



**STUDY ON MICROBES MEDIATED ORGANIC PRODUCTION FOR
KHASI MANDARIN**

THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE
REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

By

BUDDHISATYA DOWARAH

Admn. No.Ph-313/20 Regn. No. Ph.D/HOR/00453

Department of Horticulture

School of Agricultural Sciences

Nagaland University, Medziphema Campus-797106

Nagaland

April 2026



**STUDY ON MICROBES MEDIATED ORGANIC PRODUCTION FOR
KHASI MANDARIN**

THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE
REQUIREMENTS FOR THE DEGREE OF DOCTOR OF
PHILOSOPHY

By

BUDDHISATYA DOWARAH

Admn. No.Ph-313/20 Regn. No. Ph.D/HOR/00453

Department of Horticulture
School of Agricultural Sciences
Nagaland University, Medziphema Campus-797106
Nagaland
April 2026

STUDY ON MICROBES MEDIATED ORGANIC PRODUCTION FOR KHASI
MANDARIN

BY

Name of the Candidate–Buddhisatya Dowarah

Name of the Supervisor-Prof. Pauline Alila

Submitted

In partial fulfillment of the requirements for the Degree of Doctor of
Philosophy in Horticulture of Nagaland University

**DEDICATED
TO
MY FAMILY**

Nagaland University

November, 2025

I, Buddhisatya Dowarah, hereby declare that the subject matter of this Thesis is the record of work done by me, that the contents of this Thesis did not form basis of the award of any previous degree to me or to the best of my knowledge to anybody else, and that the thesis has not been submitted by me for any research degree in any other University/Institute.

This is being submitted to the Nagaland University for the degree of Doctor of Philosophy in Horticulture.

(BUDDHISATYA DOWARAH)



(Head)

Dr. Pauline Alila
(Supervisor)

NAGALAND UNIVERSITY
Medziphema Campus
School of Agricultural Sciences
Medziphema – 797 106, Nagaland

Dr. Pauline Alila
Professor
Department of Horticulture

CERTIFICATE – I

This is to certify that the thesis entitled “**Study on microbes mediated organic production for Khasi mandarin**” submitted to Nagaland University in partial fulfillment of the requirements for the award of degree of Doctor of Philosophy (Agriculture) in Horticulture is the record of research work carried out by BUDDHISATYA DOWARAH Registration No. Ph.D./HOR/00453 under my personal supervision and guidance.

The result of the investigation reported in the thesis have not been submitted for any other degree or diploma. The assistance of all kinds received by the student has been duly acknowledged.

Date :
Place :

.....

Dr. Pauline Alila
Supervisor

NAGALAND UNIVERSITY
Medziphema Campus
School of Agricultural Sciences
Medziphema – 797 106, Nagaland

CERTIFICATE – II

VIVA VOCE ON THESIS OF DOCTOR OF PHILOSOPHY IN HORTICULTURE

This is to certify that the thesis entitled “**Study on microbes mediated organic production for Khasi mandarin**” submitted by BUDDHISATYA DOWARAH, Admission No. Ph-313/20 Registration No. Ph.D./HOR/00453 to the NAGALAND UNIVERSITY in partial fulfillment of the requirements for the award of degree of Doctor of Philosophy in Horticulture has been examined by the Advisory Board and External examiner on

The performance of the student has been found **Satisfactory/Unsatisfactory.**

Member	Signature
1. Dr. Pauline Alila (Supervisor)	
2. Dr. (External examiner)	
3. Pro –Vice Chancellor’s nominee (Dean, SAS: NU)	
4. Dr. C.S. Maiti	
5. Dr. A. Sarkar	
6. Dr. S.P. Kanaujia	
7. Dr. N. Tiamerao Ao	

Head
Department of Horticulture

Dean
School of Agricultural Sciences

ACKNOWLEDGEMENTS

First, I thank the Almighty 'God' for His abundant blessings and grace throughout my research programme. Nothing would have been accomplished without His help.

With immense pleasure, I would like to express my deepest gratitude to my supervisor Dr. Pauline Alila, Professor, Department of Horticulture, SAS, Nagaland University for her guidance, support and supervision in all my works, without whose help this thesis would have been incomplete.

I would also like to sincerely thank the members of Advisory Committee, Dr. S. P. Kanaujia, Professor and Head, Department of Horticulture; Dr. C. S. Maiti, Professor; Dr. A. Sarkar, Associate Professor, Department of Horticulture; Dr. N. Tiameren Ao, Professor, Department of Plant Pathology for their valuable suggestions and inputs throughout the period of study.

I also express my gratitude to then Dean Dr. L. Daiho, SAS, Nagaland University for his consistent support during my study period and all the college's assistance.

I would also like to acknowledge the help of STA and the non-teaching staff of the Department of Horticulture for their constant valuable help throughout my research work. I am also thankful to Mr. Mhonbemo Ngullie, Deputy Librarian and his staff for the assistance and help provided whenever needed.

My appreciation and thanks goes to the family of Laseng Umbon as they had supported me in every possible way and allowed me to conduct my research work in their orchard for which I will be greatly indebted to them.

I would like to show my gratitude to Dextrose Technologies Pvt. Ltd as they had supported me by providing the microbial studies information of my research work for which I am greatly thankful.

I am immensely thankful to my friends- Somorjit M., Jarman Gadi, Sridhar Rathod, Charan Singh Choudhary, Gangaram Rana and all my seniors and juniors for their constant help, support and encouragement throughout my studies and research work. I will forever be indebted to you all.

The debts of gratitude I owe to my mother, father, aunties and sisters cannot be comprehended. I thank them for their sacrifice, blessings, unconditional love, support, and unfailing patience and for being the strength behind all my endeavours.

Dated :

Place: Medziphema

(Buddhisatya Dowarah)

CONTENTS

CHAPTER	TITLE	PAGE No.
I.	INTRODUCTION	1-8
II.	REVIEW OF LITERATURE	9-28
III.	MATERIALS AND METHODS	29-50
	3.1 Experiment site	
	3.1.1 Location and Climate	
	3.1.2 Soil conditions	
	3.2 Experiment I	
	3.2.1 Technical details	
	3.2.2 Collection of rhizospheric soil	
	3.2.3 Seedling studies	
	3.2.4 Soil microbial diversity	
	3.3 Experiment II	
	3.3.1 Technical details	
	3.3.2 General information	
	3.3.3 Fertilization time and method	
	3.3.4 Irrigation	
	3.3.5 Weeding	
	3.3.6 Physical attributes	
	3.3.7 Fruit quality attributes	
	3.3.8. Soil analysis	
	3.3.9 Economics of cultivation	
	3.3.10 Statistical analysis	
IV.	RESULTS AND DISCUSSIONS	51-134
	4.1 Seedling studies	
	4.2 Microbial diversity studies	
	4.3 Studies with organic inputs and microbial consortium	
	4.3.1 Tree height (m)	
	4.3.2 Tree spread (m)	
	4.3.3 Canopy volume (m ³)	
	4.3.4 Stem girth (cm)	
	4.3.5 Number of flowers per metre shoot length	
	4.3.6 Initial fruit set per metre shoot length	
	4.3.7 Final fruit set per metre shoot length	
	4.3.8 Fruit drop per tree (%)	
	4.3.9 Fruits per tree at harvest	

- 4.3.10 Yield per tree (kg)
- 4.3.11 Fruit attributes
- 4.3.12 Fruit quality attributes
- 4.3.13 Shelf life studies
- 4.3.14 Soil characteristics
- 4.3.15 Economic attributes

V.	SUMMARY AND CONCLUSIONS	135-140
	REFERENCES	i-xxii
	APPENDICES	a-f

LIST OF TABLES

TABLE No.	TITLE	PAGE No.
4.1	Effect of rhizosphere treatments on plant height (cm) of different ages of seedlings	52
4.2	Stem girth (cm) of Khasi mandarin seedlings as influence by various rhizosphere treatments	52
4.3	Influenced of rhizosphere treatments on the number of leaves in Khasi mandarin seedlings	54
4.4	Leaf nutrient element composition of Khasi mandarin seedlings	56
4.5	Effect of microbial consortium along with organic amendment on plant growth characteristics of Khasi mandarin	69
4.6	Effect of microbial consortium with organic amendments on number of flowering characteristics of Khasi mandarin	73
4.7	Effect of microbial consortium with organic amendments on yield characteristics	76
4.8	Effect of microbial consortium with organic amendments on yield attributes	80
4.9	Effect of microbial consortium along with organic amendments on fruit characteristics	83
4.10	Effect of microbial consortium with organic amendments on fruit qualitative characteristics of Khasi mandarin	90-91
4.11	Effect of microbial consortium and organic amendments on peel oil content (%) of fruits in Khasi mandarin	93
4.12	Sensory evaluation of Khasi mandarin as affected by different treatments	95
4.13	Effect of microbial consortium with organic amendments on physiological loss in weight (%)	98-99
4.14	Effect of microbial consortium with organic amendments on juice recovery (%) during storage	102-103

4.15	TSS(° Brix) during storage as affected by microbial consortium and organic amendment	106-107
4.16	Effect of microbial consortium with organic amendments on titrable acidity (%) in fruits during storage	109-110
4.17	Effect of microbial consortium with organic amendments on total sugar content (%) in fruits during storage	113-114
4.18	Effect of microbial consortium with organic amendments on reducing sugar content (%) in fruits during storage	117-118
4.19	Influence of microbial consortium with organic amendments on ascorbic acid content (mg/ 100ml) in fruits during storage	121-122
4.20	Effect of microbial consortium with organic amendments on soil characteristics	124
4.21	Economics in cultivation in organic mediated Khasi mandarin plants	134

LIST OF FIGURES

FIGURE No.	CAPTION	IN BETWEEN PAGES
3.1	Graphical representation of meteorological data during the period of investigation (January, 2023 to October, 2024)	29-30
4.1	Seedling plant height (cm) with different rhizosphere treatments	52-53
4.2	Stem girth (cm) of Khasi mandarin seedlings as influenced by various rhizosphere treatments	52-53
4.3	Rhizosphere treatments on number of leaves in Khasi mandarin seedlings	54-55
4.4	Leaf nutrient content in seedling plants grown on different rhizosphere	54-55
4.5	Leaf micronutrient content (ppm) as influenced by different rhizosphere	56-57
4.6	Raw data summary and quality assessment	58-59
4.7	Amplicon processing summary	58-59
4.8	Taxonomic composition and relative abundance at the species level	60-61
4.9	Taxonomic composition and relative abundance at the genus level	61-62
4.10	Taxonomic composition and relative abundance at the phylum level	64-65
4.11	Rarefaction curve to estimate the species richness in the sample	65-66
4.12	Alpha diversity analysis to estimate the richness of the community in the sample	65-66
4.13	Tree height (m) of Khasi mandarin as influenced by organic inputs and microbial consortium	69-70
4.14	Effect of microbial consortium and organic inputs on canopy spread (m) of Khasi mandarin	69--70

4.15	Influence of microbial consortium and organic inputs on canopy volume (m ³) of Khasi mandarin	69-70
4.16	Effect of microbial consortium and organic amendments on stem girth (cm) of Khasi mandarin	69-70
4.17	Influence of microbial consortium and organic amendments on fruit set per metre shoot of Khasi mandarin	73-74
4.18	Effect of organic amendments and microbial consortium on number of fruits per metre shoot at harvest	73-74
4.19	Effect of microbial consortium and organic amendments on fruits per tree in Khasi mandarin	76-77
4.20	Influence of microbial consortium and organic amendments on yield per tree (kg)	76-77
4.21	Influence of microbial consortium and organic amendments on fruit juice content (%)	91-92
4.22	Influence of microbial consortium along with organic amendments on TSS (°Brix)	91-92
4.23	Effect of microbial consortium and organic amendments on titrable acidity (%) of Khasi mandarin	91-92
4.24	Effect of microbial consortium and organic amendments on TSS and acidity ratio	91-92
4.25	Effect of microbial consortium and organic amendments on fruit total sugar (%) of Khasi mandarin	91-92
4.26	Effect of microbial consortium and organic amendments on fruit reducing sugar (%) of Khasi mandarin	91-92
4.27	Influence of microbial consortium along with organic amendments on ascorbic acid content (mg/100ml)	91-92

4.28	Physiological loss in weight (%) of fruits during storage as influenced by microbial consortium and organic amendments during 2023	99-100
4.29	Physiological loss in weight (%) of fruits during storage as influenced by microbial consortium and organic amendments during 2024	99-100
4.30	Juice recovery (%) of fruits during storage as influenced by microbial consortium and organic amendments during 2023	103-104
4.31	Juice recovery (%) of fruits during storage as influenced by microbial consortium and organic amendments during 2024	103-104
4.32	Total soluble solids (° Brix) of fruits during storage as influenced by microbial consortium and organic amendments during 2023	107-108
4.33	Total soluble solids (° Brix) of fruits during storage as influenced by microbial consortium and organic amendments during 2024	107-108
4.34	Titration acidity (%) of fruits during storage as influenced by microbial consortium and organic amendments during 2023	110-111
4.35	Titration acidity (%) of fruits during storage as influenced by microbial consortium and organic amendments during 2024	110-111
4.36	Total sugar (%) of fruits during storage as influenced by microbial consortium and organic amendments during 2023	114-115
4.37	Total sugar (%) of fruits during storage as influenced by microbial consortium and organic amendments during 2024	114-115
4.38	Reducing sugar (%) of fruits during storage as influenced by microbial consortium and organic amendments during 2023	118-119

4.39	Reducing sugar (%) of fruits during storage as influenced by microbial consortium and organic amendments during 2024	118-119
4.40	Ascorbic acid content (mg/100ml) of fruits during storage as influenced by microbial consortium and organic amendments during 2023	122-123
4.41	Ascorbic acid content (mg/100ml) of fruits during storage as influenced by microbial consortium and organic amendments during 2024	122-123
4.42	Influence of microbial consortium with organic inputs on soil pH in two years of study	124-125
4.43	Influence of microbial consortium with organic inputs on soil organic carbon (%) in two years of study	124-125
4.44	Influence of microbial consortium with organic inputs on available soil nitrogen (kg ha^{-1}) in two years of study	126-127
4.45	Influence of microbial consortium with organic inputs on available soil Phosphorous (kg ha^{-1}) in two years of study	126-127
4.46	Influence of microbial consortium with organic inputs on available soil Potassium (kg ha^{-1}) in two years of study	127-128

LIST OF PLATES

PLATE No.	CAPTION	IN BETWEEN PAGES
3.1	General view of the orchard	30-31
3.2	Interculture and nutrient management practices at the orchard	32-33
4.1	Seedling plants of Khasi mandarin in different rhizosphere	56-57
4.2	Flowering and fruit development stages of Khasi mandarin	73-74
4.3	Laboratory analysis for physico-chemical characteristics of Khasi mandarin	95-96
4.4	Harvested fruits from various treatments	122-123

LIST OF ABBREVIATIONS

16S rRNA	16S ribosomal ribonucleic acid
AAU	Assam Agricultural University
AMF	Arbuscular mycorrhizal fungi
AMVs	Amplicon Sequence Variants
AOAC	Association of Official Analytical Collaboration
ASTM	American Society for Testing and Materials
B:C	Benefit- cost ratio
CCRI	Central Citrus Research Institute
CD	Critical difference
CEC	Cation exchange capacity
NASA	National Aeronautics and Space Administration
DADA2	Division Amplicon Denoising Algorithm 2
DAS	Days after storage
DNA	Deoxyribonucleic acid
DTPL	Khasi mandarin rhizosphere metagenomic sample
<i>et al.</i>	<i>Et allia</i> (and other)
U.S. RDA	United States recommended daily allowance
E-W	East-West
FAO	Food and agriculture organization
OC	Organic carbon
GC	Guanine-Cytosine
PCR	Polymerase chain reaction
PLW	Physiological loss in weight
N-S	North-South
IPNS	Integrated plant nutrient system
FYM	Farmyard manure
M Seqs	Mean sequence

ABSTRACT

The present investigation entitled “Study on microbes mediated organic production for Khasi Mandarin” was conducted from 2022 to 2024 under the Department of Horticulture, School of Agricultural Sciences, Nagaland University, Medziphema Campus. The investigation consisted of two experiments, where the first experiment was to observe the influence of rhizospheric soil on seedling growth and development and also the soil microbial diversity. The second experiment was to observe the influence of organic manure along with microbial consortium on already established mandarin orchard. The first experiment consisted of applying rhizospheric soil collected from the tree base of healthy elite mandarin trees and mixed in the soil mixture where Khasi mandarin seedling were planted and their growth and chemical parameter were observed. The above rhizosphere were collected from an orchard at Pangna Gaon, Tinsukia, Assam. The experiment was laid out in a Completely Randomized Design (CRD) with four replications and five treatments. Leaf nutrient analyses showed rhizosphere of T₁ and T₂ resulted in high N and Ca content (%) respectively while T₄ gave high P, K and Mg. Micronutrients Mn and Zn was found higher in treatment with T₁ while Cu and Fe was obtained from T₄. Greatest (2.20 cm) was obtained with T₁ while greatest number of leaves (50.03) and seedling height (33.37 cm) after 180 days was obtained with T₄. The metagenomic analyses of Khasi mandarin rhizosphere soil, derived from the combined T₁ and T₄ rhizospheric samples, revealed a high-quality sequencing dataset with excellent read integrity, minimal duplication, and balanced GC content, confirming the reliability of downstream microbial profiling. Taxonomic analysis showed a strong dominance of the Firmicutes phylum, followed by Proteobacteria, Actinobacteria, and Bacteroidetes, reflecting a metabolically versatile and stress-tolerant microbial community. At the genus level, *Clostridium*, *Lysinibacillus* and *Bacillus* were most abundant, indicating active participation in nutrient cycling, organic matter decomposition, and plant growth promotion. Dominant species such as *Clostridium sartagoforme*, *C. perfringens*, *Terrisporobacter glycolicus* and *Bacillus thuringiensis* were associated with cellulose degradation, nitrogen transformation and pathogen suppression, contributing to soil fertility and plant vigour. In the second experiment, the treatments

undertaken were application of organic manures with or without microbial consortium conducted on standing trees of Khasi mandarin. The treatments included T₁: control(conventional method), T₂: control plus microbial consortium 100 ml, T₃: FYM(40 kg/plant), T₄: FYM(20 kg/plant) plus microbial consortium 100 ml , T₅ poultry manure(4 kg/plant), T₆: poultry manure(2 kg/plant) plus microbial consortium 100 ml, T₇: pig manure(8 kg/plant), T₈: pig manure(4kg/plant) plus microbial consortium 100ml,T₉ : vermicompost(4kg/plant), T₁₀: vermicompost (2kg/plant) plus microbial consortium 100ml. The experiment was laid out in RBD with 4 replications (2 trees as one replication). The pooled data of two years indicated that flower intensity (flowers per metre of shoot length) and fruit set (fruits per metre of shoot length was maximum in T₂ with 33.42 and 3.40 respectively. However the total number of fruits per plant at harvest (120.80) and greatest yield per tree (11.10 kg) was obtained with treatment T₁₀. With respect to tree growth characters such as tree height, tree spread, canopy volume and stem girth treatments T₂ and T₁₀ had better influence on the trees. In terms of fruit biochemical characters and post harvest shelf life T₁₀ showed significantly better results. The benefit-cost ratio of treatments was found greater in T₁₀ with 2.072 in 2023 and 3.176 in 2024. The organic manure along with the microbial consortium improved the activities of the rhizospheric microbes which further helped in increasing the nutrient uptake.

Keywords: Khasi Mandarin, Rhizosphere, Organic manure, Microbial Consortium

CHAPTER I

INTRODUCTION

INTRODUCTION

The loose-skinned Khasi mandarin (*Citrus reticulata* Blanco, $2n = 18$) of the family Rutaceae—locally called “Sohniampttra” (Khasi), “Humthira/Komola” (Assamese), and “Komla” (Bengali, Manipuri) is among the world’s most economically important mandarins, occupying about 4.28 lakh hectares and yielding roughly 51.01 lakh tonnes (NHB, 2017-18). The northeastern region of India is considered as one of the natural home or primary gene centre (Ziegler and Wolfe, 1961; Ghosh, 1977; Govind and Yadav, 1999; Ray and Deka, 2000; Ghosh, 2007) and reservoir of various citrus species including mandarin orange (Tanaka, 1958; Singh and Chadha, 1993; Chadha, 1995; Hazarika, 2012). Khasi mandarin requires deep loose well aerated soil devoid of any hard pan and ideal pH range for 5.5 to 7.5 (AAU, 2021), which explains its concentration across the region’s eight states and its presence in two global biodiversity hotspots (Indo-Burma; Eastern Himalaya). Around 1 lakh ha of land is under mandarin cultivation scattered over eight states namely, viz. Assam, Arunachal Pradesh, Meghalaya, Manipur, Mizoram, Nagaland, Tripura, and Sikkim where this high value crop contributes significantly to the small farm economy.

Mandarin (*Citrus reticulata* Blanco) is one of the most widely consumed citrus fruits across the world, valued not only for its pleasant flavour and aroma but also for its therapeutic and nutritional properties (Zhang *et al.*, 2012). Traditionally, various parts of the mandarin plant have been used in herbal medicine for treating several ailments. The fruits are consumed to alleviate fever and catarrh, while the fresh rind is applied to acne, and poultices made from roasted pulp are used for treating skin diseases. Infusions prepared from immature fruits are known to aid in the treatment of stomach and intestinal disorders (Morton, 1987; Anon, 2014).

In Chinese traditional medicine, a vinous decoction of husked orange seeds is prescribed for urinary ailments, and the dried peel is used to relieve abdominal swelling, improve digestion, and reduce phlegm. Various parts of the plant are used to treat cutaneous problems, hemiplegia, snake bites, fever, loss of taste, chronic

rheumatism, stomachache, menorrhagia, splenomegaly, edema, cardiac diseases, bronchitis, and asthma (Xian, 2007). Similarly, in Italy, decoctions prepared from dried leaves and flowers are employed as antispasmodic, cardiac sedative, antiemetic, digestive, and carminative agents (Morton, 1987). In conventional Chinese medicine, the dried mature fruit peels of *C. reticulata* have long been used as remedies for indigestion and inflammatory conditions of the respiratory tract (Yung-Sheng, 2010).

Citrus fruits, in general, have been recognized for their health-promoting effects for centuries. Beyond their high vitamin C content, they are rich sources of β -carotene (a potent antioxidant), magnesium (for blood pressure regulation), potassium (for cardiovascular health), and thiamine (for energy metabolism) (Anon, 2009). They also contain dietary fiber, folates, niacin, pantothenic acid, pyridoxine, riboflavin, and vitamins A, E, and K, along with a variety of phytonutrients that enhance overall health. Folate in citrus help prevent neural tube defects and lower serum homocysteine levels, contributing to heart health. The pectin present in citrus fruits aids in reducing serum cholesterol, controlling hypercholesterolemia, and promoting the excretion of fats and bile acids (Baker, 1994). Moreover, pectin exhibits growth-suppressing effects on prostate cancer cells (Hsieh and Wu, 1995).

According to Rouseff and Nagy (1994), a 227 ml serving of either grapefruit or orange juice can meet 100% of the U.S. Recommended Daily Allowance (RDA) for vitamin C. Apart from its nutritional and medicinal values, *C. reticulata* has significant economic importance for its essential oils, which are rich in aromatic compounds (Minh Tu *et al.*, 2002). The exocarp of *C. reticulata* is widely used for flavouring liquors, and several studies have reported the chemical composition of its peel oil (Shaw, 1979; Lawrence, 1992).

Among citrus different species exhibit distinct growth habits ranging from spreading to drooping and erect types and deviations from these habits often indicate stress. Khasi mandarin trees are distinctly erect in nature, a characteristic feature that differentiates them from other citrus species (Anon., 2014; Singh *et al.*, 2016). In the Garo Hills of Meghalaya, plant height ranged from 4.60 m to 6.48 m (Hangsing

et al., 2016), while Kakoti *et al.* (2019) observed heights between 7.03 m and 8.20 m and girth between 14.00 cm and 15.50 cm in Manipur.

Leaf characteristics are also important indicators of plant health and identity. CCRI, Nagpur, reported fully expanded Khasi mandarin leaves with a length of 7–8 cm and a width of 3–4 cm (Singh *et al.*, 2016). Barbora *et al.* (2019) found the maximum leaf length and width as 8.27 cm and 4.17 cm, respectively. Canopy spread and volume, which represent vegetative vigour, varied from 3.40–4.67 m (N–S) and 3.57–5.10 m (E–W), with canopy volumes ranging between 38.67 m³ and 49.67 m³ (Barbora *et al.*, 2019). Hangsinget *al.* (2016) reported similar spreads of 3.50–4.82 m and 3.56–5.25 m, and canopy volume between 8.3 m³ and 16.9 m³.

The performance of Khasi mandarin is influenced by the age of the plant. Trees aged 21–30 years were found to exhibit the best yield and fruit quality, while trees older than 40 years showed poor productivity (Hangsinget *al.*, 2016). Rymbaiet *al.* (2022) reported that six-year-old trees could produce 40–50 fruits per plant, though the optimum productive phase is reached after several years.

Fruit morphological traits play a significant role in yield determination. CCRI, Nagpur, documented fruit weights of 110–140 g, fruit diameters of 60–70 mm, lengths of 55–65 mm, and rind thickness of 2–3 mm with deep orange colour (Singh *et al.*, 2016). In Manipur, fruit weight ranged from 133.31 g to 243.55 g, fruit length from 5.23–7.33 cm, and fruit breadth from 6.67–8.43 cm (Kakoti *et al.*, 2019). In Meghalaya, fruit weight ranged from 80.59–130.69 g, fruit length from 49.25–66.42 mm, and diameter from 55.25–68.41 mm (Hangsinget *al.*, 2016). Barbora *et al.* (2019) reported similar ranges with 5.40–7.13 cm fruit length and 6.57–8.57 cm fruit width.

Qualitative characteristics such as juice content, total soluble solids (TSS), acidity, and ascorbic acid content are critical indicators of fruit quality. CCRI, Nagpur, reported juice content above 45%, TSS over 11°Brix, and acidity between 0.5–0.7% (Singh *et al.*, 2016). In the Garo Hills, Hangsinget *al.* (2016) recorded TSS between 10.36–10.98°Brix, acidity from 0.73–0.81%, total sugars between 7.27–8.99%, and ascorbic acid from 28.10–31.46 mg/100 ml.

Fruit yield serves as the ultimate indicator of tree performance. Kakoti *et al.* (2019) reported a maximum of 126 fruits per plant and yield of 28.33 kg per tree in Tamenglong, Manipur, while Hangsing *et al.* (2016) recorded fruit numbers ranging from 66.67 to 124 and productivity between 1.47–4.70 t/ha in Meghalaya. Barbora *et al.* (2019) reported a maturity period of 231–249 days from fruit set to marketable stage.

Citrus is a heavy-feeder perennial; all essential elements influence vegetative growth, reproductive development, fruit quality and tree longevity (Srivastava, 2012). Indiscriminate use of agrochemicals depletes beneficial soil microbiota and degrades soil function; integrated use of organic manures and biofertilisers with chemical fertilizers (INM) maintains long-term fertility and sustains productivity better than any single component alone (Srivastava and Singh, 2009). Organic amendments also improve soil carbon, water retention and nutrient buffering, reducing losses from leaching on the high-rainfall, sloping soils common in the Khasi mandarin area (Hazarika and Malsawmkimi 2023).

Nutrient management plays a decisive role in the growth, yield and fruit quality of Khasi mandarin. Nitrogen (N) promotes vegetative growth, leaf expansion, and flower initiation; however, excessive N leads to vigorous vegetative growth at the expense of yield and reduces total soluble solids (TSS) (Gogoi *et al.*, 2018). Phosphorus (P) enhances root and flower development, photosynthate translocation and sugar accumulation, improving fruit TSS (Liet *et al.*, 2021), while potassium (K) regulates fruit size, colour, juice content and acidity, and is vital for stomatal and water balance (Toor *et al.*, 2021). Secondary nutrients like calcium (Ca), magnesium (Mg) and sulphur (S) maintain structural integrity, photosynthesis and enzyme activity, ensuring physiological stability and balanced macronutrient uptake (Barthakur, 2018). Micronutrients (Zn, Fe, Mn, Cu, B) are crucial for enzyme activation, hormone synthesis and reproductive processes.

Integrated nutrient management combining reduced chemical fertilizer rates (e.g., 75% RDF) with biofertilizers such as *Azospirillum*, *Azotobacter*, PSB, VAM and *Trichoderma* has shown improved yield, fruit quality (higher juice %, TSS,

sugars, ascorbic acid; lower acidity) and soil fertility with higher B:C ratios than full RDF (Gogoi *et al.*, 2018). Organic manures like vermicompost, FYM and pig manure enhance soil carbon and long-term nutrient availability (Hazarika *et al.*, 2011). Tree nutrient demand is stage-specific, N is critical during flowering and early fruiting, while P and K dominate during fruit enlargement and quality formation thus, stage-wise split application and timely foliar feeding improve efficiency under NEH conditions (Marschner, 2012). Region-specific DRIS norms (N 2.26–2.83%, P 0.11–0.16%, K 1.86–2.07%) correlated positively with yield, highlighting their utility in diagnosing imbalances, reducing indiscriminate fertilization, and enhancing cost-effective and sustainable Khasi mandarin production.

Integrated regimes (reduced RDF + biofertilisers + organics) produced higher juice content (48-49%), higher TSS (11-13°Brix), higher ascorbic acid and total sugars, lower acidity, earlier maturity and longer shelf life in some trials, together with improved soil NPK and higher B:C ratios (Gogoi *et al.*, 2018).

Sole inorganic high NPK tends to maximize vegetative vigor and sometimes yield but may increase peel weight/thickness, acidity and reduce TSS:acid ratio; organics (FYM/PM/VC) often improved certain quality components like segment weight and maintained stem diameter and long-term soil health. Soils in the eastern Himalayas are acidic, low in multiple nutrients (N, P, K, Zn, Ca, Mn, Mg) and subject to erosion and leaching due to heavy rainfall and sloping terrain; this necessitates both soil and foliar measures, organic matter rebuilding, contour/terrace conservation and locally calibrated fertilization (Srivastava and Singh, 2002).

The rhizospheric soil, the narrow zone surrounding plant roots is a dynamic and biologically active interface where crucial plant–microbe interactions occur. It is densely populated by diverse microorganisms including fungi, bacteria, protists, nematodes, and invertebrates. Plant roots secrete an assortment of primary metabolites such as organic acids, carbohydrates and amino acids and secondary metabolites (e.g., alkaloids, terpenoids, and phenolics) which are believed to shape, signal, interfere with, or in some way affect the rhizosphere microflora. This zone is characterized by intense biological activity owing to the release of root

exudates, which stimulate or inhibit rhizosphere organisms. Rhizosphere processes, such as nutrient mobilization and movement, in addition to root proliferation and symbioses, have an important role in controlling efficient nutrient acquisition by crops. Studying the rhizosphere of citrus is particularly important because this zone harbours diverse microbial communities that directly influence plant health, nutrition, and resilience to environmental stresses.

As citrus originated in Southeast Asia and is now cultivated in over 140 countries, it provides an excellent global model for understanding plant–microbiome relationships (Xu *et al.*, 2013). The metagenomic studies of the citrus rhizosphere have revealed that a core microbiome, comprising taxa such as *Pseudomonas*, *Agrobacterium*, *Bradyrhizobium*, *Rhizobium*, and *Sphingomonas*, is consistently enriched across biogeographical regions (Xu *et al.*, 2018). Many of these microbes are known to promote plant growth by regulating hormone balance, enhancing nutrient uptake, and suppressing pathogens (Lemanceau *et al.*, 2017). Similarly, certain core fungal genera like *Fusarium* (non-pathogenic forms) and *Hirsutella* act as potential biocontrol agents, while others contribute to stress tolerance through hormone synthesis and phosphorus solubilization (Wang *et al.*, 2016).

Understanding the composition and function of rhizosphere microbes is therefore essential for developing strategies to enhance sustainable citrus production, especially under the increasing challenges of environmental and disease pressures (Wang *et al.*, 2015). Insights from global-scale metagenomic analyses, such as those conducted by the International Citrus Microbiome Consortium (Wang *et al.*, 2016), lay a foundation for harnessing beneficial microbes to improve citrus health, productivity, and resilience—making rhizosphere studies a critical component of modern citrus research and management.

Due to rapid increase of world population which expected reach to 9 billion by 2050 and 12 billion by 2100, there is dramatic increase of food and agricultural commodities demands more than available production (FAO, 2017), so, the greatest potential to fulfill this gap is to increase the productivity per unit area of cultivated land which may be achieved by, enhancing soil fertility through the use of alternate

fertilizers as organic and biofertilizers along with chemical nutrients, in the same time horticultural production is facing various threats like challenges of climate change and increase environmental pollution (Abobatta, 2020), moreover, chemical fertilizers cause series environmental problems, as loss of soil nutrients, soil degradation, and reducing beneficial microorganisms (Suhag, 2016). Organic and bio-fertilizers such as compost, vermicompost, biochar, humic substances, farm yard manure (FYM), *Azotobacter*, *Azospirillum*, vascular arbuscular mycorrhiza (VAM), plant growth-promoting rhizobacteria (PGPR), are being an essential component of nutrient management for all crops, on one hand, they improve the soil biodiversity which is very important to preserve soil health, and improve root growth due to change in the rhizosphere and microclimate of the plants, on the other hand, organic and biofertilizers could use as an alternative for pesticides in the integrated pest management system. The modern agricultural production system emphasizes the use of organic fertilizers to substitute for chemical fertilizers in plant nutrition studies. In India, considering the present pace of population growth, mere application of organic fertilizers would not serve the purpose to feed billions of people. Nobel Laureate Dr. Norman E. Borlaug said on this issue that “We can use all the organic that are available but we are not going to feed billions of people with organic fertilizers”. Therefore, the aim should be to maintain or adjust the soil fertility and plant nutrient supply to an optimum level for sustaining the desired crop productivity through optimization of the benefits from all possible sources of plant nutrients in an integrated (organic and inorganic) manner. Integrated plant nutrient systems maintain soil fertility and plant nutrient supplies at an optimum level for sustaining desired crop productivity and improving farmer’s profitability through optimization of benefits from all possible sources of plant nutrients in an integrated manner (Marathe and Bharambe, 2007; Bhalerao *et al.*, 2009; Hazarika *et al.*, 2011). Taking the above into consideration, the present study entitled, “Study on microbes mediated organic production for Khasi mandarin” was be carried out with the following objectives:

1. Microbial diversity analysis of rhizosphere of Khasi mandarin.
2. Evaluation of organic manures alone and in combination with microbial consortium on growth, yield and quality of Khasi mandarin.

3. Evaluation of organic production module for post-harvest shelf-life of Khasi mandarin.
4. Economic analysis of organic production module of Khasi mandarin.

