantageous for fresh consumption due to ease of peeling.

Seed number per fruit varied markedly, with 'Seminole' tangelo having the highest number of seeds (16.60 seeds fruit^{-1}), closely followed by 'Ortanique' tangor (15.40) and 'Murcott' (14.30). In contrast, 'Star ruby' grapefruit had the lowest seed number (2.20). This indicates that grapefruit genotypes generally tend to have lower seed content compared to tangelo and tangor, which are often characterized by higher seed numbers, affecting their consumer preference and market acceptability.

Yield and yield components

The number of fruits per tree varied across genotypes, with the highest number recorded in 'Shamber' grapefruit (112.50 fruits tree^{-1}), followed by 'Henderson' (107.75) and 'Ellendale' (102.50). In contrast, 'Reed' produced the lowest number of fruits per tree (70.50), indicating a trade-off between fruit size and fruit number.

Yield per hectare exhibited a similar trend, with 'Shamber' grapefruit producing the highest yield (32.08 mt ha^{-1}), followed closely by 'Reed' (29.11 mt ha^{-1}) and 'Henderson' (21.32 mt ha^{-1}). The high yield in 'Shamber' can be attributed to its relatively high fruit number per tree combined with moderately large fruit size. Although 'Reed' produced the largest fruits, its comparatively lower fruit number resulted in a slightly reduced yield than 'Shamber'.

Among tangelo and tangor genotypes, 'Ellendale' tangor recorded the highest yield (13.78 mt ha^{-1}), followed by 'Minneola' tangelo (11.52 mt ha^{-1}) and 'Seminole' tangelo (11.43 mt ha^{-1}). In contrast, the lowest yields were observed in 'Murcott' (7.79 mt ha^{-1}) and 'Ortanique' (7.71 mt ha^{-1}). These results indicate that tangor genotypes, particularly 'Ellendale', perform relatively better in terms of yield compared to other tangelo and tangor types, although their yield remains lower than that of the superior grapefruit genotypes.

Table 10. Fruit physical and yield attributing parameters of grapefruit, Tangor and Tangelo genotypes at NCRP, Paripatle, Dhankuta during 2081/82

Genotypes	Fruit weight (g)	Fruit diameter (mm)	Fruit height (mm)	Peel thickness (mm)	Nos. of seeds $fruit^{-1}$	Nos. fruits $tree^{-1}$	Yield (mt ha^{-1})
Henderson (Grapefruit)	208.96	79.38	66.81	4.58	4.75	107.75	21.32
Star ruby (Grapefruit)	118.22	63.21	56.67	3.26	2.20	90.00	10.70
Reed (Grapefruit)	498.24	105.03	103.73	8.64	15.00	70.50	29.11
Pink ruby (Grapefruit)	164.51	73.69	62.42	4.84	4.13	98.33	14.70
Shamber (Grapefruit)	293.03	89.05	76.40	3.63	4.00	112.50	32.08
Minneola (Tangelo)	128.40	59.04	64.83	2.69	13.00	97.00	11.52
Seminole (Tangelo)	102.23	59.19	50.83	1.98	16.60	85.00	11.43
Murcott (Tangor)	82.52	56.70	44.93	1.76	14.30	90.00	7.79
Ellendale (Tangor)	122.22	63.70	54.19	1.90	10.90	102.50	13.78
Ortanique (Tangor)	119.26	61.86	54.33	2.38	15.40	66.67	7.71

Juice content

The physicochemical analysis of grapefruit, tangor, and tangelo genotypes revealed considerable variation in juice percentage. Among all genotypes, Ellendale (Tangor) recorded the highest Juice content (56.87%), followed by Minneola (Tangelo) (52.12%) and Murcott (Tangor) (48.99%). In contrast, the lowest Juice content was observed in Star Ruby (Grapefruit) (32.09%) and Reed (Grapefruit) (32.90%) (Table 11).

Higher Juice content in tangor and tangelo genotypes suggests their suitability for fresh consumption and processing industries, particularly for juice extraction. Grapefruit genotypes, especially those with lower juice percentage, may be comparatively less efficient for juice processing but could still be preferred for fresh fruit markets due to other quality attributes (Table 11).

Total soluble solids (TSS)

Total soluble solids(TSS), an indicator of sweetness, varied moderately among the genotypes. Reed (Grapefruit) exhibited the highest TSS value (11.90%), followed closely by Ellendale (Tangor) (11.41%). Other genotypes, including Murcott (10.99%), Ortanique (10.72%), and Star Ruby (10.50%), showed intermediate TSS levels, while Minneola (10.08%) had the lowest.

Higher TSS values in Reed and Ellendale indicate better sugar accumulation, making these genotypes more acceptable in terms of taste and market preference. Similar variation in TSS among citrus genotypes has been widely reported and is largely governed by genetic factors as well as environmental conditions during fruit development.

Titratable acidity (TA)

Titratable acidity showed significant variation across genotypes. The highest TA was recorded in Ortanique (Tangor) (10.45%) and Shamber (Grapefruit) (10.39%), indicating strongly acidic fruit types. In contrast, Ellendale (Tangor) exhibited the lowest TA (1.31%), followed by Seminole (Tangelo) (1.93%) and Reed (Grapefruit) (2.35%).

High acidity is generally associated with a sharp taste, while lower acidity contributes to a sweeter and more balanced flavor. The observed variation in acidity among genotypes reflects differences in metabolic activity and organic acid accumulation during fruit maturation.

DA value

The DA (difference in absorbance) value, which is often used as an indicator of fruit maturity and chlorophyll degradation, also varied among genotypes. Reed (0.19) recorded the highest DA value, suggesting a higher level of pigment transformation and possibly advanced maturity. Several genotypes, including Star Ruby and Ellendale, recorded a DA value of 0.00, indicating lower pigment degradation or differences in fruit maturity at harvest.

These variations in DA values suggest genotype-specific differences in fruit maturation behavior, which can influence harvesting time and postharvest quality.

Chlorophyll content index (CCI)

The CCI values showed considerable variation, indicating differences in pigment composition among the genotypes. The highest CCI was recorded in Seminole (Tangelo) (14.37), followed by Minneola (11.95) and Ortanique (11.86)**.** In contrast, the lowest CCI was observed in Reed (Grapefruit) (1.91). Higher CCI values in tangelo and tangor genotypes suggest greater pigment concentration, which may contribute to enhanced fruit color and nutritional quality. Lower CCI in Reed indicates reduced pigment content, which may be associated with its large fruit size and different physiological characteristics.

Overall quality implications

The physicochemical properties indicate clear differences in fruit quality among grapefruit, tangor, and tangelo genotypes. Ellendale and Reed demonstrated superior TSS and Juice content, respectively, while Seminole and Minneola showed higher pigment concentration (CCI). However, genotypes like Ortanique and Shamber**,** despite high acidity, may offer stronger flavor profiles suitable for specific consumer preferences or processing purposes.

Table 11. Physicochemical properties of grapefruit, tangor, and tangelo genotypes at NCRP, Paripatle, Dhankuta during 2081/82

Variety	Juice (%)	TSS (%)	TA (%)	DA value	CCI value
Henderson (Grapefruit)	38.25	10.45	2.83	0.02	2.32
Star ruby (Grapefruit)	32.09	10.50	3.39	0.00	2.81
Reed (Grapefruit)	32.90	11.90	2.35	0.19	1.91
Pink ruby (Grapefruit)	37.12	10.18	2.54	0.10	2.35
Shamber (Grapefruit)	41.34	10.28	10.39	0.09	2.30
Minneola (Tangelo)	52.12	10.08	2.52	0.09	11.95
Seminole (Tangelo)	44.31	10.39	1.93	0.05	14.37
Murcott (Tangor)	48.99	10.99	2.37	0.10	7.54
Ellendale (Tangor)	56.87	11.41	1.31	0.00	8.85
Ortanique (Tangor)	47.62	10.72	10.45	0.08	11.86

Overall, the results suggest that Ellendale, Minneola, and Murcott are promising genotypes for juice quality and consumer acceptance due to their higher Juice content, moderate TSS, and balanced acidity, whereas genotypes with extreme acidity (e.g., Ortanique, Shamber) may require blending or processing to improve palatability. These findings highlight the importance of genotype selection in optimizing citrus fruit quality under mid-hill conditions of Nepal.

3.2 Disease management research

3.2.1 Effect of different chemical pesticides on citrus canker management of acid lime

Citrus fruits cultivated all over the world in tropical and sub-tropical regions having suitable soil and climatic conditions. Mid hills of Nepal ranging from 800 to 14,00 masl altitude all across the country are considered favorable for all types of citrus fruits cultivation. However, pumelo, acid lime and lemon can be cultivated successfully in up-land condition of terai, inner-terai, foothills and river basin areas of Nepal. Citrus crops cover about 30% of the total area under fruit cultivation. Citrus crop are potential exportable commodities particularly to India and Bangladesh. Districts with more than 1,000 ha area under cultivation are Taplejung, Tehrathum, Dhankuta, Ramechhap, SIndhulli, Kavrepalanchowk, Lamjhung, Syangja, Salyan and Dailekh. However, there are some biotic factors hindering the production of citrus and canker is one of them.

Citrus canker is the common disease of citrus that is caused by the bacteria *Xanthomonas campestris* pv. *citri*. Citrus canker is generally seen in acid lime during the rainy season. However, it is also found to infest mandarin. At the beginning of infestation, small brown spots are seen, and these spots develop to become lesions of 4-5 mm diameter. Leaves and fruit start to fall off the plant and twigs start to die from the top in heavy infestation. In addition, the lesion on fruit deteriorates the fruit appearance thus decreasing the market value of fruit. Therefore, various antibiotics available in the market were tested for their efficacy against citrus canker of acid lime.

Methodology

The effectiveness of six antibiotics for controlling citrus canker was studied in acid lime ʻSunkagati-2ʹ at an orchard of NCRP in 2024. The trial was set-up in randomized complete block design with three replications. The plots were sprayed with antibiotics four times at fifteen daysʹ interval during April 28 and June 30. One twig from each direction was tagged for observation per tree. The total number of leaves and total number of leaves infested with cnaker were couted on tagged twigs. Disease severity and mean effectiveness were calculated. The treatments were:

Table 12. Treatment details of the experiment “Effect of different chemicals pesticide on citrus canker management of acid lime” conducted at NCRP, Paripatle, Dhankuta during 2081/82

S.N.	Treatment
1	Streptomycin Sulphate 9% + Tetracycline Hydrochloride 1% WP @ 0.2 g l^{-1}
2	Validamycin A 10% SL @ 1.5 ml l^{-1}
3	Kasugamycin 3% SL @ 2 ml l^{-1}
4	1 % Bordeaux mixture (1 lit water: 10 gm lime: 10 gm copper sulphate)
5	Copper oxychloride 50% WP @ 2 g l^{-1}
6	Zinkicide @ 3.51ml l^{-1} (200 ppm)
7	Control (Water)

Disease severity (DS) and mean effectiness was calculated using the following formula:

$$\text{Disease severity (\%)} = \frac{\text{Number of canker infected leaves} \times 100}{\text{Total number of leaves}}$$

Mean effectivesness = Disease severity at the first observation − disease severity at the final observation

Results

Disease severity decreased at final observation for every treatment except for control. The highest decrease in disease severity was observed in plants sprayed with Bordeaux mixture followed by copper oxychloride and streptomycin sulphate + tetracycline hydrochloride. During the first observation (before spray), disease severity was 24.39% while it was 16.65% after fourth subsequent spray of Bordeaux mixture. Similarly, disease severity decreased from 21.36% to 13.77% for the plant sprayed with copper oxychloride. Meanwhile, unlike other treatment disease severity increased from 19.49% to 22.15% for the plants sprayed with only water (control) at final observation. Further, plant sprayed with zinkicide has shown a slight decrease in canker severity after 4th spray relative to first observation i.e. 19.14% to 18.18% (Table 13).

All the treatments used in the trial was seen effective for the management of citrus canker in acid lime except control (water spray). The highest mean effectiveness was recorded in the plants sprayed with 1% Bordeaux mixture (7.74 %) followed by zinkicide (7.58%), streptomycin sulphate + tetracycline hydrochloride (6.27 %) and and Kasugamycin (5.89 %). On the other hand, the mean effectiveness was seen negative in plants sprayed with water (-2.65 %). The plants sprayed with zinkicide had mean effective of 0.96% and Validamycin was 3.52% (Table 13).

Table 13. Disease severity (%) for each observation and mean effectiveness of different chemicals against citrus canker in acid lime at NCRP, Paripatle, Dhankuta during 2081/82

Treatment	Disease severity (%)					Mean effectiveness of each treatment (%)
	1st observation	2nd observation	3rd observation	4th observation	5th observation	
T1	21.50	21.30	20.69	18.41	15.23	6.27
T2	26.58	26.56	28.33	27.87	23.06	3.52
T3	22.16	15.93	17.46	20.81	16.27	5.89
T4	24.39	21.74	23.89	19.50	16.65	7.74
T5	21.36	18.78	17.91	13.29	13.77	7.58
T6	19.14	13.98	20.92	21.40	18.18	0.96
T7	19.49	22.75	21.40	24.53	22.15	-2.65

3.3 Insect pest management research

3.3.1 Efficacy study of different insecticides on citrus leaf miner management

The citrus leaf miner, Phyllocnistis citrella, is a destructive microlepidopteran pest that significantly affects citrus cultivation worldwide. This pest primarily attacks young and actively growing shoots, making it particularly problematic in nursery seedlings and newly established orchards. The larvae feed by creating serpentine mines on both the upper and lower surfaces of tender leaves, leading to characteristic curling, distortion, and reduced photosynthetic efficiency of the foliage. Severe infestations of citrus leaf miner can substantially hinder vegetative growth and reduce the vigor of nursery plants and young trees, ultimately affecting their establishment and future productivity.

However, its impact on mature citrus trees is comparatively less pronounced due to their greater tolerance and established canopy structure. The pest has a wide host range within citrus species, including oranges, mandarins, lemons, limes, grapefruit, and other related varieties.

In addition to direct damage, infestation by citrus leaf miner predisposes plants to secondary infections. The feeding activity creates entry points for pathogens such as Citrus Bacterial Canker, thereby increasing disease incidence and severity, particularly in susceptible crops like mandarin and lime. This interaction further exacerbates economic losses in citrus production systems. Given the economic importance of citrus, especially mandarin cultivation, effective management of citrus leaf miner is essential. Among various control strategies, chemical control using insecticides remains a widely adopted approach for rapid and reliable suppression of pest populations. Therefore, the present study was undertaken to evaluate the effectiveness of different insecticides in managing citrus leaf miner in mandarin, with the aim of identifying suitable control measures for sustainable citrus production.

Methodology

The present study was conducted in a mandarin orchard located at the National Citrus Research Program, Paripatle, Dhankuta, Nepal. The experiment was laid out in a Randomized Complete Block Design (RCBD) with seven treatments and three replications. Five-year-old mandarin trees (*Citrus reticulata*) grafted on Poncirus trifoliata were selected for the study. From each experimental tree, newly emerged flushes or young shoots from four directions (north, south, east, and west) were selected and properly tagged to ensure uniform observation. The treatments consisted of six different insecticides along with an untreated control (water spray). The insecticides were applied four times during the months of Jestha and Ashad at 14-day intervals using a hand sprayer. The treatment details are as follows:

Table 14. Treatment details of the experiment "Efficacy study of different insecticides on citrus leaf miner management" conducted at NCRP, Paripatle, Dhankuta during 2081/82

S.N.	Treatment
1	Thiamethoxam @ 0.5 ml l^{-1}
2	Chlorpyriphos 50% + Cypermethrin 5% EC @ 2 ml l^{-1}
3	Imidacloprid @ 1 ml per 3 l water
4	Dimethoate @ 2 ml l^{-1}
5	Azadirachtin @ 5 ml l^{-1}
6	Emamectin benzoate + Chlorfenapyr @ 1 ml l^{-1}
7	Control (water spray)

Observations on leaf miner infestation caused by *Phyllocnistis citrella* were recorded before each spray and after each subsequent spray. For each tagged branch, the total number of leaves and the number of leaves damaged by leaf miner were counted.

The average percentage of infestation and the percentage decrease in infestation were calculated using the following formulae:

$$\text{Average damage (\%)} = \frac{\text{Number of leaves damaged} \times 100}{\text{Number of leaves observed}}$$

$$\text{\% decrease in damage} = \frac{(\text{Average damage before spray} - \text{Average damage after final spray}) \times 100}{\text{Average damage before spray}}$$

The collected data were tabulated and analyzed to compare the efficacy of different insecticidal treatments in reducing leaf miner infestation in mandarin.

Results and discussion

The initial (pre-spray) infestation ranged from 21.92% to 36.01%, indicating a relatively uniform distribution of pest pressure across treatments. After successive sprays, all insecticidal treatments reduced leaf damage compared to the control (Table 15).

Among the treatments**,** Imidacloprid (1 ml 3l^{-1}) recorded the highest reduction in leaf damage (64.88%), followed by Emamectin benzoate + Chlorfenapyr (1 ml l^{-1}) (53.15%) and Thiamethoxam (0.5 ml l^{-1}) (51.85%). Imidacloprid showed a sharp decline in damage after the third spray (7.37%), although a slight increase was observed after the final spray (9.05%), possibly due to reinfestation or reduced residual activity.

Thiamethoxam demonstrated a gradual and consistent reduction in damage from 35.31% before spraying to 17.00% after the final spray. Similarly, Emamectin benzoate + Chlorfenapyr showed a substantial decline after the third spray (12.85%), maintaining relatively low damage levels thereafter.

Azadirachtin (5 ml l^{-1}), a botanical insecticide, also reduced damage moderately (46.83%), though its effect was slower compared to synthetic insecticides. Dimethoate (2 ml l^{-1}) and the combination of Chlorpyriphos 50% + Cypermethrin 5% EC (2 ml l^{-1}) were less effective, with reductions of 38.05% and 41.57%, respectively.

The control (water spray) showed minimal reduction in damage (15.33%), confirming that the observed effects in treated plots were due to insecticidal applications.

Table 15. Effect of different chemical insecticides on average damage and decrease in damage after the management of citrus leaf miner in mandarin orchard of NCRP, Paripatle, Dhankuta during 2081/82

Insecticides	Average damage (%)					Decrease in damage (%)
	Before spray	After 1st spray	After 2nd spray	After 3rd spray	After final spray	
Thiamethoxam 0.5 ml l^{-1}	35.31	25.66	28.83	20.94	17.00	51.85
Chlorpyriphos 50% + Cypermethrin 5% EC 2 ml l^{-1}	36.01	36.57	32.93	26.87	21.04	41.57
Imidacloprid 1 ml $3l^{-1}$	25.77	22.97	22.19	7.37	9.05	64.88
Dimethoate 2 ml l^{-1}	21.92	18.53	16.87	15.21	13.58	38.05
Azadirachtin 5 ml l^{-1}	22.23	21.53	18.56	18.46	11.82	46.83
Emamectin benzoate + Chlorfenapyr 1 ml l^{-1}	28.52	22.08	23.53	12.85	13.36	53.15
Control	22.23	21.53	18.56	18.46	18.82	15.33

The superior performance of Imidacloprid can be attributed to its systemic mode of action, which allows it to penetrate leaf tissues and effectively target leaf miner larvae feeding within the leaf mines. This is particularly important for citrus leaf miner management, as the larvae are protected within leaf tissues.

Thiamethoxam, another neonicotinoid insecticide, also performed well due to its systemic and translaminar properties, though slightly less effective than Imidacloprid. The combination of Emamectin benzoate and Chlorfenapyr exhibited strong efficacy, likely due to the dual mode of action—Emamectin affecting nerve transmission and Chlorfenapyr disrupting cellular respiration—resulting in enhanced control. The moderate efficacy of Azadirachtin suggests that botanical insecticides can be a viable component in integrated pest management (IPM), though they may require more frequent applications or integration with other control measures for optimal results. Lower efficacy observed in Dimethoate and Chlorpyriphos + Cypermethrin treatments may be due to their limited penetration into leaf tissues, reducing their effectiveness against internal feeders like leaf miners.

Overall, the findings suggest that systemic insecticides, particularly Imidacloprid, are more effective for managing citrus leaf miner. However, considering resistance development and environmental concerns, rotation of insecticides and inclusion of biopesticides like Azadirachtin should be encouraged as part of a sustainable IPM strategy.