CHAPTER II

REVIEW OF LITERATURE

REVIEW OF LITERATURE

Organic and bio-fertilizers such as compost, vermicompost, pig manure, poultry manure, farm yard manure (FYM), *azotobacter*, *azospirillum*, vascular arbuscular mycorrhiza (VAM), plant growth-promoting rhizobacteria (PGPR), are an essential component of nutrient management for all crops as they improve the soil biodiversity which is very important to preserve soil health, and improve root growth due to change in the rhizosphere and microclimate of the plants. With respect to citrus, the rhizosphere soil consists of different organisms, which may either be macro/microscopic in nature, harmful/beneficial in nature, different soil components, minerals, etc. In this chapter, an attempt has been made to present the literature pertaining to the microbial diversity of the Khasi mandarin and also the influence of microbial consortium and organic manure on growth, yield and quality and shelf life of Khasi mandarin and other fruits under the following heads:

Microbial Diversity in the Rhizosphere

Usha *et al.* (2004) reported that inoculation with *Glomus deserticola*, when compared with *Azotobacter chroococcum*, significantly modified the rhizosphere environment of Kinnow mandarin, enhancing soil nutrient availability and uptake by plants, which in turn resulted in improved vegetative growth, fruit yield, and quality. The observed improvement was attributed to the synergistic influence of arbuscular mycorrhizal fungi on nutrient mobilization and root physiology. Changes in the chemical properties of the rhizosphere directly affect the composition and abundance of microbial communities, which in turn regulate nutrient dynamics and plant nutrition (Rengel and Marschner, 2005). Supporting this, Turpault *et al.* (2007) investigated temporal variations between rhizosphere and bulk soil chemistry in a Douglas fir stand and found that the rhizosphere plays a pivotal role in maintaining the soil–plant continuum, influencing the biogeochemical cycling processes that sustain forest ecosystem productivity. Similarly, Berendsen *et al.* (2012) demonstrated that rootstocks could selectively enrich beneficial microbial taxa, including plant growth-promoting rhizobacteria (PGPR) such as *Pseudomonas* and *Bacillus*, indicating that genotype and rootstock–scion interactions can actively shape

the rhizosphere microbial community composition to favor plant health and growth. These findings collectively underscore that the rhizosphere acts as a dynamic interface regulating nutrient transformation, microbial diversity, and overall plant performance in perennial fruit crops like citrus.

Larsen *et al.* (2015) examined biotic interactions within the rhizosphere in relation to soil and plant nutrient dynamics and highlighted that an abundant and diverse rhizosphere biome, comprising bacteria, fungi, and soil fauna, plays a central role in driving biogeochemical processes governing soil carbon (C), nitrogen (N), and phosphorus (P) cycling. The study emphasized that plant-derived carbon photosynthates, allocated to roots and the rhizosphere, act as a primary energy source stimulating microbial activity, which in turn enhances nutrient mineralization and availability for plant uptake. Similarly, Dotaniya and Meena (2015) investigated the rhizosphere effect on soil nutrient availability and its uptake by plants, demonstrating that rhizospheric bacteria are key participants in the geochemical cycling of essential nutrients particularly nitrogen, phosphorus, and micronutrients—thereby determining their accessibility to both plants and associated microbial communities. They further suggested that nutrient use efficiency could be significantly improved through manipulation of the rhizosphere environment using agronomic interventions or crop breeding approaches that favor beneficial microbial associations. In agreement with these findings, Ramezani *et al.* (2015) isolated and characterized several phosphate-solubilizing bacterial strains from the rhizosphere of orange trees, notably *Bacillus thuringiensis*, which exhibited strong potential to enhance plant growth. The presence of *Bacillus* and *Enterobacter spp.* with phosphate-solubilizing ability in the root zone was found to improve nutrient availability and overall growth performance of citrus, underscoring the vital role of rhizosphere microorganisms in promoting nutrient acquisition and plant productivity.

Research into the citrus rhizosphere reveals a complex and diverse microbial community critical for plant health. For instance, a study on 29-year-old Satsuma mandarin roots and soil identified substantial Arbuscular Mycorrhizal Fungi (AMF) diversity using SSU rRNA, yielding 193 and 190 operational taxonomic units (OTUs) respectively, with *Glomus* dominating roots and *Glomus* and *Claroideoglomus*

prevalent in the rhizosphere, and Glomus Glo20 showing the highest abundance across all samples (Wu *et al.*, 2017). Broadening this scope, Xu *et al.* (2018) performed a comprehensive metagenomic analysis of the global citrus rhizosphere, finding predominant bacterial phyla like Proteobacteria, Actinobacteria, Acidobacteria, and Bacteroidetes, and defining a core citrus rhizosphere microbiome that includes plant-beneficial genera such as *Pseudomonas*, *Agrobacterium*, *Bradyrhizobium*, *Rhizobium*, and *Sphingomonas*. Furthermore, the management of the soil environment, such as intercropping, has been shown to be a key modifier of these communities; Zhang *et al.* (2019) observed that intercropping significantly enhanced the richness and diversity of fungal communities in mulberry, altering the structure of dominant phyla and increasing the relative abundance of beneficial fungi to improve soil nutrient utilization, demonstrating that both planting patterns and soil physicochemical properties collectively shape the crucial soil microbial structure.

Citrus Rhizosphere Microbial Community Dynamics

Soil management practices significantly influence the microbial communities in the citrus rhizosphere. Conventional fertilization tends to reduce overall microbial diversity, favoring fast-growing copiotrophic bacteria (Li *et al.*, 2019). In contrast, the application of organic amendments promotes greater microbial richness and functional diversity, which aligns with sustainable management goals. Analysis of citrus rhizospheres reveals a wide array of microbial life, with dominant bacterial phyla commonly including Proteobacteria, Actinobacteria, Firmicutes, Bacteroidetes, and Acidobacteria. Abundant bacterial genera such as *Pseudomonas*, *Burkholderia*, *Bacillus*, and *Streptomyces* are crucial for nutrient cycling, plant growth promotion, and the suppression of soil-borne pathogens. Similarly, the fungal community is typically dominated by Ascomycota and Basidiomycota, with genera like *Fusarium*, *Aspergillus*, *Penicillium*, and *Trichoderma* frequently identified (Xu *et al.*, 2020). These observations underscore that soil management choices are a powerful tool for shaping the rhizosphere's structure and function to benefit citrus health and productivity.

Recent research highlights the significant roles of the citrus rhizosphere microbiome in plant health, particularly in biocontrol and growth promotion. The bacterial strain *Bacillus subtilis* K4-4, isolated from the citrus rhizosphere, demonstrates high potential as a biocontrol agent against disease, completely suppressing it in greenhouse trials, and is also useful as a bio-fertilizer for sustainable agriculture (Ezrari *et al.*, 2021). Metagenomic studies have provided deeper insights into community structure: Handique *et al.* (2024) revealed that the rhizospheres of healthy Khasi mandarin plants possess a highly diverse community rich in beneficial taxa like *Trichoderma*, *Penicillium*, *Bacillus*, and *Bradyrhizobium*, whereas *Phytophthora*-infected plants show dominance by harmful species like *Pythium* spp., emphasizing that disease status correlates with microbial composition. This biodiversity is extensive, with studies on other plant species showing hundreds of genera (e.g., 24 phyla, 110 genera in RAM species) where dominant taxa include Proteobacteria, Ascomycota, and Basidiomycota, and this structure differs between wild and cultivated soils (Song *et al.*, 2023). Furthermore, the exploration of commercial citrus growing areas has successfully isolated high diversity, recovering 91 bacterial genera in the laboratory from the root microbiome, providing valuable data for identifying and developing new Plant Growth-Promoting Rhizobacteria (PGPR) strategies to enhance overall crop productivity (Lima *et al.*, 2024).

Influence of Soil and Nutrient Management on Citrus Productivity

Soil properties and effective nutrient management are paramount for successful citrus production, with studies revealing a strong link between soil texture and flowering, alongside the clear benefits of Integrated Nutrient Management (INM) over sole chemical fertilization. Srivastava *et al.* (1997) found that the physico-chemical properties of black clay soils, specifically the proportion of clay, sand, coarse fragments, and free CaCO₃, played a vital role in regulating the flowering behavior of Nagpur mandarin under water-deficit conditions. Orchards exhibiting regular flowering had higher contents of sand, coarse fragments, and free CaCO₃, and less clay, resulting in significantly higher flower intensity (28.4-70.3) flowers/m shoot length) compared to irregular flowering orchards. Conversely, research across citrus and other horticultural crops consistently demonstrated the superiority of INM,

which combines organic manures with reduced chemical fertilizers. For example, the application of FYM (15 kg/plant) with chemical NPK maximized vegetative growth (leaf area, height, spread) in Nagpur orange by improving soil structure and microbial activity (Goramnagar *et al.*, 2000), while a combination of pig manure (80kg/tree) and N and P₂O₅ significantly increased acid lime fruit yield due to better nutrient supply and soil aeration (Dubey and Yadav, 2001). Similar beneficial effects on growth and yield were observed when using banana compost in banana or poultry manure in guava and grapevine, where the latter provided a slow and sustained release of nitrogen and enhanced rhizosphere microbial activity (El-Naby, 2000). Collectively, these findings stress that optimizing both soil texture for drainage and aeration, and adopting INM for sustained nutrition and microbial support, are crucial for promoting the vigour and productivity of mandarin and related fruit crops.

Durgapal *et al.* (2002) explored methods to improve mycorrhizal associations in *Cedrus deodara* and *Pinus wallichiana* by using suitable rhizosphere soil and found that mixed soil promoted better mycorrhizal development than pure rhizosphere soil, as reflected by higher fungal populations resulting from soil inoculation. In a similar context, Chui *et al.* (2002) analyzed the physicochemical properties of rhizosphere and bulk soils of *Tsuga* and *Yushania* in a temperate rainforest and observed that the rhizosphere soil exhibited lower pH but higher organic carbon and C:N ratio than the bulk soil, primarily due to greater root exudation and organic colloid accumulation. Aslantas *et al.* (2007) evaluated the influence of plant growth-promoting rhizobacteria (PGPR) on the growth and yield of young apple trees under orchard conditions and reported significant yield enhancement across all inoculated treatments, with variations depending on the rootstock, cultivar, and strain applied. The stimulatory effects were mainly attributed to the production of plant growth hormones by the PGPR strains. Likewise, Omar and Belal (2008) investigated the combined use of biofertilizers, organic, and inorganic sources in mango cultivation and found that inoculation with *Azotobacter chroococcum* in conjunction with organic or half-mineral fertilizers improved both physical (fruit size and weight) and biochemical (TSS, vitamin C, total sugars) traits while reducing acidity. Their findings emphasized that integrating biofertilizers with

organic and inorganic nutrient sources offers an effective and sustainable approach to enhance fruit yield and quality while reducing reliance on chemical fertilizers.

Management Strategies for Enhanced Growth and Yield in Fruit Crops

Studies across a variety of fruit crops consistently reinforce the significant benefits of Integrated Nutrient Management (INM) over inorganic fertilizers alone, particularly in enhancing plant growth and yield. For guava cv. L-49, Dutta *et al.* (2009) found that combining 100% N + 100% P₂O₅ with the bio-fertilizers *Azospirillum* and Vesicular Arbuscular Mycorrhiza (VAM) resulted in a significantly increased plant height and spread compared to the control. Similarly, in banana, the combined use of organic booster slurry or FYM and bio-fertilizers (*Azospirillum* and PSB) with 100% recommended NPK doses led to superior outcomes, recording a maximum bunch weight of 18.4 kg and 81.8t yield per hectare, along with increased nutrient availability in the soil and leaf tissues, and a shortened crop cycle (Ziauddin, 2009). While some studies on papaya show that solely inorganic treatments can produce the highest fruit yield (e.g., 55 t/ha vs. 26.9–38 t/ha for organic treatments) (Reddy *et al.*, 2010), the combined INM approach often optimizes growth and fruit quality. Specifically, in papaya, the application of (75%) Recommended Dose of Fertilizer (RDF) in combination with (25%) vermicompost and rhizosphere bacteria culture achieved maximum values for key growth and yield parameters, including plant height (185.35 cm), trunk girth (0.26m), number of leaves (18.73), number of fruits (46), fruit weight (0.85 kg), and pulp thickness (3.5cm) (Singh *et al.*, 2010). Other strong INM combinations, such as FYM or Agrigold with 150% RDF, also resulted in higher plant heights than the control (Shivakumar, 2010), confirming that the strategic integration of organic and microbial inputs is highly effective for maximizing productivity in many horticultural crops.

Singh *et al.* (2010) investigated the influence of integrated nutrient management on the growth and yield of papaya cv. Surya, applying different combinations of recommended fertilizer dose (200:250:250 g NPK/plant), FYM, vermicompost, poultry manure, and rhizosphere bacterial culture. They observed that 75% RDF combined with 25% vermicompost produced the maximum number of leaves (18.73) and trunk girth (0.26 m), while 100% RDF alone recorded the highest

plant height (185.35 cm) and petiole length (8.42 cm). Reddy *et al.* (2010) found that inorganic fertilizer treatments resulted in higher growth and fruit yield (55 t ha⁻¹) compared to organic treatments (26.9-38 t ha⁻¹) in papaya cv. Surya. Similarly, Singh *et al.* (2010) further reported that the combination of 75% RDF + 25% vermicompost + rhizosphere bacterial culture yielded maximum plant height (185.35 cm), number of leaves (18.73), trunk girth (0.26 m), number of fruits per plant (46), fruit weight (0.85 kg), and pulp thickness (3.5 cm). Baviskar *et al.* (2011) evaluated various combinations of organic, inorganic, and biofertilizers in sapota and recorded the highest fruit yield (kg/plant and number of fruits/plant) with the treatment of 1125:750 g NPK + 15 kg vermicompost + 250 g *Azotobacter* + 250 g phosphate-solubilizing bacteria per plant. Yadav *et al.* (2011a) studied the influence of integrated nutrient sources on papaya cv. Pusa Dwarf and found significantly greater plant height, girth, fruit setting, and fruiting height with the application of 10 kg vermicompost + 100% RDF + 25 g *Azotobacter*, followed by 30 kg FYM + 100% RDF + 25 g *Azotobacter*. In a subsequent study, Yadav *et al.* (2011b) reported that the same combination also enhanced yield parameters such as fruit weight, number of fruits per plant, and total yield (kg/plant and q/ha). Likewise, Goswami *et al.* (2012) observed that application of 225 g N + 195 g P + 150 g K along with 50 kg FYM enriched with *Azospirillum* improved vegetative growth and increased leaf N and K content in guava, with the highest leaf nutrient content recorded in treatments receiving half the recommended fertilizer dose along with FYM, *Trichoderma* (250 g), and *Pseudomonas fluorescens* (250 g).

Devi *et al.* (2012) highlighted the superior performance of integrated organic and biofertilizer applications over the use of organic manures alone in guava, noting significant improvements in fruit growth and physico-chemical characteristics. Their findings suggested that the combined use of *Azotobacter*, phosphorus solubilizers, and potash mobilizers along with FYM at 26 kg per tree per year, applied in two splits (January and August), was the most profitable option for organic cultivation of ‘Sardar’ guava. Patel *et al.* (2012) emphasized that the inclusion of organic amendments such as castor cake and microbial inoculants (*Azotobacter* or *Azospirillum*) alongside inorganic nitrogen substantially enhanced vegetative vigour

and yield in banana cv. Grand Naine, with the highest yield obtained from 300 g nitrogen plus *Azotobacter*, owing to the cultivar's high nutrient demand and vigorous growth habit. In papaya cv. Taiwan Red Lady, Bhalerao and Patel (2012) demonstrated that foliar supplementation with calcium nitrate (1000 mg/L), borax (30 mg/L), zinc sulphate (200 mg/L), and ferrous sulphate (200 mg/L) at regular intervals (60, 90, and 120 days after planting) significantly improved physiological traits such as photosynthetic rate, transpiration, and chlorophyll concentration, leading to enhanced nutrient uptake and yield. Similarly, Kuttimani *et al.* (2013) found that banana plants receiving 100% RDF (165:52.5:495 g NPK/plant) combined with 40% Wellgro soil exhibited thicker pseudostems, more leaves, and a shorter growth duration, reflecting superior plant vigor. Dhokane *et al.* (2011) observed in guava cv. Sardar that substituting 25% of nitrogen from urea with neem cake not only improved fruit weight (243.80 g) but also increased yield per tree (58.1 kg) and per hectare (23.26 t/ha). Further, Kuttimani *et al.* (2013) confirmed that the integration of 100% RDF with FYM @ 10 kg/plant significantly boosted physiological parameters such as leaf area index, crop growth rate, chlorophyll content, and soluble protein in banana cv. Grand Naine. Complementing these findings, Dwivedi (2013a) demonstrated that in guava, both 50% RDF supplemented with FYM and vermicompost and 100% RDF with micronutrient sprays (Zn, B, Mn) and organic mulching markedly enhanced yield and fruit quality, underscoring the efficacy of integrated nutrient management strategies for sustainable fruit production.

Across multiple horticultural crops, integrated nutrient management (INM) provides superior results in enhancing growth, yield, and soil health compared to using inorganic fertilizers alone, with the optimal combination varying by crop. In guava (Sharma *et al.*, 2013), the best growth, yield, and quality (including pectin content) were achieved by applying 25% N through FYM combined with 75% inorganic N, demonstrating improved nutrient availability and uptake efficiency. The INM advantage is particularly clear in banana; treatments combining 50% Recommended Dose of Fertilizer (RDF) with FYM, bio-fertilizers (*Azotobacter*, PSB), and VAM (*G. fasciculatum*) yielded maximum bunch weight (19.31 kg) and yield (85.80 t/ha) (Patil and Shinde, 2013), and Lenka and Lenka (2014) found that

100% RDF plus PSB and *Azospirillum* was superior across all fruit parameters. Similarly, in a complex INM study on mango (Hasan *et al.*, 2013), the inclusion of vermicompost, bio-fertilizers (*Azospirillum*, PSB), and micronutrients (ZnSO_4 , borax) alongside NPK significantly increased fruit weight (273.20 g), length, and pulp content. For grapevines (Shaheen *et al.*, 2013), the best system for vegetative growth, leaf mineral content, and yield was a 50% blend of compost, rock phosphate, feldspar, and 50% mineral NPK plus bio-fertilizer. INM also optimizes physiological activity, as seen by Tandel *et al.* (2014), where 50% inorganic N combined with 50% N from bio-compost and castor cake resulted in higher plant growth and better physiological parameters like photosynthetic rate and total chlorophyll. The long-term benefits are highlighted in strawberry (Verma and Rao, 2013), where 50% RDF plus *Azotobacter*, PSB, and vermicompost significantly increased post-harvest soil organic carbon (1.95%) and available N, P, and K, while the combination of vermicompost and PSB alone maximized flowering and fruiting (Kumar *et al.*, 2015). Furthermore, high B:C ratios and maximum fruit yield in plum (28.11 kg/tree) were achieved with 75% NPK plus bio-fertilizers and green manuring (Thakur and Thakur, 2014), and a 50% RDF combined with FYM, Neem cake, *Azotobacter*, and PSB was deemed the optimum nutrient combination for superior growth in banana cv. Sugandham (Naik *et al.*, 2015). Finally, the effectiveness of INM for vegetative vigor was confirmed in custard apple (Sharma *et al.*, 2014), where 50% RDF plus 50 % N from vermicompost and bio-fertilizers (*Azotobacter*, PSB, VAM) resulted in a significant increase in growth parameters like plant height and girth. For custard apple (Bhatnagar and Singh, 2015), combining vermicompost with 50% Recommended Dose of Fertilizer (RDF) and biofertilizers significantly maximized all vegetative growth parameters (height, girth, spread) and enhanced soil NPK content, confirming that this combination provides a comprehensive supply of macro- and micronutrients. Similarly, studies on Nagpur mandarin reveal that while 100% RDF achieved the highest yield, treatments like 75% RDF plus 25% vermicompost and microbial culture resulted in significantly better fruit quality and superior soil quality parameters like soil microbial biomass and soil microbial biomass nutrients (Srivastava *et al.*, 2015; Hadoleet *et al.*, 2015), strongly supporting the adoption of INM. This integrated approach allows for the effective compensation of chemical

fertilizers, as demonstrated in Eureka lemon where FYM and bio-fertilizers helped substitute 50% of chemical fertilizer without a significant reduction in yield, while simultaneously optimizing growth, yield, quality, and nutritional status (Ennab, 2016b). In mango, combining bio-fertilizers (*Azotobacter* and PSM) with 50% inorganic fertilizer boosted growth and physicochemical fruit characters, while bio-fertilizers alone improved quality parameters like total soluble solids and beta-carotene, and increased shelf life (Dutta *et al.*, 2016; Ram *et al.*, 2017). Most effectively, the application of 40kg compost plus 1/2 recommended NPK in Kinnow mandarin resulted in minimum flower drop, maximum yield, and superior fruit quality (Ahmad *et al.*, 2017). Furthermore, integrating 25% N as vermicompost with inorganic N and bio-inoculants in Kinnow mandarin maximized fruit number, weight, size, yield, TSS, total sugars, and ascorbic acid (Bakshi *et al.*, 2017), unequivocally establishing INM as the superior strategy for achieving high productivity with improved fruit quality and sustained soil fertility.

INM and Microbial Interventions for Growth and Productivity

In mandarin, Chhetri *et al.* (2017) found that INM treatments yielded fruits with greater diameter (5.26cm), weight (83.32 g), and Total Soluble Solids (TSS) (14.53 °Brix), along with lower titratable acidity, directly indicating the system's positive governance over fruit quality. For the commercially important Khasi mandarin (Gogoi *et al.*, 2018), a specific INM module-75% RDF combined with VAM, PSB, *Azospirillum*, and *T. harzianum* proved highly effective, delivering superior quality (highest juice content: 48.95%; TSS: 13.7 % lowest acidity: 0.37%), a strong B:C ratio (4.75), significantly higher N, P, K leaf content, and the shortest maturity time. This positive effect is fundamentally biological in sapota (Manjareet *et al.*, 2018), integrating *Azotobacter* with the full RDF maximized fruit number and yield by improving nitrogen fixation and overall nutrient absorption, thereby supporting both productivity and soil health. The role of organic amendments in shaping the soil ecosystem is further established by research on kiwifruit (Liu *et al.*, 2019), where long-term organic fertilization was shown to improve productivity by increasing rhizosphere bacterial diversity and network complexity while simultaneously reducing plant pathogenic fungi. Similarly, the use of organic manure

with mineral fertilizers in Washington Navel orange not only improved growth, yield, and quality but also enhanced soil chemical properties by decreasing pH and heavy metals (Cd, Pb) while increasing organic matter, N forms, and Zn (Ennabet *et al.*, 2019). Even specific supplements show profound effects: field trials on Kinnow mandarin revealed that supplementing farmer's practices with humic acid (HA) and multinutrient foliar fertilizer resulted in marked improvements in growth (up to 32.5 % increase in height), fruit set (22.2 %), yield (89.81% increase), and fruit quality (ascorbic acid, total sugars), thus confirming that strategic nutrient intervention, particularly through organically sustainable inputs, translates directly into superior tree performance and fruit characteristics (Hameed *et al.*, 2018).

Integrated Nutrient Management (INM) is key to optimizing the growth, yield, and quality of fruit trees by creating a favorable nutritional and microbial environment. In aonla, maximum vegetative growth (plant height, spread, and canopy volume) was achieved by combining 100 % nitrogen as urea with *Azotobacter* (Kour *et al.*, 2019). This effect is attributed to FYM ability to supply and solubilize nutrients, while *Azotobacter* promotes nitrogen fixation and biosynthesizes plant growth regulators like IAA and GA₃ (Kour *et al.*, 2019). Similarly, the most effective INM combination in sweet orange involved a mixture of FYM, PSB, *Azospirillum*, and specific doses of N P K, which significantly improved plant height, canopy spread, leaf parameters, and, crucially, enhanced the soil's nutrient status (EC, N, P, K) and reduced disease incidence (Lakra *et al.*, 2019). The positive influence of organic and biological inputs extends to fruit characteristics, as seen in Murcott tangerine, where the best results for growth, yield, and nutritional status were observed with 75 % inorganic N plus 25% organic chicken manure supplemented with 150 ml of the biofertilizer EM (Effective Microorganisms) (Fikry *et al.*, 2020). Moreover, the physical quality of sweet orange fruits, including maximum length and diameter, was markedly improved by treatments combining FYM with *Azotobacter* and VAM, likely due to the balanced availability of nutrients and growth-promoting hormones synthesized by the biofertilizers, leading to better fruit filling (Rana *et al.*, 2020). Finally, in Kinnow mandarin, FYM plus biofertilizer combinations significantly enhanced key reproductive phases like flowering and fruit-set

parameters when compared to conventional treatments (Rawat *et al.*, 2020), underscoring the integrated approach as a superior method across the entire life cycle of fruit crops

Srivastava (2021) investigated the long-term effects of Integrated Soil Fertility Management (ISFM) in Nagpur mandarin and found that microbial consortium-mediated ISFM modules significantly improved fruit yield and quality, with higher final fruit set under ISFM compared to conventional fertilization. Ngoc *et al.* (2021) conducted a long-term field study on pomelo (*Citrus maxima*) to evaluate the impact of compost and poultry manure on soil quality and productivity. Their results showed that poultry manure application markedly enhanced soil organic matter, microbial biomass, and nutrient availability, thereby improving soil fertility over time. However, despite these improvements, reproductive performance and fruit yield did not increase consistently, suggesting a possible trade-off between vegetative growth and fruit production under nutrient-rich conditions. The study emphasized that while poultry manure supports long-term soil sustainability, balanced nutrient management is essential to maintain both soil health and optimal fruit yield in citrus orchards. Nakade *et al.* (2021) also reported that integrated nutrient management (INM) modules involving microbial consortia in Nagpur mandarin improved growth, fruit set, and yield over conventional fertilization, highlighting the beneficial role of microbial interventions. Similarly, Anwar *et al.* (2022) explored the integrated application of growth hormones and nutrients to manage premature fruit drop in citrus orchards in Pakistan. Their study revealed that foliar treatments combining salicylic acid with 2,4-D (SA + 2,4-D) significantly enhanced fruit weight and size, while the combination of SA + K + Zn improved photosynthetic activity and reduced fruit drop. These findings demonstrated that integrated hormonal and nutrient management effectively enhances yield and fruit quality while mitigating physiological fruit losses. Fikry *et al.* (2022) further showed that combining inorganic and organic nitrogen sources with biofertilizers in Murcott mandarin improved fruit set, yield, and quality compared to conventional fertilizer use, providing empirical evidence for the synergistic benefits of microbial and organic amendments. Likewise, Kumar, (2022) concluded that microbial consortia enhanced nutrient availability, hormonal

regulation, and reproductive development in fruit trees, thereby mechanistically explaining the observed increase in fruit set under biofertilizer-based integrated nutrient management systems.

Dong *et al.* (2023) conducted a two-year field experiment on a 15-year-old Newhall orange orchard using varying spring and summer fertilization ratios (60/40, 80/20, and 100/0) and found that soil nutrient dynamics, particularly under the 80/20 ratio, significantly influenced fruit yield and quality, recording a 35.14% yield increase, higher total soluble solids, and reduced acidity suggesting 80/20 as the optimum fertilization schedule for enhanced productivity. Complementarily, Hazarika *et al.* (2024) demonstrated in Khasi mandarin that biodynamics-enriched organic amendments combining vermicompost, Cow Pat Pit, and biodynamic preparations BD 500 and BD 501 significantly improved canopy growth, chlorophyll content, soil carbon fractions, and microbial populations, highlighting the strong synergistic effect of biodynamic and organic amendments on nutrient enrichment and soil health. Similarly, Bhattacharjee *et al.* (2024) reported in Sweet orange cv. Phule Mosambi that integrated nutrient management involving 50% RDN + FYM + castor cake + Bio NPK consortium + micronutrient foliar spray produced the highest yield (17.35 and 17.01 t/ha) and improved both soil and plant nutrient status, notably nitrogen, potassium, iron, copper, and boron levels, demonstrating the efficiency of partial substitution of chemical fertilizers with organics and microbial inoculants. In a related study, Cheke *et al.* (2024) and Cheke and Patil (2024) observed that applying a rhizosphere microbial consortium derived from *Ficus* rhizosphere soil in Sweet orange orchards significantly enhanced fruit yield, fruit set, and retention while improving soil health, further confirming the potential of microbial consortia in sustainable citrus production. Huang *et al.* (2024) also found that combining microbial and organic manure fertilization in 'Orah' citrus altered fruit characteristics and enriched the rhizosphere microbiome composition, indicating that microbial–organic integration positively influences fruit development and ecosystem functioning. Supporting these findings, Kadlag *et al.* (2025) reported that biofertilizers containing plant growth-promoting rhizobacteria (PGPR) markedly increased fruit set, yield, and quality parameters in citrus through enhanced nutrient

solubilization, root growth, microbial activity, and hormone synthesis, leading to improved flowering, fruiting, and superior fruit quality with higher total soluble solids, vitamin C content, and better peel coloration. Collectively, these studies affirm that integrated nutrient management approaches—combining organic, inorganic, and microbial inputs—significantly enhance soil fertility, plant physiology, and fruit productivity in citrus, establishing microbial consortium-based strategies as vital tools for sustainable citrus cultivation.

Organic Management and Fruit Storability

Yadav *et al.* (2013a) evaluated the post-harvest behavior of organically and conventionally cultivated Kinnow mandarin and found that organically grown fruits exhibited significantly lower physiological loss in weight (6.2%) and decay incidence (12.5%) after 20 days of ambient storage, compared to conventionally managed fruits which recorded 10.5% PLW and 21.4% decay. The enhanced storability of organic fruits was attributed to firmer peel texture, higher antioxidant activity, and improved nutrient balance that strengthened cell wall integrity, thereby reducing post-harvest losses and enhancing economic returns. In a similar observation, Yadav *et al.* (2013b) reported that organic nutrient management practices effectively minimized physiological weight loss and decay, prolonging fruit shelf life and maintaining post-harvest quality. Extending this trend, Yadav *et al.* (2014) demonstrated that organically cultivated guava fruits retained higher total soluble solids (TSS), ascorbic acid, and antioxidant content, extending their storage life by 3–5 days, reinforcing the consistency of organic systems in improving storability across fruit crops including Khasi mandarin. Likewise, Sharma *et al.* (2015) noted that Khasi mandarin fruits from organic orchards exhibited higher TSS/acid ratio, superior peel coloration, and slower ascorbic acid degradation during ambient storage, indicating better post-harvest performance. In another study, Sharma *et al.* (2015) assessed the combined influence of bio-organic nutrient sources-farmyard manure, vermicompost, green manure, biofertilizers, and vermiwash on kiwifruit (*Actinidia deliciosa*), and found that their integrated use (FYM 15 kg + GM + VC 15 kg + BF 50 g + VW 2 kg/vine) markedly improved plant growth, fruit quality, and leaf nutrient composition, with elevated macro- (N 2.49%, P 0.26%, K 1.48%) and micronutrient (Fe 208 mg/kg, Cu

17.8 mg/kg, Zn 36.2 mg/kg, Mn 88.3 mg/kg) concentrations. These findings highlighted the synergistic effect of bio-organic inputs in enhancing fruit nutritional quality and promoting soil–plant health sustainability. Similarly, Singh *et al.* (2016) reported that sweet orange fruits produced under organic management retained higher TSS (11.8 °Brix), acidity (0.73%), and ascorbic acid (41.2 mg/100 g) than conventionally grown fruits, resulting in better biochemical stability and extended storage life. Collectively, these studies demonstrate that organic and bio-integrated nutrient management systems not only enhance fruit quality and nutritional composition but also play a crucial role in maintaining post-harvest longevity and reducing storage losses across citrus and other fruit crops.

Wu *et al.* (2016a) demonstrated that organically grown citrus fruits exhibited 28% lower decay incidence after 14 days of storage compared to conventionally produced fruits, a result attributed to elevated phenolic compounds and antioxidant activity that reinforced the fruit’s natural defense mechanisms. Supporting these findings, Reganold and Wachter (2016) emphasized that organic production systems enhance soil organic matter and nutrient uptake efficiency, leading to improved plant physiological performance and stronger cell wall integrity—factors directly associated with delayed post-harvest deterioration and prolonged shelf life. Complementing this, Romanazzi *et al.* (2016) reviewed induced resistance as an eco-friendly strategy for managing post-harvest decay, explaining that biological, chemical, and physical elicitors can activate systemic acquired resistance (SAR) and induced systemic resistance (ISR) pathways through mechanisms such as increased phenolic synthesis, activation of defense enzymes like PAL, chitinase, and glucanase, and callose deposition, often in conjunction with biocontrol agents or mild physical treatments. These processes collectively strengthen host defense and reduce decay without reliance on synthetic fungicides. In parallel, Singh *et al.* (2016) analyzed the biochemical composition of various fruits and vegetables and reported that fruits, particularly their peels, are rich in total phenolics and antioxidants—including gallic acid, catechin, quercetin, and resveratrol—which contribute to superior nutritional value and enhanced storage stability. Reinforcing this perspective, Wu *et al.* (2016b) further observed that organic and biological management practices enhance host

resistance to post-harvest fungal pathogens by promoting phenolic accumulation, up regulating defensive enzyme activity, encouraging beneficial microbial antagonism, and improving overall fruit physiological status. Collectively, these studies affirm that organic and biologically based systems not only improve soil and plant health but also fortify intrinsic defense mechanisms, resulting in reduced post-harvest decay, extended shelf life, and enhanced nutritional and antioxidant profiles of fruits. Patil *et al.* (2017) found that organically produced mango fruits maintained significantly firmer texture and exhibited lower physiological loss in weight (PLW) during storage compared to conventionally cultivated ones, attributing these advantages to enhanced cell wall integrity, slower respiration rate, and balanced nutrient uptake supported by higher antioxidant activity under organic management. Similarly, Mditshwa *et al.* (2017), through an extensive review, concluded that organically grown fruits generally possess higher levels of vitamin C, phenolic compounds, and overall antioxidant capacity, which collectively delay senescence, improve fruit firmness, and extend storage life. In a related study, Pathak *et al.* (2018) reported that mandarin (*Citrus reticulata*) fruits produced under organic nutrient management exhibited stronger peel structure and delayed rind breakdown compared to conventionally managed fruits, a result linked to balanced mineral uptake and higher phenolic accumulation that reduced fungal infection and physiological decay. These findings underscored that organic nutrient practices enhance storability and maintain post-harvest quality by improving fruit structural and biochemical resilience. Complementing this evidence, Shen *et al.* (2018) demonstrated that adoption of organic production systems in citrus orchards substantially increased soil microbial biomass and enzymatic activity, leading to enhanced nutrient cycling, improved soil fertility, and better fruit quality and shelf stability. Collectively, these studies reinforce that organic nutrient management not only improves soil biological health and nutrient dynamics but also strengthens fruit structural integrity and biochemical defenses, resulting in reduced post-harvest deterioration and superior storage performance in citrus and other fruit crops.

Integrated nutrient management (INM) strategies offer significant dual benefits by improving post-harvest fruit quality and enhancing disease suppression

through the deliberate manipulation of the soil microbiome. Studies on Khasi mandarin show that adopting integrated organic modules-specifically incorporating farmyard manure (FYM), neem cake, vermicompost, oil cakes, and biofertilizers-significantly enhances post-harvest parameters compared to conventional methods (Das *et al.*, 2019; Borah *et al.*, 2020). These practices are effective in reducing physiological loss in weight (PLW) and decay incidence, while improving juice recovery, total sugars, and fruit firmness (Das *et al.*, 2019). The improved storability is attributed to better nutrient uptake, enhanced antioxidant activity, and a strengthened cell wall structure, which together delay senescence and enhance Vitamin C retention (Borah *et al.*, 2020), ultimately maintaining better marketability. Beyond post-harvest benefits, INM provides a sustainable solution for plant health by actively reconstructing the soil microbiome to suppress pathogens (Shen *et al.*, 2019). For instance, an integrated agricultural strategy applied in banana production caused a marked shift in soil microbial composition, leading to an increased abundance of beneficial microbial taxa and functional genes linked to nutrient cycling and pathogen suppression. This reconstructed microbiome correlated with a substantial reduction in the incidence and severity of banana Panama disease (caused by *Fusarium oxysporum* f. sp. *cubense*), demonstrating that manipulating soil microbial communities through targeted agronomic practices is a sustainable and effective strategy to control major soil-borne diseases (Shen *et al.*, 2019).