3.3.2 Efficacy of selected insecticides on citrus rust mite management

The citrus rust mite (*Phyllocoptruta oleivora* Ashmead), is a microscopic eriophyid pest of major economic importance in citrus-growing regions worldwide. Due to its minute size, the mite is barely visible to the naked eye, yet it can cause significant damage to citrus fruits and foliage. The pest primarily feeds on the exposed outer surface of developing fruits by piercing epidermal cells and extracting their contents, leading to the destruction of rind tissues.

The feeding activity of citrus rust mite results in characteristic symptoms on fruits, including a silvery appearance on lemons, a rust-brown discoloration on mature oranges, and a dark or blackened surface on green fruits. Such damage adversely affects the external quality of the fruit, making it less attractive for fresh market consumption. In addition, affected fruits are often smaller in size and exhibit poor storage quality, thereby reducing their market value and overall economic returns.

Under severe infestation, the pest may also attack leaves and green twigs, causing bronzing symptoms and a decline in tree vigor. The mites tend to prefer the sun-exposed side of fruits, resulting in uneven damage, which is more pronounced on the outer canopy of the tree. This feeding behavior further contributes to significant quality deterioration, particularly in commercial orchards where fruit appearance is a critical factor.

Given the importance of citrus as a high-value fruit crop and the direct impact of rust mite infestation on fruit quality and marketability, effective management of this pest is essential. Chemical control using insecticides and acaricides remains one of the primary approaches for managing citrus rust mite populations. Therefore, the present study was undertaken to evaluate the efficacy of several insecticides for the management of citrus rust mite, with the objective of identifying effective treatments for improving fruit quality and sustaining citrus production.

Methodology

The present study was conducted on grafted sweet orange (Citrus sinensis) trees at the National Citrus Research Program, Dhankuta, Nepal. The experiment was designed to evaluate the efficacy of different insecticidal treatments against citrus rust mite, Phyllocoptruta oleivora. The experiment consisted of eight treatments, including a control, and each treatment was replicated three times. Individual trees served as experimental units. The selected trees were uniform in age, vigor, and bearing status to minimize experimental error. The treatments were applied as foliar sprays using a hand sprayer, ensuring thorough coverage of the entire tree canopy. Spraying was carried out three times at weekly intervals. The treatment details were as follows:

Table 16. Treatment details of the experiment "Efficacy of selected insecticides on citrus rust mite management" conducted at NCRP, Paripatle, Dhankuta during 2081/82

S.N.	Treatment
1	Dimethoate 30% EC @ 2 ml l^{-1}
2	Azadirachtin 0.03% EC @ 5 ml l^{-1}
3	Horticultural mineral oil (Servo) @ 10 ml l^{-1}
4	Cow urine (1:10 dilution)
5	Abamectin 1.8% EC @ 0.5 ml l^{-1}
6	Detergent @ 10 g L^{-1}
7	Bifenazate 24% EC @ 0.5 ml l^{-1}
8	Control (no spray)

Data on fruit damage were recorded at the time of harvesting. From each experimental tree, the total number of fruits and the number of fruits damaged by citrus rust mite were counted. The percentage of fruit damage was calculated using the following formula:

$$\text{Fruit damage (\%)} = \frac{\text{Number of damaged fruits} \times 100}{\text{Total number of fruits}}$$

Results and discussion

The effectiveness of different treatments against citrus rust mite (*Phyllocoptruta oleivora*) was evaluated based on the percentage of fruit damage recorded at harvest. The results indicated considerable variation among treatments in reducing fruit damage (Table 17).

Table 17. Effect of different insecticides on average damage sweet orange fruit due to the citrus rust mite at NCRP, Paripatle, Dhankuta, during 2081/82

S.N.	Treatment	Average fruit damage (%)
1	Dimethoate 30% EC 2 ml l^{-1}	10.50
2	Azadirachtin 0.03% EC 5 ml l^{-1}	13.81
3	Horticulture mineral oil (Servo) 10 ml l^{-1}	16.72
4	Cow urine 1:10	7.69
5	Abamectin 1.8% EC 0.5 ml l^{-1}	8.31
6	Detergent 10 g l^{-1}	16.31
7	Bifenazate 24%EC 0.5 ml l^{-1}	10.40
8	Control	25.29

The lowest fruit damage was recorded in the cow urine (1:10 dilution) treatment (7.69%), indicating the highest level of effectiveness among all treatments. This was closely followed by Abamectin 1.8% EC (0.5 ml l^{-1})**,** which resulted in 8.31% fruit damage. Among the chemical insecticides, Bifenazate 24% EC (0.5 ml l^{-1}) and Dimethoate 30% EC (2 ml l^{-1}) also performed effectively, recording 10.40% and 10.50% fruit damage, respectively. Moderate levels of control were observed with Azadirachtin 0.03% EC (5 ml l^{-1}) (13.81%) and Detergent (10 g l^{-1}) (16.31%). The horticultural mineral oil (Servo) (10 ml l^{-1}) treatment showed comparatively higher fruit damage (16.72%), indicating relatively lower efficacy.

The control treatment recorded the highest fruit damage (25.29%), confirming the significant impact of citrus rust mite infestation in the absence of any management practice. The superior performance of cow urine in reducing fruit damage suggests its potential as an effective and eco-friendly alternative for managing citrus rust mite. Its efficacy may be attributed to its repellent properties and possible inhibitory effects on mite feeding and development.

Abamectin showed high effectiveness due to its strong acaricidal activity and translaminar action, which enables it to penetrate plant tissues and target mites feeding on the fruit surface. Similarly, Bifenazate, a selective acaricide, provided effective control by disrupting mite physiological processes, resulting in reduced infestation. Dimethoate also demonstrated good efficacy, likely due to its systemic mode of action; however, its performance was slightly lower compared to Abamectin, which may be due to differences in persistence and specificity against mites.

Botanical insecticide Azadirachtin showed moderate effectiveness, which can be attributed to its antifeedant and growth-regulating properties. However, its comparatively slower action may limit its effectiveness under high pest pressure. Likewise, horticultural mineral oil and detergent treatments were less effective, possibly due to their primarily physical mode of action, which may not adequately control high mite populations. The significantly higher fruit damage observed in the control treatment highlights the economic importance of managing citrus rust mite infestations to maintain fruit quality and marketability.

Overall, the findings suggest that Abamectin, Bifenazate, and Dimethoate are effective chemical options, while cow urine presents a promising low-cost and environmentally friendly alternative for managing citrus rust mite in sweet orange orchards. Integration of these treatments into pest management programs could enhance sustainable citrus production.

3.3.3 Effect of different practices on the management of fruit piercing moth in satsuma mandarin

The fruit piercing moth, primarily belonging to the genus Eudocima, is a serious pest of citrus in tropical and subtropical regions. Among the species, Eudocima fullonia is widely reported to cause significant economic damage. Adult moths possess a specialized proboscis capable of piercing the rind of mature and ripening citrus fruits to feed on the juice. This feeding activity results in direct yield loss and predisposes fruits to secondary infections by pathogens, leading to fruit rot and premature drop. The pest is nocturnal in habit and highly mobile, making its management challenging. Infestations are particularly severe during the fruiting season, thereby affecting both fruit quality and marketability.

Methodology

A field experiment was conducted to evaluate different management practices against fruit piercing moth (FPM), mainly Eudocima fullonia, in citrus. The trial was initiated in the second week of *Shravan* (July–August) and continued until *Mangsir* (November–December), coinciding with the peak fruiting and infestation period. The experiment was laid out using a randomized block design (RBD) with eight treatments and appropriate replications. The treatments included: (1) jaggery bait, (2) neem oil spray, (3) netting, (4) banana bait, (5) fruit bagging, (6) horticultural mineral oil (HMO), (7) light trap, and

(8) untreated control. Each treatment was applied to selected citrus trees of uniform age, vigor, and fruit load.

Bait treatments (jaggery and banana) were prepared and placed in traps within the tree canopy to attract and capture adult moths. Neem oil and HMO were applied as foliar sprays at recommended concentrations during the evening hours to target adult activity. Netting was used to physically exclude moths by covering the tree canopy, while individual fruit bagging was performed using suitable protective materials at the marble stage of fruit development. Light traps were installed within the orchard to attract and trap nocturnal adult moths.

Observations were recorded at 15 days' intervals throughout the study period. The number of damaged fruits per tree was assessed by counting fruits showing characteristic piercing marks and associated rotting symptoms. Additionally, the number of fruit piercing moths entrapped in each treatment (baited and light traps) was recorded periodically.

Results and discussion

The effectiveness of different management practices against fruit piercing moth (FPM), particularly *Eudocima phalonia*, was evaluated based on the number of damaged fruits and moths entrapped under each treatment (Table 18).

Among the treatments, fruit bagging and light traps recorded *zero fruit damage*, indicating complete protection of fruits from moth infestation. Bagging acts as a physical barrier, preventing adult moths from accessing the fruit surface, thereby eliminating the possibility of oviposition and feeding damage. Similarly, the absence of fruit damage under light traps suggests their role in reducing moth population, although only a small number of moths (2) were actually entrapped, indicating limited trapping efficiency but possible behavioral disruption. The netting treatment was also highly effective, recording only 5 damaged fruits, which can be attributed to its ability to physically exclude moth entry into the canopy. Jaggery bait showed moderate effectiveness, with 13 damaged fruits and 15 moths entrapped, suggesting that it can attract and reduce moth population to some extent, thereby lowering fruit damage.

In contrast, banana bait entrapped the highest number of moths (47), demonstrating strong attractiveness to adult moths. However, it also recorded the highest fruit damage (66 fruits), indicating that although it is effective as an attractant, it may inadvertently increase local moth activity if not properly managed, leading to higher infestation levels.

Chemical treatments such as neem oil and horticultural mineral oil (HMO) were found to be less effective, recording 50 and 55 damaged fruits, respectively, with no moths entrapped. This suggests that these treatments have limited impact on adult moth behavior and feeding activity, possibly due to the nocturnal and mobile nature of the pest. The untreated control recorded 43 damaged fruits, reflecting the natural level of infestation in the absence of any control measures.

Table 18. Effect of different management practices on the management of fruit piercing moth at NCRP, Paripatle, Dhankuta during 2081/82

S.N.	Treatments	Nos. of fruit damage	Nos. of FPM entrapped
1	Jaggery	13	15
2	Neem oil	50	0
3	Net	5	0
4	Banana bait	66	47
5	Bagging	0	0
6	HMO	55	0
7	Light	0	2
8	Control	43	0

Overall, physical methods such as bagging and netting proved to be the most effective strategies for managing fruit piercing moth in citrus. Although baiting techniques, particularly banana bait, showed high trapping potential, their effectiveness in reducing fruit damage depends on proper trap management and integration with other control measures. These findings emphasize the importance of integrated pest management (IPM) approaches combining physical exclusion and behavioral control methods for sustainable management of FPM.

3.4 Crop husbandry

3.4.1 High density planting trial of mandarin orange

Methodology

'Khoku Local' mandarin saplings, grafted onto trifoliate orange rootstock were transplanted in 2068 at Dhunge block of NCRP, Paripatle orchard which is located 1,300 masl altitude. The saplings were planted at eight different spacing. The plants were replicated three times in terraced land. The vegetative growth, yield and yield contributing parameters as well as physicochemical data were recorded and analyzed with the help of R studio program.

Results and discussion

Yield and fruit quality parameters of 'Khoku Local' mandarin under different planting densities

The data presented in Table 16 indicate that planting density had non-significant (NS) effects on most fruit quality attributes, except for the number of segments per fruit, which was significantly influenced ($P<0.05$). However, notable numerical variations were observed across treatments for yield and yield-contributing traits.

Fruit physical characteristics

Fruit weight ranged from 98.30 g (1.50 × 3.00 m) to 108.00 g (1.15 × 3.00 m), with a grand mean of 102.84 g. Although closer spacing (1.15 × 3.00 m) produced relatively heavier fruits, the variation was statistically non-significant, suggesting that fruit size in mandarin is largely governed by genetic factors rather than spacing alone. Similar non-significant trends were observed for fruit diameter (60.40–62.00 mm) and fruit height (51.50–53.10 mm) (Table 19).

Peel thickness varied from 2.01 mm to 2.27 mm, with the highest value recorded at 1.50 × 3.00 m. Despite slight differences, the non-significant F-test indicates that planting density did not markedly affect rind development. This implies that peel characteristics are relatively stable across spacing levels, likely due to inherent varietal traits and physiological buffering.

Internal fruit quality

The number of segments per fruit showed a significant response to planting density, ranging from 9.25 to 9.95 segments. The highest segment number was recorded at 1.15 × 3.00 m (9.95), which was statistically superior to wider spacings such as 2.50 × 3.00 m (9.25). This suggests that closer spacing may enhance segment development, possibly due to mild competition-induced physiological adjustments that favor internal fruit differentiation.

In contrast, the number of seeds per fruit (11.40–13.10) was not significantly affected. The highest seed count was observed at 1.50 × 3.00 m, while the lowest was at 1.15 × 3.00 m, but the differences were within the experimental variability (CV=8.72%). This indicates that seed formation is less sensitive to planting density and more influenced by pollination dynamics and genetic factors.

Yield-contributing traits

A wide variation was observed in the number of fruits per tree, ranging from 179 (1.15 × 3.00 m) to 363 (2.50 × 3.00 m). Generally, wider spacing tended to increase fruit number per tree due to reduced inter-plant competition, allowing better canopy expansion, light interception, and assimilate availability.

However, despite higher fruit numbers at wider spacing, yield per hectare showed a different trend. The highest yield (58.90 mt ha^{-1}) was recorded at 1.80 × 3.00 m, followed by 1.15 × 3.00 m (55.60 mt ha^{-1}) and 1.75 × 3.00 m (51.00 mt ha^{-1}). The lowest yield (26.80 mt ha^{-1}) was obtained at the widest spacing (3.00 × 3.00 m).

This inverse relationship between fruit number per tree and yield per hectare highlights the importance of plant population density. Although individual trees at wider spacing produced more fruits, the reduced number of trees per unit area significantly lowered total productivity. Conversely, closer spacing increased plant population, compensating for lower fruit numbers per tree and ultimately enhancing yield per hectare.

Variability and experimental precision

The coefficient of variation (CV) was relatively low for fruit quality parameters (2.63–8.30%), indicating good experimental precision. However, higher CV values for number of fruits per tree (49.33%) and yield (45.91%) suggest greater variability in yield-related traits, possibly due to tree-to-tree differences, micro-environmental variation, or management factors.

Overall interpretation

The findings clearly demonstrate that planting density plays a crucial role in optimizing yield rather than fruit quality in ‘Khoku Local’ mandarin. While most quality attributes remained unaffected, moderately closer spacing (1.80 × 3.00 m) proved optimal for maximizing yield per hectare. Extremely close spacing (1.15 × 3.00 m) also performed well but may lead to long-term competition issues, whereas wider spacing reduced overall productivity despite higher per-tree performance.

Table 19. Yield and fruit quality parameters of 'Khoku Local' mandarin under various planting densities at NCRP, Paripatle, Dhankuta during 2081/82

Spacing (m)	Fruit weight (g)	Fruit diameter (mm)	Fruit height (mm)	Peel thickness (mm)	Nos. of segments	Nos. seed per fruit	Nos. fruits per tree	Yield (mt ha^{-1})
1.15×3.00	108.00	61.40	53.10	2.13	9.95	11.40	179.00	55.60
1.50×3.00	98.30	60.40	52.70	2.27	9.65	13.10	215.00	47.80
1.75×3.00	101.00	60.60	52.00	2.22	9.72	11.90	258.00	51.00
1.80×3.00	104.00	60.70	52.60	2.14	9.90	12.30	316.00	58.90
2.25×3.00	104.00	60.90	51.80	2.08	9.78	12.60	274.00	42.30
2.50×3.00	102.00	60.80	51.50	2.04	9.25	12.60	363.00	49.10
3.00×3.00	105.00	62.00	52.10	2.11	9.28	12.70	231.00	26.80
3.50×3.00	101.00	60.70	53.00	2.01	9.38	11.80	300.00	28.70
Grand Mean	**102.84**	**60.93**	**52.33**	**2.13**	**9.61**	**12.28**	**266.96**	**45.04**
LSD (P<0.05)	-	-	-	-	0.40	-	-	-
F-test	NS	NS	NS	NS	**	NS	NS	NS
CV (%)	7.07	2.63	3.67	8.30	2.80	8.72	49.33	45.91

Physicochemical properties of 'Khoku Local' mandarin under different planting densities

The data presented in Table 20 reveal that planting density had a non-significant (NS) effect on all measured physicochemical attributes of 'Khoku Local' mandarin, including Juice content, Total soluble solids(TSS), Titratable acidity (TA), DA meter readings, and Chlorophyll content index (CCI). This indicates that fruit biochemical composition remained relatively stable across different spacing regimes

Juice content

Juice content ranged from 38.10 ml (1.50 × 3.00 m) to 47.10 ml (3.00 × 3.00 m), with a grand mean of 42.50 ml. Similarly, juice percentage varied from 38.30% to 45.30%, with the highest value recorded at the widest spacing (3.00 × 3.00 m). Although wider spacing tended to produce fruits with slightly higher Juice content and percentage, the differences were statistically non-significant.

This trend may be attributed to reduced inter-plant competition at wider spacing, allowing better water uptake and assimilate partitioning into fruit juice. However, the absence of statistical significance suggests that juice characteristics are relatively insensitive to planting density and are more influenced by genetic and environmental factors.

Total soluble solids (TSS)

TSS values ranged narrowly between 11.00% and 11.30%, with a mean of 11.14%, indicating minimal variation among treatments. The highest TSS (11.30%) was observed at 1.80 × 3.00 m, while the lowest (11.00%) was recorded at 1.15 × 3.00 m and 3.00 × 3.00 m.

The very low coefficient of variation (CV = 0.99%) further confirms the consistency of TSS across different planting densities. This suggests that sugar accumulation in mandarin fruits is largely governed by varietal characteristics and maturity stage rather than spacing.

Titratable acidity (TA)

Titratable acidity ranged from 0.79% to 0.89%, with the highest acidity recorded at 2.25 × 3.00 m (0.89%) and the lowest at 1.80 × 3.00 m (0.79%). Despite these numerical differences, the variation was statistically non-significant, indicating that planting density did not significantly influence acid metabolism in the fruits.

The balance between TSS and TA is crucial for fruit taste, and the relatively narrow range observed here suggests uniform flavor quality across all treatments.

DA meter readings and chlorophyll content index (CCI)

DA meter readings (an indicator of chlorophyll degradation and fruit maturity) ranged from 0.05 to 0.17, while CCI values varied between 9.66 and 10.80. The highest CCI (10.80) was recorded at 3.00 × 3.00 m, indicating slightly better peel coloration at wider spacing, possibly due to improved light penetration within the canopy.

However, the high coefficient of variation for DA meter readings (CV = 68.97%) suggests considerable variability and lower precision for this parameter. Despite this, the non-significant F-test indicates that planting density did not exert a consistent effect on fruit maturity indices.

Overall interpretation

The results clearly demonstrate that planting density does not significantly affect the physicochemical quality of ‘Khoku Local’ mandarin fruits. While minor numerical differences were observed—such as higher Juice content and better coloration at wider spacing—these variations were not statistically meaningful.

This stability in fruit quality across spacing levels suggests that growers can optimize planting density primarily for yield (as observed in Table 16) without compromising internal fruit quality attributes such as sweetness, acidity, and Juice content.