Economic Evaluation of Nutrient Management Practices in Fruit Production

Economic analyses across multiple fruit crops confirm that Integrated Nutrient Management (INM) and organic production systems significantly enhance profitability, although the financial advantage varies with crop and market conditions. In guava (Dwivedi, 2013b), two distinct INM practices yielded comparable superior economic returns (ranging from ₹53,204 to ₹53,439 per hectare): the first was a reduced chemical program (50% RDF) supplemented with FYM and vermicompost; the second was 100% RDF augmented with foliar micronutrients and organic mulching, both indicating that integrated use enhances productivity and profitability. Similarly, Sharma *et al.* (2016) reported the highest economic returns in mango cv. Amrapali from a robust INM module, which combined 100% RDF with

vermicompost, oil cake, and a suite of bio-inoculants (*Azotobacter*, VAM, *Trichoderma viride*, PSB), achieving a maximum B:C ratio of 1.94. The economic viability of citrus is also strong, with Coorg mandarin cultivation showing a healthy B:C ratio of approximately 1.96 (Bopanna, 2016), reflecting positive growth trends in both area and production, although marketing constraints like seasonal gluts and inadequate storage were identified. Furthermore, the highest profitability was seen in organic production systems where a premium price could be secured; Sgroi *et al.* (2015) concluded that organic lemon orchards had higher profitability than conventional ones despite lower yields, due to higher market prices guaranteed by certification and lower production costs relative to conventional farming's high input needs. This is reinforced by Ram and Verma (2015), who reported a high B: C ratio of 3.74 for organic mango cultivation attributed to enhanced fruit quality and reduced synthetic input costs. However, the study also notes contrasting results, such as a lower maximum B:C ratio of 1.48 observed in conventional apple production (Akdemir *et al.*, 2012), underscoring that the relative economic advantage of organic systems is highly dependent on the specific crop, local input costs, and access to premium markets.

Research across citrus and other fruit crops consistently demonstrates that Integrated Nutrient Management (INM) significantly boosts profitability by achieving high yields and superior quality, despite increased initial investment. For Kinnow mandarin (Bakshiet *al.*, 2018), INM, specifically the application of 50%nitrogen as poultry manure and 50% as urea augmented with *Azotobacter*, yielded the highest cost:benefit ratio (B:C) of 1:3.28. Although INM increased the cost of cultivation compared to using inorganic fertilizers alone, the resulting higher yield and fruit quality translated into greater net returns per hectare. Similarly, in pomegranate cv. Bhagwa (Kirankumar *et al.*, 2022), the highest net returns and an excellent B:C ratio of 3.45 were achieved by applying 75% RDF combined with a comprehensive blend of vermicompost, poultry manure, *Azospirillum*, PSB, and KSB, slightly outperforming the 100% RDF plus organic/biofertilizer combination (B:C = 3.42). These findings align with broader economic studies on mandarin cultivation, which confirm its high profitability; for instance, a survey in Nepal (Dahal, 2023) reported

an average productivity of 14.6 t/ha and a highly favorable B:C ratio of 5.07, despite challenges like pest infestation and inadequate irrigation. However, Baral (2021) emphasized that mandarin profitability is highly sensitive to yield variation and market price fluctuations, underscoring the necessity of robust sensitivity analysis and region-specific interventions (e.g., improved storage and collective marketing) to stabilize and optimize producer margins. Recent studies solidify the economic and environmental advantages of Integrated Nutrient Management (INM) in fruit production, contrasting it with the high costs and market constraints of conventional systems. Research on apricot (Kumar *et al.*, 2024) demonstrated that an INM combination of 50% inorganic N (Urea), 50% organic N, *Azotobacter*, PSB, and vermicompost was the most beneficial and cost-effective treatment. This finding promotes INM as a low-cost, eco-friendly method for sustainable fruit production that also minimizes environmental concerns. This focus on cost-efficiency is crucial, as the overall cultivation cost for Nagpur mandarin is significant (₹ 238,322.49 ha⁻¹), with manure and plant protection being major expenses (₹35,004.92 and ₹19,540.20, respectively) (Bhajan *et al.*, 2024). While prevailing practices in Nagpur mandarin show profitability (average productivity 15.89 t ha⁻¹ and B:C ratio of 1.87), major constraints, including high input costs and significant fruit drop from environmental factors and pests, necessitate improved management. Consequently, studies on mandarin (Brahma *et al.*, 2024) emphasize that the best integrated packages combining reduced chemical RDF with vermicompost/FYM and biofertilizers produce higher net returns and a superior B:C ratio compared to sole chemical fertilizers. This conclusion is reached after critically accounting for on-farm organic inputs (reducing purchased fertilizer needs) and factoring in the improved post-harvest performance (quality and storability) achieved by INM. However, realizing the full economic potential of these superior orchard practices is often hampered by structural constraints within the Khasi mandarin value chain (Phawa *et al.*, 2024), including pervasive middlemen dominance, seasonal market gluts forcing distress sales, inadequate cold-chain infrastructure, and weak farmer organization. Therefore, while INM provides the necessary agronomic foundation for high-quality, sustainable yields, maximizing producer profitability requires parallel interventions to strengthen

organizations, improve post-harvest handling, and promote direct marketing links (Phawa *et al.*, 2024).

CHAPTER III

MATERIALS AND METHODS

MATERIALS AND METHODS

The study entitled “**Study on Microbes mediated Organic Production for Khasi Mandarin**” was carried out at the farmer Shri Laseng Umbon’s orchard in Pangna Gaon, Tinsukia and also at School of Agricultural Sciences, Nagaland University, Medziphema during the years from 2022 to 2024. During the course of investigation, the details of materials used and procedures followed are described in this chapter.

3.1 Experimental site

3.1.1 Location and Climate

The Orchard is located at a distance of 346.2 km from the School of Agricultural Sciences, Medziphema. The orchard is situated at latitude of 27°21' North and longitude of 95°44' East and at an altitude of 141 meters above mean sea level. It falls in the humid subtropical region where the minimum temperature range from 10-11°C in winter months and maximum temperature range from 32-36°C in summer. The average rainfall is about 2500 mm throughout the year, the pre-monsoon showers start from the month of March, normal monsoon commences from June and continue up to the month of September. From October month onward the rainfall intensity decreases and is minimum during December and January months. The meteorological data during the period of investigation are given in appendix 1 and graphically represented in Fig 3.1, as recorded at the NASA power data access viewer.

3.1.2 Soil conditions

The soil is characterized by acidic reactions and falls under old alluvial group. With low content of organic carbon along with medium range of nitrogen, K₂O and P₂O₅ soil respectively. Samples of soil were collected randomly from the plot where the experiment was conducted to ascertain the fertility status of the soil. Soil samples were collected from all parts of the orchard in zig-zag manner with the help of soil auger after that the samples were dried in shade at room temperature after mixing it thoroughly. After drying sample was sieved and analysed in the laboratory. The chemical properties of the soil at the experimental plot prior to the application of

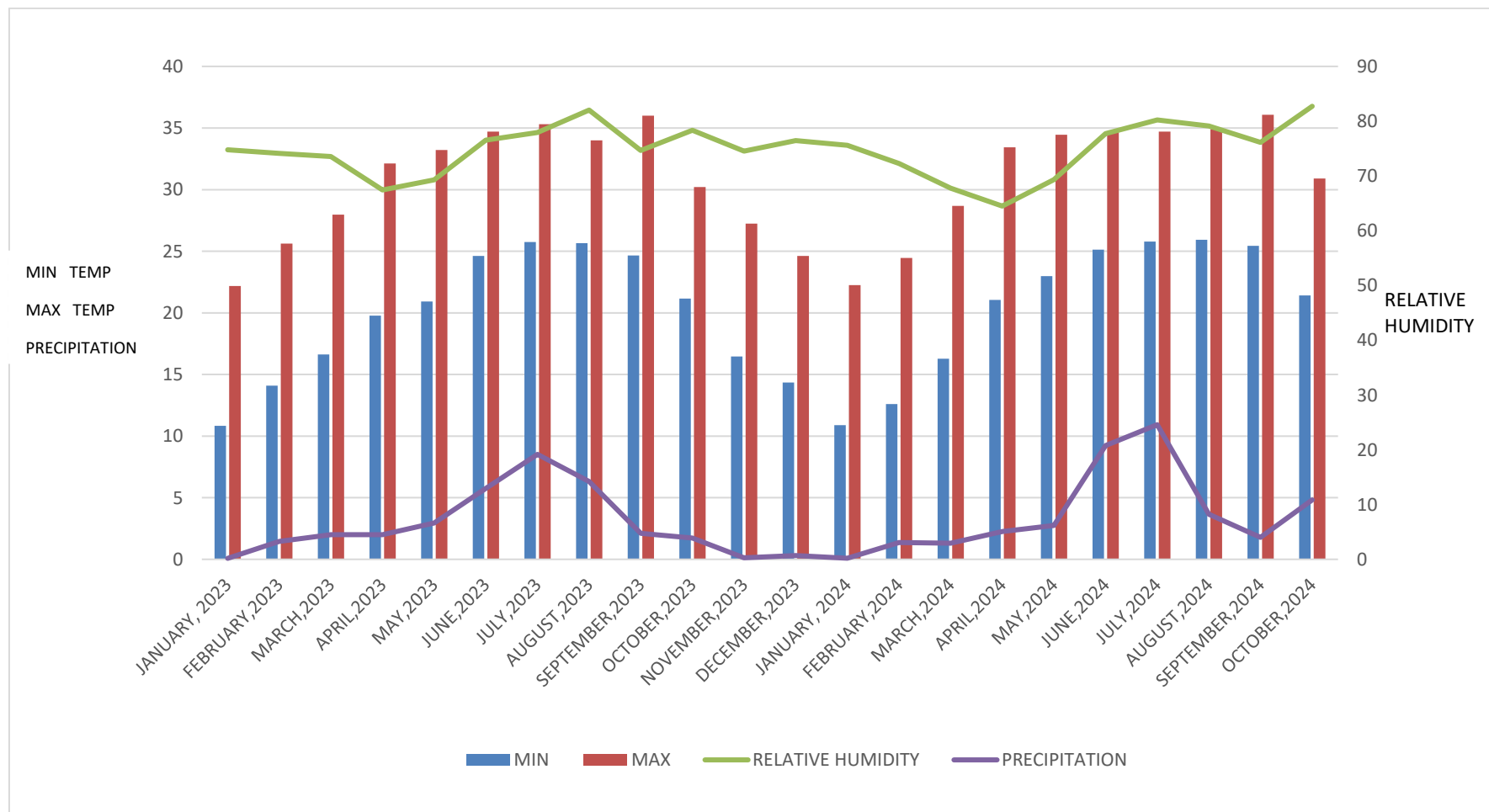


Fig 3.1 Graphical representation of meteorological data during the period of investigation (January, 2023 to October, 2024)

treatments were analyzed to establish the baseline fertility status. The soil exhibited a slightly acidic reaction with a pH of 5.94, as determined by the glass electrode pH meter method (Jackson, 1973). The organic carbon content was recorded at 0.89%, estimated using the wet digestion method (Piper, 1966) indicating moderate organic matter status. The available nitrogen content of the soil was 325 kg ha⁻¹, determined by the modified Kjeldahl's method (Jackson, 1973), suggesting medium fertility in terms of nitrogen availability. The available phosphorus content was found to be 23.41 kg ha⁻¹, analyzed using Bray's method (Jackson, 1973), representing a medium range of phosphorus availability. The available potassium content was 208 kg ha⁻¹, as measured by the flame photometric method (Jackson, 1973), indicating a medium level of potassium in the soil. Overall, the soil was moderately fertile with slightly acidic pH, suitable for the growth and production of Khasi mandarin. The rating charts for soil NPK values and for experimental field are represented in annexure 2 and 3.

3.2 Experiment I: Growth and quality of Khasi mandarin seedlings raised in various citrus rhizospheres

3.2.1 Technical details:

Design- Completely Randomized Design (CRD)

Replication – 4 (20 plants per replication)

Treatments- 5

T₁ - Rhizospheric soil from elite tree 1

T₂ - Rhizospheric soil from elite tree 2

T₃- Rhizospheric soil from elite tree 3

T₄ - Rhizospheric soil from elite tree 4

T₅ - Rhizospheric soil from elite tree 5

3.2.2 Collection of rhizospheric soil

The soils were collected from rhizospheric region of elite Khasi mandarin trees in the orchard. Selections of rhizospheric soils were done based on trees having good vegetative growth and bearing maximum number of fruits. Five kg (5 kg) of soils from rhizosphere region were thus collected and brought to experimental farm of



Plate 3.1 General view of the orchard

Horticulture, SAS, Medziphema. These soils were added in the soil media mixture which was filled in polybags for raising the Khasi mandarin seedlings.

3.2.3 Seedling studies

The nucellar seedlings were allowed to grow for six months in the rhizospheric soils and after every fixed interval (15 days) the growth characters such as seedling girth, seedling height number of leaves per seedling were observed. After six months the leave samples were collected treatment wise to access the nutrient status of the leaves and also to observe if there are any differences among the treatments.

3.2.3.1 Seedling height (cm)

With the help of a ruler the seedling height was measured from the base of the plant upto the top most leaves. The seedling height was expressed in centimetres. The first reading was taken when the seedlings were 75 days old and the final reading upto 180 days of seedling age.

3.2.3.2 Number of leaves

Number of leaves per seedling was count and then the average was recorded. The first reading was taken when the seedlings were 75 days old and the final reading upto 180 days of seedling age.

3.2.3.3 Seedling girth (cm)

Seedling girth was measured by gently wrapping a flexible, no stretchable measuring tape around the stem at its widest point (marked with permanent marker pen), just above the soil line, ensuring that the tape is snug but not too tight and recording the measurement in centimeters. The first reading was taken when the seedlings were 75 days old and the final reading upto 180 days of seedling age.

3.2.3.4. Leaf sampling

After 180 days of seedling age the leaves were collected from the mid-section of terminal shoots located on different sides of the plant. Leaves were collected from the interior portion of the plant, no more than 10 leaves from any one

plant. The leaf samples were washed with acidified detergent solution (Bhargava, 2002), rinsed in distilled water, dried in hot air circulation oven at 65 ± 2 °C till constant weight was obtained and ground in stainless leaf grinding machine. The powdered samples were stored in polythene bags.

After that 500mg of homogeneous leaf sample was transferred to a neatly washed and dried 100 ml volumetric flask and 10 ml of diacid mixture (10 parts HNO_3 and 4 parts HClO_4) was added to it. The samples were digested by keeping a funnel on conical flask by putting it on a hot plate for digestion first on slow heat and then vigorously and continued the digestion till the acid mixture became colourless and no residue was left. The residue was dissolved in double distilled water and final volume was made to 50 ml. The dissolved material was filtered through Whatman 42 filter paper. A blank was also run simultaneously having no plant material. The following procedures were adopted for various analyses:

Total P: It was determined spectrophotometrically at 420 nm wave length. The yellow colour was developed by using vanadomolybdate reagent as described by Tandon (2005).

Total K: Potassium content in leaf samples was estimated following the procedure outlined by Jackson (1973) using a flame photometer after nitric acid–hydrogen peroxide digestion.

Total Ca and Mg: Calcium (Ca) and magnesium (Mg) in leaf samples were determined after wet digestion. Concentrations of Ca and Mg were measured by flame atomic absorption spectrophotometry. (ECIL 731 Model)

Total Fe: Total iron (Fe) in plant tissue is determined after acid digestion of dried leaf material. The digested extract is analyzed using atomic absorption spectrophotometer.

Total copper (Cu): Total Cu in plant tissue is estimated after digestion of the oven-dried leaf material with concentrated nitric acid and hydrogen peroxide. The digested extract is analyzed using atomic absorption spectrophotometer.

Total manganese (Mn): Total manganese in plant tissue is liberated by acid digestion ($\text{HNO}_3\text{--H}_2\text{O}_2$) of oven-dried leaf material. The clear digest is analysed by atomic absorption spectrophotometry.

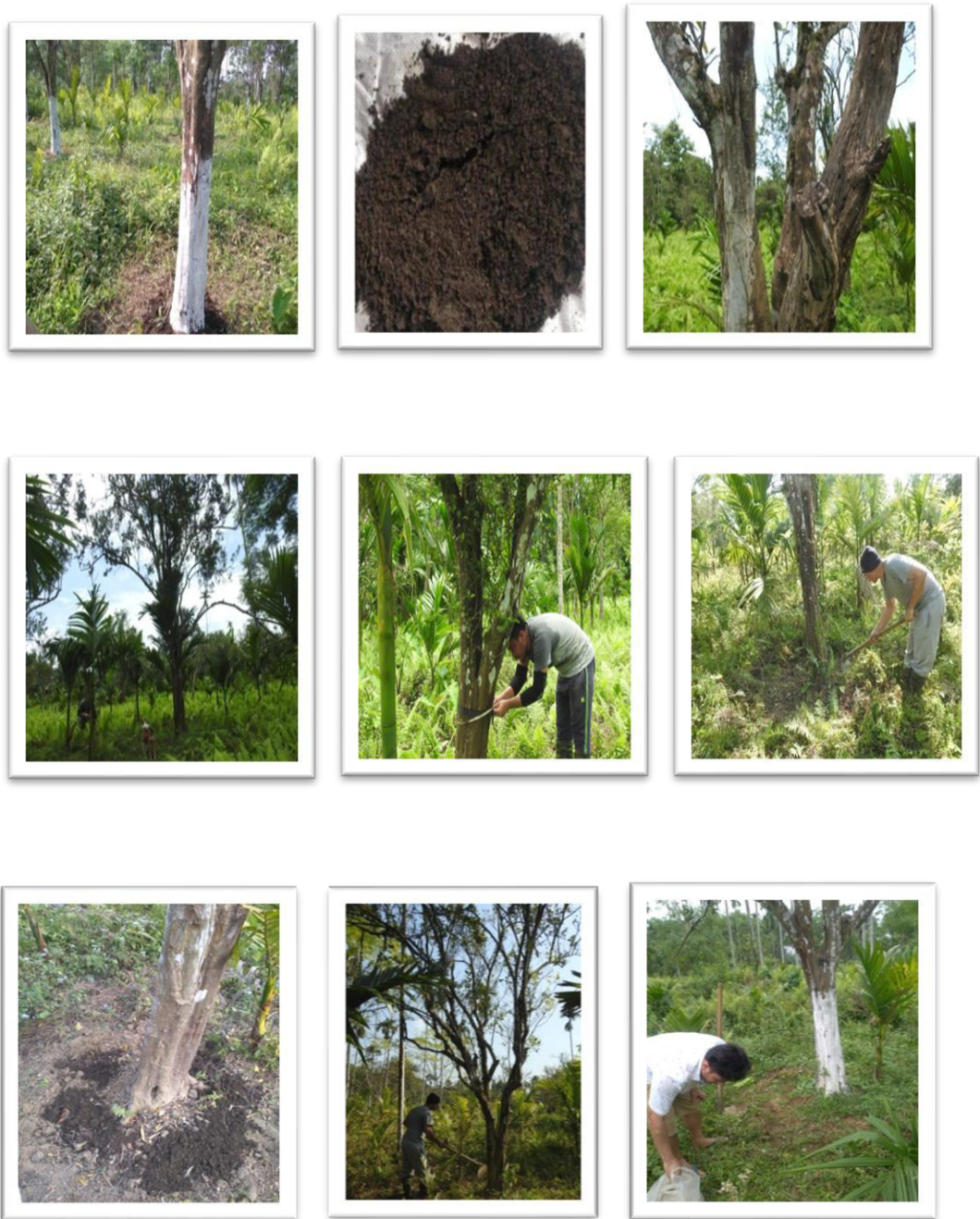


Plate 3.2 Interculture and nutrient management practices at the orchard

Total Zn: It was determined in diacid digest with the help of atomic absorption spectrophotometer after suitable dilution. (ECIL- 731 Model)

Total nitrogen: It was determined with the help of Kjeldahl's digestion and distillation method. The leaf samples were analyzed for nitrogen by micro-Kjeldahl method as described in Tandon (2005) using K_2SO_4 , $CuSO_4$ and Selenium powder as digestion mixture in the ratio of 100: 10: 1 in a block digester and distillation was carried out in an all-glass steam distillation apparatus. The distillates were collected in 4% boric acid solution and the amount of NH_3 absorbed was titrated against N/10 H_2SO_4 , in presence of mixed indicator (methyl red and bromocresol green).

3.2.4 Soil microbial diversity

Soil samples of the seedling plants which showed the best physical growth and better nutrient uptake of both macro and micronutrients was selected for the microbial diversity studies. The soil samples were collected with the help of sterilize soil auger to avoid any contamination and after that the samples were sealed in a sterile containers and was send to Dextrose Technologies Private Limited company laboratory, Bangalore where they did the metagenomic analysis to study the microbial diversity.

3.2.4.1 Amplicon processing

Soil samples collected from the rhizosphere zone were processed for total microbial DNA extraction. The extraction of genomic DNA was carried out using the Qiagen DNeasy Power Soil Kit following the manufacturer's protocol. Approximately 0.25–0.5 g of homogenized soil sample was used for each extraction. Mechanical lysis using bead beating was employed to ensure efficient disruption of microbial cells present in the soil matrix. The extracted DNA was eluted in sterile nuclease-free water and stored at $-20^{\circ}C$ until further use. The quality and integrity of the extracted DNA were assessed by agarose gel electrophoresis (0.8–1.0%), while the concentration and purity were determined using a NanoDrop spectrophotometer. Samples showing an A260/A280 ratio between 1.8 and 2.0 were considered suitable for downstream applications. The bacterial community composition was analyzed by amplification of the V3–V4 hypervariable region of the 16S rRNA gene. PCR amplification was performed using the universal primer pair 341F (5'-

CCTACGGGNGGCWGCAG-3') and 806R (5'-GACTACHVGGGTATCTAATCC-3'). The PCR reaction was carried out in a total volume of 25 μ L containing 1–2 μ L of template DNA, 0.5 μ M of each primer, 200 μ M dNTPs, 1 $\times$ PCR buffer with $MgCl_2$, and 1 U of Taq DNA polymerase. The amplification was performed under the following thermal cycling conditions: initial denaturation at 95°C for 3 minutes, followed by 30 cycles of denaturation at 95°C for 30 seconds, annealing at 55°C for 30 seconds, and extension at 72°C for 45 seconds, with a final extension at 72°C for 5 minutes.

PCR products showing clear and specific bands were purified using the QIAquick PCR Purification Kit to remove residual primers, nucleotides, and enzymes. In cases where non-specific amplification was observed, gel extraction was performed to obtain the desired amplicon.

The amplified PCR products were verified by electrophoresis on 1.5% agarose gel stained with an appropriate nucleic acid dye and visualized under UV illumination. The expected amplicon size corresponding to the targeted region of the 16S rRNA gene was confirmed by comparison with a DNA ladder.

PCR products showing clear and specific bands were purified using the QIAquick PCR Purification Kit to remove residual primers, nucleotides, and enzymes. In cases where non-specific amplification was observed, gel extraction was performed to obtain the desired amplicon. The purified amplicons were subjected to library preparation using the Illumina Nextera XT Library Prep Kit according to the manufacturer's instructions. During this process, sequencing adapters and dual indices were attached to the amplicons to facilitate multiplex sequencing. The prepared libraries were quantified, normalized, and pooled in equimolar concentrations. High-throughput sequencing was carried out on the Illumina MiSeq platform using paired-end sequencing (2 $\times$ 250 bp). This approach enabled comprehensive coverage of the targeted 16S rRNA gene region for accurate bacterial community profiling.

The raw sequencing data obtained was processed using standard bioinformatics pipelines. Initial quality assessment of the reads was performed using FastQC, followed by trimming of low-quality bases and removal of adapter sequences using Trimmomatic.

Subsequent processing, including denoising, error correction, and chimera removal, was performed using the DADA2 algorithm implemented within the QIIME 2 environment. This resulted in the generation of high-resolution Amplicon Sequence Variants (ASVs). Taxonomic classification of the ASVs was carried out using the SILVA database as a reference. Classification was performed using a naïve Bayes classifier to assign sequences to different taxonomic levels, including phylum, family, and genus (Callahan *et al.*, 2016; Bolyen *et al.*, 2019)

Microbial diversity analysis was conducted to evaluate both within-sample (alpha diversity) variations. Alpha diversity indices such as Shannon diversity index, Simpson index and Chao1 richness estimator were calculated (Shannon, 1948; Simpson, 1949; Whittaker, 1972). Ordination techniques such as Principal Coordinate Analysis (PCoA) were employed to visualize the differences in microbial community structure across samples.

The processed sequencing data were submitted to the NCBI Sequence Read Archive to ensure data accessibility and reproducibility. The results obtained were used to characterize the bacterial community composition, identify dominant taxa, and evaluate the influence of environmental conditions on soil microbial diversity. The processed data were represented through bar plots, heatmaps, rarefaction curves, and functional pathway maps. These visualizations allowed interpretation of microbial community structure, abundance, and potential metabolic functions. The flowchart of workflow analysis is represented in annexure 4.

3.3 Experiment II: Effect of organic manures and microbial consortium for growth, yield, quality and post- harvest changes in Khasi mandarin

3.3.1 Technical details:

Design: Randomized Complete Block Design (RBD)

Number of treatments: 10

Number of replications: 4(2 trees per replication)

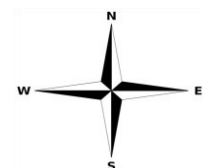
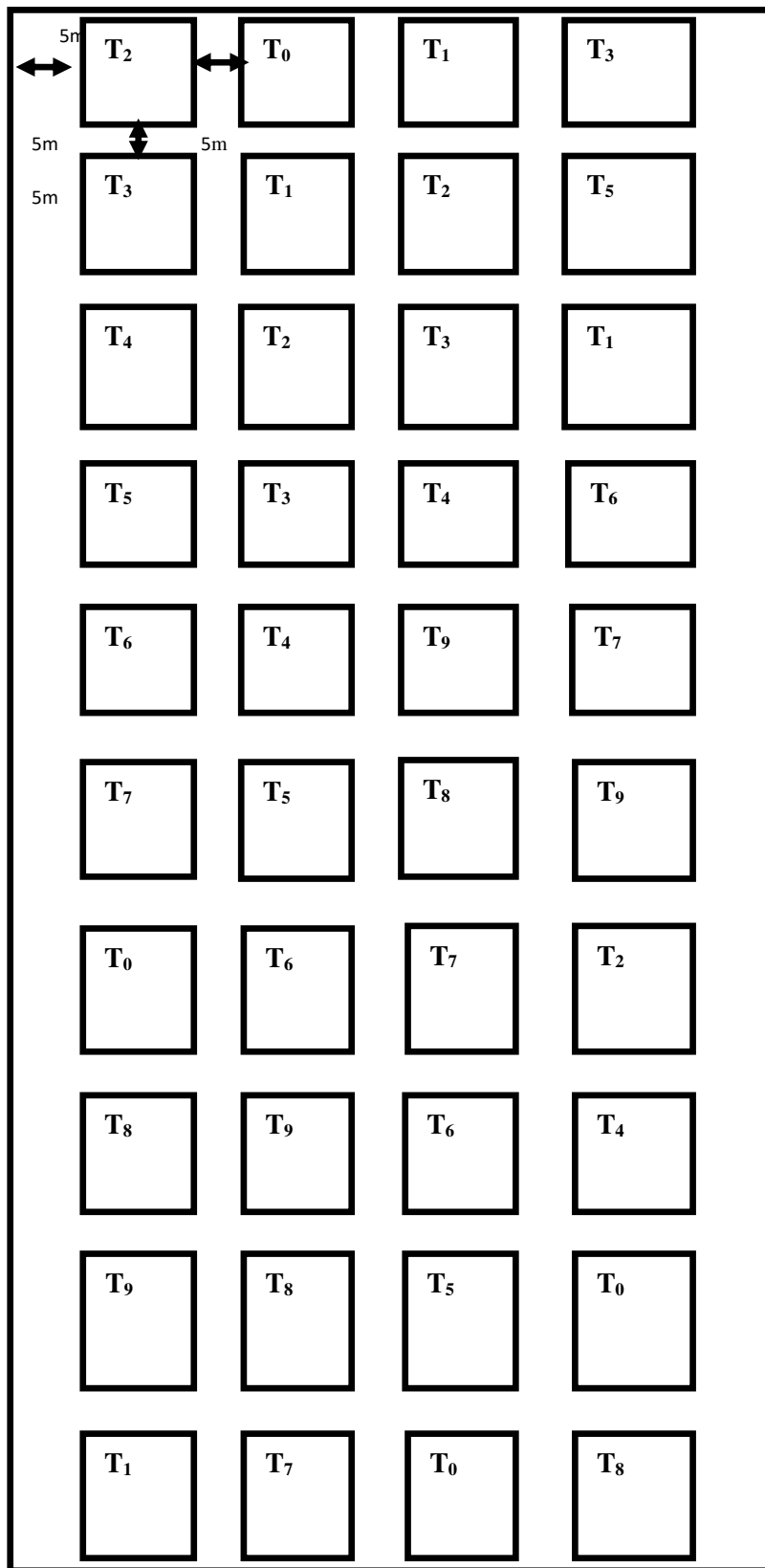
Spacing: 5x5 m²

Treatment details:

T₁ Control (conventional practices of citrus grower)

T₂ Control plus Microbial Consortium (100 ml per plant)

- T₃ FYM (40 kg per plant)
- T₄ FYM (20 kg per plant) plus Microbial Consortium (100 ml per plant)
- T₅ Poultry Manure (4 kg per plant)
- T₆ Poultry Manure (2 kg per plant) plus Microbial Consortium (100 ml per plant)
- T₇ Pig Manure (8 kg per plant)
- T₈ Pig Manure (4 kg per plant) plus Microbial Consortium (100 ml per plant)
- T₉ Vermicompost (4 kg per plant)
- T₁₀ Vermicompost (2 kg per plant) plus Microbial Consortium (100 ml per plant)



Layout of the Experimental Plot

3.3.2 General information

The Khasi mandarin trees were planted at the distance of 5m x 5m. The general health of most trees were not very good, therefore pruning of branches and uniform orchard floor practices were done on all trees prior to implementation of study. Based on farmer's information, the trees were 35 years old at the time of present investigation.

3.3.2.1 Source and details of organic inputs

Fertilizers, FYM, Poultry manure, Pig Manure, Vermicompost, and microbial consortium in alone and in combination were applied in varying amounts as basal application in the ring around the trunk in two split doses i.e., first dose in January and second split dose in early September. Nutrients were supplied in the month of the January to support the entire upcoming crop cycle as heavy rains in later months can cause leaching of fertilizers but applying in January reduces nutrient loss and increases the efficiency and also to prepare the plant for flowering, ensuring efficient nutrient uptake and ultimately improve fruit yield and quality. The second dose of fertilizers applied around September to support the crop during its fruit development stage and post-monsoon recovery.

Inorganic fertilizers were supplied through urea (46% N), SSP (16% P_2O_5), MOP (60% K_2O) and Rock phosphate (24% P_2O_5). Inorganic fertilizers were purchased from the agricultural store at Margherita and were applied in conventional practices.

Farm yard manure (FYM)- It is mainly formed of cow dung, cow urine, grass waste and other products of dairy which contains almost all the macro and micronutrients. Near around 0.5 percent nitrogen, 0.25 per cent phosphorus and 0.5 percent potassium was present in farm yard manure. FYM was collected from local farm located near to the orchard at Pangna Gaon.

Vermicompost-It is formed by the turning organic debris into worm castings. The vermicompost contained about 1.5% N, 0.9% P, 1.5% K, along with enzymes and hormones. The vermicompost was purchased from a local nursery at Margherita.

Poultry manure is the excreta of domesticated birds, often mixed with bedding materials like straw, sawdust, or wood shavings, as well as spilled feed and

feathers and is used as organic fertilizer. The poultry manure contained 0.7% N, 0.4% P, and 1.2% K. Poultry manure was purchased online at minimal rate.

Pig manure being rich in nutrients like nitrogen, phosphorus and other metal ions made it a potential organic fertilizer for farm land. The pig manure contained 0.7% N, 0.5% P, and 0.4% K. Direct application of manure is associated with health risks, and hence composting of pig manure is the simplest option for upgrading the manure for fertilizer use. Pig manure was collected from the local farm situated near to the orchard at Pangna Gaon.

Microbial Consortium is a biofertilizer that contains microbes that help plants grow by fixing nitrogen, solubilizing phosphorus, and mobilizing potassium. It is a consortium of *Rhizobium* Bacteria, *Azotobacter* Bacteria, *Acetobacter* Bacteria, Phospho Bacteria *Pseudomonas* and Potassium Solubilizing Bacillus bacterial culture. Microbial Consortium was purchased online from IIFCO (Indian Farmers Fertilizer Cooperative Limited) company.

3.3.3 Fertilization time and method

Organic, inorganic and bio-fertilizers were applied in two split doses i.e., first dose in January and second split dose in early September as basal application in the soil after mixing thoroughly 30 cm away from the trunk under the spread of trees in ring method and was later covered up by soil properly.

3.3.4 Irrigation

Irrigation was done by ring method after fruit setting as per the requirement depending upon presence of moisture in soil and rainfall. Irrigation was withheld after January to the flowering time to reduce vegetative growth which is detrimental to flowering.

3.3.5 Weeding

By manual method at regular interval the mandarin block was kept free of unwanted weeds. Dead, dried or diseased branches were checked regularly and removed properly.

3.3.6. Physical attributes

3.3.6.1 Tree height (m)

Use of measuring tape to determine the vertical distance from the ground level to the highest point of the tree canopy, ensuring measuring from the base of the trunk to the topmost leaf or branch, ignoring any significantly drooping branches.

3.3.6.2 Tree spread (m)

Tree spread was measured by the help of a measuring tape. East-West spread and North-South spread was recorded by measuring the shadow during in E-W and N-S directions respectively. The edges of shadows in each direction were measured by measuring tape for different trees and the mean was calculated. The spread of tree of each plant was expressed in metres.

3.3.6.3 Canopy volume (m³)

The canopy volume was calculated by using the equation: $CV = 0.524 HD^2$ where H and D stand for height and diameter, respectively (Castle, 1983)

3.3.6.4 Stem girth (cm)

Stem girth was measured by gently wrapping a flexible, non stretchable measuring tape around the stem at its widest point or most suitable at the breast height (1.3m) ensuring the tape is snug but not too tight and recording the measurement in centimetres.

3.3.6.5 Number of flowers per metre shoots

To measure number of flowers per metre shoot length, the number of flowers present on a designated length of a shoot (usually one metre) was counted and then divided that number by the measured length of the shoot in metres; essentially, this calculates the average number of flowers per metre of shoot length.

3.3.6.6 Number of fruits per metre shoots

To measure number of fruits per metre shoot length, the number of fruits present on a designated length of a shoot (usually one metre) was counted and then

divided that number by the measured length of the shoot in metres; essentially, this calculates the average number of fruits per metre of shoot length.

3.3.6.7 Fruit drop per tree (%)

Representative plants were tagged, and the initial fruit set per tree was recorded. Fallen fruits were collected weekly using ground collection or mesh sheets, and the number of dropped fruits per plant was noted. Cumulative fruit drop was calculated by summing all fallen fruits, and final retained fruits were counted at harvest. Data were averaged across replicates and statistically analyzed to compare treatment effects

3.3.6.8 Number of fruit per tree at harvest

To measure the number of fruits per tree at harvest, representative sample of trees were selected and carefully all the mature fruits on each sampled tree was counted, and then the average number of fruits per tree was calculated.

3.3.6.9 Yield per tree (kg)

To measure yield per tree, the number of fruits during harvest was counted and weighed, and then the average number of fruits weight per tree was calculated.

3.3.6.10 Fruit weight (g)

Fruits were harvested at the appropriate stage and individually weighed using a digital balance. Data were recorded in grams and statistically analyzed to compare differences among treatments.

3.3.6.11 Pulp weight (g)

Fruits were harvested at the appropriate stage, peeled, and the edible pulp was separated from seeds and skin. The pulp from each fruit was weighed using a digital balance. Data were recorded in grams and statistically analyzed to compare treatment effects.

3.3.6.12 Pulp and Peel ratio

Fruits were harvested at the appropriate stage and separated into pulp and peel. Both components were weighed using a digital balance. The pulp and peel ratio

was calculated as Pulp weight/Peel weight. Data were statistically analyzed to compare treatment effects.

3.3.6.13 Fruit length (cm)

Fruit length was measured from the base to the tip using a vernier caliper at the appropriate maturity stage. The representative fruits were sampled for each treatment. The mean fruit length per plant was calculated, and data were recorded in centimeters and statistically analyzed to compare treatment effects.

3.3.6.14 Fruit diameter (cm)

Fruit diameter was measured at the widest part of each fruit using a vernier caliper at the appropriate stage. The representative fruits were sampled for each treatment. The mean fruit diameter was calculated, and data were recorded in centimeters and statistically analyzed to compare treatment effects.

3.3.6.15 Fruit Volume (cm³)

Fruit volume was measured using the water displacement method. Each fruit was submerged in a graduated cylinder filled with water, and the volume of water displaced was recorded in milliliters. The representative fruits were sampled for each treatment. The mean fruit volume was calculated, and data were statistically analyzed to compare treatment effects.

3.3.6.16 Peel Thickness (mm)

Peel thickness of fruits was measured after separating the peel from the pulp and then at the equatorial region of the peel using a vernier caliper the thickness was measure. The mean peel thickness per fruit was calculated, and data were recorded in millimetres and statistically analyzed to compare treatment effects.

3.3.7 Fruit Quality attributes

3.3.7.1 Juice content (ml)

Fruits were harvested at the appropriate stage, peeled, and juice was extracted using a manual juicer. The volume of juice obtained from each fruit was

measured using a graduated cylinder. The mean juice content per fruit was calculated, recorded in millilitres, and statistically analyzed to compare treatment effects.

3.3.7.2 Total soluble solids (° Brix)

Total soluble solids (TSS) of fruit juice were measured using a hand-held refractometer at room temperature (AOAC, 2016). Juice was extracted from fruits, and readings were expressed in °Brix. Data were averaged for each treatment and statistically analyzed to compare differences in soluble solids content.

3.3.7.3 Titrable Acidity (%)

Titration acidity (TA) of fruit juice was measured by titrating a known volume of freshly extracted juice with 0.1 N sodium hydroxide (NaOH) using phenolphthalein as an indicator until a light pink end point persisted for 30 seconds. The TA was calculated and expressed as a percentage of citric acid. The mean TA per treatment was calculated, and data were statistically analyzed to compare differences among treatments.

Here's the standard formula to calculate Titratable Acidity (TA) of fruit juice:

$$\text{TA (\% citric acid)} = \frac{V \times N \times E \times 100}{V_s}$$

Where:

V = volume of NaOH used for titration (ml)

N = normality of NaOH

E= equivalent weight of the acid (for citric acid, 0.064 g/ml)

V_s = volume of juice sample (ml)

This gives TA as a percentage of citric acid in the juice.

3.3.7.4 Total soluble solids: Titrable acidity

Total soluble solids (TSS) of fruit juice were measured using a hand-held refractometer and expressed in °Brix: Titrable acidity (TA) was determined by titrating a known volume of juice with 0.1 N NaOH using phenolphthalein as an indicator, and expressed as % citric acid (AOAC, 2016). The TSS/TA ratio was calculated by dividing the TSS (°Brix) by the TA (% citric acid) for each sample and

mean values per treatment were statistically analyzed to compare differences among treatments.

3.3.7.5 Ascorbic acid (mg/100ml)

Ascorbic acid content in fruit juice was determined using the 2,6-dichlorophenolindophenol (DCPIP) dye titration method (AOAC, 2016). Fresh fruits were harvested at the appropriate maturity stage, and juice was extracted using a manual juicer. The juice was filtered to remove pulp and seeds. A known volume of juice (typically 10 ml) was titrated against standardized DCPIP solution until a persistent light pink color appeared for 15–30 seconds, indicating the endpoint. The volume of DCPIP used was recorded, and ascorbic acid content was calculated using the formula:

$$\text{Ascorbic acid (mg/100 ml)} = V \times C \times 100 / V_s$$

where V = volume of DCPIP used (ml), C = concentration of DCPIP (mg/mL), and V_s = volume of juice (ml). The representative fruits per plant were analyzed, and mean values per treatment were calculated and statistically compared to assess differences in ascorbic acid content among treatments.

3.3.7.6 Total Sugar (%)

Total sugar content was determined as per Lane and Eynon method (Ranganna, 2019) using the Fehling's titration technique. Fresh fruits were harvested, washed, peeled, and the pulp homogenized. A known weight of pulp (typically 10 g) was diluted with distilled water and filtered to obtain a clear juice extract. An aliquot of the filtrate was hydrolyzed with dilute acid, neutralized, and then subjected to Fehling's solution titration using methylene blue as an internal indicator. The reducing sugars in the sample reduced copper (II) ions to copper(I) oxide, and the volume of titrate used was recorded. For total sugar determination by titration (Fehling's method), the total sugar content can be calculated using the formula:

$$\text{Total Sugar (\%)} = V \times N \times 0.05 \times 100 / W$$

Where:

V = volume of titrate (Fehling's solution) used (ml)

N = normality of Fehling's solution

0.05 = equivalent weight of glucose (g) per ml of 1 N Fehling's solution

W = weight of fruit sample (g)

This gives the total sugar content as a percentage of fresh weight.

3.3.7.7 Reducing Sugar(%)

Reducing sugars in fruit samples were determined following Lane and Eynon,(1923) titrimetric method using Fehling's solutions. A known weight of homogenized fruit tissue (10 g) was extracted with distilled water, filtered through Whatman No. 1 paper, and the extract made up to a definite volume. An aliquot of the extract was pipetted into a conical flask and titrated against a previously standardized mixture of Fehling's A and Fehling's B solutions (1:1) by boiling, using methylene blue as the internal indicator. The endpoint was noted by the decolorization of the indicator from blue to brick-red due to the reduction of cupric ions to cuprous oxide. The reducing sugar content was calculated using the following formula and expressed as percentage on fresh weight basis:

$$\text{Reducing sugar (\%)} = (F \times 100 \times V) / (W \times 1000)$$

Where F= Fehling's factor (mg glucose equivalent to 1 ml Fehling's solution), V = volume of sample extract required to completely reduce 10 ml Fehling's solution (ml), and W= weight of fruit sample taken (g).

3.3.7.8 Peel oil content (%)

Extraction of mandarin peel essential oil was done using (Clevenger hydrodistillation) Clevenger (1928). Mature mandarin fruits were washed, air-dried, and the peels removed; 50.0 g of fresh peel (cut into 5-10 mm pieces) was weighed and placed in a 1 L round-bottom flask. To the flask was added 500 ml of distilled water and the flask fitted with a Clevenger-type apparatus and reflux condenser. The assembly was heated and the mixture brought to gentle boiling; hydrodistillation was continued for 3 hours from the first drop of distillate, maintaining a moderate boil to ensure steady condensation without bumping. The essential oil that collected in the calibrated arm of the Clevenger was allowed to separate; the oil layer was collected with a micropipette into a pre-weighed amber vial through a small funnel. Residual

water was removed by adding anhydrous sodium sulfate (a pinch) to the collected oil, swirling, and decanting; the oil vial was then re-weighed to determine oil mass. All extractions were performed in triplicate. The crude oil was stored at 4 °C in the dark until analysis.

Calculation of oil yield: Express oil yield as volume or mass per 100 g fresh peel. Common reporting formats:

Volume basis ($v \cdot w^{-1} \%$):

$$\text{Oil (\% v/w)} = \text{Voil (ml)} \times 100 / \text{Wsample (g)}$$

Where, Voil is the volume of oil collected (ml) and Wsample is sample weight (g).

Mass basis ($w \cdot w^{-1} \%$), preferred if oil mass is measured:

$$\text{Oil (\% w/w)} = \text{Moil (g)} \times 100 / \text{Wsample (g)}$$

where Moil is the mass of dried oil (g). If only volume is measured and you wish to convert to mass, determine oil density (measure by weighing a known volume) and use $M = \rho \times V$

3.3.7.9 Physiological loss in weight (%)

Representative lot of fruits was used to determine physiological loss in weight (PLW) during storage. For each treatment (or storage condition) $n=3$ replicates were prepared; each replicate consisted of uniform fruits (or a known batch mass), unless otherwise specified. All samples were labelled and initial weight was recorded immediately before storage using an analytical balance (readability 0.01 g) that was calibrated daily with standard weights. Initial weight (W_0) for each replicate was the total weight of the replicate (g). Samples were then stored under the assigned conditions, and weights were measured at predetermined intervals (e.g., 5, 10, 15, 20 days) by removing the replicates briefly, blotting surface condensation with a paper towel when present, and recording the weight to the nearest 0.01 g. Care was taken to handle samples gently and to tare the balance before each measurement. At each sampling date the weight recorded was W_t (g).

Physiological loss in weight for each replicate at time t was calculated as:

$$PLW (\%) = (W_0 - W_t) / W_0 \times 100$$

where W_0 = initial weight of the replicate (g) and W_t = weight of the same replicate at sampling time t (g). Mean PLW (%) and standard deviation were computed from the three replicates for each treatment and sampling time.

3.3.7.10 Sensory evaluation

Sensory evaluation was conducted to assess the organoleptic quality of the samples. A panel of 10–12 semi-trained adult assessors (age 22–55 years) were recruited from the department staff and postgraduate students; all panelists reported no allergies or sensory impairments and had prior experience with sensory testing. The test was performed in the sensory laboratory under controlled conditions (22 ± 2 °C; neutral lighting) between 10:00-12:00 h. Samples (25-30 g) were coded with three-digit random numbers, presented monadically in randomized order, and served at room temperature on white plates; water and unsalted crackers were provided for palate cleansing.

Hedonic sensory protocols were used: Hedonic (consumer-type) test- Overall acceptability and four attributes (appearance, aroma, taste, texture) were rated on a 9-point hedonic scale (1 = dislike extremely, 9 = like extremely). Each assessor completed one replication per sample.

3.3.8 Soil Analysis

3.3.8.1 Soil pH

Soil pH was determined using the glass electrode method as described by AOAC (2000). Fresh composite soil samples were air-dried, ground with a wooden pestle, and sieved through a 2 mm mesh. For each determination, 10.0 g of processed soil was transferred into a 50 ml beaker and 25.0 ml of distilled water (soil: water ratio 1:2.5 w/v) was added. The suspension was stirred thoroughly with a glass rod for 30 minutes and allowed to stand for 1 hour to equilibrate, with intermittent stirring to ensure uniform suspension. The pH of the supernatant was then measured using a calibrated digital pH meter (make/model), standardized with buffer solutions of pH 4.0, 7.0, and 9.2 prior to measurement. All samples were analyzed in triplicate, and the mean values were reported.

3.3.8.2 Organic Carbon (%)

Soil organic carbon content was determined by the wet oxidation method of Walkley and Black (1934). Air-dried and sieved soil samples (1.0 g, <2 mm) were transferred into a 500 ml conical flask, to which 10 ml of 1 N potassium dichromate ($K_2Cr_2O_7$) solution was added, followed by 20 ml of concentrated sulphuric acid (H_2SO_4). The contents were mixed thoroughly and allowed to stand for 30 minutes for complete oxidation of organic matter. After dilution with 200 ml of distilled water, 10 mL of orthophosphoric acid and 1 ml of diphenylamine indicator were added. The residual dichromate was titrated against standardized 0.5 N ferrous ammonium sulfate solutions (FAS) until the color changed from violet-blue to brilliant green. A blank titration (without soil) was run simultaneously. The organic carbon (%) was calculated using the following formula:

$$\text{Organic carbon (\%)} = \{(V_b - V_s) \times N \times 0.003 \times 100\} / W$$

Where:

V_b = volume of FAS used in blank (ml)

V_s = volume of FAS used in sample (ml)

N = normality of FAS

W = weight of soil sample (g)

0.003 = milliequivalent weight of carbon (g).

The results were expressed as percentage organic carbon in soil (% OC).

3.3.8.3 Available Nitrogen ($kg\ ha^{-1}$)

Available nitrogen in soil was determined by the Kjeldahl method (AOAC, 2000). Air-dried and sieved soil samples (10.0 g, <2 mm) were transferred into a 500 mL Kjeldahl digestion flask and mixed with 10 g potassium sulphate, 0.5 g copper sulphate (as catalyst), and 25 ml concentrated sulfuric acid (H_2SO_4). The mixture was digested on a digestion block at 350-400 °C until the suspension became clear, indicating complete oxidation of organic matter and conversion of organic nitrogen to ammonium sulfate. After cooling, the digest was diluted with distilled water and transferred to a Kjeldahl distillation unit. The ammonia released on addition of 40% sodium hydroxide (NaOH) was distilled into 20 ml of 2% boric acid solution containing mixed indicator (bromocresol green–methyl red). Distillation was

continued until about 100 ml of distillate was collected. The trapped ammonia was titrated with standardized 0.02 N H₂SO₄ to a pink end point. A reagent blank was run in parallel. The available nitrogen content was calculated from the titre values and expressed as kg N ha⁻¹.

Calculation of available nitrogen: The nitrogen content of soil was calculated from the titration values using the following formula:

$$\text{Available N (kg ha}^{-1}\text{)} = \{(V_s - V_b) \times N \times 14.01 \times V_T \times 10^4\} / W \times V_a$$

Where:

V_s = volume of standard H₂SO₄ used for sample titration (ml)

V_b = volume of standard H₂SO₄ used for blank (ml)

N = normality of standard acid (eq. L⁻¹)

14.01 - atomic weight of nitrogen (mg per meq)

W = weight of soil sample taken (g)

V_t = total volume of digest after dilution (ml)

V_a = aliquot volume of digest taken for distillation (ml)

10⁴ = factor for converting mg g⁻¹ to kg ha⁻¹ (assuming soil depth 15 cm and bulk density 1.0 g cm⁻³).

The results were expressed as kg available nitrogen per hectare (kg ha⁻¹).

3.3.8.4 Available Phosphorous (kg ha⁻¹)

Available phosphorus in soil was determined colorimetrically using a spectrophotometer as described by Olsen *et al.* (1954) for neutral to alkaline soils (or Bray and Kurtz, 1945 for acidic soils). Air-dried and sieved soil samples (2.5 g, <2 mm) were placed in a 100 ml conical flask and extracted with 50 ml of 0.5 M sodium bicarbonate solution (pH 8.5) containing 0.5 g activated charcoal. The suspension was shaken on a mechanical shaker for 30 minutes and then filtered through Whatman No. 42 filter paper. A 5 ml aliquot of the clear extract was transferred into a 25 ml volumetric flask, to which 5 ml of ammonium molybdate reagent and 1 ml of stannous chloride solution were added. The mixture was diluted to volume with distilled water, and the intensity of the blue color developed (molybdenum blue

complex) was measured at 660 nm using a UV-Vis spectrophotometer against a reagent blank. A calibration curve was prepared using standard KH_2PO_4 solutions of known concentrations, and available phosphorus content of the soil samples was calculated from the standard curve and expressed as kg P ha^{-1} .

Calculation of available phosphorus: The concentration of phosphorus in the soil extract was obtained from the calibration curve prepared with KH_2PO_4 standards and expressed initially in mg L^{-1} (ppm). The available phosphorus content in soil was calculated using the following formula:

$$\text{Available P (kg ha}^{-1}\text{)} = \{(\text{C} \times \text{Ve}) / \text{W}\} \times 2.24$$

Where:

C = concentration of phosphorus in extract from standard curve (mg L^{-1})

Ve = volume of extractant used (ml)

W = weight of soil taken (g)

2.24 = conversion factor to express ppm of P in soil as kg P ha^{-1} (assuming soil depth of 15 cm and bulk density of 1.33 g cm^{-3}).

The final results were expressed as kg available phosphorus per hectare (kg ha^{-1}).

3.3.8.5 Available potassium (kg ha^{-1})

Available potassium in soil was determined by the neutral ammonium acetate extraction method as described by Jackson (1973). Air-dried and sieved soil samples (5.0 g, <2 mm) were transferred into a 100 mL conical flask and extracted with 25 ml of 1 N neutral ammonium acetate ($\text{NH}_4\text{CH}_3\text{CO}_2$, pH 7.0). The suspension was shaken on a mechanical shaker for 30 minutes and filtered through Whatman No. 42 filter paper. The concentration of potassium in the clear extract was measured directly using a flame photometer (make/model), previously calibrated with standard KCl solutions of known concentrations (e.g., 5, 10, 15, 20 mg L^{-1} K). The readings from the flame photometer were plotted to prepare a standard calibration curve, and the potassium concentration of soil samples was determined by reference to this curve. Available potassium content was then expressed as kg K ha^{-1} .

Calculation of available potassium:

The potassium concentration in the soil extract was obtained from the calibration

curve prepared with KCl standards and expressed in mg L⁻¹. The available potassium content in soil was then calculated using the following formula:

$$\text{Available K (kg ha}^{-1}\text{)} = \{(C \times V_e) / W\} \times 2.24$$

Where:

C = concentration of potassium in extract from standard curve (mg L⁻¹)

V_e = volume of extractant used (ml)

W = weight of soil sample taken (g)

2.24 = conversion factor to express ppm (mg kg⁻¹) of K in soil as kg K ha⁻¹ (assuming soil depth of 15 cm and bulk density of 1.33 g cm⁻³).

The results were expressed as kg available potassium per hectare (kg ha⁻¹).

3.3.9 Economic of cultivation

Cost of cultivation was found out by adding the cost of organic manures, chemical fertilizers, biofertilizer, and labour cost which includes application of fertilizer, irrigation, weeding, and plant protection etc. during the period of experiment as per the current existing rate.

For working out the economics, under individual treatment, the yield obtained was taken into consideration. Based on the total cultivation cost, gross returns, net returns, the benefit: cost ratio was worked out and was computed per hectare. The benefit cost ratio was evaluated by the formula given below:

$$\text{Benefit: Cost} = \text{Net return} / \text{Total cost of cultivation}$$

3.3.10 Statistical analysis

The experiment was laid out in Randomized Block Design (RBD) with four replications and two plants per replication and eight plants per treatment. The statistical analysis of the data in the growth and quality components of fruits and plants was done according to the standard procedure given for the randomized complete block design (Panse and Sukhatme, 1967). The total variation for the different treatments was tested for significance by “F” test using analysis of variance technique.

CHAPTER IV

RESULTS AND DISCUSSIONS

RESULTS AND DISCUSSIONS

The findings of the experiment entitled “Study on microbes mediated organic production for Khasi mandarin” conducted during the years from 2022 to 2024 are presented in this chapter. An attempt has been made to compare the present results with reports of other workers. The results have been presented with suitable tables, graphs and photographs.

4.1 Seedling studies

4.1.1 Plant height (cm)

The effect of different treatments on seedling height at successive growth stages is presented in Table 4.1 and Fig 4.1. Seedling height increased progressively with age of seedlings under all treatments. The seedling height varied significantly on all days of observation. At the initial stage of observation the greatest height (29.30 cm) was found with T₂ treatment, however as the age of the seedlings progressed upto 180 days the greatest height (33.34 cm) was observed with treatment T₄. These results suggest that different treatments had a marked influence on seedling height. Initially, T₂ showed a slight advantage in early growth (75 and 105 days), however as the seedlings advanced in age, T₄ and T₅ consistently outperformed other treatments and produced the tallest seedlings. On the contrary, T₃ remained the least effective throughout the growth period, indicating poor vegetative response. The enhanced height under T₄ and T₅ may be attributed to better nutrient utilization and vigorous cell elongation, while the restricted height under T₃ suggests inadequate growth stimulation.

4.1.2 Plant girth (cm)

The effect of different treatments on plant stem girth at successive growth stages is presented in Table 4.2 and Fig 4.2. A gradual increase in stem girth was recorded with the advancement of crop age across all treatments, though the magnitude of increase varied. The stem girth was found greatest with T₂ (1.93 cm) at 75 days of seedling age which progressed upto 180 days (2.21 cm). T₅ treatment showed the least stem girth of 1.71 cm at 75 days which progressed to a size of 2.10

Table 4.1 Effect of rhizosphere treatments on plant height (cm) of different ages of seedlings

Treatments	75	105	120	135	150	165	180
	Days						
T ₁	29.06	29.55	31.28	32.52	32.65	32.78	32.97
T ₂	29.30	30.59	31.07	31.64	31.86	32.07	32.37
T ₃	28.37	28.76	28.81	29.19	29.43	29.67	30.07
T ₄	27.46	29.15	31.68	32.48	32.79	32.94	33.34
T ₅	26.64	29.31	31.83	32.42	32.62	32.81	33.12
S Em±	0.83	0.46	0.42	0.71	0.70	0.40	0.77
CD at 5%	1.79	0.98	0.9	1.52	1.50	0.86	1.64

Table 4.2 Stem girth (cm) of Khasi mandarin seedlings as influence by various rhizosphere treatments

Treatments	75	105	120	135	150	165	180
	Days						
T ₁	1.87	1.90	1.97	2.04	2.08	2.13	2.19
T ₂	1.93	1.95	1.99	2.04	2.13	2.19	2.21
T ₃	1.88	1.91	1.97	2.02	2.07	2.11	2.18
T ₄	1.83	1.87	1.92	2.01	2.06	2.10	2.17
T ₅	1.71	1.75	1.79	1.86	1.93	2.04	2.10
S Em±	0.04	0.05	0.04	0.04	0.03	0.03	0.04
CD at 5%	0.09	0.11	0.09	0.08	0.06	0.07	0.08

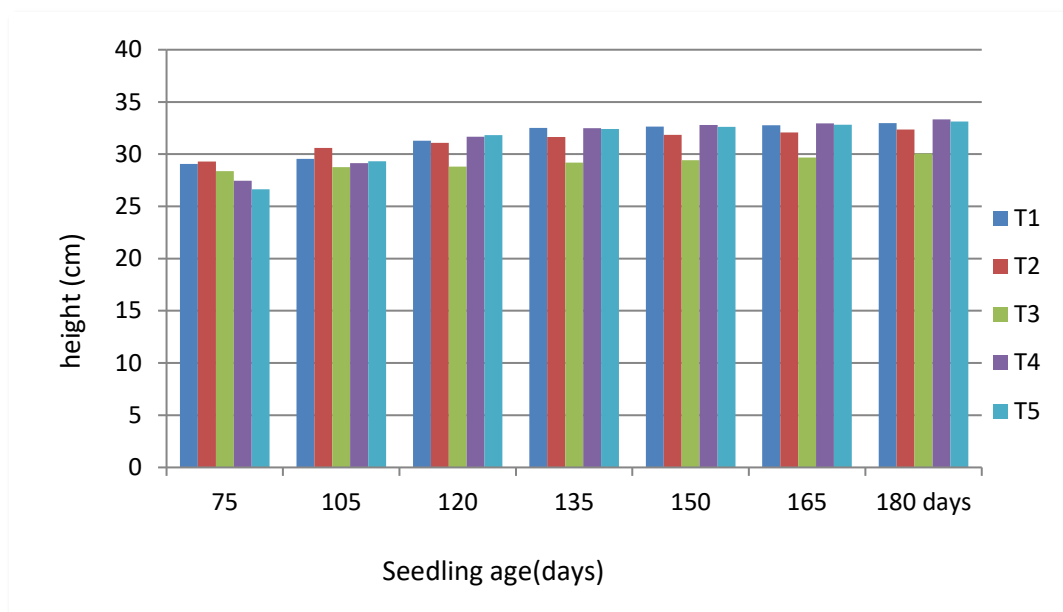


Fig 4.1 Seedling plant height (cm) with different rhizosphere treatments

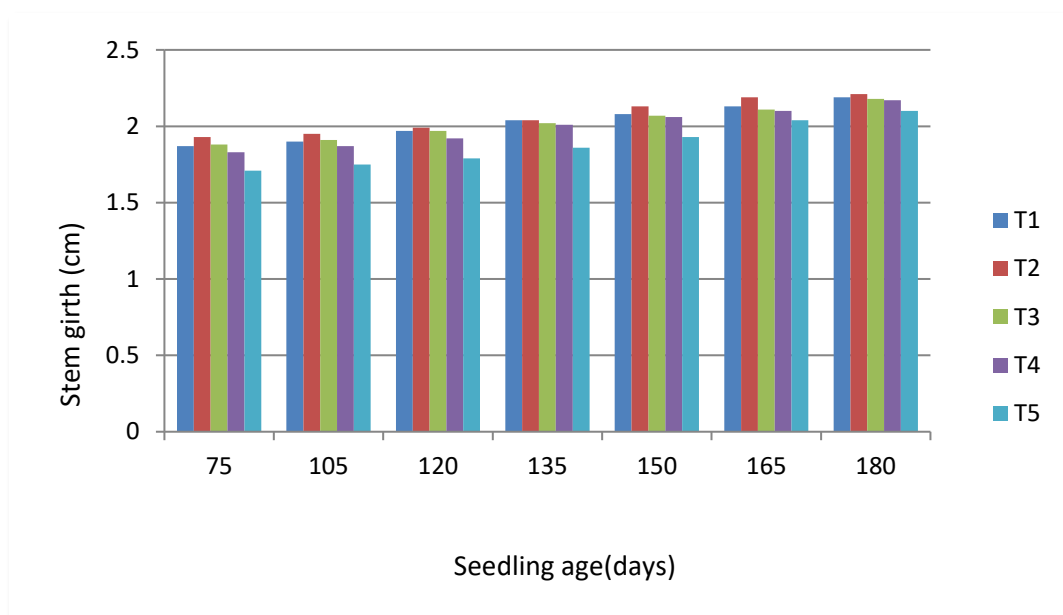


Fig 4.2 Stem girth (cm) of Khasi mandarin seedlings as influenced by various rhizosphere treatments

cm at 180 days. The statistical analysis revealed that treatment differences were significant at all stages. The progressive increase in stem girth across the growth period reflects active cambial growth and thickening of seedlings, which was positively influenced by treatments enhancing nutrient availability and metabolic activity. The consistently superior performance of T₂ may be attributed to its role in balanced nutrient uptake, which promoted vigorous vegetative growth. T₁, being on par with T₂, also indicated favorable growth conditions for stem thickening. On the contrary, the lowest values in T₅ throughout the observation period suggest poor nutrient utilization and restricted growth. Thus, the results clearly demonstrate that T₂ was the most effective treatment for improving seedling stem girth, followed closely by T₁, while T₅ proved least effective.

4.1.3 Number of leaves per plant

The number of leaves per plant at successive growth stages as influenced by different treatments is presented in Table 4.3 and Fig 4.3. At the initial 75 days of seedling growth the maximum number of leaves were observed in T₃ (15.37) and when the growth progressed upto 180 days the maximum number of leaves were observed in T₄ (50.03). These results clearly indicate that treatments significantly influenced leaf production throughout the growth period. T₄ and T₅ showed a marked superiority in increasing leaf numbers, which could be attributed to better nutrient assimilation and enhanced photosynthetic activity, leading to greater vegetative growth. T₁ and T₃ showed moderate performance, while T₂ remained the least effective treatment in terms of leaf production at almost all stages. Overall, it can be concluded that T₄ and T₅ were most effective in enhancing leaf number per seedling, whereas T₂ consistently recorded the lowest values.

4.1.4 Leaf nutrient composition

Table 4.4 and Figs 4.4, 4.5 depict the leaf nutrient composition of leaves of Khasi mandarin seedlings grown on different rhizospheric soils. A close scrutiny of the table shows that the various nutrients varied significantly among the treatments barring phosphorous which was found to be non- significant.

Table 4.3 Influenced of rhizosphere treatments on the number of leaves in Khasi mandarin seedlings

Treatments	75	105	120	135	150	165	180
	Days						
T ₁	15.25	17.75	26.62	32.88	36.12	39.37	43.88
T ₂	12.00	22.12	25.38	28.62	31.81	35.00	38.67
T ₃	15.37	18.38	25.12	28.12	33.50	38.87	42.67
T ₄	13.12	27.25	38.62	43.50	44.75	46.01	50.03
T ₅	13.12	31.87	37.25	41.87	43.81	45.75	49.87
S Em±	0.35	0.62	0.75	0.89	0.80	0.55	1.17
CD at 5%	0.74	1.33	1.62	1.90	1.71	1.18	2.51

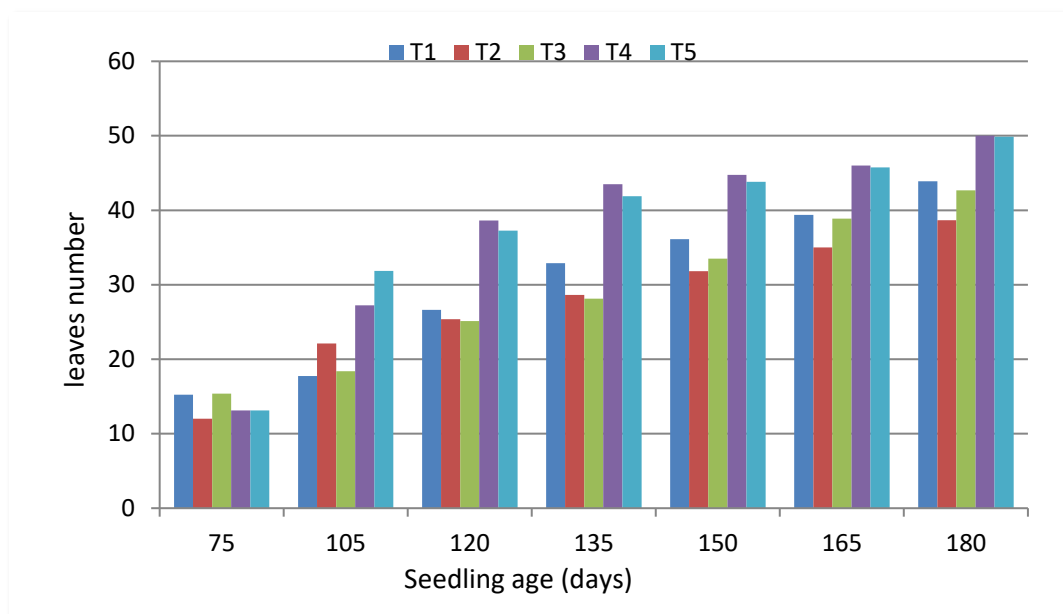


Fig 4.3 Rhizosphere treatments on number of leaves in Khasi mandarin seedlings

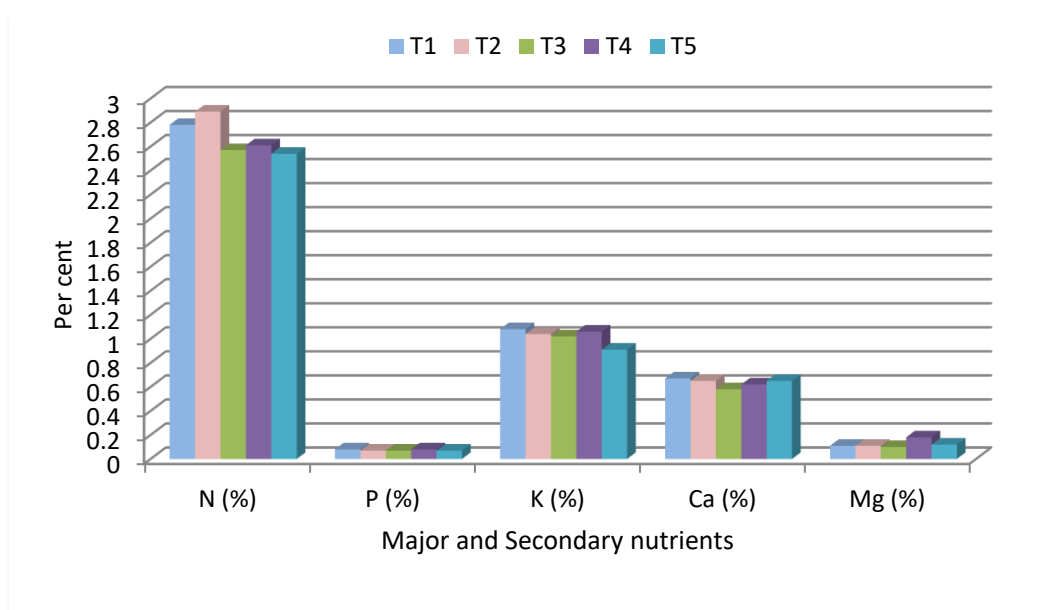


Fig 4.4 Leaf nutrient content in seedling plants grown on different rhizosphere

Nitrogen (N) content in leaf was found greatest with T₂ (2.89%) followed by T₁ (2.78%) which were found to be statistically at par. This was followed by T₄ (2.61%) and the least was recorded with T₅ treatment (2.54%). The enhanced nitrogen accumulation under T₂ might be attributed to improved N mineralization and rhizosphere nitrogen-fixing efficiency induced by microbial diversity present, leading to greater uptake and assimilation. Similar improvements in leaf N concentration with microbial inoculants were also reported by Chakraborty *et al.* (2016a) in citrus.

Phosphorous (P) content showed a narrow range (0.07–0.08%) and remained statistically non-significant among treatments, suggesting uniform phosphorus availability in the soil. However, in general P (0.08%) content was recorded highest with T₁ and T₄ treatments, while T₂, T₃ and T₅ recorded P content of 0.07%.

The highest potassium (K) content (1.08%) in leaf was observed in T₁ closely followed by T₄ (1.06%) which was found to be statistically at par with one another, while the lowest K was found in T₅ (0.91%). Enhanced K accumulation in organically treated plots may be associated with improved cation exchange and nutrient retention in the rhizosphere.

The calcium (Ca) content in leaf (0.67%) was found highest with treatment T₁ closely followed by treatments T₂ and T₅ (0.65%). The least Ca content (0.58%) was observed in T₃ followed by T₄ (0.62%). The highest magnesium (Mg) content (0.18%) in leaf was observed in T₄ while the least (0.10%) was recorded in T₃ treatments. The increased Mg content under T₄ reflects enhanced enzymatic activity and chlorophyll formation, supported by organic matter-mediated nutrient chelation and root absorption efficiency.