Table 20. Physicochemical properties of ʻKhoku Localʼ mandarin under various planting densities at NCRP, Paripatle, Dhankuta during 2081/82

Spacing (m)	Juice (ml)	Juice (%)	TSS (%)	TA (%)	DA Meter	CCI
1.15×3.00	41.00	38.30	11.00	0.83	0.17	10.50
1.50×3.00	38.10	41.30	11.20	0.82	0.05	10.30
1.75×3.00	41.20	41.00	11.10	0.81	0.12	10.50
1.80×3.00	41.20	39.90	11.30	0.79	0.11	9.66
2.25×3.00	45.00	44.30	11.10	0.89	0.16	10.30
2.50×3.00	44.60	44.20	11.10	0.81	0.11	9.93
3.00×3.00	47.10	45.30	11.0	0.82	0.06	10.80
3.50×3.00	41.70	42.20	11.10	0.81	0.15	10.30
Grand mean	**42.50**	**42.06**	**11.14**	**0.82**	**0.12**	**10.26**
LSD (P<0.05)	-	-	-	-	-	-
F-test	NS	NS	NS	NS	NS	NS
CV (%)	12.08	8.80	0.99	7.09	68.97	5.36

3.4.2 Effect of different rootstocks on growth and yield of major citrus crops

Rootstocks and scions are the foundations of many tree fruit industries of the world. Together, those components establish profitability, but it can be argued that the rootstock is the critical component; otherwise, scions would be grown on their own roots everywhere. There is no precedent for the failure of the citrus industry because of an inadequate scion variety, but serious problems have occurred because of a less than satisfactory rootstock. A rootstock primarily provides a reduction in juvenility (time to bearing) and tree vigor when compared with seedling trees; thus, citrus trees propagated with a rootstock combined with a pathogen-free scion bring a much-improved degree of uniformity and consistency to an orchard. They influence various horticultural traits and provide tolerance to pests and diseases and certain soil and site conditions that contribute significantly to orchard profitability. Also important are rootstock nursery traits such as the degree of nucellar embryony that is related to the ease, expense, and consistency of propagation.

3.4.2.1 Effect of different rootstocks on 'Khoku Local' mandarin

Methodology

The trial was established with planting two years old sapling of Mandarin cv. Khoku local grafted saplings in FY 2063/64 in NCRP orchard at an altitude of 1,250 masl. Eight species of rootstocks were used while preparing saplings as shown below. The saplings were planted at the spacing of 3m × 3 m with six replications.

Table 21. Treatment details of the experiment "Effect of different rootstocks on 'Khoku Local' mandarin" conducted at NCRP, Paripatle, Dhankuta during 2081/82

S.N.	Rootstock	Scion
1	Carrizo Citrange	Mandarin cv 'Khoku Local'
2	Citrange C-35	Mandarin cv 'Khoku Local'
3	Citrumelo 4475	Mandarin cv 'Khoku Local'
4	Flying Dragon	Mandarin cv 'Khoku Local'
5	Poncerous-Pomeroy	Mandarin cv 'Khoku Local'
6	Trifoliate	Mandarin cv 'Khoku Local'
7	Volkameriana	Mandarin cv 'Khoku Local'
8	Rangpur lime	Mandarin cv 'Khoku Local'

Result and discussion

The present study on the effect of different rootstocks on Khoku Local mandarin demonstrated significant variation in fruit physical characteristics, while yield and number of fruits per tree were found to be non-significant. The F-test revealed highly significant differences ($P<0.001$) for fruit weight, diameter, height, peel thickness, and seed number, and significant differences ($P<0.01$) for number of segments per fruit. However, the number of fruits per tree and yield (mt ha^{-1}) were non-significant, indicating that rootstock had a stronger influence on fruit quality attributes than on productivity under the given conditions (Table 22 & 23).

Fruit weight and size attributes

Fruit weight varied significantly among rootstocks, ranging from 91.20 g (Rangpur Lime Red) to 150.00 g (Flying Dragon), with a mean of 116.43 g. Rootstocks such as Flying Dragon (150.00 g), Trifoliate (124.00 g), and Citrumelo-4475 (123.00 g) produced significantly larger fruits. This was further supported by higher fruit diameter and height, where Flying Dragon recorded the maximum diameter (70.30 mm) and height (60.00 mm) (Table 22).

In contrast, Rangpur Lime Red produced the smallest fruits in terms of both weight and size parameters. The low coefficients of variation for diameter (2.16%) and height (3.44%) indicate that these traits are largely genetically controlled and reliably influenced by rootstock.

Peel thickness

Peel thickness ranged from 1.85 mm (Rangpur Lime Red) to 2.59 mm (Flying Dragon), with a mean of 2.21 mm. Rootstocks such as Flying Dragon (2.59 mm), Citrumelo-4475 (2.44 mm), and Rough Lemon (2.44 mm) exhibited thicker peels, which may enhance fruit durability and storage potential. Conversely, thinner peel observed in Rangpur Lime Red (1.85 mm) and Trifoliate (1.98 mm) may be advantageous for consumer preference due to ease of peeling. The moderate CV (6.50%) suggests a balanced influence of genetic and environmental factors on this trait.

Number of segments and seeds per fruit

The number of segments per fruit showed limited variation (9.24 to 10.40), with a mean of 9.93. Rootstocks such as Citrange-Carrizo and Rough Lemon recorded the highest number of segments (10.40), while Citrumelo-4475 showed the lowest (9.60). The low CV (4.16%) indicates that this trait is relatively stable.

Seed number per fruit varied significantly from 10.50 (Citrange-Carrizo) to 14.60 (Citrumelo-4475). Lower seed numbers were observed in Citrange-Carrizo and Trifoliate (11.00), which is a desirable trait for fresh consumption. In contrast, higher seed numbers in Citrumelo-4475 (14.60) and Rough Lemon (13.60) may reduce consumer preference. The moderate CV (10.58%) indicates some environmental influence.

Number of fruits per tree and yield

The number of fruits per tree ranged widely from 90.00 (Rough Lemon) to 368.00 (Citrumelo-4475), with a very high coefficient of variation (81.96%). Similarly, yield ranged from 10.70 $^{mt\ ha-1}$ (Citrange C-35) to 50.40 mt ha^{-1} (Citrumelo-4475), with a CV of 83.49%. Despite these large numerical differences, the statistical analysis indicated non-significant effects of rootstock on these parameters. This suggests that the observed variability in yield and fruit number may be largely attributed to environmental factors, management practices, or tree-to-tree variation rather than rootstock effects alone.

Relationship between rootstock and yield components

Although rootstock significantly influenced fruit size and quality traits, its effect on yield was inconsistent. For instance, Citrumelo-4475 produced the highest number of fruits per tree (368.00) and the highest yield (50.40 mt ha^{-1}), but this effect was not statistically significant. Similarly, Flying Dragon produced the largest fruits but did not translate this into higher yield. This indicates that while rootstock can enhance fruit quality attributes such as size and peel thickness, its direct impact on yield may be limited or influenced by other interacting factors such as scion-rootstock compatibility, nutrient uptake efficiency, and environmental conditions.

Overall performance and implications

Among the rootstocks, Citrumelo-4475 showed promising performance in terms of higher fruit number and yield, along with acceptable fruit size. Flying Dragon was superior for fruit size attributes but less effective in enhancing yield. Citrange-Carrizo and Trifoliate demonstrated balanced performance with moderate fruit size and lower seed content, making them suitable for quality fruit production. Rangpur Lime Red and Rough Lemon were inferior in terms of fruit size and yield, suggesting limited suitability for improving Khoku Local mandarin performance under the tested conditions.

Table 22. Fruit quality parameters of mandarin ʻKhoku Localʼ grafted onto different rootstocks at NCRP, Paripatle, Dhankuta during 2081/82

Rootstock	Fruit weight (g)	Fruit diameter (mm)	Fruit height (mm)	Peel thickness (mm)	Nos. of Segment	Nos. seed $fruit^{-1}$	Nos. of fruit $tree^{-1}$	Yield (mt ha^{-1})
Citrange C-35	97.00	59.30	52.00	2.20	10.20	12.00	98.40	10.70
Citrange-Carrizo	119.00	63.80	53.10	2.08	10.40	10.50	119.00	16.20
Citrumelo- 4475	123.00	66.50	53.50	2.44	9.60	14.60	368.00	50.40
Flying Dragon	150.00	70.30	60.00	2.59	9.96	11.40	112.00	16.40
Poncirus- Pomeroy	117.00	62.70	54.70	2.27	10.10	12.50	236.00	33.10
Rangpur Lime red	91.20	57.20	49.80	1.85	9.24	12.40	197.00	20.30
Rough Lemon	117.00	63.90	53.60	2.44	10.40	13.60	90.00	11.60
Trifoliate	124.00	65.30	55.70	1.98	10.20	11.00	185.00	25.00
Volkameriana	109.00	62.00	51.10	2.29	9.72	13.10	108.00	13.30
Grand mean	**116.43**	**63.4**	**53.74**	**2.21**	**9.93**	**12.17**	**177.78**	**23.17**
LSD (P<0.05)	10.82	1.77	2.40	0.19	0.53	1.67	-	-
F-test	***	***	***	***	**	***	NS	NS
CV (%)	7.18	2.16	3.44	6.50	4.16	10.58	81.96	83.49

The influence of different rootstocks on the biochemical quality parameters of Khoku Local mandarin revealed significant to highly significant variation among treatments. The F-test indicated highly significant differences ($P < 0.001$) for Juice content, Total soluble solids (TSS), Titratable acidity (TA), and DA value, while Chlorophyll content index (CCI) was significant at $P < 0.05$. These results demonstrate that rootstocks play a crucial role in modifying internal fruit quality attributes, likely through their influence on water relations, nutrient uptake, and physiological processes (Table 23).

Juice content (%)

Juice content varied significantly from 35.70% (Flying Dragon) to 50.20% (Rangpur Lime Red), with a grand mean of 45.08%. Rootstocks such as Rangpur Lime Red (50.20%), Volkameriana (49.40%), and Poncirus-Pomeroy (47.30%) enhanced juice recovery, indicating their suitability for improving processing quality. In contrast, Flying Dragon (35.70%) and Rough Lemon (37.40%) resulted in comparatively lower Juice content. This reduction may be attributed to their influence on fruit structure and dry matter accumulation. The relatively low CV (7.08%) suggests that Juice content is moderately stable and strongly influenced by rootstock selection.

Total soluble solids (TSS)

TSS ranged from 7.60% (Rough Lemon) to 10.90% (Citrange C-35), with a mean of 10.24%. Higher TSS values were recorded in Citrange C-35 (10.90%), Citrumelo-4475 (10.80%), and Flying Dragon (10.30%), indicating improved sugar accumulation and better sweetness. Rough Lemon showed a markedly lower TSS (7.60%), suggesting inferior sweetness and reduced eating quality. The low CV (2.85%) confirms that TSS is a stable trait with strong genetic and rootstock influence.

Titratable acidity (TA)

Titratable acidity varied from 0.67% (Rangpur Lime Red and Rough Lemon) to 0.95% (Trifoliate), with a mean of 0.79%. Higher acidity in Trifoliate (0.95%) and Citrumelo-4475 (0.89%) contributes to a more pronounced sour taste, while lower acidity in Rangpur Lime Red (0.67%) and Volkameriana (0.70%) results in a milder flavor. The balance between TSS and TA is critical for flavor quality. Rootstocks such as Citrange C-35 (TSS: 10.90%, TA: 0.84%) and Citrumelo-4475 (TSS: 10.80%, TA: 0.89%) likely provide a desirable sugar-acid balance. The moderate CV (12.51%) indicates some environmental influence on acidity.

Difference in absorbance (DA Value)

The DA value ranged from 0.11 (Citrumelo-4475) to 0.43 (Flying Dragon), with a mean of 0.24. Higher DA values, as observed in Flying Dragon (0.43) and Citrange-Carrizo (0.28), indicate greater chlorophyll degradation and advanced maturity. Lower DA values in Citrumelo-4475 (0.11) and Rangpur Lime Red (0.17) suggest delayed degreening or slower ripening. The relatively high CV (40.41%) indicates that DA value is highly influenced by environmental factors and may vary depending on harvest timing and climatic conditions.

Chlorophyll content index (CCI)

CCI values ranged from 8.27 (Rangpur Lime Red) to 10.50 (Poncirus-Pomeroy), with a mean of 9.41. Higher CCI values in Poncirus-Pomeroy (10.50), Flying Dragon (9.95), and Citrange-Carrizo (9.81) indicate better peel coloration, which enhances market appeal. Lower CCI values in Rangpur Lime Red (8.27) and Trifoliate (8.95) suggest comparatively less intense coloration. However, the relatively low CV (9.39%) indicates moderate stability of this trait.

Overall quality assessment

The results indicate that rootstocks significantly influence fruit internal quality, and no single rootstock excelled across all parameters. Rangpur Lime Red and Volkameriana were superior in enhancing Juice content but had comparatively lower TSS. Citrange C-35 and Citrumelo-4475 showed higher TSS and moderate acidity, indicating better flavor balance. Poncirus-Pomeroy exhibited the highest CCI value, suggesting improved external appearance, along with moderate Juice content and acceptable TSS. Flying Dragon, while promoting earlier maturity (high DA value), resulted in lower Juice content, indicating a trade-off between maturity and juice recovery. Rough Lemon was inferior in terms of TSS and Juice content, making it less suitable for improving fruit quality despite its common use as a rootstock.

Table 23. Fruit physicochemical properties and yield characteristics of mandarin 'Khoku Local' grafted onto different rootstocks at NCRP, Paripatle, Dhankuta during 2081/82

Rootstock	Juice (%)	TSS (%)	TA (%)	DA value	CCI value
Citrange C-35	46.50	10.90	0.84	0.21	8.96
Citrange-Carrizo	44.10	10.10	0.74	0.28	9.81
Citrumelo-4475	42.30	10.80	0.89	0.11	9.67
Flying Dragon	35.70	10.30	0.81	0.43	9.95
Poncirus-Pomeroy	47.30	10.10	0.73	0.25	10.50
Rangpur Lime red	50.20	9.39	0.67	0.17	8.27
Rough Lemon	37.40	7.60	0.67	0.26	9.21
Trifoliate	45.10	10.20	0.95	0.26	8.95
Volkameriana	49.40	10.10	0.70	0.17	9.21
Grand mean	**45.08**	**10.24**	**0.79**	**0.24**	**9.41**
LSD (P<0.05)	4.13	0.38	0.13	0.12	1.44
F-test	***	***	***	***	*
CV (%)	7.08	2.85	12.51	40.41	9.39

3.4.2.2 Effect of different rootstocks on 'Tehrathum Local' acid lime

Methodology

The trial was established with planting two years old acid lime 'Terhathum Local' grafted saplings in FY 2063/64 in NCRP orchard at an altitude of 1250 masl. Eight species of rootstocks were used while preparing saplings as shown below. The saplings were planted at the spacing of 3m × 3 m with six replications (Table 24).

Table 24. Treatment details of the experiment "Effect of different rootstocks on 'Tehrathum Local' acid lime" conducted at NCRP, Paripatle, Dhankuta during 2081/82

S.N.	Rootstock	Scion
1	Citrange-C 35	Tehrathum Local
2	Citrange-Carizzo	Tehrathum Local
3	Citron	Tehrathum Local
4	Citrumelo 4475	Tehrathum Local
5	Flying Dragon	Tehrathum Local

6	Poncerous-Pomeroy	Tehrathum Local
7	Rangpur lime	Tehrathum Local
8	Volkamerina	Tehrathum Local

Results and discussion

The present investigation on the effect of different rootstocks on 'Tehrathum Local' acid lime revealed highly significant differences (P<0.001) for all studied traits, including fruit physical attributes, seed content, and yield parameters. This indicates a strong influence of rootstock on both fruit quality and productivity, highlighting the importance of rootstock selection in acid lime cultivation under Nepalese conditions.

Fruit weight and size attributes

Fruit weight varied significantly from 38.90 g (Trifoliate) to 52.60 g (Rough Lemon), with a grand mean of 44.45 g. Rootstocks such as Rough Lemon (52.60 g), Poncirus Pomeroy (46.70 g), and Flying Dragon (46.50 g) produced comparatively larger fruits. Similarly, fruit diameter ranged from 40.40 mm (Citrange Carrizo) to 45.00 mm (Rough Lemon), with the highest values observed in Rough Lemon (45.00 mm) and Trifoliate (44.10 mm).

The relatively low coefficients of variation for fruit weight (4.97%) and diameter (2.06%) suggest that these traits are largely governed by genetic and rootstock effects with minimal environmental influence.

Peel thickness

Peel thickness showed significant variation, ranging from 1.51 mm (Trifoliate) to 2.37 mm (Flying Dragon), with a mean of 1.84 mm. Rootstocks such as Flying Dragon (2.37 mm) and Citrumelo-4475 (2.30 mm) produced thicker peels, which may enhance fruit durability and shelf life. In contrast, thinner peel in Trifoliate (1.51 mm) and Citrange Carrizo (1.54 mm) may be advantageous for juice extraction and consumer preference. The moderate CV (10.01%) indicates a combination of genetic and environmental influence on this trait.

Seed content

The number of seeds per fruit varied from 4.10 (Citrange C-35) to 6.90 (Flying Dragon), with a mean of 5.46. Rootstocks such as Citrange C-35 (4.10), Trifoliate (4.25), and Volkameriana (4.50) resulted in lower seed content, which is desirable for consumer preference. In contrast, Flying Dragon (6.90), Rough Lemon (6.65), and Poncirus Pomeroy (6.40) produced higher seed numbers. The relatively higher CV (18.27%) indicates moderate variability and environmental influence on seed development.

Yield per tree and yield

Yield per tree ranged from 3.98 kg (Rough Lemon) to 8.09 kg (Rangpur Lime), with a mean of 6.64 kg. Similarly, yield per hectare ranged from 4.42 mt ha^{-1} (Rough Lemon) to 8.98 mt ha^{-1} (Rangpur Lime), with a mean of 7.38 mt ha^{-1}. Rangpur Lime (8.98 mt ha^{-1}) and Volkameriana (8.71 mt ha^{-1}) recorded the highest yields, followed by Poncirus Pomeroy (8.22 mt ha^{-1}) and Flying Dragon (8.09 mt ha^{-1}). These rootstocks demonstrated superior performance in enhancing productivity of 'Tehrathum Local' acid lime. In contrast, Rough Lemon, despite producing the largest fruits, recorded the lowest yield (4.42 mt ha^{-1}), indicating that larger fruit size did not translate into higher productivity. This may be due to reduced fruit number or poor scion-rootstock compatibility affecting overall yield.

Relationship between fruit size and yield

The results indicate a lack of direct positive correlation between fruit size and yield. Rootstocks such as Rough Lemon produced larger fruits but had significantly lower yield, while Rangpur Lime and Volkameriana produced moderate-sized fruits with higher yields. This suggests that yield in acid lime is influenced more by overall tree performance, including fruit set and retention, rather than individual fruit size alone. Efficient assimilate partitioning and compatibility between scion and rootstock likely play key roles in determining productivity.

Overall performance and implications

Among the evaluated rootstocks, Rangpur Lime emerged as the most promising due to its highest yield per tree and per hectare, along with acceptable fruit size and moderate seed content. Volkameriana and Poncirus Pomeroy also demonstrated superior yield performance with balanced fruit characteristics. Flying Dragon produced larger fruits with higher peel thickness but moderate yield, indicating its suitability for quality-oriented production. Citrange C-35 and Trifoliate showed advantages in reducing seed content but had comparatively lower yields. Rough Lemon was inferior in terms of yield despite producing larger fruits, suggesting limited suitability for enhancing productivity of 'Tehrathum Local' acid lime under the tested conditions.

Table 25. Fruit quality and yield parameter of acid lime 'Tehrathum Local' grafted onto different rootstocks at NCRP, Paripatle, Dhankuta during 2081/82

Rootstock	Fruit weight (g)	Fruit diameter (mm)	Peel thickness (mm)	No. of seed per fruit	Yield per tree (kg)	Yield (mt ha^{-1})
Citrange C-35	41.5	41.6	1.71	4.1	6.21	6.9
Citrange carrizo	40.8	40.4	1.54	4.55	6.39	7.1
Citrumelo-4475	44.6	41.1	2.3	6.15	6.58	7.31
Flying Dragon	46.5	43.9	2.37	6.9	7.28	8.09
Poncirus Pomeroy	46.7	43.3	1.71	6.4	7.4	8.22
Rangpur Lime	43.3	42.1	1.98	5.65	8.09	8.98
Rough Lemon	52.6	45	1.72	6.65	3.98	4.42
Trifoliate	38.9	44.1	1.51	4.25	5.98	6.64
Volkameriana	45.1	42.1	1.73	4.5	7.84	8.71
Grand mean	**44.45**	**42.63**	**1.84**	**5.46**	**6.64**	**7.38**
LSD (P<0.05)	3.22	1.28	0.27	1.46	1.57	1.75
F-test	***	***	***	***	***	***
CV (%)	4.97	2.06	10.01	18.27	16.24	16.25

Physicochemical parameters

The evaluation of biochemical quality parameters of 'Tehrathum Local' acid lime as influenced by different rootstocks revealed differential effects on fruit acidity, maturity indices, and peel coloration, while Total soluble solids(TSS) remained statistically non-significant. The F-test indicated non-significant variation for TSS, significant differences (P<0.01) for Titratable acidity (TA) and Chlorophyll content index (CCI), and highly significant differences (P<0.001) for DA value. This suggests that rootstocks exert a stronger influence on fruit maturity and acidity than on sugar accumulation (Table 26).

Total soluble solids (TSS)

TSS ranged narrowly from 7.44% (Volkameriana) to 7.88% (Trifoliate), with a grand mean of 7.62%, and the differences were statistically non-significant. This indicates that sugar accumulation in acid lime is largely independent of rootstock influence under the given conditions. The low coefficient of variation (3.07%) further confirms the stability of TSS, suggesting strong genetic control by the scion rather than modification by rootstock. Thus, selection of rootstock may not be critical when targeting improvements in sweetness in acid lime.

Titratable acidity (TA)

Titratable acidity showed significant variation, ranging from 6.44% (Flying Dragon) to 7.49% (Citrange Carrizo), with a mean of 7.06%. Higher acidity was observed in Citrange Carrizo (7.49%), Trifoliate (7.45%), and Poncirus Pomeroy (7.35%), indicating their potential for enhancing the characteristic sourness of acid lime, which is a key quality attribute. Lower acidity in Flying Dragon (6.44%), Citrumelo-4475 (6.69%), and Rangpur Lime (6.77%) may result in comparatively milder fruits. The moderate CV (5.65%) suggests a combination of genetic and environmental influences on acidity.

Difference in absorbance (DA Value)

DA value varied significantly from 0.477 (Rough Lemon) to 0.958 (Citrange C-35), with a mean of 0.69. Rootstocks such as Citrange C-35 (0.958), Trifoliate (0.843), and Poncirus Pomeroy (0.80) recorded higher DA values, indicating more advanced chlorophyll degradation and fruit maturity. Conversely, lower DA values in Rough Lemon (0.477), Volkameriana (0.515), and Rangpur Lime (0.525) suggest delayed maturity or slower degreening. The relatively high CV (19.99%) indicates that DA value is influenced by both rootstock and environmental conditions.

Chlorophyll content index (CCI)

CCI values exhibited wide variation, ranging from -1.23 (Citrange C-35) to 1.85 (Rangpur Lime), with a mean of 0.19. Positive CCI values, as observed in Rangpur Lime (1.85), Citrange Carrizo (0.652), and Flying Dragon (0.615), indicate better peel coloration, while negative values in Citrange C-35 (-1.23) and Citrumelo-4475 (-0.447) indicate greener fruits. However, in acid lime, green peel coloration is often preferred in the market, and thus lower or negative CCI values may not necessarily be undesirable. The extremely high CV (436.53%) indicates substantial variability, likely due to environmental factors and sensitivity of the measurement.

Overall quality assessment

The findings suggest that rootstocks significantly influence acidity and maturity-related traits in acid lime, while having minimal impact on TSS. Rootstocks such as Citrange Carrizo and Trifoliate enhanced acidity, contributing to stronger flavor, while Citrange C-35 and Trifoliate promoted earlier maturity as indicated by higher DA values. Rangpur Lime, which was earlier identified as the highest-yielding rootstock, also showed favorable peel coloration (highest CCI) with moderate acidity, indicating a balance between yield and external quality. Flying Dragon produced fruits with lower acidity but better coloration, suggesting suitability for specific market preferences. Rough Lemon and Volkameriana exhibited lower DA values, indicating delayed maturity, which may affect harvest timing and market supply.

Table 26. Fruit physicochemical and yield parameter of acid lime ʻTehrathum Localʼ grafted onto different rootstocks at NCRP, Paripatle, Dhankuta during 2081/82

Rootstock	TSS %	TA %	DA value	CCI value
Citrange C-35	7.71	6.8	0.958	-1.23
Citrange Carrizo	7.75	7.49	0.713	0.652
Citrumelo-4475	7.69	6.69	0.742	-0.447
Flying Dragon	7.52	6.44	0.61	0.615
Poncirus Pomeroy	7.58	7.35	0.8	-0.44
Rangpur Lime	7.5	6.77	0.525	1.85
Rough Lemon	7.49	7.35	0.477	0.313
Trifoliate	7.88	7.45	0.843	0.02
Volkameriana	7.44	7.23	0.515	0.385
Grand mean	**7.62**	**7.06**	**0.69**	**0.19**
LSD (P<0.05)	-	0.58	0.2	1.22
F-test	NS	**	***	**
CV (%)	3.07	5.65	19.99	436.53

3.4.2.3 Effect of different rootstocks on ʻWashington Navelʼ sweet orange

Methodology

The trial was established with planting ʹWashington Navelʹ sweet orange grafted saplings in FY 2063/64 in NCRP orchard at an altitude of 1250 masl. Eight species of rootstocks were used while preparing 2-years old saplings as shown below. Statistical analysis of seven treatments were only possible due to lack of fruiting on three rootstock varieties though there were six replications (Table 27).

Table 27. Treatment details of the experiment "Effect of different rootstocks on ʻWashington Navelʼ sweet orange" conducted at NCRP, Paripatle, Dhankuta during 2081/82

S.N.	Rootstock	Scion
1	Citrumelo 4475	Washington Navel
2	Rangpur lime	Washington Navel
3	Trifoliate orange	Washington Navel
4	Poncerous-Pomeroy	Washington Navel

5	Volkamerina	Washington Navel
6	Carizo Citrange	Washington Navel
7	Citrange C-35	Washington Navel
8	Flying Dragon	Washington Navel

Results and discussion

The effect of different rootstocks on 'Washington Navel' sweet orange revealed significant variation in fruit physical characteristics, seed content, and yield parameters, indicating a strong influence of rootstock on both fruit development and productivity. The F-test showed significant differences (P<0.05 to P< .01) for most traits, while peel thickness was non-significant, suggesting that some quality attributes are more stable across rootstocks than others (Table 28).

Fruit weight and size attributes

Fruit weight varied significantly from 125.00 g (Poncirus-Pomeroy) to 169.00 g (Trifoliate), with a grand mean of 149.37 g. Rootstocks such as Trifoliate (169.00 g) and Citrumelo-4475 (161.00 g) produced the heaviest fruits, indicating their superior ability to enhance fruit development. In contrast, Poncirus-Pomeroy (125.00 g) resulted in comparatively smaller fruits. Similarly, fruit height ranged from 61.70 mm (Poncirus-Pomeroy) to 70.80 mm (Citrumelo-4475), and fruit diameter ranged from 61.20 mm to 68.50 mm, with Trifoliate producing the largest fruits in terms of diameter. The low coefficients of variation (3.10–6.92%) suggest that fruit size attributes are relatively stable and strongly influenced by rootstock genetics.

Peel thickness

Peel thickness ranged from 3.28 mm (Poncirus-Pomeroy) to 4.48 mm (Citrumelo-4475), with a mean of 3.76 mm. Although the differences were statistically non-significant, rootstocks such as Citrumelo-4475 (4.48 mm) and Rangpur Lime (3.97 mm) tended to produce thicker peels, which may enhance postharvest shelf life and resistance to mechanical damage.

Seed number

Seed number per fruit varied significantly, ranging from 0 (Flying Dragon) to 0.73 (Volkameriana), with a mean of 0.29. Flying Dragon produced completely seedless fruits, which is a highly desirable trait for fresh consumption. Low seed numbers were also observed in Citrumelo-4475 (0.07) and Rangpur Lime (0.19), making them favorable for improving fruit quality. Volkameriana (0.73) and Poncirus-Pomeroy (0.60) had comparatively higher seed numbers, which may reduce consumer acceptability. However, the extremely high CV (94.31%) indicates high variability and strong environmental influence on seed development.

Yield per tree and yield

Yield varied significantly among rootstocks, with Trifoliate (7.75 mt ha^{-1}) and Citrange C-35 (6.84 mt ha^{-1}) producing the highest yields, while Flying Dragon (3.83 mt ha^{-1}) recorded the lowest yield. Similarly, fruit number per tree ranged from 26.00 (Volkameriana) to 46.00 (Citrange C-35), with a mean of 34.00.

Trifoliate and Citrange C-35 demonstrated superior yield performance due to higher fruit numbers per tree, indicating better scion-rootstock compatibility and efficient assimilate partitioning. In contrast, Flying Dragon, despite producing high-quality seedless fruits, resulted in significantly lower yield, suggesting a trade-off between fruit quality and productivity. The moderate CV values for fruit number (13.39%) and yield (14.40%) indicate that these traits are influenced by both genetic and environmental factors.

Overall performance and implications

Among the tested rootstocks, Trifoliate emerged as the most productive, producing the highest yield (7.75 mt ha^{-1}) along with large fruit size and acceptable seed content. Citrange C-35 also performed well, combining high yield with good fruit quality and moderate fruit size. Flying Dragon is notable for producing completely seedless fruits, making it highly desirable for premium markets, although its lower yield limits its commercial potential. Citrumelo-4475 also showed good fruit size and relatively low seed content, along with moderate yield performance. Poncirus-Pomeroy and Volkameriana exhibited lower productivity and higher seed content, making them less favorable compared to other rootstocks under the given conditions.

Table 28. Fruit quality and yield parameters of sweet orange ʹWashington Navelʹ grafted onto different rootstocks grown at NCRP, Paripatle, Dhankuta during 2081/82

Rootstock	Fruit weight (g)	Fruit height (mm)	Fruit diameter (mm)	Peel thickness (mm)	Seed number fruit^{-1}	Nos. fruits tree^{-1}	Yield (mt ha^{-1})
Citrange C-35	140.00	63.90	63.00	3.52	0.133	46.00	6.84
Citrumelo-	161.00	70.80	66.90	4.48	0.07	29.00	5.12

4475							
Flying Dragon	153.00	66.40	66.60	3.44	0.00	28.7	3.83
Poncirus-Pomeroi	125.00	61.70	61.20	3.28	0.60	34.7	4.34
Rangpur Lime	145.00	65.30	64.10	3.97	0.19	30.00	4.62
Trifoliate	169.00	68.50	68.50	3.94	0.33	43.70	7.75
Volkameriana	153.00	67.50	65.80	3.69	0.73	26.00	4.04
Grand mean	**149.37**	**66.29**	**65.16**	**3.76**	**0.29**	**34.00**	**5.22**
LSD (P<0.05)	18.40	3.44	3.66	-	0.49	8.10	1.34
F-test	**	**	*	NS	*	***	***
CV (%)	6.92	3.10	3.15	11.47	94.31	13.39	14.40

The biochemical quality parameters of 'Washington Navel' sweet orange were significantly influenced by different rootstocks, particularly affecting Juice content, TSS, Titratable acidity, and DA value, while the Chlorophyll content index (CCI) remained non-significant. The F-test indicated highly significant differences (P<0.001) for Juice content and TA, significant differences (P<0.05–0.01) for TSS and DA value, and non-significant variation for CCI. This highlights that rootstocks have a pronounced effect on internal fruit quality rather than external coloration (Table 29).

Juice content (%)

Juice percentage varied widely from 13.30% (Citrumelo-4475) to 34.40% (Citrange C-35), with a mean of 25.41%. Rootstocks such as Citrange C-35 (34.40%), Trifoliate (31.40%), and Rangpur Lime (29.60%) produced higher Juice content, indicating their superiority in enhancing fruit juiciness and processing quality. In contrast, Citrumelo-4475 (13.30%) and Volkameriana (16.20%) showed significantly lower Juice content, suggesting reduced suitability for juice production. The moderate CV (8.66%) indicates that Juice content is relatively stable but still influenced by rootstock selection.

Total soluble solids (TSS)

TSS ranged from 9.31% (Volkameriana) to 10.90% (Citrange C-35 and Flying Dragon), with a mean of 10.46%. Rootstocks such as Citrange C-35, Flying Dragon, and Rangpur Lime maintained higher TSS levels, indicating better sugar accumulation and improved taste quality. Volkameriana (9.31%) and Trifoliate (10.10%) showed comparatively lower TSS. The relatively low CV (3.86%) indicates that TSS is a stable trait with limited environmental variation, although rootstock effects are still significant.

Titratable acidity (TA)

Titratable acidity varied significantly from 0.74% (Trifoliate) to 1.08% (Citrumelo-4475), with a mean of 0.85%. Higher acidity in Citrumelo-4475 (1.08%) and Volkameriana (0.95%) contributes to a stronger sour taste, which may be desirable for certain consumer preferences and processing uses. Lower acidity in Trifoliate (0.74%), Rangpur Lime (0.79%), and Poncirus-Pomeroy (0.79%) suggests milder taste. The low CV (3.95%) indicates that acidity is relatively stable and strongly influenced by rootstock genetics.

Difference in absorbance (DA Value)

DA value ranged from 0.05 (Poncirus-Pomeroy) to 0.19 (Volkameriana), with a mean of 0.11. Lower DA values in Poncirus-Pomeroy (0.05) and Citrange C-35 (0.07) indicate slower degreening and delayed fruit maturity, whereas higher values in Volkameriana (0.19) suggest faster chlorophyll degradation and advanced ripening. The relatively high CV (34.26%) indicates that DA value is highly variable and influenced by environmental conditions and harvest timing.

Chlorophyll content index (CCI)

CCI values ranged from 5.62 (Poncirus-Pomeroy) to 7.68 (Flying Dragon), with a mean of 6.30. Although the differences were statistically non-significant, rootstocks like Flying Dragon (7.68) and Trifoliate (7.01) tended to produce fruits with better external coloration. Lower CCI values in Poncirus-Pomeroy (5.62) and Citrumelo-4475 (5.86) indicate comparatively less color development. The non-significant F-test and moderate CV (12.52%) suggest that peel coloration is less influenced by rootstock and more by environmental or post-harvest conditions.

Overall quality assessment

The results indicate that rootstocks significantly influence Juice content, acidity, and maturity-related traits in ‘Washington Navel’ sweet orange. Citrange C-35 emerged as the best rootstock for Juice content and TSS, making it highly suitable for both fresh consumption and processing purposes. Flying Dragon maintained high TSS and good color development but showed moderate Juice content. Trifoliate and Rangpur Lime also performed well in maintaining a balance between Juice content and TSS. Citrumelo-4475 and Volkameriana showed lower Juice content and higher acidity, making them less desirable for juice-oriented production but potentially suitable for specific taste profiles.

Table 29. Fruit physicochemical and yield parameter of sweet orange ʻWashington Navelʼ grafted onto different rootstocks at NCRP, Paripatle, Dhankuta during 2081/82

Rootstock	Juice (%)	TSS (%)	TA (%)	DA value	CCI value
Citrange C-35	34.40	10.90	0.80	0.07	6.06
Citrumelo-4475	13.30	10.50	1.08	0.16	5.86
Flying Dragon	27.30	10.90	0.80	0.11	7.68
Poncirus-Pomeroi	25.60	10.80	0.79	0.05	5.62
Rangpur Lime	29.60	10.70	0.79	0.12	5.85
Trifoliate	31.40	10.10	0.74	0.10	7.01
Volkameriana	16.20	9.31	0.95	0.19	6.01
Grand mean	**25.41**	**10.46**	**0.85**	**0.11**	**6.30**
LSD (P<0.05)	3.91	0.72	0.06	0.07	-
F-test	***	**	***	*	NS
CV (%)	8.66	3.86	3.95	34.26	12.52

3.5 Citrus decline management research

Citrus decline represents a critical constraint to the sustainability and economic viability of the citrus industry in Nepal, particularly in mandarin-dominated production systems. The problem has assumed widespread severity across major citrus-growing regions, posing a serious threat to long-term productivity. As emphasized by Roistacher (1996), failure to effectively manage citrus decline could jeopardize the future of citrus cultivation in the country. One of the principal underlying causes is the establishment of citrus nurseries at elevations below 1000 meter above mean sea level, which favor the proliferation of insect vectors responsible for transmitting destructive diseases such as Huanglongbing (HLB) and Citrus tristeza virus. In addition to these viral and bacterial pathogens, the etiology of citrus decline is multifactorial, involving biotic and abiotic stresses such as root rot, inadequate orchard management practices, suboptimal edaphoclimatic conditions, and the use of inferior or infected planting materials. Nevertheless, empirical evidence suggests that the incidence and severity of citrus decline can be substantially reduced through integrated orchard management approaches. These include systematic canopy management through pruning, regulated irrigation scheduling, and effective plant protection strategies. Furthermore, balanced nutritional management—specifically the application of 300–500 g nitrogen, 200–250 g phosphorus, and 250–350 g potassium per bearing tree—has been shown to enhance tree vigor, improve physiological resilience, and mitigate decline symptoms over time. Therefore, a comprehensive, science-based management framework, encompassing the production of certified disease-free planting materials and the adoption of improved cultural and nutritional practices, is essential for sustaining citrus productivity and revitalizing orchards affected by decline.

Soil and leaf tissue analysis are essential diagnostic tools for assessing the nutritional status and overall health of citrus orchards, enabling precise and site-specific nutrient management. Soil analysis provides information on key physicochemical properties such as pH, organic matter content, cation exchange capacity, and the availability of macro- and micronutrients, thereby guiding pre-planting amendments and fertilizer recommendations. However, since soil nutrient availability does not always reflect actual plant uptake, leaf tissue analysis serves as a more reliable indicator of the tree's nutritional status. In citrus, fully expanded leaves from non-fruiting terminals—typically collected from the middle canopy during a defined growth stage—are commonly used for analysis to determine concentrations of essential nutrients such as nitrogen, phosphorus, potassium, calcium, magnesium, and trace elements. The integration of soil and leaf analysis allows for the identification of hidden deficiencies, nutrient imbalances, or toxicities that may not be visually apparent but can significantly affect growth, yield, and fruit quality. Moreover, periodic monitoring through these analyses supports the development of balanced fertilization programs, enhances nutrient use efficiency, and contributes to sustainable orchard management by preventing over- or under-application of fertilizers.

3.5.1 Determination of the soil nutrient content of declining orchard of different districts of Nepal

Methodology

Soil sampling and analysis were conducted to determine the physicochemical properties and nutrient status of the citrus orchard. Representative soil samples were collected from the rhizosphere zone of selected trees at a depth of 0–30 cm using a soil auger. To ensure uniformity, subsamples were collected from four directions around each tree canopy and composited into a single sample per experimental unit. The collected samples were air-dried under shade, ground gently using a wooden pestle, and passed through a 2 mm sieve to obtain a homogeneous sample for analysis.

The processed soil samples were analyzed for key parameters following standard procedures. Soil pH was determined using a digital pH meter in a 1:2.5 soil-to-water suspension. Organic matter content was estimated by the Walkley and Black wet oxidation method. Total nitrogen was determined using the Kjeldahl method, while available phosphorus was estimated by the Olsen extraction method using a spectrophotometer. Available potassium was determined by flame photometry after extraction with neutral ammonium acetate. Exchangeable calcium and magnesium were analyzed using titration methods, whereas micronutrients such as zinc, iron, manganese, and copper were extracted using DTPA solution and quantified using an atomic absorption spectrophotometer.

All analyses were carried out in accordance with established laboratory protocols, and the results were expressed on an oven-dry soil basis. The obtained data were used to evaluate soil fertility status and to formulate appropriate nutrient management recommendations for improving citrus growth, yield, and fruit quality.

Results and discussion

The soil analysis across four citrus-growing districts of Nepal—Dhankuta, Panchthar, Gulmi, and Dadeldhura—revealed considerable variability in soil fertility status when compared with established optimum ranges for citrus cultivation (Table 30).

Soil pH ranged from 5.5 (Dhankuta) to 6.79 (Dadeldhura). Dhankuta and Panchthar soils were slightly acidic and below the optimum range (6–7), which may limit nutrient availability, particularly phosphorus and micronutrients. In contrast, Gulmi and Dadeldhura soils fell within or near the optimal pH range, favoring better nutrient uptake.

Organic carbon content varied widely, with Gulmi (0.46%) and Dhankuta (0.79%) showing deficient levels compared to the optimum range (1.45–2.91%), indicating poor soil organic matter status and potential limitations in soil structure and microbial activity. Conversely, Dadeldhura (2.58%) exhibited adequate organic carbon, suggesting better soil health and nutrient retention capacity.