The micronutrient content of Manganese (Mn) was found to be highest in T₁ with 44 ppm which was significantly superior to all other treatments. The micronutrient contents of zinc (Zn) were found to be highest in T₁ and T₄ with 30 ppm. Copper (Cu) content was significantly higher in T₄ (4.60 ppm) compared to other treatments, indicating better availability of transition metals in organically enriched soils and iron (Fe) contents were highest in T₄ with 409 ppm suggesting

Table 4.4 Leaf nutrient element composition of Khasi mandarin seedlings

Treatments	N	P	K	Ca	Mg	Mn	Zn	Cu	Fe
	%					ppm			
T ₁	2.78	0.08	1.08	0.67	0.11	44	30	4.20	341
T ₂	2.89	0.07	1.04	0.65	0.11	24	26	2.19	237
T ₃	2.57	0.07	1.02	0.58	0.10	30	24	2.39	395
T ₄	2.61	0.08	1.06	0.62	0.18	20	30	4.60	409
T ₅	2.54	0.07	0.91	0.65	0.12	28	24	2.19	231
S Em±	0.06	NS	0.01	0.01	NS	0.27	0.27	0.04	3.69
CD at 5%	0.19	NS	0.04	0.03	0.01	0.83	0.83	0.13	11.2

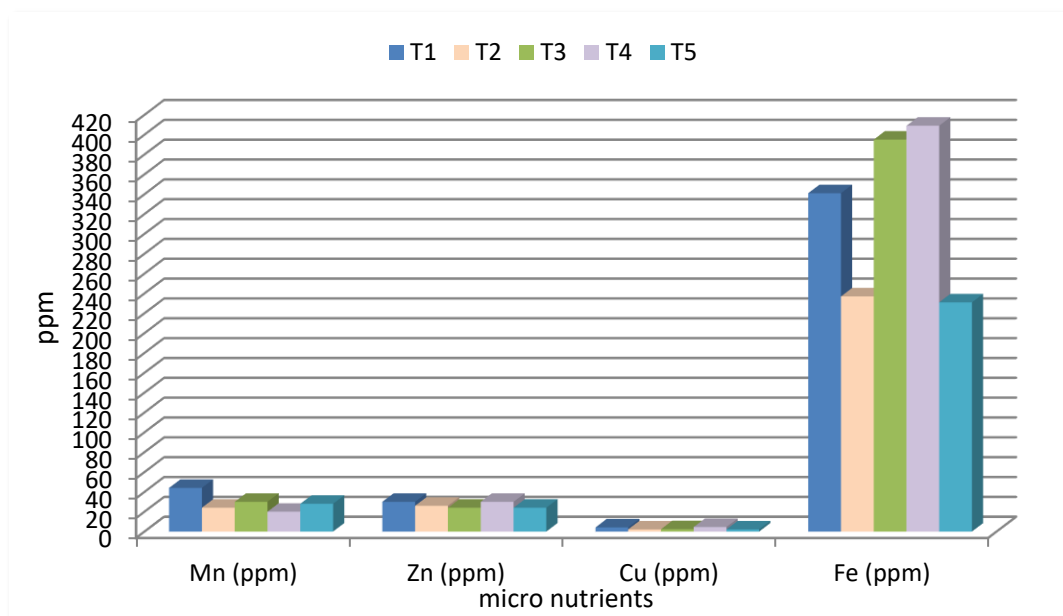


Fig 4.5 Leaf micronutrient content (ppm) as influenced by different rhizospheres



Seedlings at 75 days



Seedlings at 120 days



Seedlings at 165 days



Seedlings at 180 days

Plate 4.1 Khasi mandarin seedlings with age progression in different rhizosphere

that rhizospheric soil inputs enhance micronutrient solubilization and root uptake through improved microbial chelation.

Overall, the combined data indicated that T₄ excelled in improving Ca, Mg, Cu, and Fe concentrations. T₁ maintained the highest levels of potassium, manganese, and zinc. These results suggested that use of rhizospheric soil substantially enhances nutrient bioavailability and plant uptake efficiency in Khasi mandarin. Comparable findings were reported by Sarma *et al.* (2018a) and Patel *et al.* (2020), who observed that microbial community and organic matter present in the rhizospheric region improved macro- and micronutrient composition in citrus leaves by fostering favorable soil–microbe interactions.

4.2 Microbial diversity studies

The study on the growth and leaf nutrient content of Khasi mandarin seedling grown on the different rhizosphere collected from the mandarin orchard showed the beneficial effects influencing the overall growth and nutrient content in the seedling plants. On close scrutiny of the data obtained, it was evident that T₄ performed better on the growth characteristics of plants while some nutrient elements were recorded higher with T₁. Therefore the rhizospheric soils of T₁ and T₄ were mixed together thoroughly and the homogenous sample was analysed further to study the microbial diversity in an attempt to identify the possible beneficial microorganisms affecting plants positively on their growth and productivity in the Khasi mandarin orchard.

4.2.1 Raw data summary and quality assessment

The sequencing data generated for the Khasi mandarin rhizosphere metagenomic sample (DTPL) exhibited high-quality reads with excellent base composition and minimal loss during trimming as indicated in Fig 4.6. A total of paired-end reads (R1 and R2) were obtained, each with an average GC content of 57% prior to trimming, which lies within the expected range for bacterial genomic DNA, indicating balanced nucleotide composition and minimal sequencing bias. The average read length of 301 bp for both forward and reverse reads confirmed that the Illumina sequencing run successfully captured the V3-V4 region of the 16S rRNA

gene, which is widely used for bacterial community profiling due to its high taxonomic resolution.

Post quality control and adapter trimming, the percentage of trimmed sequences was only 10.9% for R1 and 1.2% for R2, signifying minimal sequence loss and high data integrity. The mean sequence percentage (M_Seqs) remained nearly constant before and after trimming (96.1% and 96.0% for R1; 91.2% and 93.3% for R2), indicating efficient read retention. Moreover, the duplicate read percentage after trimming reduced from 0.18% to 0.16%, reflecting low redundancy and confirming that the data were largely unique and non-repetitive. The GC content after trimming (53%) remained consistent across both forward and reverse reads, showing that trimming did not alter the nucleotide composition or introduce sequence bias.

The overall results demonstrate that the raw sequencing data were of high quality, with negligible duplication, adequate GC balance, and sufficient read length to ensure reliable downstream analysis. The excellent sequence quality obtained through DADA2 processing supports the accuracy of subsequent amplicon sequence variant (ASV) detection and taxonomic classification.

4.2.2 Amplicon processing summary

After quality control and adapter trimming, the sequencing reads were subjected to amplicon processing through the DADA2 pipeline, which performs stringent quality filtering, denoising, merging, and chimera removal to yield high-confidence Amplicon Sequence Variants (ASVs) as indicated in Fig 4.7. From an initial total of 158,408 paired-end reads, a remarkable 99.73% merging efficiency was achieved, resulting in 157,979 successfully merged reads. This indicates excellent sequence overlap and base-pair complementarity between the forward (R1) and reverse (R2) reads of the 16S rRNA V3-V4 region.

Subsequent quality filtering retained 156,784 high-quality reads, while denoising produced 151,051 reads (95.36%), effectively minimizing sequencing errors and distinguishing true biological variants from artefacts. After removal of chimeric sequences, 96,094 non-chimeric reads (60.66%) were retained for

		RAW					TRIMMED				
		Pairs	M_Seqs	Percent_Dup	Percent_GC	Length	Percent_Trimmed	M_Seqs_Trimmed	Percent_Dup_Trimmed	Percent_GC_Trimmed	Length_Trimmed
DTPL	R1	0.18	96.1	57	301	10.9	0.16	96	53	298	
	R2	0.18	91.2	57	301	1.2	0.16	93.3	53	297	

Fig 4.6 Raw data summary and quality assessment

sample	input	merged	%merged	filtered	%filtered	denoisedF	%denoised	non-chimeric	%non-chimeric
DTPL	158408	157979	99.73%	156784	155762	151051	95.36%	96094	60.66%

Fig 4.7 Amplicon processing summary

downstream taxonomic analysis. This high percentage of non-chimeric reads confirms that the dataset is free from significant PCR-induced artefacts and suitable for accurate microbial community profiling.

The high merging and denoising efficiency observed in this dataset reflects the overall robustness of the sequencing and bioinformatics workflow. According to Callahan *et al.* (2016), the DADA2 algorithm precisely models and corrects sequencing errors, thereby enabling accurate identification of unique microbial variants without clustering at arbitrary similarity thresholds. The low proportion of chimeric sequences further supports the reliability of the amplicon data and the overall integrity of the 16S rRNA gene amplification process.

These results collectively demonstrate that the sequencing data obtained for the Khasi mandarin rhizosphere sample are of high quality, with minimal noise, adequate read depth, and strong sequence integrity, providing a sound basis for subsequent taxonomic classification, diversity analysis, and functional interpretation of the microbial community structure.

4.2.3 Taxonomic composition and relative abundance at the species level

The metagenomic analysis of the Khasi mandarin rhizosphere (sample DTPL) revealed the presence of several dominant bacterial species belonging primarily to the phyla Firmicutes, indicating a microbiome largely composed of Gram-positive, spore-forming bacteria. As shown in the relative abundance plot Fig 4.8, the bacterial community was overwhelmingly dominated by *Clostridium sartagoforme*, which constituted the major proportion of the total reads. This species is known for its strong cellulolytic and fermentative ability, playing an important role in the decomposition of organic residues and nutrient cycling in soil ecosystems (Li *et al.*, 2020).

The second most abundant taxon was *Clostridium perfringens*, followed by *Terrisporobacter glycolicus*, both of which belong to the Clostridiaceae family. These species contribute to organic matter degradation under anaerobic conditions, releasing

simple organic acids and other metabolites that can enhance soil fertility. Minor but significant representation was also observed for *Bacillus thuringiensis*, *Bacillus anthracis-cereus*, *Clostridium amylolyticum-polynesiense*, and *Lysinibacillus xylanilyticus*, which are recognized for their plant growth-promoting and biocontrol properties (Kumar *et al.*, 2012; Compant *et al.*, 2005). Particularly, *Bacillus thuringiensis* and *Lysinibacillus xylanilyticus* are known to produce extracellular enzymes and metabolites that suppress phytopathogens and improve rhizosphere health.

The detection of diverse species from both *Bacillus* and *Clostridium* genera suggests a functionally dynamic rhizosphere microbiome capable of performing a wide range of metabolic activities, including nitrogen fixation, phosphate solubilization, and decomposition of complex organic compounds. The coexistence of aerobic (*Bacillus*) and anaerobic (*Clostridium*) taxa implies that the rhizosphere environment sustains micro-niches with variable oxygen availability, supporting a rich and functionally complementary microbial community.

Overall, the predominance of beneficial taxa such as *Clostridium sartagoforme* and *Bacillus thuringiensis* indicates that the Khasi mandarin rhizosphere harbors a biologically active and potentially growth-promoting microbiome. This microbial structure is consistent with earlier findings by Mishra *et al.* (2019) and Saha *et al.* (2021), who reported that citrus rhizospheres often contain Firmicutes-dominated communities contributing to plant nutrient uptake and soil enzymatic activity.

4.2.4 Taxonomic composition and relative abundance at the genus level

The metagenomic analysis of the Khasi mandarin rhizosphere (sample DTPL) revealed that the bacterial community was predominantly composed of members of the Firmicutes phylum, distributed across several genera with varying relative abundances. The genus-level bar plot Fig 4.9 indicates that *Clostridium* was the most dominant genus, accounting for the majority of the total bacterial reads. Members of this genus are well known for their versatile metabolic activities, including fermentation, cellulose degradation, and production of organic acids, which

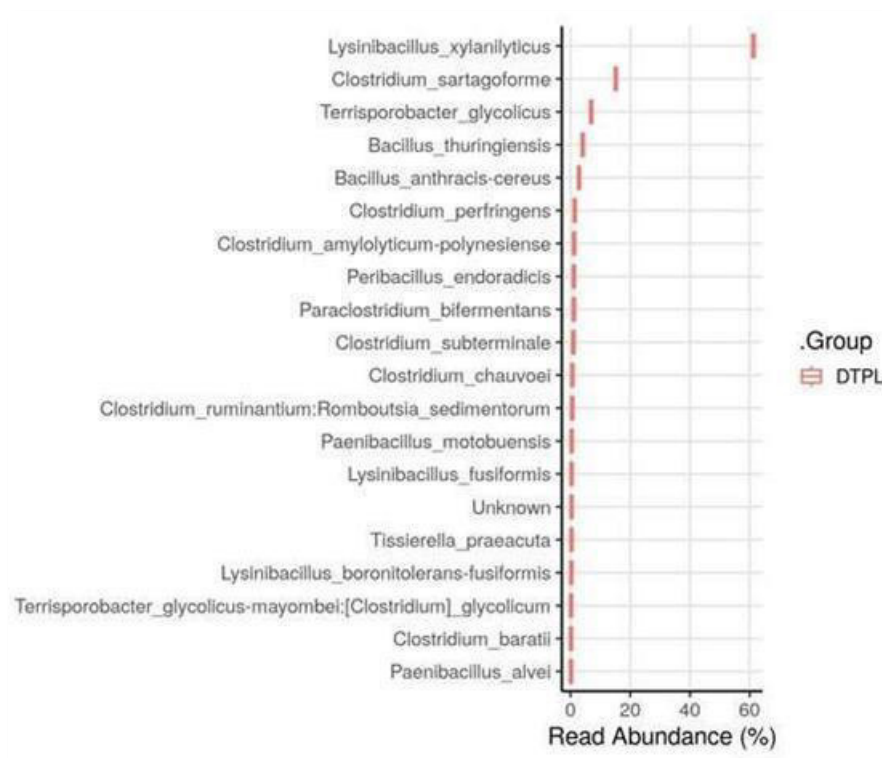
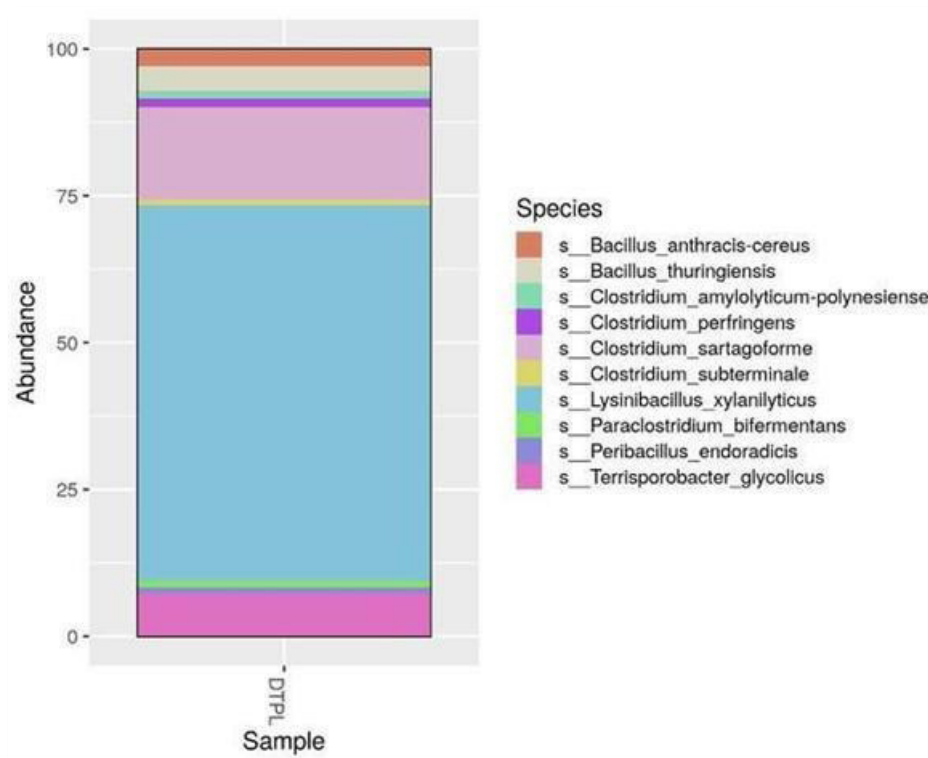


Fig 4.8 Taxonomic composition and relative abundance at the species level

contribute significantly to the turnover of soil organic matter and maintenance of rhizosphere nutrient dynamics (Li *et al.*, 2020).

The second most abundant genus observed was *Lysinibacillus*, followed closely by *Bacillus* and *Terrisporobacter*. These genera are commonly associated with plant growth-promoting rhizobacteria (PGPR) known to enhance plant health through phosphate solubilization, production of indole-3-acetic acid (IAA), siderophores, and various extracellular enzymes (Compant *et al.*, 2005; Bhattacharyya and Jha, 2012). The abundance of *Lysinibacillus* and *Bacillus* suggests that the Khasi mandarin rhizosphere harbors beneficial bacterial communities capable of promoting root growth and suppressing phytopathogens through antagonistic metabolites.

Minor but ecologically relevant genera such as *Paraclostridium*, *Paenibacillus*, *Peribacillus*, and *Tissierella* were also detected at lower relative abundances. *Paenibacillus* species, in particular, are known to fix atmospheric nitrogen and produce hydrolytic enzymes, enhancing soil fertility and organic matter decomposition (Grady *et al.*, 2016). The occurrence of *Paraclostridium* and *Tissierella* may reflect the presence of facultatively anaerobic microhabitats within the rhizosphere, which support diverse metabolic processes under variable oxygen levels.

The combined presence of aerobic (e.g., *Bacillus*, *Lysinibacillus*) and anaerobic (e.g., *Clostridium*, *Paraclostridium*) taxa demonstrates a complex and functionally redundant microbial network, suggesting that the Khasi mandarin rhizosphere supports a dynamic equilibrium of microbial guilds that cooperate in nutrient transformation and plant–microbe interactions. Such taxonomic diversity contributes to enhanced soil resilience and ecosystem stability, as also reported by Mendes *et al.* (2011) and Berendsen *et al.* (2012) in citrus and other perennial crops.

Overall, the dominance of beneficial genera such as *Clostridium*, *Lysinibacillus*, and *Bacillus* highlights a microbiome structure favorable for plant growth and soil nutrient cycling. This microbial composition aligns with the

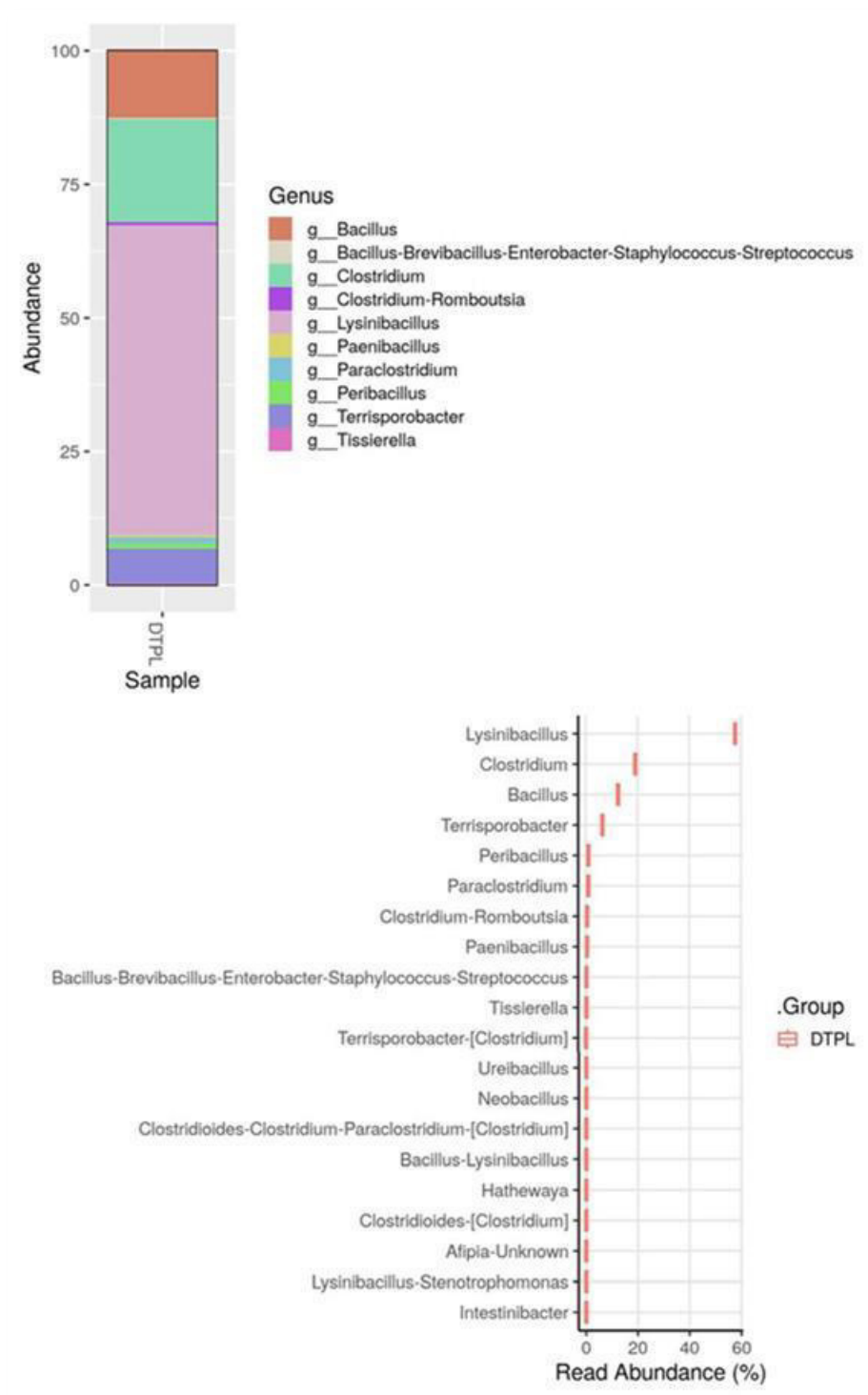


Fig 4.9 Taxonomic composition and relative abundance at the genus level

functional requirements of a healthy rhizosphere ecosystem, reinforcing the role of microbial diversity in sustaining Khasi mandarin productivity under organic or biologically enriched soil management systems.

4.2.5 Taxonomic composition and relative abundance at the phylum level

The phylum-level analysis of the 16S rRNA metagenomic data from the Khasi mandarin rhizosphere (sample DTPL) demonstrated a clear dominance of Firmicutes, which constituted the major portion of the bacterial community as indicated in Fig 4.10. Members of this phylum are well recognized for their physiological versatility and resilience under variable soil conditions. They include numerous genera such as *Clostridium*, *Bacillus*, and *Lysinibacillus*, which are capable of forming endospores and surviving environmental stress. The predominance of *Firmicutes* indicates that the rhizosphere environment supports a microbiome adapted to fluctuating nutrient and moisture conditions, typical of field soils in subtropical regions.

The second most represented group was the Proteobacteria, followed by Actinobacteria and Bacteroidetes, which were detected in lower proportions. Proteobacteria are often associated with rhizosphere competence and active participation in nutrient cycling, including nitrogen fixation and sulfur oxidation. Actinobacteria, though less abundant, play vital roles in the degradation of complex organic matter and production of antibiotics that suppress soil-borne pathogens (Ventura *et al.*, 2007). Bacteroidetes are known for their involvement in the breakdown of polysaccharides and other plant-derived organic compounds, supporting overall soil fertility.

The overwhelming dominance of Firmicutes suggests that the Khasi mandarin rhizosphere is enriched with metabolically diverse, spore-forming bacterial communities that can contribute to long-term soil stability and plant health. This pattern aligns with earlier reports by Mishra *et al.* (2019) and Saha *et al.* (2021), who observed Firmicutes as the predominant phylum in citrus rhizosphere soils due to their roles in organic matter turnover and tolerance to fluctuating oxygen conditions.

The coexistence of both aerobic and anaerobic phyla further indicates a heterogeneous rhizosphere environment with microzones of varying redox potential, supporting broad microbial functionality. Such diversity is essential for balanced nutrient mobilization and enzymatic activities critical to root growth and soil productivity.

Overall, the phylum-level microbial composition reflects a functionally rich and ecologically balanced microbial community in the Khasi mandarin rhizosphere, dominated by Firmicutes but complemented by Proteobacteria, Actinobacteria, and Bacteroidetes. This taxonomic structure underscores the capacity of the soil microbial assemblage to maintain nutrient availability, suppress pathogens, and enhance plant vigor—hallmarks of a biologically active and sustainable citrus rhizosphere ecosystem.

The metagenomic profiling of the Khasi mandarin rhizosphere (sample DTPL) provided a comprehensive overview of the microbial community structure at multiple taxonomic levels. The predominance of the Firmicutes phylum across all levels of classification underscores the dominance of spore-forming, metabolically versatile bacteria that thrive under diverse soil and climatic conditions. Within this group, the genera *Clostridium*, *Lysinibacillus*, and *Bacillus* emerged as the most abundant, reflecting a microbiome rich in plant growth-promoting and nutrient-cycling organisms. These taxa are known to participate in critical soil functions, including decomposition of organic matter, nitrogen transformation, phosphate solubilization, and production of secondary metabolites that enhance plant health and disease resistance.

At the species level, *Clostridium sartagoforme*, *Clostridium perfringens*, and *Terrisporobacter glycolicus* were particularly prominent, suggesting active involvement in anaerobic organic matter degradation and release of beneficial metabolites within the rhizosphere. The consistent presence of beneficial *Bacillus* species such as *B. thuringiensis* further indicates the potential of the Khasi mandarin rhizosphere microbiome to contribute to biological control of soil-borne pathogens and to promote root growth through the synthesis of plant-stimulatory compounds.

The coexistence of both aerobic (e.g., *Bacillus*, *Lysinibacillus*) and anaerobic (e.g., *Clostridium*, *Paraclostridium*) bacterial groups reflects the formation of micro-niches within the rhizosphere, each supporting specialized microbial processes. This balance between functional guilds promotes nutrient mineralization, microbial resilience, and soil structural stability. The overall taxonomic profile thus indicates a functionally diverse, ecologically balanced, and biologically active microbial ecosystem that supports the health and productivity of Khasi mandarin plants.

These findings corroborate earlier studies by Mendes *et al.* (2011), Ventura *et al.* (2007), and Saha *et al.* (2021), which emphasized the importance of Firmicutes- and Proteobacteria-dominated communities in maintaining soil fertility and plant-microbe symbiosis in citrus rhizospheres. Collectively, the results confirm that the Khasi mandarin rhizosphere hosts a rich consortium of beneficial microorganisms with potential roles in nutrient mobilization, plant growth promotion, and suppression of phytopathogens—key indicators of a sustainable and biologically vibrant soil ecosystem.

4.2.6 Rarefaction and Alpha Diversity Analysis

The rarefaction analysis as indicated in Fig 4.11 revealed a clear trend toward saturation, indicating that the sequencing depth was sufficient to capture the majority of microbial taxa present in the rhizosphere sample. The flattening of the rarefaction curve signifies that most of the microbial species had been detected and that further sequencing would contribute only a minimal increase in operational taxonomic units (OTUs) or amplicon sequence variants (ASVs). This suggests that the microbial community was adequately represented and that the sequencing coverage was sufficient for robust diversity estimation. Similar observations were reported by Caporaso *et al.* (2010) and Kuczynski *et al.* (2012), who noted that a plateau in the rarefaction curve indicates comprehensive sampling of microbial richness in environmental samples.

Complementing this observation, the alpha diversity indices as indicated in Fig 4.12, particularly the Shannon and Simpson measures, further characterized the

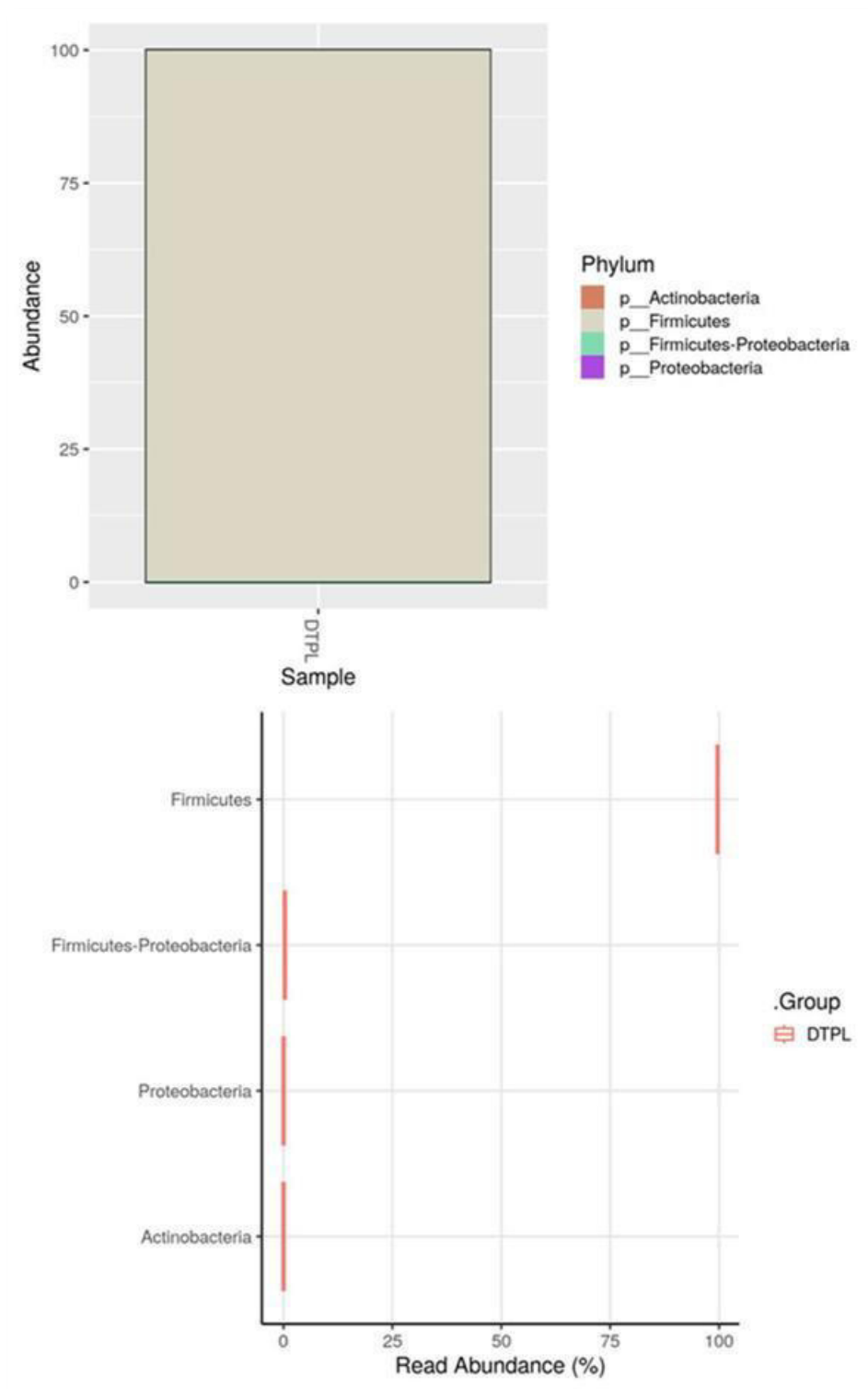


Fig 4.10 Taxonomic composition and relative abundance at the phylum level

community structure within the Khasi mandarin rhizosphere. The Shannon index, which accounts for both species richness and evenness, reflected a high diversity value, indicating the presence of a wide array of bacterial taxa distributed relatively evenly across the community. Conversely, the Simpson index, which emphasizes the dominance of abundant species, exhibited comparatively lower values, confirming that no single taxon overwhelmingly dominated the population. This balance between richness and evenness reflects a stable and functionally diverse microbial community capable of supporting nutrient cycling and plant growth processes.

The combined interpretation of rarefaction and alpha diversity metrics suggests that the microbial assemblage associated with the Khasi mandarin rhizosphere is taxonomically diverse and ecologically balanced. Such diversity is often associated with enhanced soil health, nutrient mobilization, and disease suppression (Nannipieri *et al.*, 2003; Mendes *et al.*, 2011). The adequate sequencing coverage confirmed by the rarefaction curve strengthens the reliability of downstream taxonomic and functional analyses. Therefore, it can be inferred that the microbial community structure observed in this study accurately represents the *in situ* diversity and ecological potential of the Khasi mandarin rhizosphere.

4.3 Studies with organic inputs and microbial consortium

4.3.1 Tree height (m)

Table 4.5 and Fig 4.13 shows the height of tree in standing orchard as influenced by the various treatments in the first and second year of investigation and the pooled data. A close scrutiny of the table reveals that there was significant variation in tree height amongst the treatments. The greatest height (0.085m) which was significantly greatest was recorded in T₂ treatment followed by T₁₀ (0.074). In the second year T₂ and T₁₀ showed significantly greatest height (0.140 m) of trees. The shortest height (.042 and 0.089 m) in both years was observed with treatment T₅.