Total nitrogen (TN) was below the optimum range (0.1–0.3%) in Dhankuta (0.07%), indicating nitrogen deficiency, while Panchthar, Gulmi, and Dadeldhura had adequate levels. Available phosphorus (P_2O_5) was within the optimal range in Dhankuta and Gulmi but excessively high in Panchthar (74.52 ppm) and particularly in Dadeldhura (190.40 ppm), which may lead to nutrient imbalance and reduced micronutrient availability.

Available potassium (K_2O) was excessively high in Panchthar (373.98 ppm) and Dadeldhura (579.18 ppm), while Gulmi (99.86 ppm) was within the optimal range and Dhankuta (166.21 ppm) was slightly above optimum. Elevated potassium levels may interfere with the uptake of calcium and magnesium, potentially affecting fruit quality.

Exchangeable calcium (Ca) and magnesium (Mg) were substantially higher than the optimum ranges across all sites. While adequate Ca is beneficial for fruit development, excessive Mg levels—particularly in Dhankuta (45.41 meq/100g)—may induce nutrient antagonism and imbalance in soil cation composition.

Sulfur (S) was critically deficient in all locations (0.05–0.49 µg/g) compared to the optimum range (9–20 µg/g), indicating a widespread limitation that could adversely affect protein synthesis and enzyme activity in citrus plants. Boron (B) levels were above the optimum range in all districts, especially in Gulmi (9.18 µg/g), suggesting potential toxicity risks that may impair fruit set and quality.

Micronutrient analysis showed that iron (Fe) was deficient in Dhankuta and Gulmi, marginal in Dadeldhura, and adequate only in Panchthar. Manganese (Mn) was within the optimum range in Dhankuta and Panchthar but deficient in Gulmi and Dadeldhura. Zinc (Zn) was within the acceptable range in all sites except Gulmi, where it was slightly deficient. Copper (Cu) levels were adequate to slightly above optimum in most locations.

Table 30. Soil sample test report of declining mandarin orchard of different districts of Nepal during 2081-82

Parameters	Panchthar	Dhankuta	Gulmi	Dadeldhura	Optimum range
pH	5.67	5.5	6.31	6.79	6-7
Org. carbon (%)	1.26	0.79	0.46	2.58	1.45-2.91
TN (%)	0.11	0.07	0.11	0.18	0.1-0.3
P2O5 (ppm)	74.52	21.10	21.79	190.40	13-25
K2O (ppm)	373.98	166.21	99.86	579.18	49-125
Ca (meq/100g)	58.93	24.90	11.62	57.27	> 5.0
Mg (meq/100g)	36.66	45.41	13.66	28.05	0.5-2.5
S (µg/g)	0.22	0.49	0.05	0.47	9-20
B (µg/g)	1.21	5.11	9.18	4.75	0.5-2.0
Fe (µg/g)	60.37	31.57	22.75	50.91	50-100
Mn (µg/g)	30.99	41.44	8.55	2.51	7.5-23.2
Zn (µg/g)	2.04	1.45	0.87	1.39	0.5-1.5
Cu (µg/g)	1.33	1.72	1.39	0.64	0.5-1.0

Overall, the results indicate significant spatial variability in soil fertility, with common issues including low organic matter, sulfur deficiency, micronutrient imbalances, and excessive accumulation of certain nutrients such as phosphorus, potassium, and boron. These findings highlight the need for site-specific and balanced nutrient management strategies, including organic matter enhancement, correction of sulfur deficiency, and careful regulation of fertilizer inputs to avoid nutrient toxicity and antagonism, thereby improving citrus productivity and sustainability.

3.5.2 Determination of the leaf tissue nutrient content of declining mandarin tree of different districts of Nepal

Methodology

Leaf tissue analysis was conducted to assess the nutritional status of declining mandarin trees (*Citrus reticulata*) across different provinces of Nepal during the year 2081–82. Representative orchards exhibiting visible symptoms of decline were selected from Dhankuta, Panchthar, Gulmi, and Dadeldhura districts.

Leaf samples were collected following standard sampling protocols to ensure accuracy and uniformity. Fully expanded, healthy leaves were collected from non-fruiting terminals of the current season's growth, typically from the मध्य (middle) portion of the canopy at a height of 1.5–2.0 m above ground level. Sampling was carried out during the active growth stage, avoiding periods of flushing or stress. From each selected tree, 20–30 leaves were collected from all four directions to form a composite sample per orchard.

The collected leaf samples were first washed with tap water to remove dust and surface contaminants, followed by rinsing with distilled water. In some cases, samples were dipped briefly in a mild detergent solution and then rinsed with dilute acid (0.1 N HCl) to eliminate any adhered mineral residues. The samples were then air-dried under shade and subsequently oven-dried at 65–70°C until a constant weight was achieved. The dried samples were ground into fine powder using a stainless steel grinder and stored in airtight containers for laboratory analysis.

The powdered samples were analyzed for major nutrients including nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), and sulfur (S), as well as micronutrients such as boron (B), iron (Fe), manganese (Mn), zinc (Zn), and copper (Cu), following standard laboratory procedures. Total nitrogen was determined using the Kjeldahl digestion method. Phosphorus was estimated using the vanadomolybdate yellow color method with a spectrophotometer. Potassium was measured using a flame photometer. Calcium and magnesium were determined through titration with EDTA, while sulfur was estimated using a turbidimetric method. Micronutrients (Fe, Mn, Zn, Cu) were analyzed using an atomic absorption spectrophotometer after wet digestion of samples, whereas boron was determined using the azomethine-H colorimetric method.

The analytical results were expressed on a dry weight basis and compared with established optimum ranges for mandarin to evaluate nutrient deficiencies, sufficiencies, or toxicities associated with citrus decline. The data generated were further used for diagnosing nutrient imbalances and formulating appropriate corrective nutrient management strategies for improving orchard health and productivity.

Results and discussion

The leaf tissue analysis of mandarin orchards from different districts of Nepal revealed significant nutrient imbalances when compared with established optimum ranges, indicating a strong association between nutritional disorders and citrus decline (Table 31).

Nitrogen (N) content varied across locations, with Dhankuta (3.38%) exceeding the optimum range (2.23–2.90%), suggesting excessive vegetative growth that may reduce fruiting efficiency. Panchthar (2.46%) was within the optimum range, while Gulmi (2.15%) and Dadeldhura (2.22%) were marginally deficient, potentially contributing to reduced vigor and chlorosis symptoms in declining trees.

Phosphorus (P) levels were deficient in Dhankuta (0.04%), Panchthar (0.05%), and Gulmi (0.07%), while only Dadeldhura (0.11%) fell within the optimum range (0.10–0.13%). This widespread deficiency may limit root development, flowering, and energy transfer processes, thereby aggravating decline symptoms.

Potassium (K) was severely deficient in Dhankuta (0.19%), Panchthar (0.30%), and Gulmi (0.71%) compared to the optimum range (1.86–2.12%), whereas Dadeldhura (2.59%) showed excessive levels. Potassium deficiency is closely linked with poor fruit development, reduced stress tolerance, and increased susceptibility to diseases, which are common in declining orchards.

Calcium (Ca) and magnesium (Mg) were excessively high in all locations, far exceeding their optimum ranges. Calcium ranged from 15.94% to 27.56% (optimum: 2.12–2.42%), and magnesium from 3.52% to 6.85% (optimum: 0.28–0.40%). Such elevated levels indicate severe nutrient imbalance and possible antagonistic effects, particularly suppressing the uptake of potassium and micronutrients, thereby exacerbating decline conditions.

Sulfur (S) was critically deficient across all sites (0.009–0.02%) compared to the optimum range (0.2–0.3%), suggesting a widespread limitation that could impair protein synthesis and enzymatic functions in citrus plants.

Micronutrients analysis revealed excessive accumulation of boron (B) in all districts, particularly in Panchthar (509.41 µg/g), far above the optimum range (31–129 µg/g), indicating potential toxicity that may lead to leaf burn, reduced fruit set, and overall decline. Similarly, iron (Fe) was excessively high in all locations, especially in Dadeldhura (345.30 µg/g), which may not necessarily translate to better plant health due to possible nutrient imbalances.

Manganese (Mn) levels were within the optimum range in Dhankuta and Dadeldhura but excessively high in Panchthar (343.52 µg/g) and deficient in Gulmi (24.49 µg/g). Zinc (Zn) was deficient in Dhankuta and Panchthar, marginal in Gulmi, and adequate in Dadeldhura, indicating variability in micronutrient availability. Copper (Cu) was within the optimum range in most sites but excessively high in Dadeldhura (27.82 µg/g), which may pose toxicity risks.

Table 31. Leaf tissue analysis report of declining mandarin tree of difference districts of Nepal during 2081/82

Parameters	Panchthar	Dhankuta	Gulmi	Dadeldhura	Optimum range
N (%)	2.46	3.38	2.15	2.22	2.23-2.90
P (%)	0.05	0.04	0.07	0.11	0.10-0.13
K (%)	0.30	0.19	0.71	2.59	1.86-2.12
Ca (%)	27.56	18.92	21.08	15.94	2.12-2.42
Mg (%)	5.08	6.85	6.78	3.52	0.28-0.40
S (%)	0.009	0.012	0.01	0.02	0.2-0.3
B (µg/g)	509.41	371.78	220.72	158.61	31-129
Fe (µg/g)	177.52	236.52	163.30	345.30	60-120
Mn (µg/g)	343.52	38.46	24.49	49.07	25-200
Zn (µg/g)	15.48	19.25	27.12	25.94	25-100
Cu (µg/g)	6.69	10.48	10.36	27.82	5-16

Overall, the results clearly demonstrate that citrus decline in these regions is strongly associated with severe nutrient imbalances rather than simple deficiencies. The coexistence of deficiencies (P, K, S, Zn) and toxicities (B, Fe, Ca, Mg) suggests disrupted nutrient uptake and internal imbalance within the plant system. These findings highlight the necessity for balanced and site-specific nutrient management strategies, including correction of deficiencies, avoidance of excessive fertilizer application, and regular monitoring through leaf analysis to restore orchard health and productivity.

3.5.3 Evaluation of effectiveness of guava inter-cropping on HLB infection

Citrus greening disease, commonly referred to as Huanglongbing (HLB), is widely recognized as one of the most destructive and incurable diseases affecting citrus globally. The disease is caused by phloem-restricted, motile bacteria belonging to the genus Candidatus Liberibacter spp. and is primarily transmitted by two psyllid vectors: the Diaphorina citri and the Trioza erytreae. In addition to vector-mediated transmission, HLB can spread through grafting, making the use of infected planting materials a critical pathway for disease dissemination. Infected trees exhibit a range of characteristic symptoms, including vein yellowing, blotchy and asymmetrical leaf mottling, stunted growth, twig dieback, and root degeneration. Advanced stages are marked by off-season flowering and eventual tree mortality. Fruits from infected trees are typically small, deformed, and possess a thick rind that remains green at maturity, accompanied by poor juice quality and a bitter taste. Although these symptoms often resemble nutrient deficiencies, HLB can be distinguished by its asymmetrical leaf chlorosis, whereas nutrient deficiencies generally produce symmetrical patterns.

In Nepal, citrus decline was first documented in the Pokhara Valley in 1968 and was subsequently identified as HLB. The disease is believed to have been introduced through infected planting materials from Sharanpur, highlighting the role of unregulated nursery practices in its spread. Subsequent surveys have confirmed the widespread occurrence of HLB across major citrus-growing regions, with initially higher severity in western areas, although recent observations indicate a rapid expansion in eastern regions as well. In response, the National Citrus Research Program (NCRP) has been promoting integrated and eco-friendly disease management strategies. One such approach, implemented in the Ilam district (Godak area) since fiscal year 2073/74, involves intercropping guava within mandarin orchards. This practice is based on the premise that guava plants release volatile organic compounds that may repel psyllid vectors, thereby reducing vector population pressure and limiting HLB transmission. Such integrated pest and disease management strategies, particularly those incorporating repellent intercrops, hold considerable potential for mitigating the spread of HLB and improving the sustainability of citrus production systems in Nepal.

Methodology

In the first year of the study, 20 guavas (*Psidium guajava*) plants were established in the experimental field at a spacing of 3 m × 3 m. In the subsequent year, 20 mandarins (*Citrus reticulata*) saplings were intercropped within the same field, maintaining the same spatial arrangement. The study was designed to evaluate the role of guava intercropping in managing citrus psyllid populations and reducing the incidence of citrus greening disease, Huanglongbing (HLB).

To monitor the population dynamics of psyllid vectors, yellow sticky traps were installed within the orchard, and observations were recorded at weekly intervals from *Falgun* to *Bhadra*. These traps were strategically placed within the canopy to capture adult psyllids and to assess fluctuations in their population over time. In parallel, the incidence and progression of HLB symptoms were periodically recorded through systematic field observations of infected trees, including visual assessment of leaf mottling, yellowing, and growth abnormalities.

To further validate the effectiveness of guava intercropping under different agro-ecological conditions, a parallel trial was established in the Bhuwaneshori area of Sindhuli, a known HLB hotspot. The same experimental design, including guava–mandarin intercropping at 3 m × 3 m spacing, along with identical monitoring protocols for psyllid population and disease incidence, was implemented at this site. This comparative approach allowed for the evaluation of the consistency and robustness of guava intercropping as a potential eco-friendly and preventive strategy for suppressing psyllid vectors and mitigating the spread of HLB across different citrus-growing regions.

Results and discussion

In the 9th year following the intercropping of mandarin with guava, the population of citrus psyllids was recorded at very low levels within the research plot, indicating a reduced vector presence under the intercropping system. Despite the low psyllid incidence, symptoms consistent with Huanglongbing (HLB) were observed in some trees, suggesting that disease transmission had occurred, albeit at a limited level. Similarly, in the parallel trial site, observations made during the 8th year after mandarin plantation revealed only a very small population of citrus psyllids. However, a few plants tested or observed positive for HLB symptoms, confirming the presence of the disease in the orchard. These findings indicate that although guava intercropping may contribute to the reduction of psyllid populations, it does not completely prevent the occurrence of

HLB under field conditions, highlighting the need for integrated insect pest and disease management strategies for controlling HLB in mandarin groves.

3.5.4 Monitoring of citrus psylla

Methodology

Yellow sticky traps provided with acetic acid were used for monitoring Asian citrus psylla in Dhankuta. Traps were installed at different altitudes ranging from 1,102 masl to 1,311 masl. Installation of the traps started in the month of Falgun and continued until Shravan. Each trap was replaced every 15 days from the date of the first installation with a new one.

Results and discussion

The monitoring of citrus psylla (Asian citrus psyllid, Diaphorina citri) across different elevations in Dhankuta revealed marked temporal and spatial variation in population abundance (Figure 2). The number of ACP recorded varied significantly across months and altitudinal gradients, indicating a strong influence of climatic conditions and host phenology on pest dynamics.

Altitudinal variation in ACP population

Across all observation periods, ACP populations were unevenly distributed along the elevation gradient (1102 m to 1311 m). The mid-altitude range (1250–1290 m) consistently supported higher psylla populations compared to lower (1102 m) and higher elevations (1311 m). For instance, the highest peak population (14 individuals) was recorded at 1290 m during Ashwin 14, followed by 12 individuals at 1250 m during Baisakh 14. In contrast, the highest elevation (1311 m) recorded negligible to zero ACP populations during most observation dates, except minor occurrences (2–3 individuals) during Jestha and Shrawan.

This trend suggests that mid-altitudes in Dhankuta provide a more favorable microclimate for ACP survival and reproduction. Moderate temperature regimes and suitable humidity at these elevations may enhance psyllid development, whereas lower populations at higher elevations could be attributed to cooler temperatures limiting insect activity and reproduction.

Seasonal fluctuation of ACP population

A clear seasonal pattern in ACP abundance was observed. The population was relatively higher during early summer (Baisakh–Jestha) and again showed a notable increase during early autumn (Ashwin). For example, at 1250 m, ACP numbers peaked in Baisakh (12 individuals) and Shrawan (10 individuals), while at 1290 m, a sharp increase was observed in Ashwin (14 individuals).

Conversely, populations declined during peak monsoon months (Shrawan–Bhadra) at certain elevations, such as 1102 m and 1274 m, where counts dropped to as low as 2–4 individuals. This reduction could be linked to heavy rainfall, which may physically dislodge nymphs and adults or negatively affect survival rates.

The resurgence of ACP during Ashwin across several elevations (notably 1290 m) indicates a strong association with post-monsoon vegetative flush in citrus plants. New flush growth is known to attract psyllids for feeding and oviposition, thereby increasing population density.

Interaction between elevation and season

The interaction between elevation and seasonal variation was evident. While mid-altitudes consistently showed higher ACP populations, the timing of peak infestation varied slightly across elevations. For instance:

- At 1102 m, the highest population was observed during Ashad (8 individuals), followed by a gradual decline.
- At 1250 m, two distinct peaks occurred in Baisakh and Shrawan.
- At 1290 m, the population sharply increased in Ashwin, indicating a delayed peak compared to lower elevations.

Such variation suggests that phenological stages of citrus and microclimatic conditions differ along elevation gradients, influencing ACP population dynamics.

Implications for pest management

The observed patterns highlight that ACP management strategies in Dhankuta should be both site-specific and season-specific. Mid-altitude orchards (1250–1290 m) are particularly vulnerable and require intensified monitoring. The critical periods for intervention appear to be:

- **Spring (Baisakh–Jestha):** initial population build-up
- **Post-monsoon (Ashwin):** peak infestation period

Targeting these windows with integrated pest management (IPM) approaches—such as timely insecticide application, biological control, and flush management—could significantly reduce ACP populations and associated risks of citrus greening disease (HLB).

Conclusion

The study demonstrates that citrus psylla populations in Dhankuta are strongly influenced by both elevation and seasonal factors. Mid-altitudes favor higher infestation levels, while population peaks correspond with periods of active vegetative growth. Understanding these dynamics is crucial for developing effective, location-specific management strategies to mitigate ACP-related crop losses.

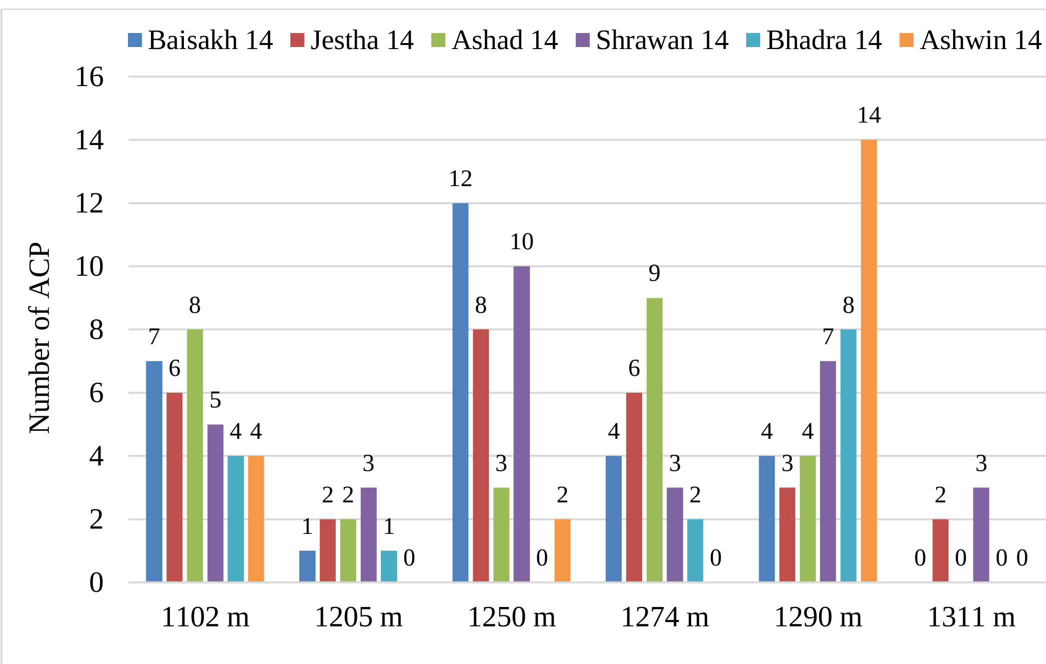

Figure 2. Population dynamics of the Asian citrus psyllid across different altitudes during 2082 at Dhankuta, Nepal

3.6 Identification of appropriate harvesting date of early and late maturing sweet orange

3.6.1 Identification of appropriate harvest date of 'Washington Navel'

Methodology

The experiment was conducted at the National Citrus Research Program to determine the optimum harvesting stage of 'Washington Navel' sweet orange under mid-hill conditions. Fruits were harvested at weekly intervals from 9th Kartik to 28th Poush. At each harvesting date, representative and uniform fruits were sampled from tagged trees.

The physicochemical parameters were analyzed using standard procedures. Juice content (%) was determined by extracting juice from fresh fruit samples and expressing it on a weight basis. Total soluble solids(TSS) were measured using a hand refractometer and expressed in °Brix. Titratable acidity (TA) was determined by titration with standard NaOH solution and expressed as percent citric acid. The maturity index was calculated as the TSS/TA ratio.

Results

The figure shows clear temporal variation in Juice content, TSS, TA, and TSS/TA ratio across different harvesting dates (Figure 3).

Juice content exhibited a declining trend throughout the harvesting period. It decreased from approximately 37–38% at early harvest (9th Kartik) to around 30% by 28th Poush. Total soluble solids(TSS) showed a gradual increasing trend, rising from about 9.0% at early harvest to approximately 11.0–11.2% at later stages.

Titratable acidity (TA) remained relatively low and stable, fluctuating around 0.8–1.1% with a slight declining tendency towards later harvest dates. The TSS/TA ratio increased steadily with advancement in harvesting time. It rose from around 10–11 at early stages to a peak of approximately 15–16 around mid-Poush (14th Poush), followed by a slight decline towards the final harvest.

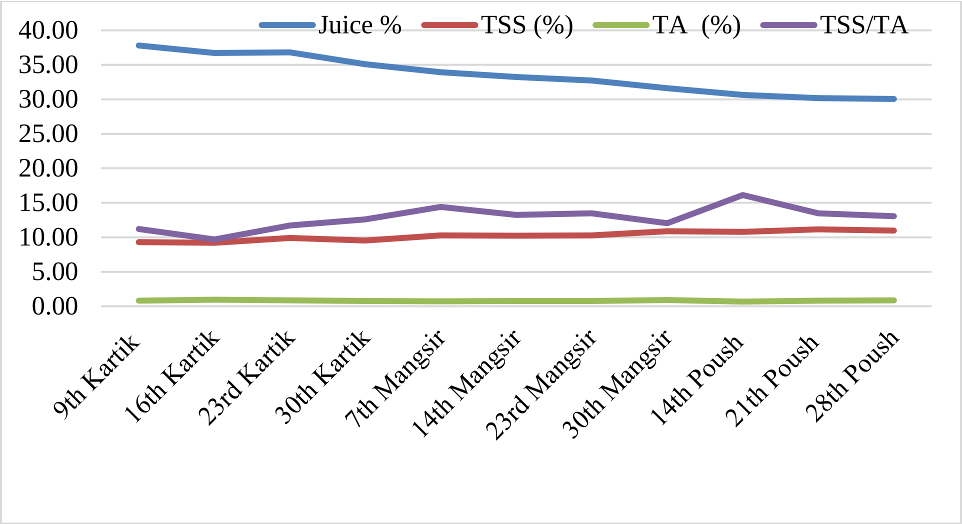

Figure 3. Identification of appropriate harvesting date of 'Washington Navel' sweet orange at NCRP, Paripatle, Dhankuta during 2081/82

Discussion

The gradual increase in TSS with delayed harvesting indicates continuous accumulation of sugars in the fruit due to ongoing metabolic processes and translocation of assimilates. This trend is consistent with the normal ripening behavior of sweet orange.

The relatively stable but slightly declining acidity suggests that organic acids are slowly metabolized during maturation, contributing to improved taste quality. Compared to late-maturing cultivars, 'Washington Navel' tends to maintain lower acidity levels during ripening, which results in an earlier attainment of acceptable flavor. The decline in Juice content with delayed harvesting may be attributed to moisture loss and senescence-related physiological changes. Environmental conditions, particularly decreasing humidity and increasing evapotranspiration during the harvesting window in Dhankuta, could have contributed to reduced juice recovery at later stages. The TSS/TA ratio, a key maturity index, increased consistently and reached its maximum around mid-Poush, indicating the most favorable balance between sweetness and acidity. The subsequent slight decline in the ratio may be due to marginal increases in acidity or stabilization of TSS.

Based on these findings, the optimal harvesting window for 'Washington Navel' sweet orange under eastern mid-hill conditions is around early to mid-Poush, particularly near 14th Poush, when the fruits exhibit desirable sweetness, acceptable acidity, and a high

TSS/TA ratio. Harvesting beyond this stage may result in reduced Juice content without significant improvement in fruit quality.

3.6.2 Identification of appropriate harvest date of 'Valencia Late'

Methodology

A field experiment was conducted at the National Citrus Research Program to determine the appropriate harvesting stage of 'Valencia Late' sweet orange. Fruits were harvested at regular 7-day intervals from 20th Magh to 5th Jestha. At each harvesting date, representative fruit samples were collected from tagged trees and analyzed for key physicochemical parameters.

Juice content (%) was determined by extracting juice from weighed fruit samples. Total soluble solids(TSS) were measured using a hand refractometer and expressed in °Brix. Titratable acidity (TA) was estimated by titrating juice against standard NaOH solution and expressed as percent citric acid. The maturity index was calculated as the TSS/TA ratio. Data were compiled and trends were analyzed descriptively to identify the optimum harvesting window based on quality attributes.

Results

The results revealed distinct temporal changes in fruit quality parameters across harvesting dates. Juice content varied markedly, ranging from about 29% to 40%. The highest juice percentage was observed during early Falgun and mid-Chaitra, followed by a decline reaching the minimum around early Baishakh. Thereafter, Juice content gradually increased towards Jestha. Total soluble solids(TSS) exhibited a gradual and consistent increasing trend throughout the harvesting period. The values increased from approximately 10.0% at early harvest (Magh) to about 11.5–11.8% during late Baishakh and Jestha. Titratable acidity (TA) showed a decreasing trend with advancement of harvesting dates. The acidity declined from around 1.8% at early stages to nearly 1.0% at later stages, with slight fluctuations during the mid-harvest period. The TSS/TA ratio increased progressively over time, rising from approximately 5.0 at early harvest to above 10.0 at later stages. The highest ratios were recorded during late Baishakh and early Jestha, indicating improved fruit maturity and eating quality (Figure 4).

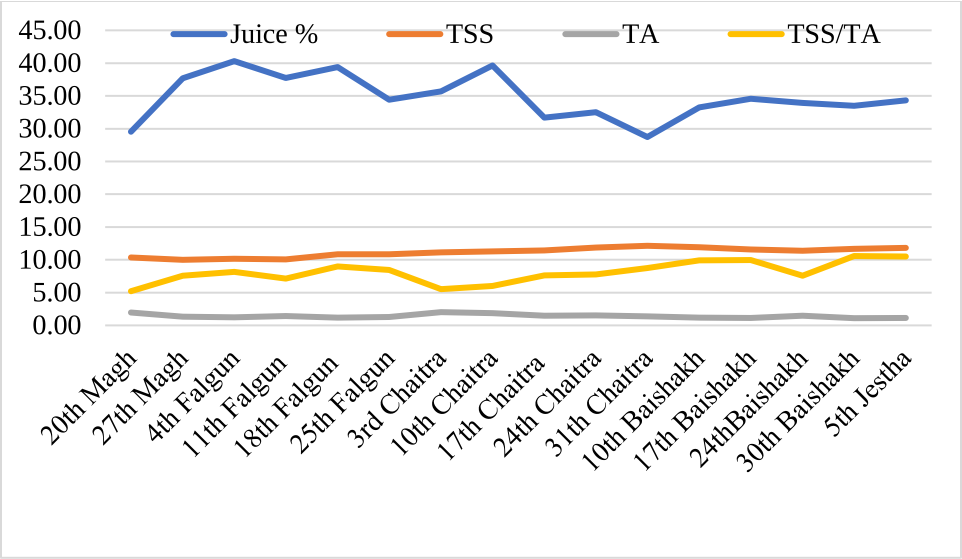

Figure 4. Identification of appropriate harvesting date of 'Valencia Late' sweet orange at NCRP, Paripatle, Dhankuta during 2081/82

Discussion

The progressive increase in TSS with delayed harvesting clearly indicates continued accumulation of sugars during fruit maturation, which is a typical characteristic of sweet orange. This increase is associated with hydrolysis of polysaccharides and translocation of photosynthates into the fruit.

The decline in Titratable acidity reflects the utilization of organic acids as respiratory substrates during ripening. This inverse relationship between TSS and acidity significantly influences flavor development. The TSS/TA ratio, considered a reliable maturity index in citrus, increased steadily throughout the harvesting period, suggesting improvement in palatability and consumer acceptability. Fruits harvested during late Baishakh to early Jestha exhibited the most desirable balance between sweetness and acidity. The fluctuation in Juice content, particularly the decline observed during early Baishakh, may be attributed to environmental stress factors such as increasing temperature and moisture deficit, which are common in eastern mid-hill conditions of Dhankuta. Such conditions can affect cell turgidity and juice recovery. The subsequent recovery in Juice content towards later harvests suggests physiological adjustment and possible late-season moisture availability.

In conclusion, findings indicate that although early harvesting ensures higher acidity and moderate Juice content, delayed harvesting significantly improves sweetness and maturity index. Therefore, the optimal harvesting window for *Valencia Late* sweet orange under eastern mid-hill conditions of Nepal lies between late Baishakh and early Jestha, when fruits attain superior quality in terms of TSS and TSS/TA ratio without substantial compromise in Juice content.

3.7 Maintenance of field gene bank

Collection and conservation of citrus genetic resources constitute a key mandate of the National Citrus Research Program (NCRP). Since 2001, a total of 140 citrus genotypes have been collected from both indigenous and exotic sources (Annex 18) and are being maintained in the field gene bank at NCRP, Paripatle, Dhankuta. These genetic resources encompass a wide range of citrus species, including mandarin, sweet orange, acid lime, grapefruit, lemon, tangor, tangelo, and several rootstock species.

Exotic germplasm has been introduced primarily from countries such as India, Pakistan, France, Japan, and Vietnam, while local genotypes have been collected from diverse agro-ecological regions of Nepal. Notably, in 2004, 39 exotic citrus varieties—including 16 mandarins, 6 sweet oranges, 4 grapefruits, 3 tangors, 3 tangelos, and 7 rootstock types—were introduced from France with the technical support of Prof. Joseph Bové of the French National Institute for Agriculture Research (INRA) and CIRAD. Earlier, in 2001, three dwarf Unshiu mandarin varieties were introduced from the Japan International Cooperation Agency, Japan. Similarly, during 2006, 12 promising sweet orange varieties were introduced from the Indian Council of Agricultural Research, India. Additional collections of sweet orange, grapefruit, and acid lime were facilitated through collaborations with International Centre for Integrated Mountain Development, Vietnam, and the Institute of Agriculture and Animal Science (IAAS), Rampur, across different periods.

Further enrichment of the germplasm collection was achieved in the fiscal year 2017/18 through the introduction of eight new varieties from Australia, comprising three mandarins, four sweet orange, and one rootstock genotype. In addition, 21 promising acid lime cultivars have been collected from various districts and local sources over time (Annex 1). These cultivars are currently undergoing systematic evaluation and screening based on fruit yield and key fruiting characteristics. Preliminary characterization has revealed considerable variability among the genotypes in terms of fruiting behavior, fruit traits, and morphological characteristics. However, further rigorous evaluation is necessary to identify superior varieties with desirable agronomic and economic attributes for recommendation and large-scale cultivation.

3.8 NAFHA project research highlights

3.8.1 Registration of 'Paripatle Agauṭe Suntala-2'

Paripatle Agauṭe Suntala-2 is a Japanese mandarin orange cultivar belonging to the Unshu (Satsuma) group, recognized for its early maturity and desirable market traits. This variety was officially recommended in 2081 B.S. following extensive long-term evaluation conducted at the National Citrus Research Program, Dhankuta. Compared to local mandarin cultivars, Paripatle Agauṭe Suntala-2 matures approximately 2.5–3 months earlier than the local mandarins, providing a significant advantage in accessing early-season markets. The fruits are slightly larger in size with a characteristically flattened shape, thin peel, and are predominantly seedless, which enhances consumer preference. However, the sweetness level is comparatively lower than that of local varieties. Fruit ripening begins in late Bhadra, aligning well with major Nepalese festivals such as Dashain and Tihar, thereby offering strong commercial potential due to high seasonal demand.

Recommended Growing Area

Mid-hill regions (1000–1600 masl)

Table 32. Varietal characteristics of 'Paripatle Agaute Suntala-2'

Description	Details
Crop	Unshu mandarin
Variety	Paripatle Agauṭe-2
Plant Height	189 cm (17 years old grafted tree)
Fruit Weight	Above 130 g
Seeds	Seedless to nearly seedless
Juice Content	56%
Acidity	0.80%
TSS	7–9%
Flowering	Falgun–Chaitra
Flower Color	White
Yield	15 mt ha^{-1}
Ripening	Late Bhadra–Early Kartik
Recommended altitude	1000–1600 m

Distinct Features

- Early maturing
- Thin peel, easy to remove
- Seedless or very few seeds
- Green peel even at harvest
- Suitable for high-density planting

3.8.2. Registration of 'Paripatle Sunaulo Nibuwa'

'Paripatle Sunaulo Nibuwa' is an economically important citrus cultivar characterized by a spreading growth habit and vigorous vegetative development. The leaves are comparatively larger and exhibit a deeper green coloration than those of acid lime, indicating a robust photosynthetic capacity. The fruits are relatively large in size, turning an attractive golden yellow upon ripening, and are distinguished by their pleasant aroma.

This cultivar holds significant potential for value addition, as it is particularly suitable for processing industries, including juice extraction, pickle preparation, and jelly production. Its adaptability to diverse agro-ecological conditions makes it well suited for cultivation in the Terai, Inner Terai, and river basin areas, where it can contribute to both fresh market supply and agro-processing sectors.

Recommended Growing Area

Up to 800 m altitude (Lower hill, terai and valleys, uplands and river basins)

Table 33. Varietal characteristics of 'Paripatle Sunaulo Nibuwa'

Description	Details
Crop	Lemon
Variety	Paripatle Sunaulo Nibuwa
Plant Height	172 cm (17 years old grafted plant)
Fruit Weight	Above 120 g
Color	Golden
Juice Content	30–40%
Acidity	4–7%
Flowering	Magh–Falgun
Yield	20–30 mt ha^{-1}
Ripening	From late Bhadra
Recommended altitude	Up to 800 m

Distinct Features

- Large fruit size
- Golden peel at maturity
- Citrus canker infection free

3.8.3 Varietal characterization of elite mandarin and sweet orange

A set of elite genotypes of sweet orange, namely ‘Dhankuta Local’, ‘Pineapple’, ‘Valencia Late’, and ‘Washington Navel’, along with a mandarin genotype, ‘Sikkime Suntala’, were systematically evaluated to assess their morphological, phenological, and pomological characteristics. The study aimed to generate comparative information on growth attributes, flowering and fruiting behavior, and fruit quality parameters among these genotypes.

The morphological observations included traits related to plant architecture, leaf characteristics, and canopy structure. Phenological parameters focused on key developmental stages such as flowering time, fruit set, and maturity period, while pomological traits encompassed fruit size, shape, peel characteristics, juice content, and overall quality attributes. The detailed findings of these evaluations are presented in the tables below.

Table 34. Fruit physicochemical and yield characteristics of elite cultivars of sweet orange and mandarin at NCRP, Paripatle, Dhankuta during 2081/82

Genotype	Fruit weight (g)	Peel thickness (mm)	Nos. seed per fruit	Juice (%)	TA (%)	Yield (mt ha^{-1})
Dhankuta Local (Sweet orange)	151.00	3.45	7.92	45.70	1.45	35.60
Pineapple (Sweet orange)	123.00	3.47	1.56	26.40	1.34	28.40
Valencia Late (Sweet orange)	121.00	2.95	4.36	38.00	1.30	38.50
Washington Navel (Sweet orange)	227.00	3.59	0.48	25.20	0.74	37.30
Sikkime Suntala (Mandarin)	99.10	2.38	10.40	38.40	1.31	57.23

Table 35. Morphological characteristics of elite cultivars of sweet orange and mandarin at NCRP, Paripatle, Dhankuta during 2081/82

Genotype	Trunk circumference (cm)	Plant height (cm)	Canopy spread (cm)	
			E-W	N-S
Dhankuta Local	24.22	282.22	270.44	246.67
Pineapple	34.50	330.00	330.00	318.00
Valencia Late	29.13	298.75	286.88	281.88
Washington Navel	33.00	306.11	311.67	335.56
Sikkime Suntala	32.71	449.43	306.86	307.43

Table 36. Phenological characteristics of elite cultivars of sweet orange and mandarin at NCRP, Paripatle, Dhankuta during 2081/82

Parameters	Dhankuta Local	Pineapple	Valencia Late	Washington Navel	Sikkime suntala
Initial flowering date	3rd week of Falgun	2nd week of Falgun	3rd week of Falgun	3rd week of Falgun	Final week of Falgun
50% flowering date	2nd week of Chaitra	3rd week of Chaitra	3rd week of Chaitra	3rd week of Chaitra	3rd week of Chaitra
50% fruit setting date	1st week of Baisakh	2nd week of Baisakh	3rd week of Baisakh	1st week of Baisakh	2nd week of Baisakh
50% fruit marble size date	2nd week of Jestha	2nd week of Jestha	Final week of Jestha	2nd week of Jestha	Final week of Jestha
50% fruit egg size date	2nd week of Ashad	Final week of Ashad	Final week of Ashad	2nd week of Ashad	3rd week of Ashad
50% fruit color date	1st week of Mangsir	Final week of Kartik	3rd week of Poush	3rd week of Kartik	1st week of Mangsir
Pedicel Length (mm)	7.57	7.53	7.50	6.03	5.60
Flower Type	Hermaphrodite	Hermaphrodite	Hermaphrodite	Hermaphrodite	Hermaphrodite
Color of Open Flower	White	White	White	White	White
Color of Anthers	Yellow	Yellow	Yellow	Yellow	Yellow
No. of Petal per Flowers	5	5	5	5	5
Calyx diameter (mm)	6.67	7.73	8.73	6.57	4.87
Petal Length (mm)	19.23	18.10	19.01	15.25	16.83
Petal Width (mm)	8.50	7.23	7.89	6.13	4.60

No. of Stamens	23	23	22	21	18
Length of anthers relative to stigma	Shorter	Shorter/ equivalent	Shorter / equivalent	Shorter / equivalent / longer	Longer/ equivalent

3.8.4 Sapling production

A total of 7,000 saplings citrus crop were produced under the NAFHA project.

Table 37. Saplings produced under NAFHA project at NCRP, Paripatle, Dhankuta during 2081/82

Species	Variety	Number of saplings produced
Mandarin	Khoku Local	1000
Acid lime	Sunkagati-1	4500
Acid lime	Tehratahum Local	1500
Total		**7000**

3.8.5 Establishment of mother plant inside the screen house

Saplings of different varieties and genotypes of mandarin were transplanted and maintained under controlled conditions within a screen house to facilitate systematic evaluation. Among the transplanted materials, some varieties have already been officially registered, while others are currently under investigation for potential registration. The use of a screen house environment ensured protection from biotic and abiotic stresses, allowing for precise observation of growth performance, morphological traits, and adaptability. This approach supports the identification and characterization of promising genotypes for future recommendation and release.

Table 38. Varieties and plant number of newly transplanted mother plant under the screen house of NCRP, Paripatle, Dhankuta during 2081/82

S.N.	Variety/genotype	Number of saplings
1	Khoku Local	4
2	Banskharka Local	2
3	Paripatle Agaute Suntala-2	2
4	Sikkime Suntala	2
5	Ponkan	2
6	Syaut Suntala	2

3.8.6 PCR test report for the conformation of HLB

Polymerase Chain Reaction (PCR) analysis was conducted during the fiscal year 2081/82 to detect the presence of targeted pathogens in citrus samples collected from farmers' fields. The sampling was carried out across major citrus-producing districts of eastern Nepal, namely Dhankuta, Ilam, Terhathum, and Sankhuwasabha, ensuring a representative assessment of pathogen incidence in the region.

A total of 74 samples were collected and analyzed under controlled laboratory conditions using PCR techniques to determine the presence or absence of the targeted pathogen. The results revealed that 24 samples (32.43%) tested positive, whereas 50 samples (67.57%) were negative.