The superior performance of treatments involving microbial consortium (T₂ and T₁₀) can be attributed to their ability to enhance nutrient mobilization, nitrogen fixation, phosphate solubilization, and production of phytohormones such as indole acetic acid and gibberellins, which promote vegetative growth (Verma *et al.*, 2014)

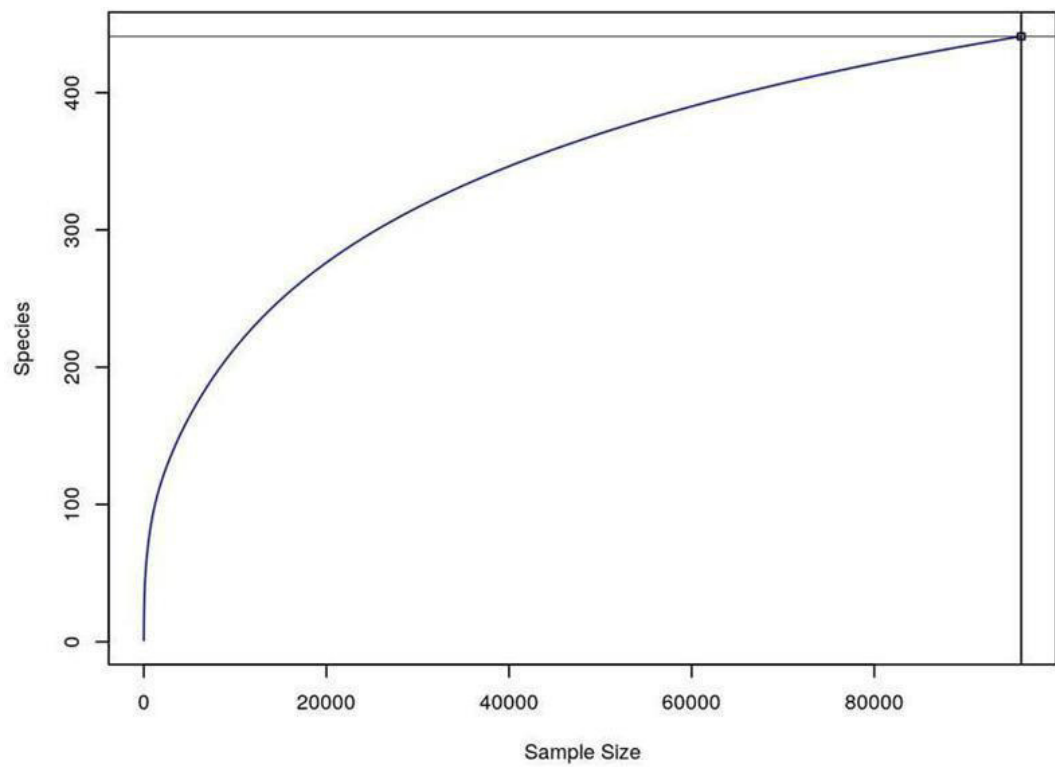


Fig 4.11 Rarefaction curve to estimate the species richness in the sample

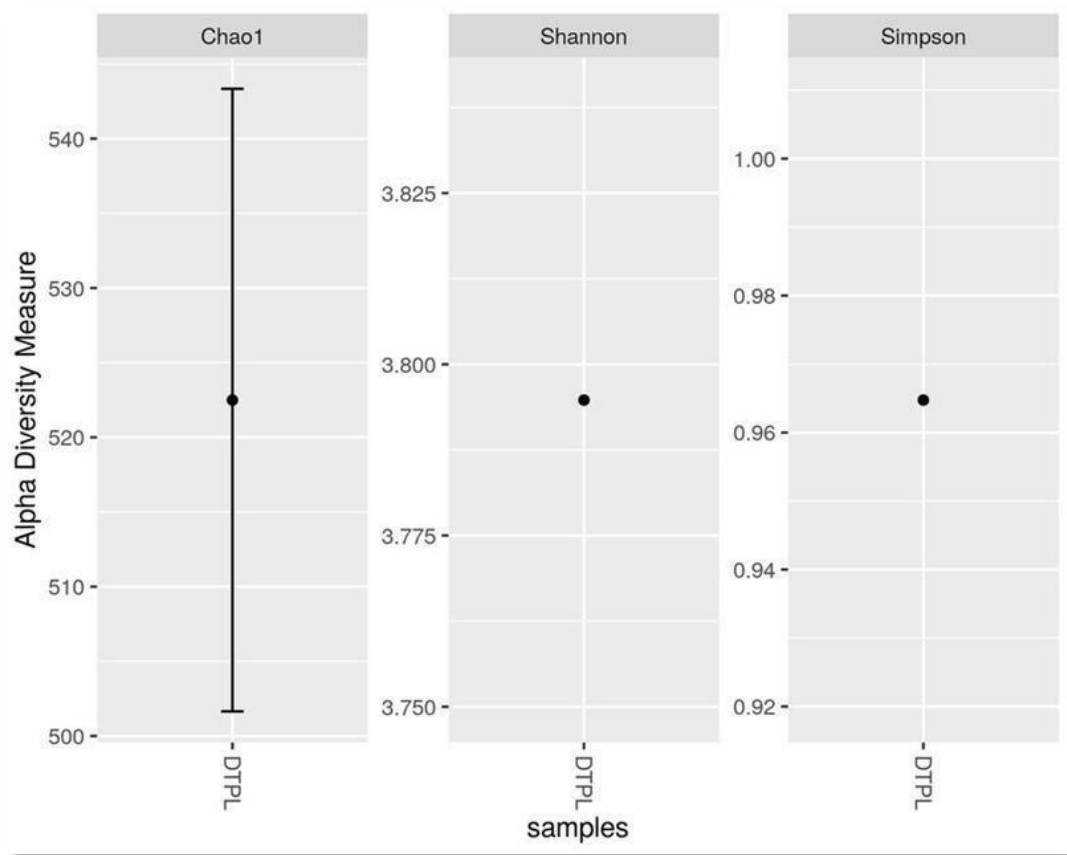


Fig 4.12 Alpha diversity analysis to estimate the richness of the community in the sample

vermicompost (T₁₀) further improves soil structure, aeration, and nutrient status, thereby creating favorable conditions for root activity and canopy growth (Arancon *et al.*, 2004). This synergistic effect explains the consistently greater increments in tree height in treatments supplemented with microbial consortium. These findings are in agreement with Dutta *et al.* (2016), who reported that integrated nutrient management practices significantly improved vegetative growth parameters, including tree height in Khasi mandarin. Similar results were observed by Singh *et al.* (2020), who noted that the use of microbial inoculants in combination with organic manures enhanced tree growth and vigour. Rana *et al.* (2020) also confirmed that vermicompost application, when combined with microbial biofertilizers, contributed to better tree height and overall growth in sweet orange. The observations of the present investigation suggest that incorporation of microbial consortium, either alone or with conventional practices (T₂) or in combination with vermicompost (T₁₀), significantly enhanced tree height in Khasi mandarin.

4.3.2 Tree spread (m)

Table 4.5 and Fig 4.14 shows the tree spread in standing orchard as influenced by the various treatments in the first and second year of investigation and the pooled data. A close scrutiny of the table reveals significant variation on the canopy spread of Khasi mandarin trees in both East–West (E–W) and North–South (N–S) directions amongst the treatments. In the first year, maximum increment in canopy spread was recorded in T₁₀ and T₂ with 0.116 m (E–W) and 0.086 m (N–S), respectively. In the second year, a similar trend was observed, with the maximum increments again in T₁₀ (0.203 m E–W) and T₂ (0.170 m N–S). When the data were pooled over both years, maximum increment in tree spread in both directions was consistently recorded in T₁₀ (0.159 m E–W) and T₂ (0.104 m N–S), whereas the minimum increments were observed in T₅ (0.122 m) in the E–W direction and T₇ (0.104 m) in the N–S direction.

The enhanced tree spread under T₁₀ and T₂ treatments can be attributed to the synergistic effect of vermicompost and microbial consortium. Vermicompost provides a steady release of nutrients, improves soil structure, and enhances microbial activity, while the microbial consortium promotes nutrient mobilization, root

proliferation, and phytohormone production, leading to better vegetative growth (Arancon *et al.*, 2004; Verma *et al.*, 2014). This results in an expanded canopy spread, which in turn supports greater photosynthetic activity and higher assimilate production. Similar findings were reported by Dutta *et al.* (2016), who observed that integrated nutrient management significantly improved canopy spread in Khasi mandarin. Singh *et al.* (2020) also highlighted that the combined application of organic manures and microbial inoculants enhanced canopy spread in citrus. Rana *et al.* (2020) further reported that vermicompost, when applied with biofertilizers, resulted in better canopy development in sweet orange compared to sole applications of organic or inorganic inputs

4.3.3 Canopy volume (m³)

Table 4.5 and Fig 4.15 shows the canopy volume of Khasi mandarin trees in standing orchard as influenced by the various treatments in the first and second year of investigation and the pooled data. A close scrutiny of the table reveals that there was significant variation in canopy volume amongst the treatments. During the first year, the maximum canopy volume was recorded in T₁₀ with 9.10 m³, whereas the minimum increment was observed in T₅ with 7.320 m³. A similar trend was observed in the second year, with T₁₀ again producing the maximum canopy volume (17.548 m³) and T₅ with the minimum increment (14.213 m³). When the data were pooled over both years, the highest canopy volume was consistently obtained under T₁₀ (13.324 m³), while the lowest pooled mean (10.766 m³) was recorded in T₅.

The superiority of T₁₀ can be attributed to the combined effects of vermicompost and microbial consortium, which improve soil fertility, structure, and microbial activity, leading to enhanced nutrient uptake and vegetative growth. Vermicompost not only supplies readily available nutrients but also improves cation exchange capacity and water-holding ability of soil, supporting sustained canopy expansion (Arancon *et al.*, 2004). Meanwhile, microbial inoculants enhance nutrient mobilization and produce growth-promoting substances, thereby stimulating root development and canopy growth (Verma *et al.*, 2014). This synergistic effect likely explains the significantly larger canopy volume in T₁₀.

4.3.4 Stem girth (cm)

Table 4.5 and Fig 4.16 shows the stem girth of Khasi mandarin trees in standing orchard as influenced by the various treatments in the first and second year of investigation and the pooled data. A close scrutiny of the table reveals that there was significant variation in stem girth amongst the treatments. During the first year, the maximum stem girth was recorded in T₅ with 1.173 cm. In the second year, however, the highest increment was obtained in T₂ with 2.255 cm. When the data were pooled over both years, T₂ consistently showed the maximum mean stem girth increment (1.704 cm), while the minimum pooled mean (1.576 cm) was observed in T₃.

The superior performance of T₂ may be attributed to the beneficial effects of microbial consortium in enhancing root growth and nutrient mobilization. Microbial inoculants improve nutrient solubilization, particularly nitrogen and phosphorus, and produce phytohormones like indole-3-acetic acid (IAA), which stimulate cell elongation and secondary growth processes, thereby contributing to stem girth increment (Verma *et al.*, 2014). Similarly, the organic amendments in T₅ supplied ample nutrients and organic matter, which initially supported better girth increment in the first year. However, the sustained effect of microbial inoculants in T₂ contributed to consistently higher stem girth over the years

4.3.5 Number of flowers per metre shoots length

Table 4.6 shows the number of flowers per metre shoot length of Khasi mandarin trees in standing orchard as influenced by the various treatments in the first and second year of investigation and the pooled data. A close scrutiny of the table reveals that there was significant variation amongst the treatments. In the first year maximum flower intensity was observed in T₂ (32.70) followed by T₈ (31.90) and minimum flower intensity was observed in T₅ (28.90). In the second year maximum flower intensity was again observed in T₂ (34.13) followed by T₈ (33.44). The pooled data clearly indicated maximum flower intensity in T₂ (33.42), which was significantly superior to all other treatments, followed by T₈ (32.67) and the minimum flower intensity was observed in T₅ (29.63). The higher values in T₂ and T₈

Table 4.5 Effect of microbial consortium along with organic amendment on plant growth characteristics of Khasi mandarin

	Tree height (m)			Tree spread (m)						Canopy volume(m ³)			Stem girth (cm)		
				East-West			North-South								
Treatments	2023	2024	Pooled	2023	2024	Pooled	2023	2024	Pooled	2023	2024	Pooled	2023	2024	Pooled
T ₁	0.045	0.100	0.072	0.100	0.180	0.140	0.080	0.160	0.120	7.650	14.663	11.156	1.091	2.105	1.600
T ₂	0.085	0.140	0.112	0.110	0.200	0.155	0.086	0.170	0.128	8.450	16.053	12.251	1.154	2.255	1.704
T ₃	0.068	0.120	0.094	0.091	0.160	0.125	0.075	0.149	0.112	8.541	16.263	12.402	1.057	2.095	1.576
T ₄	0.061	0.127	0.094	0.094	0.179	0.136	0.084	0.159	0.121	8.050	15.203	11.626	1.102	2.148	1.598
T ₅	0.042	0.089	0.065	0.088	0.160	0.122	0.075	0.140	0.107	7.320	14.213	10.766	1.173	2.193	1.625
T ₆	0.054	0.095	0.074	0.080	0.165	0.124	0.082	0.155	0.118	8.655	17.105	12.880	1.144	2.215	1.683
T ₇	0.061	0.100	0.080	0.084	0.170	0.127	0.069	0.139	0.104	7.650	14.895	11.272	1.093	2.153	1.679
T ₈	0.056	0.109	0.082	0.091	0.176	0.133	0.077	0.140	0.108	8.811	17.253	13.032	1.102	2.205	1.623
T ₉	0.068	0.130	0.099	0.092	0.190	0.141	0.084	0.150	0.117	8.350	15.975	12.162	1.120	2.115	1.617
T ₁₀	0.074	0.140	0.107	0.116	0.203	0.159	0.082	0.159	0.120	9.100	17.548	13.324	1.080	2.185	1.653
S Em±	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.002	0.001	0.120	0.140	0.150	0.020	0.017	0.025
CD at 5%	0.003	0.003	0.003	0.004	0.004	0.004	0.003	0.004	0.005	0.360	0.410	0.433	0.050	0.050	0.073

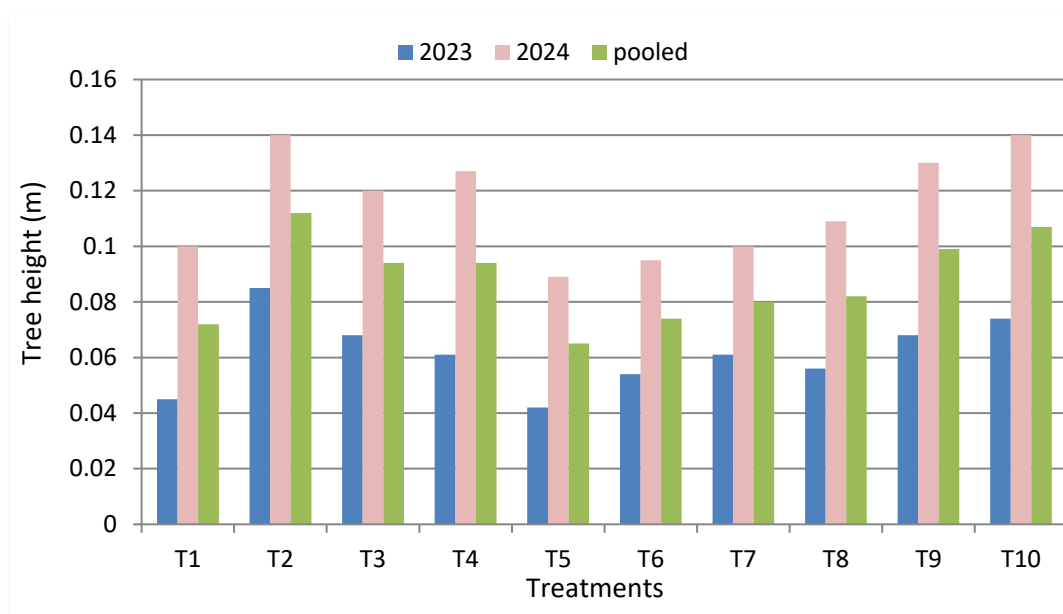


Fig 4.13 Tree height (m) of Khasi mandarin as influenced by organic inputs and microbial consortium

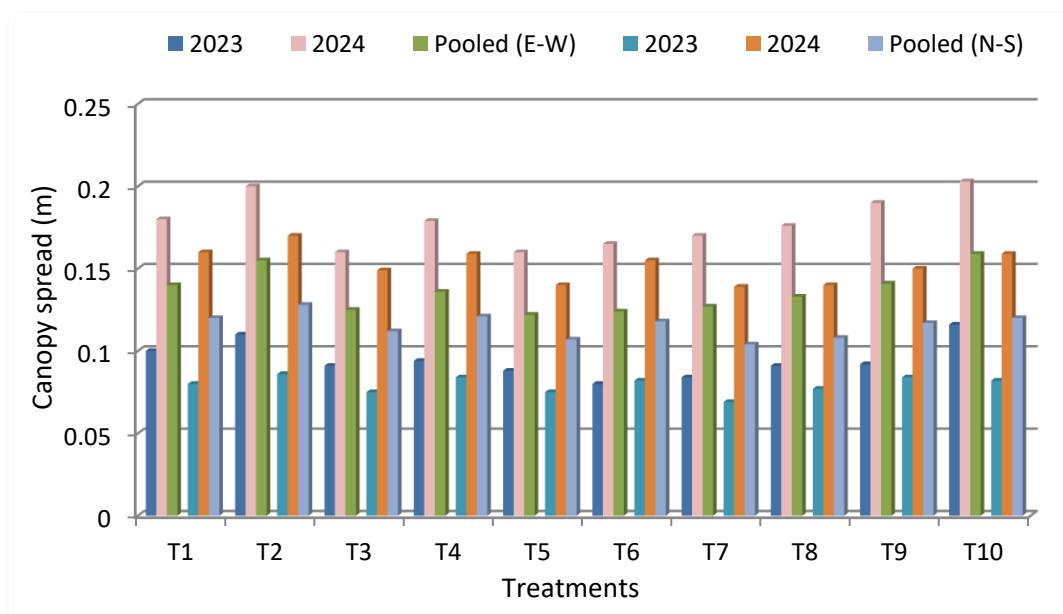


Fig 4.14 Effect of microbial consortium and organic inputs on canopy spread (m) of Khasi mandarin

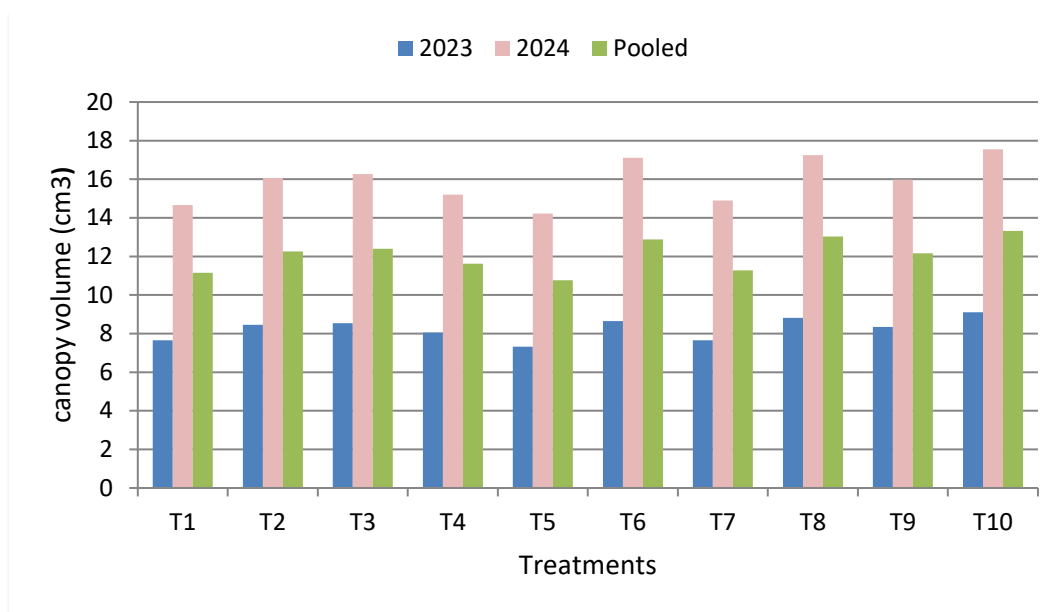


Fig 4.15 Influence of microbial consortium and organic inputs on canopy volume (m³) of Khasi mandarin

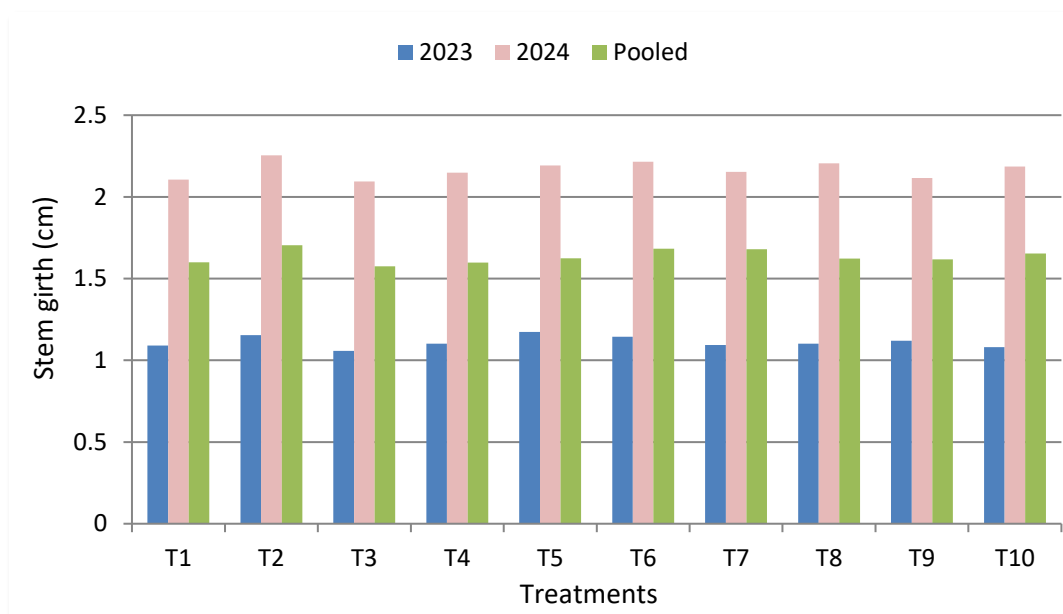


Fig 4.16 Effect of microbial consortium and organic amendments on stem girth (cm) of Khasi mandarin

may be attributed to improved nutrient uptake which favoured floral initiation and enhanced flowering. Conversely, T₅ produced fewer flowers, indicating restricted growth and poor reproductive development.

The higher flower intensity in T₂ aligns with reports where microbial consortium enhanced nutrient mobilization, root health and reproductive efficiency in citrus (Chekeet *et al.*, 2024; Srivastava, 2021). Combined organic–microbial treatments also improved flowering compared to organic manure alone, consistent with findings from integrated nutrient management studies in Nagpur mandarin (Bhosale *et al.*, 2015; Srivastava, 2021). By contrast, poultry manure alone (T₅) resulted in lower flower intensity, which is in agreement with observations that high N input from poultry manure favours vegetative vigour at the expense of floral initiation (Eissa *et al.*, 2016; Fikry *et al.*, 2022; Ngoc *et al.*, 2021). These responses may be explained by the physiological framework where nutrient status, carbohydrate partitioning and hormonal signals regulate floral initiation in citrus (Agustí *et al.*, 2022).

4.3.6 Initial fruit set per metre shoot length

Table 4.6 and Fig 4.17 shows the initial fruit set per metre shoot length of Khasi mandarin trees in standing orchard as influenced by the various treatments in the first and second year of investigation and the pooled data. A close scrutiny of the table reveals that there was significant variation amongst the treatments. In the first year maximum initiation of fruit set was under the treatment T₂ (8.30) followed by T₄ (7.95). In the second year and when averaged over the years treatment T₂ was again followed by T₄ with initial fruit set of 8.18 and 8.07 respectively. During both the years and when pooled over the years, least number of 6.60, 6.85 and 6.73 initial fruit set was observed in treatment T₁.

The field studies and reviews showed that microbial consortium and combined organic + biofertilizer modules improved nutrient availability, root health and reproductive partitioning in citrus, thereby increasing fruit set and yield compared with conventional practice.

4.3.7 Fruit set per metre shoot length

Table 4.6 and Fig 4.18 shows the final fruit set per metre shoot length of Khasi mandarin trees in standing orchard as influenced by the various treatments in the first and second year of investigation and the pooled data. A close scrutiny of the table reveals that there was significant variation amongst the treatments. In the first year of experiment, highest of 3.09 fruits was found under treatment T₂ followed by T₄ with 2.90 fruits. During the second year of investigation and when the data was pooled over the years again, highest final fruit set of 3.70 fruits and 3.40 fruits was observed under treatment T₂ followed by 3.53 fruits and 3.22 fruits with treatment T₄ respectively. Lowest fruit set of 2.44, 3.11 and 2.78 fruits were found under treatment T₅ during the first year, second year and when pooled over the years respectively.

These findings are supported by field research showing that application of microbial consortium significantly improves fruit yield and quality in citrus compared to conventional practices. Integrated fertilization strategies combining microbial inoculants with organic amendments further enhance fruit characteristics through improved rhizosphere health and nutrient availability. Conversely, while poultry manure alone can improve soil quality over time, its application does not necessarily enhance reproductive parameters such as fruit set possibly due to imbalanced nutrient dynamics favouring vegetative growth over fruit development. A long-term study in pomelo orchards showed that poultry manure improved soil quality but did not necessarily boost reproductive output suggesting a possible trade-off in fruit set, consistent with your observation of lower final fruit set under T₅.

4.3.8 Fruit drop per tree (%)

Table 4.6 shows the fruit drop of Khasi mandarin trees in standing orchard as influenced by the various treatments in the first and second year of investigation and the pooled data. A close scrutiny of the table reveals that there was significant variation amongst the treatments. Among the treatments, highest fruit drop was observed in treatment T₆ (63.66%) in the first year. In the second year T₄ (62.94 %) had the highest fruit drop and when pooled over the years T₆ (63. 28 %) showed the highest fruit drop. Lowest fruit drop per tree was observed in treatment T₉ during first year, second year and when pooled over the years with 61.07 %, 60.41 %, and 60.74

% respectively. Fruit drop in citrus is governed by a complex interaction of carbohydrate, nutrient balance, and hormonal regulation of abscission. The significantly higher fruit drop observed under poultry manure + microbial consortium (T₆) and FYM + microbial consortium (T₄) can be partly attributed to their effect on nitrogen release dynamics. Poultry manure and FYM are relatively rich in available nitrogen, which promotes vigorous vegetative growth. Excessive vegetative sink strength can divert assimilates away from developing fruitlets, leading to carbohydrate competition and the abscission of weaker fruits. This aligns with earlier reports that high nitrogen availability often reduces fruit retention in citrus by stimulating vegetative growth at the expense of reproductive organs (Agustí and Almela, 1991; Agustí *et al.*, 2022).

Carbohydrate partitioning plays a central role in fruit set and retention. Fruitlets act as strong sinks, but their retention depends on adequate carbohydrate supply from photosynthesis. When nutrient treatments stimulate high initial fruit set, the demand for assimilates often exceeds supply, triggering selective abscission of weaker fruitlets. Srivastava and Singh (2008) emphasized that sink-source imbalances under nutrient-rich conditions are a key cause of citrus fruit abscission. Hormonal control of abscission further explains the variation among treatments. Developing seeds and fruitlets are a major source of auxins and gibberellins, which suppress the formation of the abscission layer at the fruit–pedicel junction. When carbohydrate stress or excess vegetative growth reduces hormone flow, ethylene synthesis is enhanced, which accelerates abscission. Studies on citrus and other fruit crops indicate that treatments improving soil organic matter and root microbial activity, such as vermicompost (T₉), can stabilize auxin-to-ethylene ratios, reduce oxidative stress, and enhance fruit retention (Arancon *et al.*, 2004; Ngoc *et al.*, 2021).

Thus, the lower fruit drop under vermicompost application (T₉) may be explained by its slow nutrient release, balanced N supply, and improvement of soil structure, which together sustain a steady source of carbohydrates and maintain hormonal balance conducive to fruit retention.

Table 4.6 Effect of microbial consortium with organic amendments on number of flowering characteristics of Khasi mandarin

	Flower numbers			Fruit set(initial)			Fruit set (final)			Fruit drop/tree (%)		
Treatments	2023	2024	Pooled	2023	2024	Pooled	2023	2024	Pooled	2023	2024	Pooled
T ₁	30.40	31.9	31.15	6.60	6.85	6.73	2.50	3.15	2.83	62.12	61.47	61.80
T ₂	32.70	34.13	33.42	8.30	8.53	8.42	3.09	3.70	3.40	62.65	62.02	62.34
T ₃	29.50	30.52	30.01	6.94	7.19	7.07	2.60	3.21	2.91	62.53	61.86	62.20
T ₄	30.10	31.6	30.85	7.95	8.18	8.07	2.90	3.53	3.22	63.56	62.94	63.25
T ₅	28.90	30.35	29.63	6.68	6.94	6.81	2.44	3.11	2.78	63.47	62.84	63.16
T ₆	31.50	33.05	32.28	6.88	7.10	6.99	2.50	3.15	2.83	63.66	62.90	63.28
T ₇	29.70	31.05	30.38	6.69	6.94	6.82	2.54	3.19	2.87	62.08	61.41	61.75
T ₈	31.90	33.44	32.67	6.84	7.06	6.95	2.62	3.26	2.94	61.68	60.90	61.29
T ₉	29.70	31.26	30.48	7.04	7.30	7.17	2.74	3.36	3.05	61.07	60.41	60.74
T ₁₀	30.19	31.69	30.94	7.46	7.69	7.58	2.81	3.52	3.17	62.19	61.51	61.85
SEm±	0.26	0.46	0.30	0.07	0.09	0.12	0.03	0.05	0.05	0.59	0.89	0.65
CD at 5%	0.74	1.33	0.87	0.21	0.27	0.34	0.08	0.14	0.13	1.68	2.56	1.88

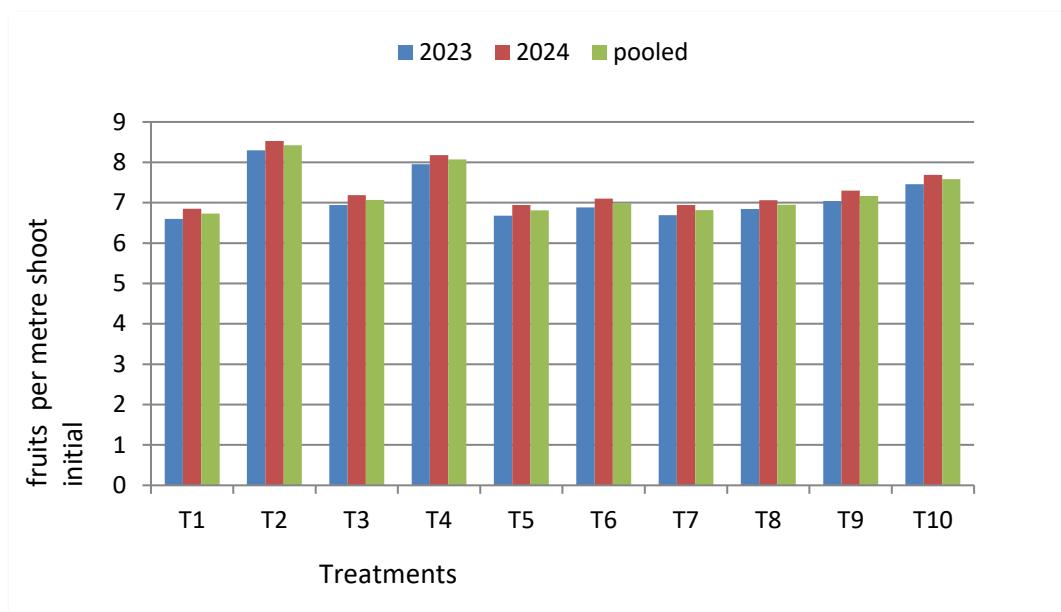


Fig 4.17 Influence of microbial consortium and organic amendments on fruit set per metre shoot of Khasi mandarin

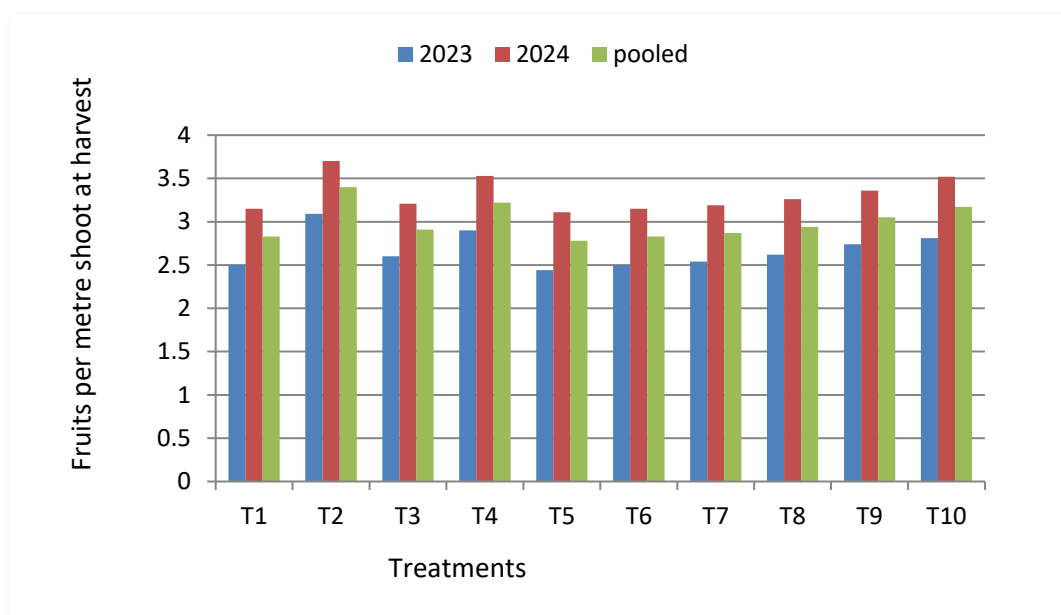


Fig 4.18 Effect of organic amendments and microbial consortium on number of fruits per metre shoots at harvest



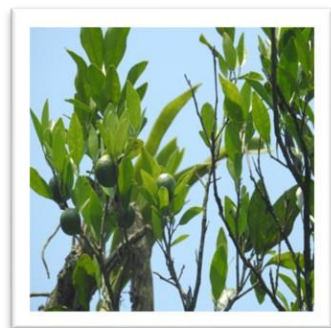
Full broom



Fruit set



Stage I



June Drop



Stage II beginning of colour break



Stage III (colour break)

Plate 4.2 Flowering and fruit development stages of Khasi Mandarin

4.3.9 Fruits per tree at harvest

Table 4.7 and Fig 4.19 showed the fruits per tree at harvest of Khasi mandarin trees in standing orchard as influenced by the various treatments in the first and second year of investigation and the pooled data. A close scrutiny of the table reveals that there was significant variation amongst the treatments. Maximum number of 100.12 fruits per tree during the first year was observed under treatment T₄. In the second year maximum number of 142.10 fruits was recorded in treatment T₁₀. The data when pooled over the year's maximum was observed in T₁₀ with 120.80 fruits. Minimum number of 86.24 fruits during the first year, 126.88 fruits during second year and 106.87 fruits when the data was pooled over the years was obtained in trees under treatment T₁, T₅ and T₁ respectively.

The enhanced fruit number under the treatments particularly those combining organic manures with microbial consortium can be ascribed to multiple agronomic and physiological benefits. Organic amendments like FYM and vermicompost improve soil structure, organic matter content, water-holding capacity, and macro- and micronutrient availability, contributing to improved tree vigour and fruit set (Lakkineni and Abrol, 1994; Kumar *et al.*, 2013). Vermicompost, in particular, is a nutrient-rich organic amendment that enhances soil aeration, microbial activity, and plant growth (Blouin *et al.*, 2019). The role of microbial consortium is equally vital. These beneficial microbes enhance nutrient uptake, stimulate root growth, and can induce systemic resistance in plant. Integrating manure with microbial inoculants leads to synergistic effects: improved soil fertility, enhanced microbial dynamics, and better physiological performance, thereby reinforcing yield components such as fruit number and quality (Rana *et al.*, 2020; Ennab, 2016a). Thus, the findings corroborate the efficacy of integrated nutrient management (INM) particularly the combination of organic manures and microbial inoculants for optimizing fruit yield in citrus. Specifically, treatments involving vermicompost or FYM plus microbial consortium significantly outperformed conventional practices, both individually and in pooled analysis, confirming their agronomic relevance and potential for sustainable citrus production.

4.3.10 Yield per tree (kg)

Table 4.7 and Fig 4.20 shows the final yield per tree of Khasi mandarin trees in standing orchard as influenced by the various treatments in the first and second year of investigation and the pooled data. A close scrutiny of the table reveals that there was significant variation amongst the treatments. In the first year of treatment highest yield was observed in treatment T₄ with 9.82 kg per tree. In the second year highest yield was obtained in treatment T₁₀ with 12.79 kg per tree which was found to be significantly at par with treatments T₂, T₆, T₈ and T₉. The data when pooled over the years, the highest was found to be T₁₀ with 11.10 kg per tree which was significantly at par with treatments T₄, T₈, and T₉. Minimum number of 8.08 kg per tree during the first year, 11.42 kg per tree during second year and 9.78 kg per tree when the data was pooled over the years was obtained in trees under treatment T₁, T₅ and T₁ respectively. The superior performance of FYM and vermicompost in combination with microbial consortium may be attributed to improved soil fertility, balanced nutrient supply, and better physiological efficiency of the plants. FYM is well known for its role in improving soil organic carbon and microbial activity, which contributes to enhanced nutrient uptake and yield in citrus (Lakkineni and Abrol, 1994; Dutta *et al.*, 2016). Vermicompost, being rich in humic substances, readily available nutrients, and beneficial microflora, enhances root growth, nutrient absorption, and photosynthetic efficiency, leading to higher yield (Blouin *et al.*, 2019; Kumar *et al.*, 2019).