These findings indicate that nearly one-third of the sampled citrus plants were infected with the targeted pathogen, suggesting a notable level of disease prevalence in the surveyed areas. However, the majority of samples were found to be pathogen-free, which reflects the existence of relatively healthy planting materials or effective management practices in certain locations. This information is crucial for guiding future disease monitoring, management strategies, and the promotion of clean planting material in citrus production systems.

4. PRODUCTION PROGRAM

A total of 12,000 mandarin saplings, 2,000 sweet orange saplings, and 14,000 acid lime saplings were produced. Additionally, 18 kg of rootstock seed and 35,000 rootstock seedlings were also produced. Fruit production comprised 15,400 kg of mandarin, sweet orange, and acid lime fruits, along with 360 kg of other fruits (Table 32).

Table 39. Production of citrus saplings, scion, rootstock seed, seedlings, and fresh fruits in FY 2081/82

S.N.	Particulars	Unit	Quantity
1	Mandarin saplings	Nos	12,000
2	Sweet orange saplings	Nos	2,000
3	Acid lime saplings	Nos	14,000
4	Rootstock seed	kg	18
5	Rootstock seedling	Nos	35,000
6	Other sapling including rose, camellia etc.	Nos	150

7	Mandarin, sweet orange/ acid lime fruits	kg	15,400
8	Other fruits	kg	360

5 TECHNOLOGY DISSEMINATION

- Operated the official website in the name of www.ncrpdhankuta.narc.gov.np
- Produce publication in Nepali language and provide to needy people.
- Planting of out-performing cultivars in the farmers' field and research stations of NARC
- Training to the technicians involving in citrus development activities
- Visit of major citrus pockets and made aeare about the major problems and their solutions
- Production and distribution of planting materials of promising genotypes of citrus

6 MARKETING

- Need to strengthen the citrus marketing system avoiding middleman-controlled marketing system for getting higher benefit to the farmer.
- Improvement on the post-harvest practices such as harvesting, packaging, and transportation with the technology adoption to minimize the losses.
- Need of cooperative marketing.
- Farmers to be trained with the knowledge for increasing bargaining power in the market.
- Develop the citrus farming as a business enterprise.

7 CALENDAR OF OPERATION

Based on research findings and field experiences, NCRP has developed a calendar of operation for citrus orchard management (Table 40).

Table 40. Calendar of operations adopted at NCRP, Paripatle, Dhankuta for the orchard management

Month	Operations
Shravan	❖ Weeding in sweet orange orchard ❖ Transplanting of rootstock seedling (Trifoliate) in the main nursery block. ❖ Remove diseased, new suckers and dry branches. ❖ Spray Sulphur 80% WP @ 2 g/L of water for the control of powdery mildew ❖ Application of systemic insecticides to control of green stinkbugs. ❖ Apply control measures of fruit sucking moth ❖ Maintenance of Pheromone (ME) traps for oriental citrus fly ❖ Spray protein bait for Chinese citrus fly management ❖ Use control measures for the control of citrus leaf miner
Bhadra	❖ Weeding in citrus orchards and nurseries ❖ Application of mineral oil @5 -10 5 ml l^{-1} water to control scale insects. ❖ Spray protein bait for Chinese citrus fly management ❖ Maintenance of Pheromone (ME) traps for oriental citrus fly ❖ Remove and destroy Chinese citrus fly infested fruits ❖ Apply control measures of fruit sucking moth ❖ Application of systemic insecticides to control of green stinkbugs. ❖ Drenching of the plant affected by root rot with Bordeaux mixture or copper oxychloride. ❖ Harvesting starts of the early season mandarin like Paripatle Agaute-1
Aswin	❖ Collect trifoliate seeds for root stock production. ❖ Cover spray with protein bait in sweet orange orchards to control Chinese citrus fly. ❖ Remove and destroy Chinese citrus fly infested fruits ❖ Maintenance of Pheromone (ME) traps for oriental citrus fly ❖ Application of insecticides for the control of green stinkbug ❖ Apply control measures of fruit sucking moth ❖ Weeding and mulching in the orchards ❖ Stacking of heavily fruiting branches ❖ Collect Chinese citrus fly infested sweet orange fruit and destroy it ❖ Harvesting of the early season mandarin like Paripatle Agaute-1
Kartik	❖ Collect Chinese citrus fly infested mandarin/sweet orange fruit and destroy it ❖ Prepared new nursery bed and sow trifoliate seed for next year production. ❖ Apply control measures of fruit sucking moth ❖ Harvesting of early maturing varieties of sweet orange like Washington Navel.
Mangsir	❖ Collect Chinese citrus fly infested mandarin/sweet orange fruit and destroy it ❖ Harvesting starts of mid-season varieties of mandarin and sweet orange ❖ Grafting for sapling production ❖ Irrigate orchard trees

Poush	❖ Harvesting of mid-season varieties of mandarin and sweet orange ❖ Grafting for sapling production ❖ Pruning and training ❖ Spray Bordeaux mixture in orchard to control fungal (pink disease) and bacterial disease (citrus canker) ❖ Apply manure and chemical fertilizers to the orchard trees based on recommendations ❖ Apply mulches to the manured trees ❖ Irrigate orchard trees after mulching
Magh	❖ Harvesting of mid-to-late season varieties of mandarin and sweet orange varieties ❖ Pruning and training ❖ Spray mineral oil to control scale insects ❖ Spray Bordeaux mixture in orchard to control fungal (pink disease) and bacterial disease (citrus canker) ❖ Application of Bordeaux paste or paints to the base of sweet orange trees ❖ Apply manure and chemical fertilizers to the orchard trees based on recommendations ❖ Apply mulches to the manured trees ❖ Irrigate orchard trees
Phalgun	❖ Harvesting continues of late varieties of mandarin and sweet orange ❖ Spray mineral oil to control scale insects ❖ Apply manure and chemical fertilizers to the orchard trees based on recommendations ❖ Apply mulches to the manured trees ❖ Foliar spray of micronutrient. ❖ Spray of systemic insecticide to control leaf miner ❖ Irrigate orchards and nursery ❖ Flowering starts, so use safe chemicals to save pollinators ❖ Remove excess flower to make balance between vegetative growth and fruiting (flower thinning) ❖ Application of Bordeaux paste or paints to the base of sweet orange trees ❖ Apply control measures for citrus leaf miner (CLM)
Chaitra	❖ Irrigate the orchard and nursery bed ❖ Uproot the diseased and very old unproductive trees and prepare pits for new plantation ❖ Flowering continues, so use safe chemicals to save pollinators ❖ Remove excess flower to make balance between vegetative growth and fruiting (flower thinning) ❖ Use control measures for citrus leaf miner

Baisakh	❖	Irrigate the orchard and nursery bed
	❖	Uproot the diseased and very old unproductive trees and prepare pits for new plantation
	❖	Remove excess fruit to make balance between vegetative growth and fruiting (fruit thinning)
	❖	Manage protein bait for Chinese citrus fly control
	❖	Use control measures for citrus leaf miner
Jestha	❖	Irrigate the orchard and nursery bed
	❖	Make a drainage system in the orchard.
	❖	Prepared the nursery bed for rootstock transplanting.
	❖	Prepare compost for next year
	❖	Application of chemical fertilizers
	❖	Remove excess fruit to make balance between vegetative growth and fruiting (fruit thinning)
	❖	Spray protein bait for Chinese citrus fly control
	❖	Spray acaricides for the control of citrus rust mite (CRM)
	❖	Use control measures for citrus leaf miner
Asar	❖	Spraying with sulfur containing fungicides to control powdery mildew.
	❖	Transplant rootstocks for next year's sapling.
	❖	Transplant saplings in orchard
	❖	Remove excess fruit to make balance between vegetative growth and fruiting (fruit thinning)
	❖	Spray protein bait for Chinese citrus fly control
	❖	Manage fruit drop due to water stagnation near the root of tree
	❖	Spray acaricides for the control of citrus rust mite (CRM)
	❖	Use control measures for citrus leaf miner

8 INFORMATION DISSEMINATION

Information regarding citrus research programs and technologies was shared with the visitors that altogether 912 visitors made their presence in NCRP (Annex 10). The visitors were mainly from farmers group, cooperatives, extension officials, entrepreneurs, NGOs/INGOs officials and others. They were acquainted with the field knowledge and experience of citrus cultivation.

9 TRAINING

During the fiscal year 2081/82, a five-day residential training program was conducted at the Technical Assistant level on the topic "Decline Management of Citrus Orchard." The training was organized to enhance the technical knowledge and practical skills of personnel involved in citrus production and management within the National Citrus Research Program. The program focused on key aspects of citrus decline, including its diagnosis, underlying causes, and integrated management strategies to improve orchard health and productivity in Nepal. The name of technicians participated in the training has been shown in Annex 17.

10 SERVICES

In the fiscal year 2081/82, the National Citrus Research Program (NCRP) supplied a total of 21,449 grafted saplings of different citrus species to farmers. The distributed planting materials included improved and locally adapted varieties such as 'Khoku Local', Paripatle Agaute-1, and Banskharka Local mandarin, along with three acid lime varieties—Sunkatagi-1, Sunkatagi-2, and Tehrathum Local—as well as sweet orange. The provision of these grafted saplings reflects the program's focus on promoting quality planting materials to enhance citrus productivity and orchard sustainability in Nepal.

In addition to sapling distribution, NCRP supported nursery development by providing scion material from mother plants of mandarin and acid lime to nearby nursery entrepreneurs in Dhankuta district. This initiative aimed to strengthen the availability of certified and disease-free planting materials at the local level, thereby improving nursery standards and encouraging private sector participation in citrus propagation.

Furthermore, the program engaged in knowledge dissemination and capacity-building activities. A total of 912 individuals visited the office for technical information and guidance, while 78 students participated in on-the-job training (OJT) and internship programs. Additionally, 205 farmers and stakeholders received counselling services, indicating NCRP's active role in providing extension support, technical advisory services, and human resource development for the citrus sector.

11 BUDGET STATEMENT

Budget and expenditure of regular program as well as beruju of the program has been presented in Annex 14.

12 MAJOR PROBLEMS

The major problems of citrus industry in Nepal are summarized as following:

- Lack of variety diversity- short crop harvest period,
- Small production scale,
- Poor orchard management,
- Lack of efficient irrigation,

- ❖ Fruit drop due to entomological, pathological and hormonal factors.
- ❖ Incidence of insects and different diseases.
- ❖ Presence of hard pan.
- ❖ Limited availability of disease free planting materials.
- ❖ Acidic soil condition including zinc, calcium and magnesium deficiency in most of the citrus orchards particularly in mid-hills of west Nepal.
- ❖ Macro and micro-nutrient deficiency.
- ❖ No information about the nutrient content of citrus orchard.
- ❖ Poor institutional mechanisms and coordination for marketing, and
- ❖ Lack of entrepreneurship

Regarding management aspect, NCRP is lacking human resources for several years. Currently, a total of 7 staffs are working in the Program although there are 37 approved positions allocated by the NARC. Among the working staffs, only three scientists are there for research execution.

13 FUTURE STRATEGIES

At present, government of Nepal has recognized citrus sector as the national important and prioritized commodity. Because of appropriate geography and climate, citrus is widely grown throughout the mid hills from east to west across the country. In addition to, acid lime could be grown in upland condition of terai. Moreover, the demand of mandarin and acid lime in the domestic markets is escalating very high in recent years. Thus, it has an enormous potential to generate income and employment including nutrition to rural farmers in the country.

However, citrus industry is still in traditional level that needs to be transformed into commercial production. Therefore, NCRP has future strategies to address the problems of short production period of existing varieties, low productivity and production, inferior fruit quality, citrus decline due to disease and pests including management factors. Similarly, problems in institutional mechanism and coordination for marketing and entrepreneurship for this crop should be adequately dealt with by the research and development. Moreover, the research focus shall be on citrus based farming system utilizing available resources and socio-economic condition of the farmers. Therefore, NCRP has prioritized following research areas for the upcoming years:

- Virus indexing program should be made compulsory by law with bud wood certification program, and it should be followed timely across citrus growing areas.
- The quality planting materials free from pathogens and resistant to various insect pest and diseases ought to be made available to the citrus growers.
- The private nurseries should be inspected routinely since the uncertified nursery plants produced from bud wood of unknown mother tree decide the future of the orchard.
- Developing disease resistant rootstock as well as identifying new dwarfing rootstocks for high density planting.
- Excessive use of fertilizers, chemical pesticides should be checked and organic citrus farming should be encouraged especially with the judicious use of bio-fertilizers and bio-control of pests with bio-pesticides.
- Postharvest processing and value addition,
- Marketing and export business,
- Cost effective and eco-friendly production technologies,
- Integrated nutrient management,
- Breeding new varieties for extended harvest period,
- Biological pest and disease management,
- Water use efficiency,
- In-vitro technology for healthy propagation,
- Citrus based farming system, and
- Socio-economic studies

14. SPECIAL PROJECT

The NAFHA project was launched at the National Citrus Research Program, Paripatle, Dhankuta, beginning in fiscal year 2081/82. The project was primarily implemented at NCRP to carry out phenological characterization of major citrus species with the objective of varietal registration and release. The study focused on mandarin, acid lime, and sweet orange, evaluating multiple varieties of each species for traits such as flowering time, fruit set, harvest duration, and the physicochemical properties of ripe fruits. The findings revealed considerable variation among varieties in terms of harvest period, fruit quality attributes, and yield potential. Based on these results, the mandarin variety 'Miyagawa Wase' and the lemon variety 'NCRP-53' are being considered for varietal registration.

ANNEXES

Annex 1. Map of NCRP, Paripatle, Dhankuta, Nepal

Annex 2. Meteorological data of Dhankuta in FY 2081/82

Month	Temperature (°C)		Rainfall (mm)	Relative humidity (%)
	Maximum	Minimum		
Shravan	30.64	21.37	5.35	82.53
Bhadra	30.58	20.33	4.85	82.42
Ashwin	28.24	18.90	12.64	84.16
Kartik	27.28	15.17	0.00	77.46
Mangsir	23.50	9.24	0.00	72.37
Poush	22.60	7.59	0.00	67.87
Magh	21.46	7.77	0.00	74.51
Falgun	23.08	9.92	0.22	69.00
Chaitra	27.74	14.14	1.13	59.05
Baishak	28.56	16.11	3.86	70.55
Jestha	28.92	18.52	3.45	78.78
Ashadh	30.47	19.99	5.27	80.40

Source: Office of Hydrology and Meteorology, Dharan

Annex 3. Laboratory facility at NCRP, Paripatle, Dhankuta

S.N.	Laboratory facility	Remarks
1	Tissue culture	Mass propagation of plants
2	Soil	Soil analysis for physicochemical parameters
3	Plant pathology	Pathological detection of fugi
4	Entomology	Entomological study
5	Fruit analysis	Physicochemical analysis of fruits
6	Biotechnology	HLB diagnosis through PCR, DNA quantification with Nanodrop

Annex 4. Human Resource of NCRP in FY 2081/82

S.N.	Name	Position	Qualification	Working area	Remarks
1	Dr. Basant Chalise	Coordinator/ Senior Scientist (S-4)	PhD (Horticulture)	Horticulture	Transferred from HRS, Rajikot
2	Mr. Shukra Raj Shrestha	Scientist (S-2)	M.Sc.Ag (Soil)	Soil	Transferred to DoAR, Lumle
3	Ms. Dipti Adhikari	Technical Officer (T-6)	M.Sc.Ag (Pathology)	Pomology	Study leave
4	Mr. Manoj Kumar Sah Teli	Technical Officer (T-6)	M.Sc.Ag (Horticulture)	Agriculture	Transferred to ARS, Pakhribas
5	Mr. Kumar Prasad Koirala	Adm Officer (A-6)	B.A	Administration	Transferred from NBRP, Tarahara
6	Mr. Tilak Prasad Rajbanshi	Account officer (A-6)	B.Com	Account	
7	Mr. Kashinath Subedi	Technical Helper-2nd level	Literate	Orchard management	
8	Mr. Dhan Kumar Rai	Technical Helper-2nd level	Test pass	Nursery management	
9	Mr. Tulasi Acharya	Technical Helper-2nd level	+2 Pass	Nursery and orchard management	

Annex 5. Human resource allocation of NCRP, Paripatle, Dhankuta in FY 2081/82

S. N.	Designation	Approved	Fulfilled	Vacant
1	Principal Scientist (S-5) - Pomology/Olericulture	1	0	1
2	Senior Scientist (S-4)- Pomology	1	1	0
3	Senior Scientist (S-3)- Pomology	1	0	1
4	Senior Scientist (S-3)- Plant pathology	1	0	1
5	Scientist (S-2) - Soil Science	1	0	1
6	Scientist (S-1) - Plant breeding and genetics	1	0	1
7	Scientist (S-1) - Entomology	1	0	1
8	Scientist (S-1) - Plant Pathology	1	0	1
9	Senior Technical Officer (T-7) -Olericulture	1	0	1
10	Senior Technical Officer (T-7) -Pomology	1	0	1
11	Technical Officer (T-6) - Pomology	3	1	2
12	Junior Technician (T-5)	3	0	3
13	Junior Technical Assistant (T-4)	5	0	5
14	Technical Helper (T-1)	13	3	10
15	Account Officer (A-6)	1	1	0
16	Administrative Assistant (A-5)	1	1	0
17	Heavy Driver	1	0	1
Total		**37**	**7**	**30**

Annex 6. Summary progress of NARC research projects and activities of NCRP in FY 2081/82

S.N.	Project	Project leader	Budget allocated	Major achievements
1	Farm Management Research Support and Production Program	Dr. B. Chalise	5,046,000	Production of 28,000 citrus grafts and 35,000 seedling rootstock; fresh fruit 15.76 mt; 18 kg rootstock seed; mother stock management; management of guest house and dormitory; laboratory management etc.
2	Promoting improved cultivation and commercialization of citrus through technology out scaling and production of standard planting materials	Dr. B. Chalise	1,581,000	25,000 grafts were prepared and sold at farmers' level under the supervision of NCRP; 72 samples of the nursery owner as well as orchard of NCRP were tested for HLB through PCR out of which 23 were reported as positive; nursery owners were provided with necessary materials for nursery production and screen house management.
3	Standardization of rootstock and development of fruit fly and root rot management technologies in citrus	Dr. B. Chalise	789,000	In acid lime Poncirus Pomeroy produced the highest yield (8.98 mt ha^{-1}) followed by Trifoliate orange (8.71 mt ha^{-1}), Flying Dragon (8.22 mt ha^{-1}). Rangpur lime yielded 7.10 mt ha^{-1} and proved as the alternative rootstock for acidlime grafting for terai region though the yield in mid-hill is lower. Fruit fly management technology

				(protein bait) effectively controlling their population as well infestation rate. Root rot problems are severe in terai region which are managed with Bordeaux mixture drenching, drenching of pseudomonas as well as trichoderma also effective in the management of root rot.
4	Development of productivity enhancement technology of mandarin and acid lime in mid hills of Nepal	Dr. B. Chalise	654,000	There were four activities under this project. Technologies in citrus canker management of acid lime is under the study. Study on HDP in mandarin is ongoing. The yield was the highest (58.90 mt ha^{-1}) in 1.8×3 m planting density. Similarly, the powdery mildew disease of citrus was effectively managed with sulfer containing fungicides. For controlling root rot disease, soil drenching with 1% bordeaux mixture or Trichoderma or Pseudomonas was effective.
5	Varietal improvement and use of emerging biotechnological approaches in citrus	Dr. B. Chalise	1,742,000	Registration of satsuma mandarin variety 'Paripatle Agaute-1' and proposal submitted for the registration of 'Paripatle Sunaulo Nibuwa'. Similarly, disease diagnonis of HLB and CTV was also done in this FY.

6	Exploration of management techniques to solve citrus greening disease problem in mid hills	Dr. B. Chalise	1,487,000	Monitoring of citrus psylla at different altitudes; use of zinkicide and GA3 to evaluate the effectiveness against HLB disease in mandarin was done.
7	Development of Integrated Orchard Management Technologies in Citrus	Dr. B. Chalise	1,247,000	Integrated management of rust mite, fruit piercing moth, leaf miner, root rot disease, establishment of organic block for mandarin was done in this FY.
8	Management of citrus decline through the development and adoption of appropriate technologies in citrus	Dr. B. Chalise	1,662,000	Training conducted on citrus decline management to the technicians working in citrus growing areas of the Koshi province of Nepal; soil and leaf sample analysis for identification of nutrient status, citrus psylla monitoring etc. were completed in this project. One activity "Study on soil moisture fluctuation on citrus decline orchard" was dropped due to the lack of soil moisture meter and hot air over at NCRP, Paripatle, Dhankuta.