The microbial consortium applied along with organic manures appears to have played a synergistic role in enhancing citrus yield. Beneficial microbes such as phosphate solubilizers, nitrogen fixers, and plant growth-promoting rhizobacteria (PGPR) are known to increase nutrient availability, stimulate root development, and improve fruit yield (Verma *et al.*, 2014; Rana *et al.*, 2020). Similar results were reported by Singh *et al.* (2020), who observed that the integration of biofertilizers with organic amendments significantly enhanced yield attributes in Khasi mandarin.

Table 4.7 Effect of microbial consortium with organic amendments on yield characteristics

Treatments	Number of fruits per tree			Yield per tree (kg)		
	2023	2024	Pooled	2023	2024	Pooled
T ₁	86.24	127.5	106.87	8.08	11.48	9.78
T ₂	96.50	136.66	116.58	8.91	12.30	10.61
T ₃	90.75	130.55	110.65	8.52	11.75	10.14
T ₄	100.12	134.77	117.45	9.82	12.13	10.98
T ₅	92.24	126.88	109.56	8.12	11.42	9.77
T ₆	98.50	136.55	117.53	8.94	12.29	10.62
T ₇	94.10	134.67	114.39	8.85	12.12	10.49
T ₈	98.75	139.11	118.93	9.22	12.52	10.87
T ₉	97.50	138.55	118.03	9.17	12.47	10.82
T ₁₀	99.50	142.10	120.80	9.40	12.79	11.10
S Em±	1.03	2.15	2.09	0.07	0.18	0.15
CD at 5%	2.93	6.22	6.05	0.21	0.53	0.44

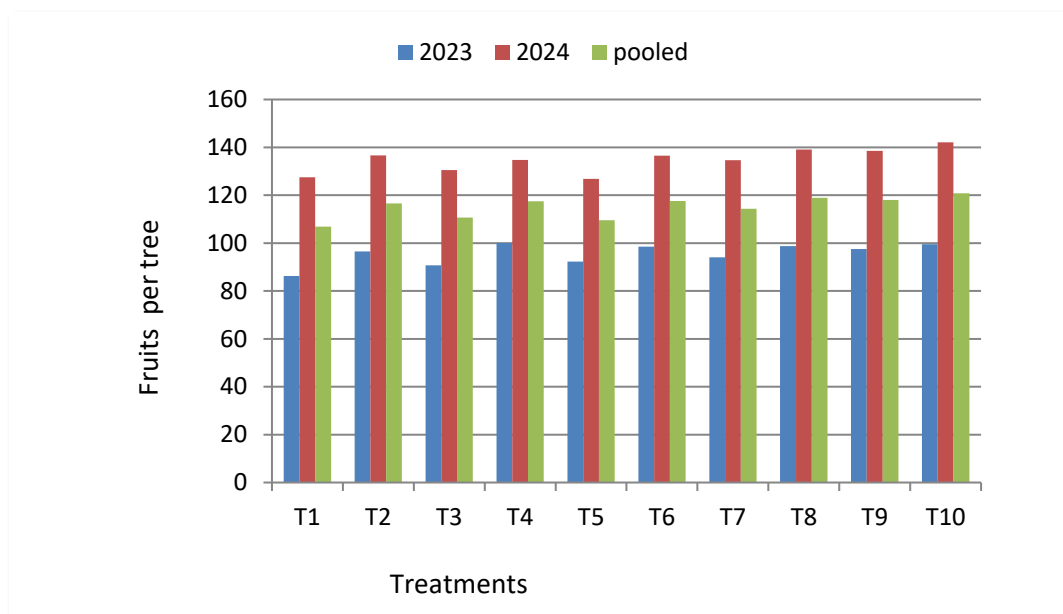


Fig 4.19 Effect of microbial consortium and organic amendments on fruits per tree in Khasi mandarin

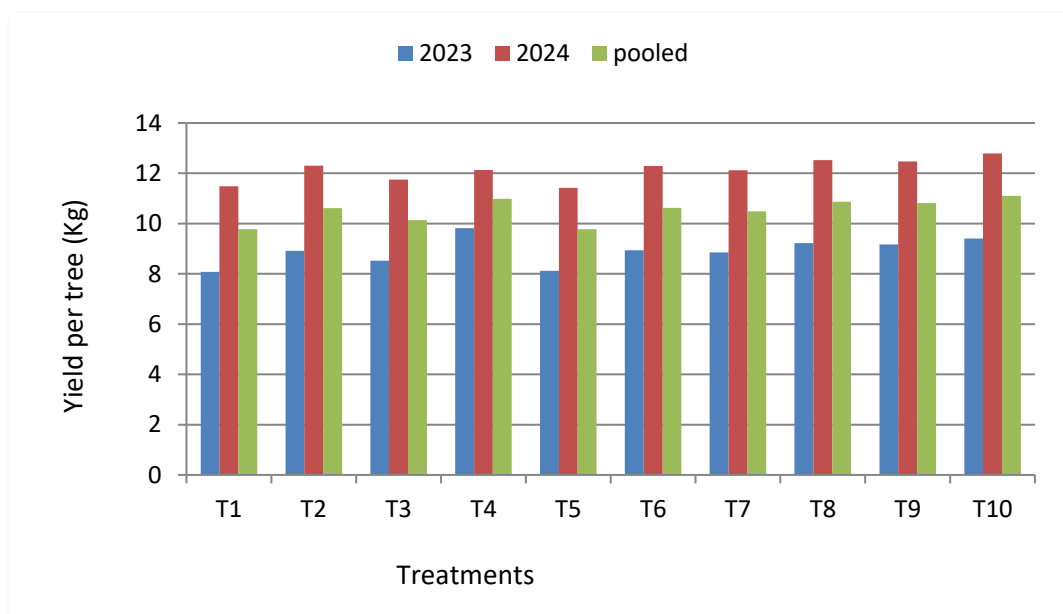


Fig 4.20 Influence of microbial consortium and organic amendments on yield per tree (kg)

4.3.11 Fruit Attributes

4.3.11.1 Fruit weight (g)

Table 4.8 shows the fruit weight of Khasi mandarin fruits as influenced by the various treatments in the first and second year of investigation and the pooled data. A close scrutiny of the table reveals that there was significant variation amongst the treatments. In the first year, the maximum fruit weight (94.82 g) was recorded in T₄, whereas the minimum (84.83 g) was obtained in T₅. A similar trend was observed during the second year, with T₄ again producing the highest fruit weight (94.92 g) and T₅ the lowest (85.01 g). When data were pooled over the two years, T₄ maintained its superiority with the highest fruit weight (94.87 g), while T₅ consistently recorded the lowest pooled mean (84.92 g).

The increase in fruit weight under the FYM treatment supplemented with microbial consortium may be attributed to the continuous and balanced supply of macro- and micronutrients, improvement of soil physical properties, and enhanced microbial activity. FYM enhances soil organic matter content, nutrient availability, and water-holding capacity, which directly contributes to fruit development and final weight (Naik and Babu, 2007). Similarly, the microbial consortium provides growth-promoting substances, improves nutrient uptake through solubilization of phosphorus and mobilization of micronutrients, and facilitates better partitioning of assimilates into the developing fruits (Verma *et al.*, 2014). Dutta *et al.* (2016) observed a marked increase in fruit weight of Khasi mandarin with integrated nutrient management practices compared to sole application of chemical fertilizers. Rana *et al.* (2020) also reported that the combined use of organic manures and biofertilizers improved fruit weight and overall fruit quality in sweet orange. Likewise, Singh *et al.* (2020) found that the application of FYM in combination with microbial consortia increased fruit weight and size in Khasi mandarin, corroborating the present findings.

4.3.11.2 Pulp weight (g)

Table 4.8 shows the pulp weight of Khasi mandarin fruits as influenced by the various treatments in the first and second year of investigation and the pooled data. A close scrutiny of the table reveals that there was significant variation amongst the treatments. In the first year, the highest pulp weight (63.84 g) was recorded in T₄,

while the lowest value (56.75 g) was obtained in T₅. A similar pattern was observed in the second year, with T₄ again producing the maximum pulp weight (64.10 g) and T₅ recording the minimum (56.92 g). When the data were pooled over both years, T₄ maintained its superiority with the maximum pulp weight (63.97 g), followed by T₈ with 63.09 g, while the lowest pooled mean (56.84 g) was observed in T₅.

The increased pulp weight under FYM and pig manure treatments in combination with microbial consortium may be attributed to their ability to enhance soil fertility, microbial biomass, and nutrient availability, thereby promoting efficient assimilate partitioning towards fruit development. FYM improves soil organic matter, aeration, and water-holding capacity, while microbial inoculants enhance nutrient uptake through biological nitrogen fixation, phosphate solubilization, and synthesis of phytohormones, all of which contribute to better pulp formation (Verma *et al.*, 2014). Dutta *et al.* (2016) observed that integrated nutrient management significantly improved pulp weight and edible portion in Khasi mandarin. Likewise, Singh *et al.* (2020) also highlighted that FYM in combination with microbial consortium enhanced pulp content and fruit quality in Khasi mandarin.

4.3.11.3 Pulp and Peel ratio

Table 4.8 shows the pulp and peel ratio of Khasi mandarin fruits as influenced by the various treatments in the first and second year of investigation and the pooled data. A close scrutiny of the table reveals that there was no significant variation amongst the treatments. However, during the first year, the highest pulp and peel ratio (2.06) was recorded in T₄ and T₈, while the lowest ratio (1.99) was observed in T₃. In the second year, a similar trend was recorded with T₄ again producing the maximum ratio (2.07) and T₃ the minimum (2.01). When the data were pooled over two years, T₄ had the maximum pulp and peel ratio (2.07), followed by T₈ and T₁₀ with 2.06, while the minimum pooled ratio (2.00) was again observed in T₃.

The pulp and peel ratio is an important indicator of fruit quality, as a higher ratio reflects a greater proportion of edible pulp relative to peel thickness. Treatments with organic manures in combination with microbial consortium consistently produced higher pulp and peel ratios, indicating improved partitioning of assimilates

towards pulp development rather than peel. This could be due to better nutrient supply, improved microbial activity, and enhanced physiological functioning under integrated nutrient management (Verma *et al.*, 2014). Dutta *et al.* (2016), who reported that integrated use of organic manures and microbial inoculants improved the pulp and peel ratio in Khasi mandarin. Similarly, Singh *et al.* (2020) observed that the application of FYM in combination with microbial consortium significantly enhanced pulp yield and edible portion in Khasi mandarin fruits. Rana *et al.* (2020) also noted that integrated nutrient management practices resulted in higher pulp and peel ratios in sweet orange, thereby improving consumer preference and market value.

4.3.11.4 Fruit volume (cm³)

Table 4.9 shows the fruit volume of Khasi mandarin fruits as influenced by the various treatments in the first and second year of investigation and the pooled data. A close scrutiny of the table reveals that there was significant variation amongst the treatments. In the first year, the maximum fruit volume (98.78 cm³) was recorded in T₄. A similar trend was observed again in the second year, where T₄ registered the highest fruit volume (98.82 cm³). When data were pooled over the two years, T₄ maintained its superiority with the highest fruit volume (98.80 cm³), which was found to be significantly at par with T₁, T₂, T₇, T₈, T₉. The minimum fruit volume was consistently recorded under T₅ with 88.36 cm³ in the first year, 88.37 cm³ in the second year, and 88.37 cm³ in the pooled mean.

The increase in fruit volume under FYM combined with microbial consortium may be attributed to the improvement in soil physico-chemical properties, organic matter enrichment, and enhanced microbial activity that collectively ensure a steady nutrient supply during the fruit growth phase. Such improvements facilitate better translocation of photosynthates into developing fruits, ultimately increasing their size and volume. Similar findings were reported by Dutta *et al.* (2016), who observed that the integration of FYM with biofertilizers improved fruit size and yield in Khasi mandarin. Likewise, Kumar *et al.* (2019) demonstrated that the combined application of vermicompost and microbial inoculants enhanced fruit growth and quality parameters in citrus.

Table 4.8 Effect of microbial consortium with organic amendments on yield attributes

	Fruit weight(g)			Pulp weight(g)			Pulp and Peel ratio		
Treatments	2023	2024	Pooled	2023	2024	Pooled	2023	2024	Pooled
T ₁	90.69	90.72	90.71	60.60	60.67	60.64	2.01	2.03	2.02
T ₂	90.99	90.92	90.96	61.08	60.83	60.96	2.04	2.04	2.04
T ₃	90.60	90.65	90.63	60.29	60.56	60.43	1.99	2.01	2.00
T ₄	94.82	94.92	94.87	63.84	64.10	63.97	2.06	2.07	2.07
T ₅	84.83	85.01	84.92	56.75	56.92	56.84	2.02	2.03	2.03
T ₆	89.19	90.10	89.65	59.66	61.92	60.79	2.02	2.03	2.03
T ₇	91.30	91.32	91.31	61.30	61.32	61.31	2.04	2.04	2.04
T ₈	93.40	93.55	93.48	62.94	63.23	63.09	2.06	2.06	2.06
T ₉	91.85	92.15	92.00	61.74	62.36	62.05	2.05	2.05	2.05
T ₁₀	92.40	92.65	92.53	62.17	62.39	62.28	2.05	2.06	2.06
S Em±	1.20	1.60	1.37	0.82	1.05	0.97	0.03	0.03	0.03
CD at 5%	3.47	4.62	3.96	2.39	3.04	2.80	0.09	0.07	0.09

4.3.11.5 Fruit length (cm)

Table 4.9 shows the fruit length of Khasi mandarin fruits as influenced by the various treatments in the first and second year of investigation and the pooled data. A close scrutiny of the table reveals that there was significant variation amongst the treatments. During the first year maximum fruit length was observed in T₄ with 6.05 cm followed by T₈ with 5.96 cm and minimum fruit length was observed in T₅ with 5.41 cm followed by T₆ with 5.69 cm. In the second year also same trend could be observed with T₄ having maximum length of 6.05 cm and T₅ with the minimum length of 5.44 cm. The data when pooled over the years also had T₄ with maximum fruit length (6.05 cm) and T₅ with minimum length (5.43 cm).

The role of microbial inoculants in enhancing fruit length cannot be overlooked. Microbial consortia supply growth-promoting substances, solubilize phosphates, and improve nutrient availability, which stimulate cell division and elongation, ultimately influencing fruit size (Verma *et al.*, 2014; Rana *et al.*, 2020). Similar findings were reported by Singh *et al.* (2020), who observed that integrated application of organic manures and microbial inoculants significantly improved fruit length in Khasi mandarin.

4.3.11.6 Fruit diameter (cm)

Table 4.9 shows the fruit diameter of Khasi mandarin fruits as influenced by the various treatments in the first and second year of investigation and the pooled data. A close scrutiny of the table reveals that there was significant variation amongst the treatments. During the first year of treatment T₄ had the maximum fruit diameter with 6.15 cm and T₅ had the minimum fruit diameter with 5.50 cm. In the second year, fruit diameter was again maximum in T₄ with 6.17 cm and T₅ had the minimum diameter with 5.60 cm. The data when pooled over the years T₄ treatment had the maximum fruit diameter with 6.16 cm followed by T₈ treatment with 6.09 cm and minimum diameter was observed in treatment T₅ treatment with 5.55 cm. The increase in fruit diameter under FYM and pig manure treatments in combination with microbial consortium may be attributed to enhanced nutrient availability,

improvement in soil physical properties, and favorable microbial dynamics that support better translocation of assimilates into developing fruits. Organic manures are known to improve soil fertility and provide a steady supply of both macro- and micronutrients, thereby enhancing fruit size and quality (Lakkineni and Abrol, 1994; Dutta *et al.*, 2016). Vermicompost and manures enriched with microbial inoculants have been shown to enhance root growth and nutrient absorption, leading to significant improvements in fruit dimensions and overall yield in citrus (Kumar *et al.*, 2019; Sharma *et al.*, 2019).

4.3.11.7 Peel thickness (mm)

Table 4.9 shows peel thickness of Khasi mandarin fruits as influenced by the various treatments in the first and second year of investigation and the pooled data. A close scrutiny of the table reveals that there was significant variation amongst the treatments. In the first year, the maximum peel thickness (2.13 mm) was recorded in T₄, while the minimum value (1.91 mm) was observed in T₅. A similar trend was observed in the second year, with T₄ again producing the maximum peel thickness (2.15 mm) and T₅ the minimum (1.98 mm). When the data were pooled over both years, T₄ maintained its superiority with the highest peel thickness (2.14 mm), followed by T₈ (2.11 mm), while the lowest pooled mean (1.95 mm) was recorded in T₅.

The improvement in peel thickness under FYM and pig manure treatments in combination with microbial consortium can be attributed to balanced nutrient availability and better physiological functioning of the plant. Organic manures such as FYM and pig manure enhance soil organic carbon and microbial activity, which improve nutrient uptake and translocation to developing fruits. This, in turn, influences peel growth and thickness. Similar observations were reported by Dutta *et al.* (2016), who found that integrated nutrient management improved peel quality traits in Khasi mandarin. Rana *et al.* (2020) also noted that the combined use of organic manures and biofertilizers increased peel thickness and juice content in sweet orange. The contribution of microbial inoculants is also important, as they enhance nutrient availability through nitrogen fixation, phosphate solubilization, and the

Table 4.9 Effect of microbial consortium along with organic amendments on fruit characteristics

	Fruit length (cm)			Fruit diameter (cm)			Fruit volume (cm ³)			Peel thickness (mm)		
Treatments	2023	2024	Pooled	2023	2024	Pooled	2023	2024	Pooled	2023	2024	Pooled
T ₁	5.78	5.81	5.80	5.88	5.91	5.90	94.48	94.51	94.50	2.04	2.04	2.04
T ₂	5.81	5.81	5.81	5.90	5.90	5.90	94.79	94.81	94.80	2.05	2.05	2.05
T ₃	5.78	5.79	5.79	5.88	5.93	5.91	94.37	94.40	94.39	2.04	2.04	2.04
T ₄	6.05	6.05	6.05	6.15	6.17	6.16	98.78	98.82	98.80	2.13	2.15	2.14
T ₅	5.41	5.44	5.43	5.50	5.6	5.55	88.36	88.37	88.37	1.91	1.98	1.95
T ₆	5.69	5.72	5.71	5.78	5.81	5.80	92.91	92.94	92.93	2.01	2.03	2.02
T ₇	5.83	5.83	5.83	5.92	5.98	5.95	95.10	95.16	95.13	2.05	2.07	2.06
T ₈	5.96	5.99	5.98	6.06	6.11	6.09	97.29	97.33	97.31	2.10	2.11	2.11
T ₉	5.86	5.9	5.88	5.96	6.05	6.01	95.68	95.69	95.69	2.07	2.09	2.08
T ₁₀	5.90	5.92	5.91	5.99	6.05	6.02	96.25	96.31	96.28	2.08	2.10	2.09
S Em±	0.11	0.09	0.10	0.11	0.09	0.11	1.77	1.36	1.51	0.03	0.03	0.03
CD at 5%	0.32	0.26	0.29	0.30	0.26	0.32	5.11	3.93	4.38	0.08	0.10	0.09

production of growth-promoting substances. These processes aid in fruit development, including peel formation and firmness (Verma *et al.*, 2014).

4.3.12 Fruit Quality Attributes

4.3.12.1 Juice Content (%)

Table 4.10 and Fig 4.21 shows the juice content of Khasi mandarin fruits as influenced by the various treatments in the first and second year of investigation and the pooled data. A close scrutiny of the table reveals that there was significant variation amongst the treatments. In the first year, the maximum juice content was observed in T₁₀ with 59.05%, closely followed by T₉ with 58.64% and T₄ with 58.59%. The lowest juice content was recorded in T₁ with 51.54%. A similar trend was recorded during the second year, with T₁₀ again producing the highest juice content (60.12%) followed by T₉ and T₄, while T₁ (52.11%) recorded the minimum. When data were pooled across the two years, the maximum juice content was recorded in T₉ (58.93%), followed by T₄ (58.79%) and T₈ (55.48%), while the minimum was recorded in the control treatment T₁ (51.83%).

The enhancement in juice content under treatments involving organic manures and microbial consortium can be attributed to improved soil health, enhanced nutrient availability, and better root activity, which in turn enhance water and assimilate translocation to the fruits. Similar findings were reported by Dutta *et al.* (2016), who observed that integrated nutrient management significantly improved juice percentage in Khasi mandarin. Singh *et al.* (2018) also demonstrated that the application of FYM, vermicompost, and biofertilizers increased juice content in citrus by enhancing physiological processes and fruit quality traits. Furthermore, Thakur *et al.* (2019) found that vermicompost application improved fruit biochemical quality in mandarin, including higher juice recovery compared to inorganic fertilization alone.

4.3.12.2 Total Soluble Solids (°Brix)

Table 4.10 and Fig 4.22 shows the total soluble solids of Khasi mandarin fruits as influenced by the various treatments in the first and second year of investigation and the pooled data. A close scrutiny of the table reveals that there was

significant variation amongst the treatments. In the first year, the maximum TSS was recorded in T₁₀ (9.00 °Brix), followed closely by T₉ (8.80 °Brix) and T₈ (8.80 °Brix), while the minimum TSS was recorded in T₁ (Control) with 8.09 °Brix. A similar trend was observed during the second year, with T₁₀ (9.05°Brix) showing the maximum, followed by T₉ (8.85 °Brix), while T₁ (8.14°Brix) recorded the lowest. When the data were pooled over two years, the maximum TSS was recorded in T₁₀ (9.03 °Brix), which was statistically at par with T₉ (8.83°Brix) and T₈(8.83 °Brix) and significantly higher than all other treatments. The minimum pooled TSS was recorded in T₁ (8.12 °Brix).

The increase in TSS under treatments involving vermicompost and microbial consortium could be due to enhanced nutrient uptake efficiency, particularly of potassium, which plays a vital role in sugar translocation and accumulation in fruits. Improved soil microbial activity in these treatments may also have enhanced carbohydrate metabolism and enzymatic activity, thereby contributing to higher sugar concentration. Similar results were reported by Singh *et al.* (2018), who found that the application of FYM, vermicompost, and biofertilizers significantly improved TSS in citrus fruits. Dutta *et al.* (2016) also observed that integrated nutrient management practices enhanced soluble solids in Khasi mandarin, while Thakur *et al.* (2019) confirmed that vermicompost application in mandarin increased fruit sweetness and flavor attributes by improving sugar accumulation.

4.3.12.3 Titrable acidity (%)

Table 4.10 and Fig 4.23 shows the titrable acidity of Khasi mandarin fruits as influenced by the various treatments in the first and second year of investigation and the pooled data. A close scrutiny of the table reveals that there was significant variation amongst the treatments. The treatment (T₁) consistently recorded the highest acidity values in first year (0.93%) and second year (0.91%), while the lowest values were associated with T₁₀ in first year (0.83%) and second year (0.79%). When pooled over the years, highest acidity was observed in T₁ (0.92%) and lowest was observed in treatment T₁₀ (0.81%).

The trend clearly demonstrates that organic nutrient management, particularly the integration of vermicompost with microbial inoculants, favours a decline in fruit acidity. This reduction is likely a result of enhanced carbohydrate metabolism during ripening, where organic acids are transformed into sugars and other derivatives. Such biochemical changes are often stimulated by improved microbial activity in the root zone, which facilitates nutrient assimilation and accelerates physiological processes (Patil *et al.*, 2012). Kaur and Kaundal (2017) reported that the application of bioorganics in kinnow led to improved sweetness and reduced acidity, thereby enhancing consumer acceptability.

4.3.12.4 TSS: acidity

Table 4.10 and Fig 4.24 clearly show the TSS: Acidity of Khasi mandarin fruits as influenced by the various treatments in the first and second year of investigation and the pooled data. A close scrutiny of the table reveals that there was significant variation amongst the treatments. In first year, the highest TSS: Acidity ratio was observed in T₁₀ (10.70) followed closely by T₈ (10.23), whereas the lowest was recorded in T₁ (8.70). A similar trend was evident in the second year, where T₁₀ (11.45) registered the maximum ratio, while T₁ (8.94) recorded the minimum. When data were pooled over two years, T₁₀ maintained the highest TSS: Acidity (11.08) followed by T₉ (10.64) and T₈ (10.58), whereas the lowest pooled ratio was observed in T₁ (8.82).

An elevated TSS: Acidity ratio is considered an indicator of improved fruit sweetness and better flavor acceptability. The significantly higher ratio under vermicompost and microbial consortium treatments may be attributed to enhanced sugar accumulation coupled with reduced organic acid concentration in fruits. The microbial consortium played an important role in improving nutrient availability and promoting enzymatic activities that hasten the conversion of acids into sugars during ripening, thereby improving the sugar–acid balance (Patil *et al.*, 2012). The present findings are in line with the results of Dutta *et al.* (2016) in Khasi mandarin and Kaur and Kaundal (2017) in kinnow, who reported that integrated nutrient management significantly, improved the TSS: Acidity over conventional practices.

4.3.12.5 Total Sugars (%)

Table 4.10 and Fig 4.25 shows the total sugar of Khasi mandarin fruits as influenced by the various treatments in the first and second year of investigation and the pooled data. A close scrutiny of the table reveals that there was significant variation amongst the treatments. In the first year, the maximum total sugar content was recorded in T₁₀ (6.55%) followed by T₈ (6.32%) and T₇ (6.11%), while the minimum was observed in T₁ (5.46%). A similar trend was observed in the second year, with T₁₀ (6.78%) recording the highest, followed by T₈ (6.52%) and T₇ (6.31%), while the lowest was again found in T₁ (5.61%). When pooled across both years, the highest total sugar content was again found in T₁₀ (6.67%), followed by T₈ (6.42%) and T₇ (6.21%), while the lowest pooled mean was recorded in T₁ (5.54%).

The improvement in sugar accumulation in treatments involving vermicompost and microbial consortium can be attributed to enhanced availability of macro- and micronutrients, especially potassium, which plays a central role in sugar metabolism and translocation. The presence of beneficial microbes further improves enzymatic activity and organic acid metabolism, leading to higher sugar synthesis and accumulation in fruits. These results are in close conformity with those reported by Dutta *et al.* (2016), who found that integrated nutrient management increased total sugar content in Khasi mandarin. Thakur *et al.* (2019) also observed that vermicompost application in mandarin improved sugar levels and overall sweetness compared to control treatments.

4.3.12.6 Reducing sugar (%)

Table 4.10 and Fig 4.26 shows the reducing sugar of Khasi mandarin fruits as influenced by the various treatments in the first and second year of investigation and the pooled data. A close scrutiny of the table reveals that there was significant variation amongst the treatments. In the first year, the maximum reducing sugar content was observed in T₁₀ with 3.97%, followed by T₈ (3.91%) and T₇ (3.83%), while the lowest was recorded in T₁ (3.73%). In the second year, the highest reducing sugar content was again recorded in T₁₀ (4.12%), followed by T₈ (4.04%) and T₇

(4.01%), while the minimum was found in T₁ (3.86%). When pooled across both years, T₁₀ (4.05%) showed the highest reducing sugar content, followed by T₈ (3.98%) and T₇ (3.95%), whereas the minimum was consistently observed in T₁ (3.80%).

The higher reducing sugar content under treatments involving vermicompost and microbial consortium can be attributed to enhanced nutrient mineralization and improved availability of potassium, which is known to play a pivotal role in carbohydrate metabolism and sugar transport (Singh *et al.*, 2018). Vermicompost improves soil enzymatic activity and microbial biomass, which in turn promotes the hydrolysis of polysaccharides into simple sugars, leading to higher accumulation of reducing sugars in fruit (Thakur *et al.*, 2019). Similarly, microbial inoculants such as *Azotobacter*, *Azospirillum* and phosphate-solubilizing bacteria increase nitrogen fixation and phosphorus solubilization, thereby enhancing enzymatic activity and sugar synthesis (Patil *et al.*, 2012). Kaur and Kaundal (2017) also observed in kinnow mandarin that organic manure combined with biofertilizers improved reducing sugar content due to improved nutrient cycling and photosynthate translocation. Further, Sharma *et al.* (2020) highlighted that bio-organic nutrient sources enhance soil microbial activity, leading to improved carbohydrate metabolism and higher reducing sugar accumulation in citrus fruits.

4.3.12.7 Ascorbic acid (mg/100ml)

Table 4.10 and Fig 4.27 clearly shows the ascorbic acid contents of Khasi mandarin fruits as influenced by the various treatments in the first and second year of investigation and the pooled data. A close scrutiny of the table reveals that there was significant variation amongst the treatments. In the first year, the maximum ascorbic acid content was recorded in T₁₀ with 34.12 mg/100 ml, followed by T₄ (32.53 mg/100 ml) and T₈ (32.50 mg/100 ml). The minimum was observed in T₁ with 29.41 mg/100 ml. A similar trend was observed in the second year, where T₁₀ (35.39 mg/100 ml) recorded the highest, followed by T₈ (33.09 mg/100 ml) and T₄ (32.96 mg/100 ml), while the lowest was again found in T₁ (29.86 mg/100 ml). When data were pooled over both years, the highest ascorbic acid content was recorded in T₁₀

(34.76 mg/100 ml), which was significantly higher than all other treatments. The lowest pooled mean was found in T₁ (29.64 mg/100 ml).

The increase in ascorbic acid content under vermicompost and microbial consortium-based treatments may be attributed to improved nutrient cycling and enzymatic activities in the rhizosphere, leading to enhanced synthesis and accumulation of ascorbic acid in fruits. Vermicompost has been reported to release humic substances and growth-promoting compounds, which enhance vitamin C biosynthesis and retention. Similar findings were reported by Dutta *et al.* (2016), who observed higher ascorbic acid levels in Khasi mandarin fruits under integrated nutrient management practices. Singh *et al.* (2018) also reported that the combined use of FYM, vermicompost, and biofertilizers increased ascorbic acid content in citrus fruits compared to inorganic fertilizers. Thakur *et al.* (2019) further emphasized that organic manures, particularly vermicompost, improved biochemical quality traits, including vitamin C content, in mandarin fruits.

Table 4.10 Effect of microbial consortium with organic amendments on fruit qualitative characteristics of Khasi mandarin

Treatments	Juice content (%)			TSS (° Brix)			Titrable acidity(%)		
	2023	2024	pooled	2023	2024	pooled	2023	2024	Pooled
T ₁	51.54	52.11	51.83	8.09	8.14	8.12	0.93	0.91	0.92
T ₂	51.92	52.42	52.17	8.16	8.20	8.18	0.91	0.87	0.89
T ₃	56.84	57.39	57.12	8.20	8.20	8.20	0.87	0.86	0.87
T ₄	58.59	58.99	58.79	8.39	8.44	8.42	0.85	0.85	0.85
T ₅	52.60	53.19	52.90	8.23	8.30	8.27	0.87	0.83	0.85
T ₆	54.08	55.15	54.62	8.39	8.40	8.40	0.87	0.84	0.86
T ₇	53.39	53.93	53.66	8.29	8.36	8.33	0.89	0.86	0.88
T ₈	55.00	55.99	55.48	8.80	8.85	8.83	0.85	0.81	0.83
T ₉	58.64	59.21	58.93	8.80	8.85	8.83	0.85	0.80	0.83
T ₁₀	59.05	60.12	57.10	9.00	9.05	9.03	0.83	0.79	0.81
S Em±	1.02	0.79	0.42	0.12	0.12	0.12	0.01	0.01	0.01
CD at 5%	2.96	2.27	1.23	0.36	0.36	0.25	0.04	0.04	0.02

Continue.....