Annex 7. Training/Workshop/Seminar organized by NCRP, Paripatle, Dhankuta in FY 2081/82

S.N.	Name of training	Duration	Target group	Nos of participants
1	Village Level Workshop	1 day	Farmers	35
2	Decline management of citrus orchard	5 days	Technical Assistant	18
3	On the Job Training/ Internship	3-6 months	B. Sc. Ag. I. Sc. Ag JT/JTA	78

Annex 8. Services provided in FY 2081/82

S.N.	Laboratory/field test/counseling services	Number	Major clients
1	HLB test through PCR	92	Official/farmers
2	Field test of CTV	15	Official
3	Counseling services	912	Farmers/students etc.

Annex 9. Publications in FY 2081/82

S.N.	Publication	Type	Language	Published number
1	Annual Report (2080/81)	Book	English	65
2	Pink disease management	Brochur	Nepali	300
3	Citrus rust mite management	Brochur	Nepali	300
4	Fruit piercing moth of citrus and its management	Brochur	Nepali	300

Annex 10. Information disseminated in FY 2081/82

S.N.	Information disseminated/area coverage	Type	Media type	Date
1	Disease and insect pest management in citrus	Interview	NTV Plus	2082-11-20
2	Varietal development in citrus	News cast	Kantipur TV	2082-02-01
3	Citus cultivation	Interview	Radio Nepal	2081-10-14

Annex 11. Visit of NCRP, Paripatle, Dhankuta in FY 2081/82

S.N.	Category	Number	Country/area	Major area of interest
1	Farmers	545	Nepal	Citrus cultivation
2	Students	205	Nepal	Citrus cultivation
3	Official visit	150	Nepal	Citrus varieties
4	Entrepreneurs	12	Nepal	Porduct diversification

Annex 12. Training/workshop/seminar attained by the staffs in FY 2081/82

S.N.	Name of staff	Position	Seminar/trainging/ worshop	Duration	Place
1	Dr. Basant Chalise	S-4	Annual review workshop-2080-81	2081-04-15	Tarahara, Sunsari
2	Dr. Basant Chalise	S-4	Interaction workshop for managing fruit piercing moth	2081-05-15	Khaniyakharka, Sindhuli
3	Dr. Basant Chalise	S-4	First trimester review workshop	2081-07-12	Virtual
4	Dr. Basant Chalise	S-4	2nd Trimester/Half yearly review workshop	2081-10-15	Tarahara, Sunsari
5	Dr. Basant Chalise	S-4	Planning workshop	2081-11-18 to 2081-11-20	Tarahara, Sunsari
6	Dr. Basant Chalise	S-4	Interaction workshop organized by PMAMP, Khumaltar	2082-03-31	Dhulikhel, Kabhre

Annex 13. Paper published in FY 2081/82

S.N.	Title	Author	Name of publication
1	Present Status and Future Strategies for Citrus Research and Development in Nepal	B Chalise UK Acharya A Katuwal	Proceedings of the 11th National Horticulture Workshop organized by NHRC, NARC
2	Mandarin Germplasm Collection, Evaluation, Sapling Production and Biosecurity and Plant Protection System in National Citrus Research Program, Paripatle, Dhankuta, Nepal	B Chalise UK Acharya D Pokhrel A Katuwal	Proceedings of the 14th National Horticulture Workshop organized by Nepal Horticulture Society

Annex 14. Regular annual budget and expenditure in 2081/82

Budget Code	Budget Heads	Annual Budget	Budget Released	Budget Expenditure	Balance
21111	Staff Salary	12673000.00	5526971.80	5526971.80	7146028.20
21121	Uniform	200000.00	80000.00	80000.00	120000.00
21131	Local Allowance	253000.00	76910.00	76910.00	176090.00
21132	Dearness Allowance	480000.00	192455.00	192455.00	287545.00
21134	Meeting Allowance	40000.00	39700.00	39700.00	300.00
21213	Insurance Fund Expenses based on Contribution	111000.00	38491.00	38491.00	72509.00
22111	Water and Electricity	436000.00	436000.00	436000.00	0.00
22112	Communication Expenses	138000.00	136400.00	136400.00	1600.00
22212	Fuel (Office Purpose)	628000.00	527422.00	527422.00	100578.00
22213	Vehicle Repair Cost	300000.00	299176.00	299176.00	824.00
22214	Insurance and Renewal Expenses	60000.00	60000.00	60000.00	0.00
22221	Repair and Maintenance of Machinery and Equipment	205000.00	170084.00	170084.00	34916.00
22291	Repair and Maintenance of other Assets	115000.00	115000.00	115000.00	0.00
22311	Office related expenses	180000.00	158892.00	158892.00	21108.00
22314	Fuel for other purposes	152000.00	30800.00	30800.00	121200.00
22315	Newspaper,Printing and News Publication Cost	136000.00	110136.00	110136.00	25864.00
22413	Contract Service Cost	30000.00	29945.00	29945.00	55.00
22419	Other Service Cost	152400.00	1382760.00	1382760.00	141240.00
22512	Training and seminar expenses	420000.00	419937.00	419937.00	63.00
22521	Production Material Service	11173000.00	10015533.00	10015533.00	1157467.00
22611	Monitoring and evaluation expenses	346000.00	225474.00	225474.00	120526.00
22612	Travel Expenses	1641000.00	1226127.00	1226127.00	414873.00

22711	Miscellaneous Expenses	100000.00	99092.00	99092.00	908.00
28143	Vehicle&Machinery Equipment Rent Cost	45000.00	0.00	0.00	45000.00
Total		**30014400**	**21397306**	**21397306**	**9988694**
Capital Expenses					
31122	Machinery Equipment	685000.00	573423.00	573423.00	111577.00
31153	Construction of electrical infrastructure	40000.00	395500.00	395500.00	4500.00
31155	Construction of irrigation infrastructure	1100000.00	1095181.00	1095181.00	4819.00
31156	Construction of drinking water infrastructure	300000.00	279816.00	279816.00	20184.00
31159	Other public constructions	1000000.00	991754.00	991754.00	8246.00
31161	Structural improvement cost of the constructed building	2000000.00	1991067.00	1991067.00	8933.00
31171	Capital improvement expenditure for public construction	1000000.00	993520.00	993520.00	6480.00
Total		**6125000**	**6320261**	**6320261**	**164739**
Grand total		**36139400**	**27717567**	**27717567**	**10153433**

Annex 15. Revenue status of FY 2081/82

S.N.	Source	Amount (NPR)	Remarks
1	Seed/sapling/Fresh fruit	42,39,937.00	
2	Guesthouse	4,800.00	
3	Administrative	3,42,001.00	
Total		**45,86,738.00**	

Annex 16. Beruju Status till FY 2081/82

Beruju	Amount	Remarks
Beruju till year 2059/60	54,000.00	
Beruju from FY 2060/61 to 2079/80	589,000.00	
Beruju FY (2081/82)	0.00	
Remaining beruju	643,000.00	

Annex 17. List of participants in the Technical Assistant's level residential training on "Decline management of citrus orchard" in 2081/82

S.N.	Name of participants	Address
1	Ms. Barsha Khatri	Sagurigadi, Bhedetar
2	Ms. Rajmati Dhami	Likhu, Okhaldunga
3	Ms. Em Kumari Tamang	Kummayak, Panchthar
4	Ms. Dipika Rai	Shadananda, Bhojpur
5	Ms. Jamuna Pradhan	Bhojpur-3, Bhojpur
6	Ms. Priya Rai	Makalu, Sankhuwasabha
7	Ms. Soniya Pun	Krishi Gyankendra, Bhojpur
8	Ms. Bishnu Maya Shrestha	Fakfokthum, Ilam
9	Ms. Sabina Chaudhari	PMAMP, Fidim, Panchthar
10	Mr. Dakendra Bastola	Diru-6, Khotang
11	Mr. Yogendra Shrestha	Solududhkunda, Solukhumbu
12	Mr. Khadka Bahadur Sawad	Sahidbhumi, Dhankuta
13	Mr. Gagan Rai	Limchungbung, Udayapur
14	Mr. Laxmi Prasad Regmi	Khotehang RM, Khotang
15	Mr. Hajendra Khatri	PMAMP, Dhankuta
16	Mr. Dilip Ghimire	Dharmadevi, Sankhuwasabha
17	Mr. Ghanendra Ghising	Chaubise RM, Dhankuta
18	Mr. Jaya Kumar Bishowkarma	Aathrai RM, Tehrathum

Annex 18. Citrus varieties released/registered by NCRP, Paripatle, Dhankuta till FY 2081/82

S.N.	Crop	Variety	Status	Year
1	Mandarin	Khoku Local	Registered	2075
2	Mandarin	Banskharka Local	Registered	2079
3	Mandarin	Paripatle Agaute-1	Registered	2080
4	Mandarin	Paripatle Agaute-2	Registered	2082
5	Acid lime	Sunkagati-1	Released	2072
6	Acid lime	Sunkagati-2	Released	2072
7	Acid lime	Tehrathum Local	Registered	2075
8	Lemon	Paripatle Sunaulo Nibuwa	Registered	2082

Annex 19. Citrus germplasm maintained at the field gene-bank of NCRP, Paripatle, Dhankuta till FY 2081/82

S.N.	Accession No	Identification/Common Name	Source
A. Mandarin *(Citrus reticulata/ unshiu)*			
1	NCRP-01	Khoku Local	Khoku, Dhankuta
2	NCRP-02	Kinnow	Pakistan
3	NCRP-03	Frutrel Early	Unknown
4	NCRP-04	Unshiu	JICA, Japan
5	NCRP-05	Miyagawawase	JICA, Japan
6	NCRP-06	Okitsuwase	JICA, Japan
7	NCRP-08	Pongan, Tangerine	ICIMOD
8	NCRP-09	Kamala	Dhankuta
9	NCRP-10	Baskharka Local (Parbat)	LAC, Lumle
10	NCRP-11	Sikkime	Tehrathum
11	NCRP-12	Calamondin	Unknown
12	NCRP-80	Satsumawase	INRA-CIRAD, France
13	NCRP-81	Satsuma Mino	INRA-CIRAD, France
14	NCRP-82	Satsuma URSS	INRA-CIRAD, France
15	NCRP-88	Fortune	INRA-CIRAD, France
16	NCRP-89	Kara	INRA-CIRAD, France
17	NCRP-90	Nova	INRA-CIRAD, France
18	NCRP-91	Pixie	INRA-CIRAD, France
19	NCRP-92	Dancy	INRA-CIRAD, France
20	NCRP-93	Avana	INRA-CIRAD, France
21	NCRP-94	Page	INRA-CIRAD, France
22	NCRP-95	Satsuma Okitsu	INRA-CIRAD, France
23	NCRP-97	Clamentine- Hernandina	INRA-CIRAD, France
24	NCRP-98	Clamentin-Oroval	INRA-CIRAD, France

S.N.	Accession No	Identification/Common Name	Source
25	NCRP-99	Clamentine-Commune	INRA-CIRAD, France
26	NCRP-100	Clamentine-Marisol	INRA-CIRAD, France
27	NCRP-101	Clamentine Nules	INRA-CIRAD, France
28	NCRP-112	Gorkhali Suntala	Gorkha, Nareswor
29	NCRP-114	Khoku-Chimera	NCRP, Dhankuta
30	NCRP-121	Daisy	Australia
31	NCRP-122	Avana Aprino	Australia
32	NCRP-123	Imperial	Australia
33	NCRP-124	Murcott	Kirtipur
34	NCRP-125	Oota Pongan	Kirtipur
35	NCRP-126	Yashida Pongan	Kirtipur
36	NCRP-127	Selection-79	Kirtipur
37	NCRP-128	Selection-04	Kirtipur
Tangor			
38	NCRP-102	Ellendale	INRA_CIRAD, France
39	NCRP-103	Murcott	INRA_CIRAD, France
40	NCRP-72	Ortanique	INRA_CIRAD, France
41	NCRP-07	Tangor, Murcott	JICA, Japan
Tangelo			
42	NCRP-73	Minneola	INRA_CIRAD, France
43	NCRP-74	Orlando	INRA_CIRAD, France
44	NCRP-75	Seminole	INRA_CIRAD, France
B. Sweet orange (*C. sinensis*)			
45	NCRP-13	Valencia Late	ICAR, India
46	NCRP-14	Sevelle Common	ICAR, India
47	NCRP-15	Navelencia	ICAR, India
48	NCRP-16	Malta Blood Red	ICAR, India
49	NCRP-17	Samauti	ICAR, India
50	NCRP-18	Masambi	ICAR, India
51	NCRP-19	Vanelle	ICAR, India
52	NCRP-20	Ruby	ICAR, India
53	NCRP 21	White Taker	ICAR, India
54	NCRP-22	Washington Navel	ICAR, India
55	NCRP 23	Hamlin	ICAR, India
56	NCRP 24	Pineapple	ICAR, India
57	NCRP-25	Yashida Navel	FDC, , Kirtipur
58	NCRP-26	Madam Vinous	GRESCO, Kathmandu
59	NCRP-27	Delicious Seedless	ICIMOD
60	NCRP-28	Skaggs Bonanza	ICIMOD
61	NCRP-29	Blood Red	ICIMOD
62	NCRP-30	Newhall Navel	ICIMOD

S.N.	Accession No	Identification/Common Name	Source
63	NCRP-31	Succari	ICIMOD
64	NCRP-32	Meisheu-9	ICIMOD
65	NCRP-33	Dhankuta Local	Dhankuta
66	NCRP-34	Lue Gim Gong	ICAR, India
67	NCRP-83	Cara Cara Novel	INRACIRAD, France
68	NCRP-84	Lane Late	INRACIRAD, France
69	NCRP-85	Pineapple	INRACIRAD, France
70	NCRP-86	Valencia Late	INRACIRAD, France
71	NCRP-87	Salustiana	INRACIRAD, France
72	NCRP-96	Tamango	INRACIRAD, France
73	NCRP-129	Atwood Navel	Australia
74	NCRP-130	Navelina Navel	Australia
75	NCRP-131	Valencia Seedless Delta	Australia
76	NCRP-132	Valencia Seedless McMohan	Australia
77	NCRP-133	Ramechhap Local	Ramechhap
78	NCRP-134	Sindhuli Local	Sindhuli
C. Grape Fruit			
79	NCRP-45	Shamber	ICIMOD
80	NCRP-76	Henderson	INRA_CIRAD, France
81	NCRP-77	Star Ruby	INRA_CIRAD, France
82	NCRP-78	Reed	INRA_CIRAD, France
83	NCRP-79	Pink Ruby	INRA_CIRAD, France
84	NCRP-44	Phultrac (Pumelo)	Vietnam
85	NCRP-43	Nam Roi (Pumelo)	Vietnam
86	NCRP-42	Phodiem (Pumelo)	Vietnam
D. Acid lime *(C. aurantifolia)*			
87	NCRP-108	Khursanibari Local	SHARP, Chitwan
88	NCRP-107	Tehrathum Local	Tehrathum
89	NCRP-117	Baitadi Local	Baitadi
90	NCRP-118	Salyan Local	Rojwal Takura, Salyan
91	NCRP-119	Bhojpur Local	Takshor, Bhojpur
92	NCRP-120	Parbat Local	Lekhpant, Parwat
93	NCRP-60	Kaptangunj Lamo	Sunsari
94	NCRP-59	Kaptangunj Golo	Sunsari
95	NCRP 58	Krishnapur Kagati	Bharatpur, Chitwan
96	NCRP-57	Krishnapur Kagati	Bharatpur, Chitwan
97	NCRP-56	Banarasi Kagati	Biratnagar
98	NCRP-55	Madrasi Kagati	Biratnagar
99	NCRP 54	Banarasi Kagati	Biratnagar
100	NCRP-52	Belepur	Morang
101	NCRP-51	Sundarpur	Morang

S.N.	Accession No	Identification/Common Name	Source
102	NCRP-50	IAAS Acc # 71 (5)	IAAS, Rampur
103	NCRP-49	IAAS Acc # 101 (3)	IAAS, Rampur
104	NCRP-48	IAAS Acc # 101 (2)	IAAS, Rampur
105	NCRP-47	IAAS Acc # 01 (17)	IAAS, Rampur
106	NCRP-46	IAAS Acc # 01 (25)	IAAS, Rampur
107	NCRP-135	Nepalgunj Local	Banke
108	NCRP-136	Mexican Lime	
109	NCRP-137	Ranitar Local	Nawalpur
110	NCRP-138	Jhapa collection	Budhabare, Jhapa
E. Lemon [*Citrus limon* (L.) Osbeck]			
111	NCRP-53	Paripatle Sunaulo Nibuwa	Chitwan
112	NCRP-61	Eureka lemon unkwown	Unknown
113	NCRP-63	Hill Lemon	Sunderpur Morang
114	NCRP-64	Eureka Lamcho lemon	Sunderpur Morang
115	NCRP-109	Thimura Local	SHARP Chitwan
116	NCRP-110	Biratnagar Local	SHARP Chitwan
117	NCRP-111	Prembasti Local	SHARP Chitwan
118	NCRP-142	Bhageshwor Local	Bhageshwor, Dadeldhura
F. Kumquat *(Citrus margarita/japonica/crassifolia)*			
119	NCRP-105	Fortunella (Oval)	Unknown
120	NCRP-106	Fortunella (Round)	Unknown
121	NCRP-115	Fortunella (Indian Muntala)	Unknown
G. Rootstocks			
122	NCRP-65	Citrange C-35	INRA_CIRAD
123	NCRP-66	Citrange- Carrizo	INRA_CIRAD
124	NCRP-67	Poncirus Pomeroy	INRA_CIRAD
125	NCRP-68	Flying Dragon	INRA_CIRAD
126	NCRP-69	Citrumelo-4475	INRA_CIRAD
127	NCRP-70	Volkameriana	INRA_CIRAD
128	NCRP-71	Rangpur lime Red	INRA_CIRAD
129	NCRP-113	Citrange old	Unknown
130	NCRP-38	Citrange	Unknown
131	NCRP-35	Citron	Unknown
132	NCRP-36	Trifoliate orange	Unknown
133	NCRP-37	Rangpur lime	Unknown
134	NCRP-39	Boxifolia	Unknown
135	NCRP-40	Rough lemon	Unknown
136	NCRP-116	Rough lemon	Paripatle Dhankuta
137	NCRP-41	Hokse	Dhankuta
138	NCRP-62	Local Bimiro	Belahara, Dhankuta
139	NCRP-104	Sweet lime	Dhankuta

S.N.	Accession No	Identification/Common Name	Source
140	NCRP-139	Troyer Citrange	Australia
141	NCRP-140	Rough lemon	Kathmandu

Annex 20. Special project (NAFH), budget, and expenditure status of FY 2081/82

Budget code	Budget head	Released budget (NPR)	Expenditure (NPR)	Balance
22212	Vehicle fuel	30,000	30000	0.00
22213	Repair and maintenance of vehicles	10,000	10,000	0.00
22311	Admin expenses (Masalanda samagri)	20,000	20,000	0.00
22521	Production expenses	50,0000	50,0000	0.00
22522	Program expenses	50,0000	50,0000	0.00
22611	Travel (monitoring) expenses	80,000	80,000	0.00
	Total	**10,30,000**	**10,30,000**	**0.00**

Annex 21. Human Resource at NCRP Supported by NAFHA Project in FY 2081/82

S.N.	Name	Position	Qualification	Working area	Remarks
1	Mr. Amrit Katuwal	Technical Officer (T-6)	B. Sc. Agiculture	Agriculture	Contract
2	Ms. Samjhana Ghimire	Technical Officer (T-6)	B. Tech. Biotechnology	Biotechnology	Contract

Participants of "Citrus decline management" training conducted for the technicians involving in citrus research and development works at Koshi Province of Nepal

Celebration of 34th NARC day at NCRP, Paripatle, Dhankuta

Visit of NCRP, Paripatle, Dhankuta by Honorable Minister for Agriculture and Livestock Development, Nepal

High density planting (HDP) trial in mandarin at NCRP, Paripatle, Dhankuta

Trifoliate orange seedling produced under the screen house at NCRP, Paripatle, Dhankuta