	TSS: acidity ratio			Total sugar (%)			Reducing sugar (%)			Ascorbic acid (mg/100ml)		
Treatments	2023	2024	Pooled	2023	2024	Pooled	2023	2024	Pooled	2023	2024	pooled
T ₁	8.70	8.94	8.82	5.46	5.61	5.54	3.73	3.86	3.80	29.41	29.86	29.64
T ₂	8.94	9.01	8.98	5.76	5.89	5.83	3.80	3.95	3.88	30.31	30.86	30.59
T ₃	9.31	9.53	9.42	5.86	6.01	5.94	3.77	3.90	3.84	31.46	31.84	31.65
T ₄	9.76	9.92	9.84	5.91	6.09	6.00	3.83	3.97	3.90	32.53	32.96	32.75
T ₅	9.19	10.11	9.65	5.72	5.86	5.79	3.75	3.87	3.81	30.87	31.06	30.97
T ₆	9.65	10.09	9.87	5.93	6.11	6.02	3.83	3.96	3.90	31.42	32.12	31.77
T ₇	9.32	9.72	9.52	6.11	6.31	6.21	3.89	4.01	3.95	31.88	32.36	32.12
T ₈	10.23	10.93	10.58	6.32	6.52	6.42	3.91	4.04	3.98	32.50	33.09	32.80
T ₉	10.22	11.06	10.64	5.98	6.12	6.05	3.77	3.97	3.87	31.95	32.49	32.22
T ₁₀	10.70	11.45	11.08	6.55	6.78	6.67	3.97	4.12	4.05	34.12	35.39	34.76
S Em±	0.94	0.14	0.12	0.09	0.11	0.07	0.06	0.07	0.04	0.54	0.53	0.21
CD at 5%	2.72	0.41	0.36	0.26	0.32	0.21	0.17	0.19	0.12	1.55	1.52	0.62

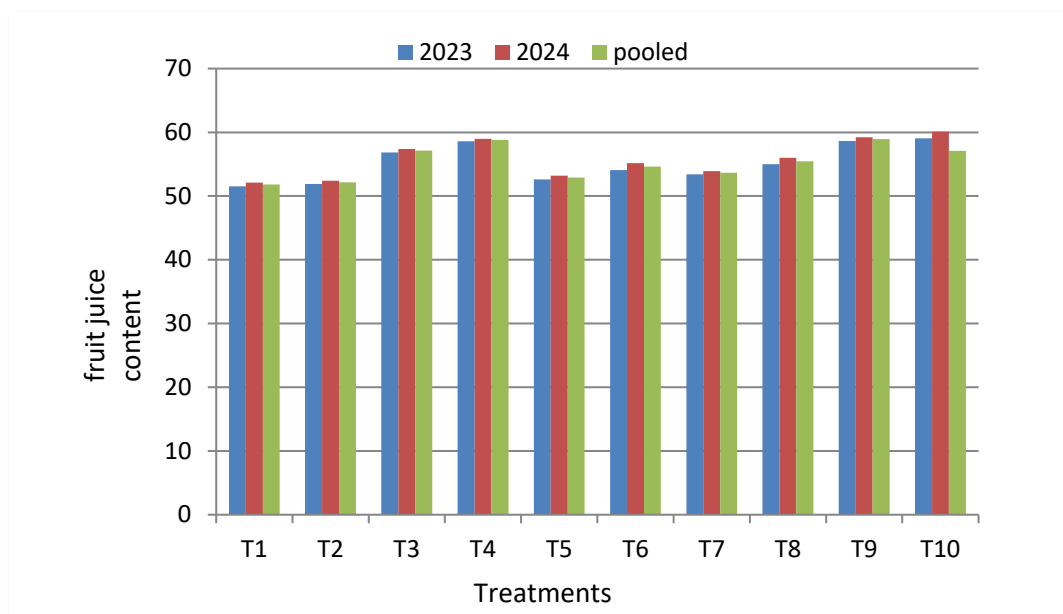


Fig 4.21 Influence of microbial consortium and organic amendments on fruit juice content (%)

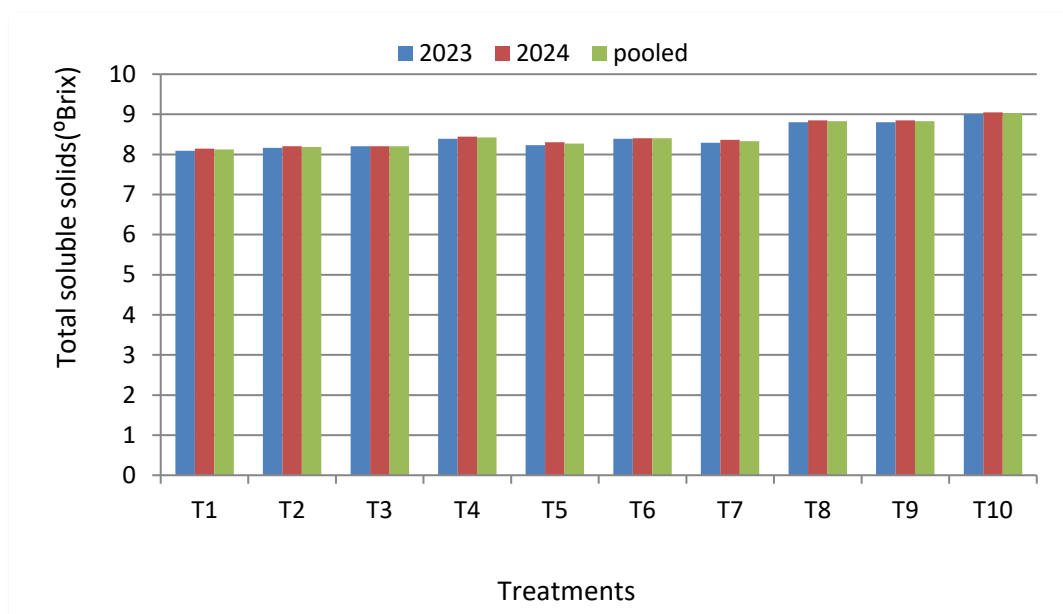


Fig 4.22 Influence of microbial consortium and organic amendments on TSS (°Brix)

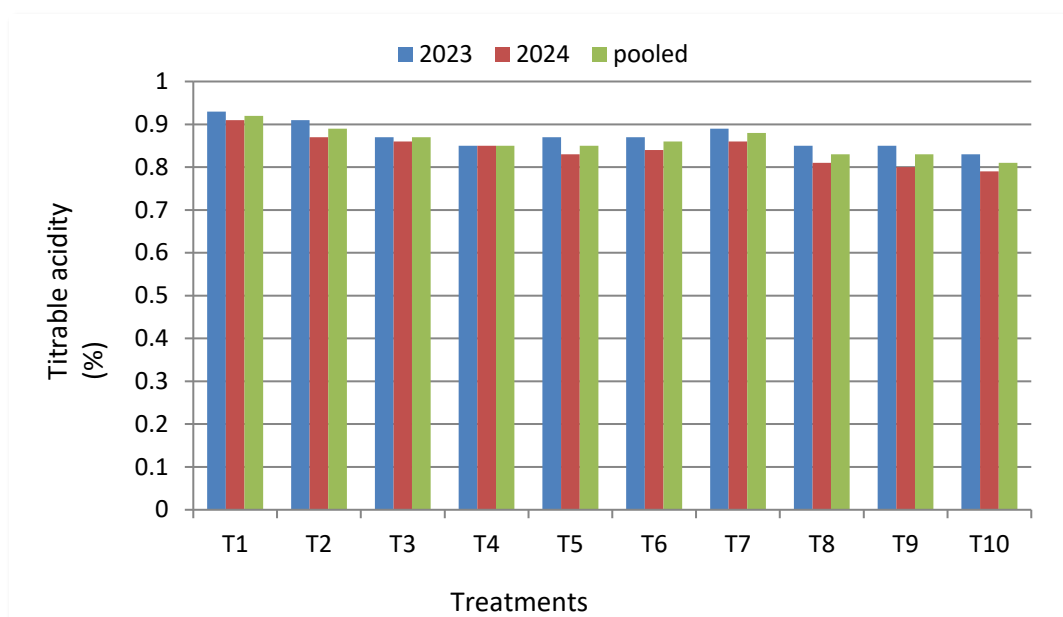


Fig 4.23 Effect of microbial consortium and organic amendments on titrable acidity (%) of Khasi mandarin

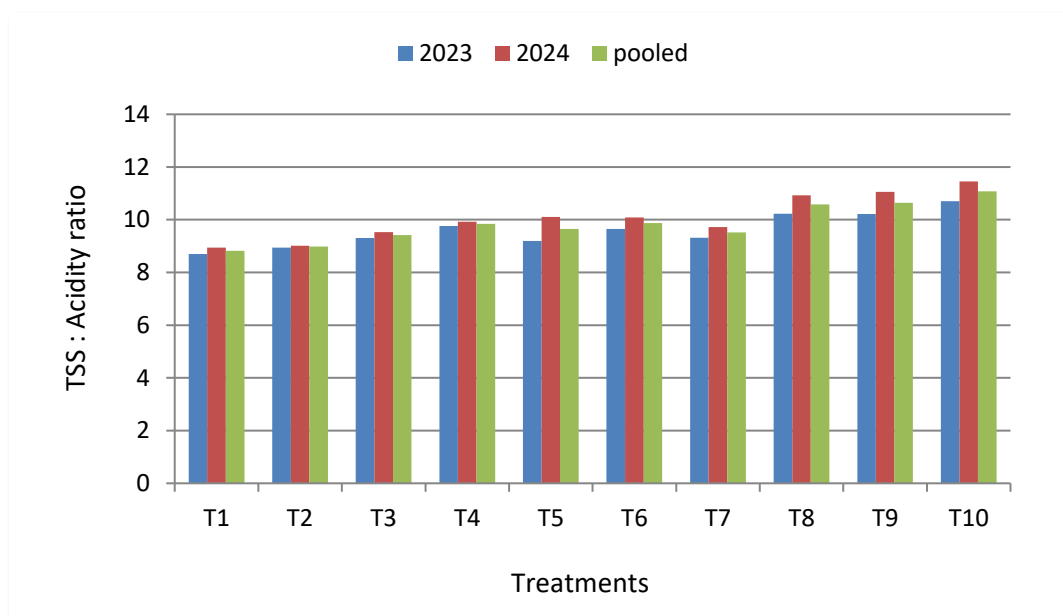


Fig 4.24 Effect of microbial consortium and organic amendments on TSS and acidity ratio

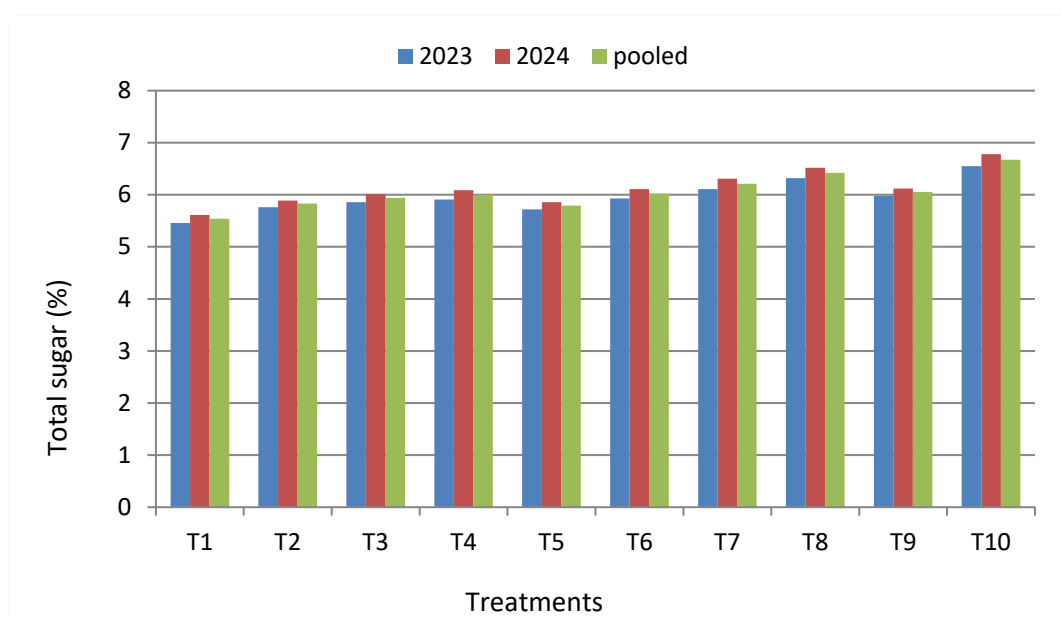


Fig 4.25 Effect of microbial consortium and organic amendments on fruit total sugar (%) of Khasi mandarin

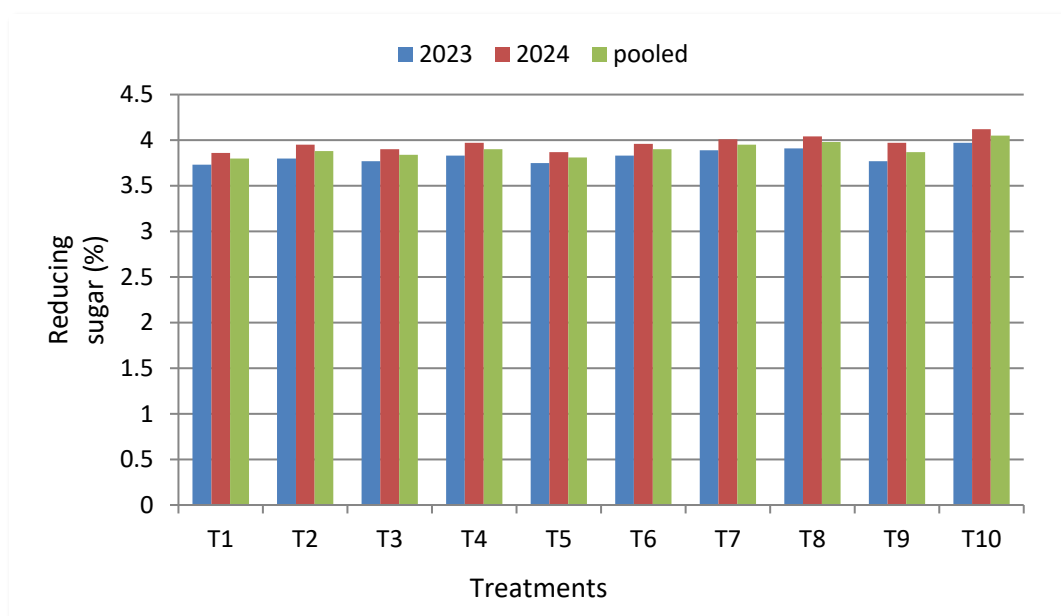


Fig 4.26 Effect of microbial consortium and organic amendments on fruit reducing sugar (%) of Khasi mandarin

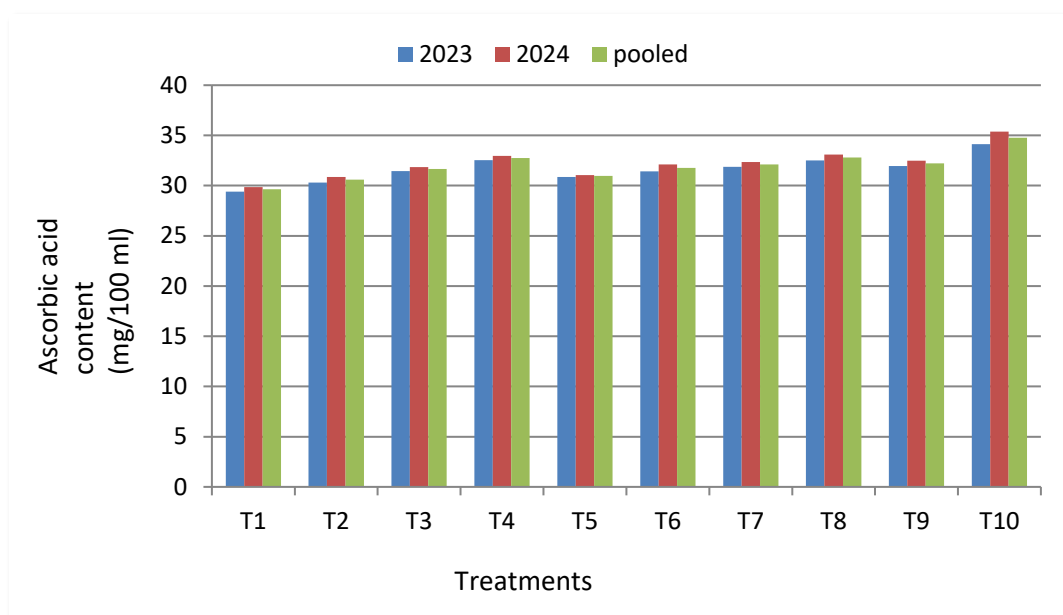


Fig 4.27 Influence of microbial consortium along with organic amendments on ascorbic acid content (mg/100ml)

4.3.12.8 Peel oil content (%)

Table 4.11 shows the peel oil content of Khasi mandarin fruits as influenced by the various treatments in the first and second year of investigation and the pooled data. A close scrutiny of the table reveals that there was significant variation amongst the treatments. In the first year, highest peel oil content was observed in treatment T₉ (5.51%) followed by T₁₀ (5.44%) whereas lowest was observed in treatment T₂ (5.10%). In the second year, highest peel oil content was observed in treatment T₉ (5.52%) followed by T₁₀ (5.50 %) whereas lowest was observed in treatment T₂ (5.12%). In the pooled data, the highest oil content (5.51%) was recorded in T₉, followed by T₁₀ (5.47%) and T₇ (5.40%), whereas the lowest oil content (5.11%) was observed in T₂, closely followed by T₁ (5.12%).

The enhancement in essential oil content under T₉ and T₁₀ may be attributed to the synergistic effect of microbial consortium and organic amendments special; vermicompost, which improve nutrient availability, particularly nitrogen and sulphur both essential elements for the synthesis of volatile compounds and secondary metabolites (Singh *et al.*, 2018). Moreover, microbial inoculants such as *Azotobacter*, *Azospirillum*, *Bacillus*, and *Pseudomonas* are known to stimulate plant growth regulators and metabolic pathways that enhance oil gland development and secretion (Bhat *et al.*, 2020). These results are in agreement with Lal, (2017), who reported that enhanced microbial activity in organically managed citrus orchards increased the synthesis of terpenoid compounds, thereby improving the essential oil yield and quality.

Table 4.11 Effect of microbial consortium and organic amendments on peel oil content (%) of fruits in Khasi mandarin

Treatments	Oil Content (%)		
	2023	2024	pooled
T ₁	5.11	5.13	5.12
T ₂	5.10	5.12	5.11
T ₃	5.15	5.20	5.18
T ₄	5.13	5.13	5.13
T ₅	5.15	5.18	5.17
T ₆	5.13	5.15	5.14
T ₇	5.40	5.40	5.40
T ₈	5.32	5.35	5.33
T ₉	5.51	5.52	5.51
T ₁₀	5.44	5.50	5.47
S Em±	0.07	0.07	0.05
CD at 5%	0.21	0.19	0.14

4.3.12.9 Sensory evaluation

In sensory (organoleptic) evaluation as shown in Table 4.12, the marking for Khasi mandarin fruits is given on the basis of specific sensory attributes, each evaluated by a panel of trained judges. Organoleptic evaluation of Khasi mandarin fruits revealed significant differences among the treatments. The overall acceptability score ranged from 6.2 (T₃) to 8.3 (T₁₀), indicating that integrated nutrient management had a pronounced influence on fruit quality attributes. Treatment T₁₀ recorded the highest scores for appearance (8.2), colour (8.4), flavour (8.3), and overall acceptability (8.3), followed closely by T₈ (8.2) and T₆ (8.1). Fruits obtained from these treatments were more attractive, juicier, and had a balanced sweetness acidity ratio, resulting in superior consumer preference. In contrast, fruits from T₃ and T₄ received lower scores, possibly due to inferior external colour and less desirable taste.

The improvement in sensory quality under treatments incorporating organic manures and microbial inoculants might be attributed to better nutrient balance, enhanced sugar–acid metabolism, and higher juice content. These findings are consistent with those reported by Bisen *et al.* (2020) and Kumar *et al.* (2019), who observed improved flavour and acceptability in citrus fruits with organic and biofertilizer supplementation.

Table 4.12 Sensory evaluation of Khasi mandarin as affected by different treatments

Treatments	Appearance	Colour	Flavour	Taste	Texture	Juiciness	Overall Accept ability
T ₁	7.2	7.4	7.1	7.0	7.3	7.1	7.2
T ₂	7.4	7.6	7.3	7.1	7.5	7.3	7.4
T ₃	6.2	6.4	6.0	6.1	6.3	6.2	6.2
T ₄	6.8	6.9	6.7	6.6	6.8	6.7	6.7
T ₅	7.6	7.8	7.4	7.5	7.6	7.5	7.6
T ₆	8.0	8.2	8.0	8.1	8.0	8.1	8.1
T ₇	7.8	8.0	7.9	7.8	7.9	7.9	7.9
T ₈	8.1	8.3	8.2	8.0	8.1	8.2	8.2
T ₉	7.9	8.0	7.8	7.9	7.9	8.0	7.9
T ₁₀	8.2	8.4	8.3	8.2	8.3	8.3	8.3

(Scores based on 9-point hedonic scale: 9 = Like extremely, 1 = Dislike extremely)

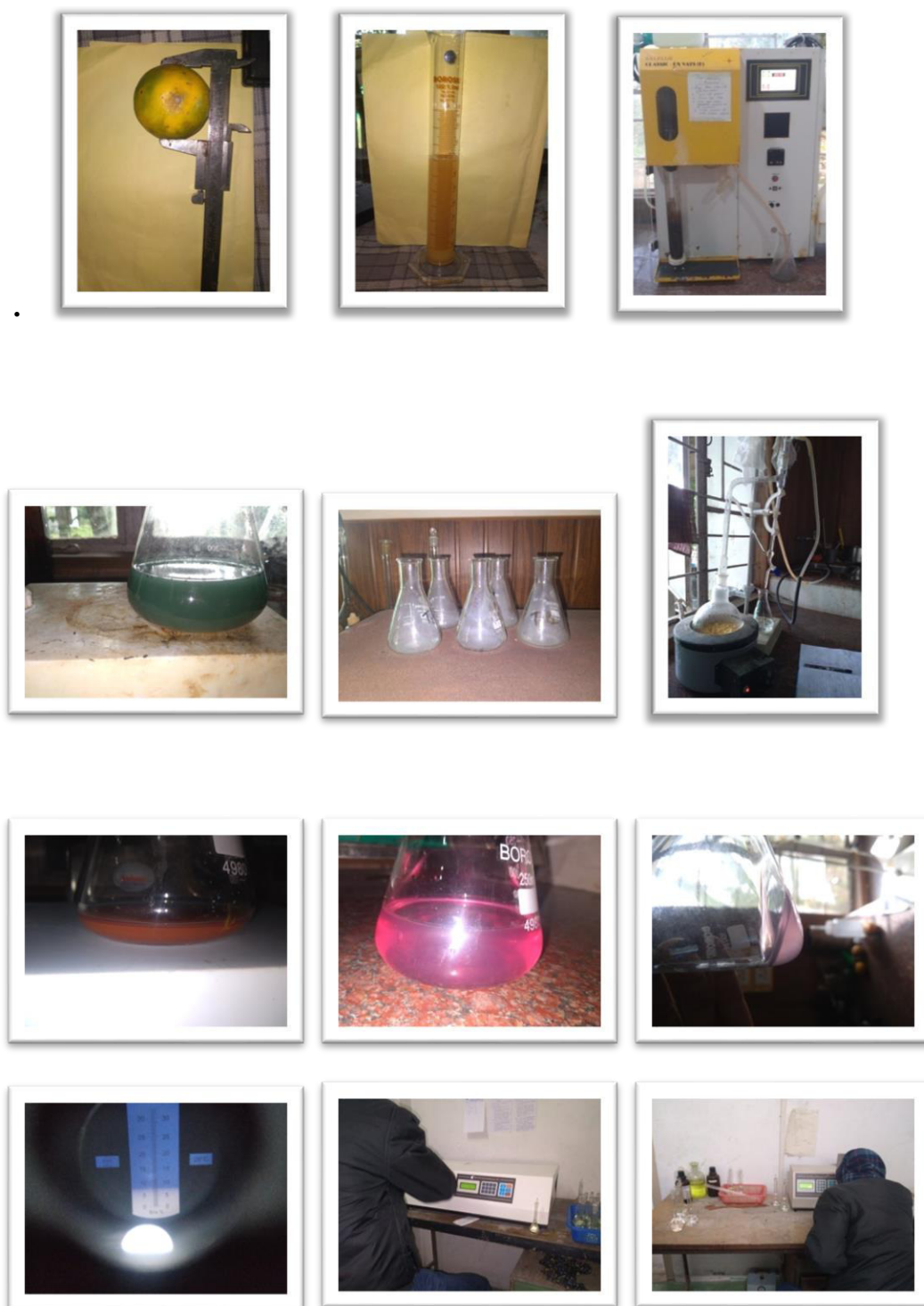


Plate 4.3 Laboratory analysis for physico-chemical characteristics of khasi mandarin

4.3.13 Shelf life studies

4.3.13.1 Physiological loss in fruit weight (%)

Table 4.13 and Figs 4.28, 4.29 shows the physiological loss in fruit weight (PLW) of Khasi mandarin fruits as influenced by the various treatments in the first and second year of investigation and the pooled data. A close scrutiny of the table reveals that there was significant variation amongst the treatments and progressed gradually with the duration of storage. At 5 days of storage, minimum PLW was recorded in T₁₀ (3.81%), followed by T₉ (4.05%) and T₄ (4.14%). The highest loss was observed in the T₁ (5.39%). This initial superiority of microbial–organic treatments may be attributed to reduced respiration rate and better surface moisture retention. A similar trend was reported in kinnow fruits where organic management significantly lowered early storage losses compared to conventional produce (Rathore *et al.*, 2007). At 10 days of storage, T₁₀ maintained the lowest PLW (6.97%), followed by T₉ (7.05%) and T₄ (7.01%), while the control showed maximum losses (8.52%). These results corroborate the findings of Singh and Nambi (2017), who stated that bio-inoculants and organic inputs help to maintain membrane integrity and reduce metabolic stress in citrus fruits, thereby minimizing moisture loss. At 15 days of storage, pooled data showed that T₁₀ fruits recorded only 9.63% weight loss compared to 11.63% in the control T₁. Lower PLW under organic and microbial treatments may be due to delayed senescence and higher antioxidant activity. Similar results were documented in sweet orange, where organic nutrient management improved storability by reducing weight loss during extended storage (Sharma *et al.*, 2019). At 20 days of storage, PLW remained lowest in T₁₀ (13.00%), closely followed by T₉ (13.34%) and T₄ (13.44%), whereas T₁ reached 14.96%. The greater effectiveness of microbial consortium treatments at this stage can be linked to their role in sustaining cell wall structure and metabolic homeostasis. Chandra *et al.* (2018) also highlighted that microbial inoculant significantly improved storability of guava by reducing physiological deterioration.

At 25 days of storage, T₁₀ fruits exhibited the lowest PLW (15.39%) compared to 17.18% in T₁. These results are in line with the findings of Kumar *et*

al. (2014), who reported that organically produced mandarin fruits had slower weight losses during prolonged storage, owing to better nutrient balance and fruit firmness. At 30 days of storage, the PLW in T₁₀ was only 17.76%, while the T₁ reached 19.63%. Treatments T₉ (18.62%) and T₄ (18.54%) also performed significantly better. These results agree with earlier findings where biofertilizer-treated Nagpur mandarin fruits retained freshness longer under storage conditions (Bisen *et al.*, 2011). At 35 days of storage, T₁₀ maintained superiority with 20.18% PLW, whereas the control T₁ recorded 21.81%. Similar benefits of microbial treatments in reducing post-harvest weight loss were earlier reported in acid lime (Mohanty *et al.*, 2015). At 40 days of storage, the PLW values indicated that T₁₀ (21.61%) and T₄ (22.16%) were superior to the control T₁ (23.87%). These findings corroborate the work of Singh *et al.* (2020), who emphasized that integrated organic nutrient management in citrus reduces weight loss during long-term storage. At 45 days of storage, fruits under T₁₀ recorded the lowest PLW (23.87%) followed by T₄ (24.66%) and T₉ (25.19%), while T₁ fruits reached the maximum (26.11%). The data confirm that microbial consortium in combination with organic amendments can significantly extend storage life. Similar prolonged storability effects were reported in organically grown guava, attributing it to higher retention of cellular integrity (Ghosh *et al.*, 2017).

Overall, across all storage intervals and both years, T₁₀ consistently minimized PLW followed by T₉ and T₄, while control fruits (T₁) exhibited the highest weight loss. These results confirm that microbial consortium with organic amendments effectively reduces post-harvest losses a conclusion supported by multiple studies across citrus and other fruit crops.

Table 4.13 Effect of microbial consortium with organic amendments on physiological loss in weight (%)

Treatments	5			10			15			20		
	DAS											
	2023	2024	Pooled	2023	2024	Pooled	2023	2024	Pooled	2023	2024	Pooled
T ₁	5.68	5.11	5.39	8.77	8.27	8.52	11.85	11.41	11.63	15.19	14.74	14.96
T ₂	4.73	4.23	4.48	8.08	7.85	7.96	11.43	11.08	11.25	14.76	14.31	14.53
T ₃	4.32	4.11	4.21	7.54	7.05	7.29	10.76	10.32	10.54	14.08	13.63	13.85
T ₄	4.30	3.98	4.14	7.22	6.80	7.01	10.13	9.69	9.91	13.66	13.23	13.44
T ₅	5.29	5.05	5.17	8.43	8.11	8.27	11.56	11.12	11.34	14.89	14.44	14.66
T ₆	4.54	4.11	4.32	7.76	7.32	7.54	10.98	10.53	10.75	14.30	13.85	14.07
T ₇	5.15	4.85	5.00	8.17	7.91	8.04	11.19	10.73	10.96	14.52	14.07	14.29
T ₈	4.46	4.03	4.24	7.67	7.43	7.55	10.88	10.43	10.65	14.22	13.75	13.98
T ₉	4.23	3.88	4.05	7.23	6.88	7.05	10.22	9.83	10.02	13.56	13.13	13.34
T ₁₀	4.07	3.56	3.81	6.97	6.54	6.97	9.86	9.41	9.63	13.22	12.79	13.00
S Em±	0.07	0.07	0.06	0.09	0.12	0.13	0.18	0.18	0.17	0.21	0.18	0.25
CD at 5%	0.19	0.20	0.17	0.25	0.34	0.38	0.53	0.52	0.49	0.61	0.52	0.74

Continue.....

Treatments	25			30			35			40			45		
	DAS														
	2023	2024	Pooled	2023	2024	Pooled	2023	2024	Pooled	2023	2024	Pooled	2023	2024	Pooled
T ₁	17.37	16.99	17.18	19.86	19.41	19.63	22.04	21.59	21.81	24.11	23.64	23.87	26.33	25.89	26.11
T ₂	17.03	16.59	16.81	19.30	18.85	19.07	21.68	21.21	21.44	23.88	23.43	23.65	25.89	25.41	25.65
T ₃	16.59	16.19	16.39	19.10	18.65	18.87	21.49	21.04	21.26	22.77	22.29	22.53	25.17	24.72	24.94
T ₄	16.22	15.79	16.00	18.77	18.32	18.54	21.17	20.72	20.94	22.39	21.94	22.16	24.89	24.44	24.66
T ₅	17.06	16.63	16.84	19.23	18.78	19.00	21.62	21.17	21.39	23.11	22.66	22.88	25.10	24.65	24.87
T ₆	16.59	16.16	16.37	18.88	18.41	18.64	21.24	20.78	21.01	22.97	22.52	22.74	25.06	24.64	24.85
T ₇	16.91	16.48	16.69	19.31	18.86	19.08	21.80	21.35	21.57	23.42	22.96	23.19	25.63	25.18	25.40
T ₈	16.64	16.19	16.41	19.05	18.64	18.84	21.55	21.10	21.32	23.07	22.61	23.07	25.20	24.75	24.97
T ₉	16.11	15.66	15.88	18.85	18.40	18.62	21.65	21.24	21.44	23.20	22.76	22.98	25.42	24.97	25.19
T ₁₀	15.61	15.17	15.39	18.00	17.53	17.76	20.40	19.96	20.18	21.84	21.39	21.61	24.11	23.63	23.87
S Em±	0.20	0.21	0.25	0.30	0.21	0.27	0.26	0.30	0.27	0.41	0.28	0.28	0.39	0.28	0.43
CD at 5%	0.57	0.60	0.72	0.85	0.62	0.78	0.75	0.88	0.79	1.19	0.80	0.81	1.12	0.82	1.24

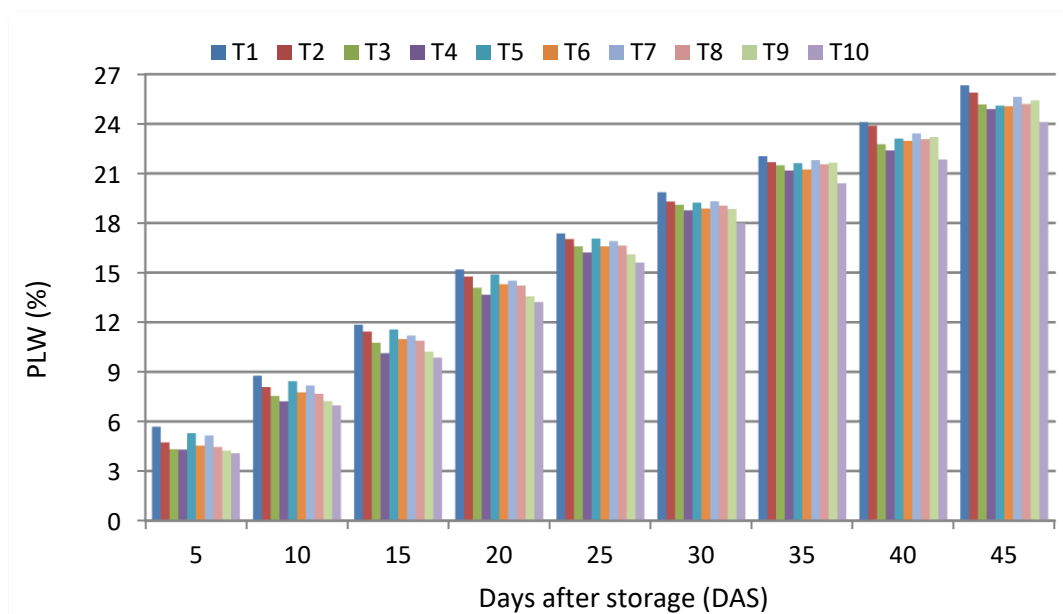


Fig 4.28 Physiological loss in weight (%) of fruits during storage as influenced by microbial consortium and organic amendments during 2023

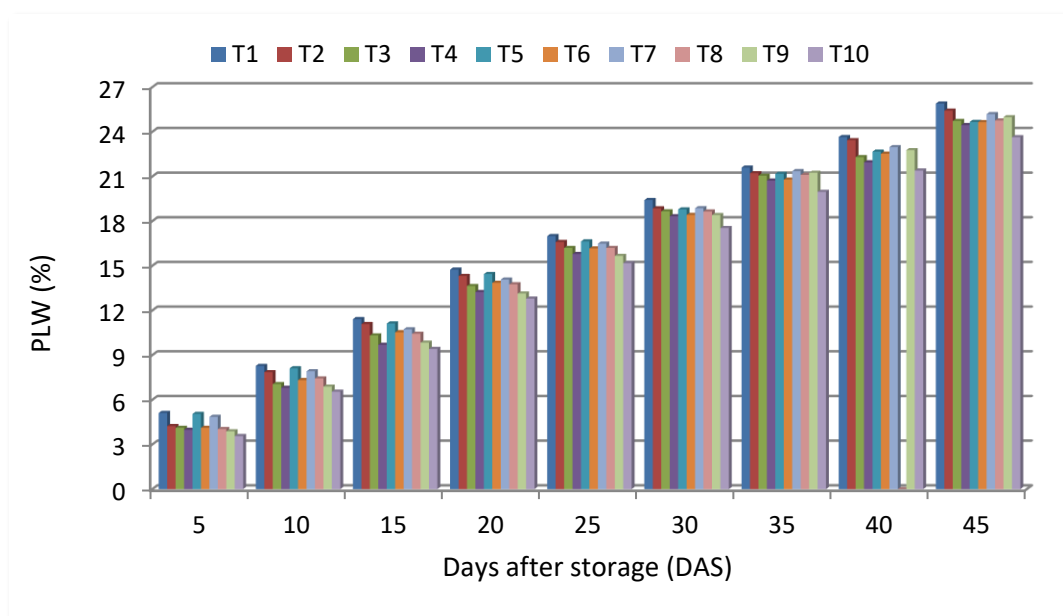


Fig 4.29 Physiological loss in weight (%) of fruits during storage as influenced by microbial consortium and organic amendments during 2024

4.3.13.2 Juice recovery in fruits

Table 4.14 and Figs 4.30, 4.31 clearly shows juice recovery of Khasi mandarin fruits as influenced by the various treatments in the first and second year of investigation and the pooled data. A close scrutiny of the table reveals that there was significant variation amongst the treatments. Data from the table, indicates that at the start of storage (5 DAS), juice recovery ranged from 46.62% (T₁) to 51.93% (T₁₀). Among the treatments, T₁₀ recorded the highest juice content, followed by T₉ and T₄, while T₁ was significantly lower. By 10 DAS, the pattern persisted, with T₁₀ maintaining 46.92% juice recovery compared with 43.83% in the control T₁. At 15 DAS, juice recovery had declined slightly in all treatments, but T₁₀ (42.52%) and T₄ (42.00%) still maintained superior values to T₁ (41.03%). This trend indicates that microbial and organic inputs may improve cell water retention and delay the loss of juice through enhanced membrane stability and osmotic adjustment. Similar findings were reported in mandarins and sweet oranges where biofertilizers maintained higher juice content during early storage by preserving cell integrity (Bhattacharya and Chandra, 2017; Mitra *et al.*, 2018). At 20 DAS, T₁₀ retained 38.64% juice, markedly higher than the control T₁ (37.54%). By 25 DAS, T₁₀ held 35.14% juice compared to 34.04% in the control. At 30 DAS, T₁₀ registered 31.31% juice, again significantly higher than the control (29.82%). This sustained advantage indicates that microbial consortia combined with organic amendments slow the rate of water loss, possibly through improved cuticular integrity and delayed senescence, as documented in citrus and papaya under similar treatments (Saikia and Pathak, 2020; Sharma *et al.*, 2019). During the later storage period, juice recovery declined sharply in all treatments due to tissue breakdown, respiratory water loss, and degradation of cell wall polysaccharides. Nonetheless, T₁₀ consistently maintained the highest juice recovery (26.02% at 40 DAS and 24.49% at 45 DAS) compared with the control (22.11% at 40 DAS and 22.32% at 45 DAS). The superior retention of juice in T₁₀ reflects delayed senescence and slower metabolic turnover. Previous research on mandarins and kinnow showed that microbial inoculants or bio-enhanced nutrition could significantly reduce postharvest dehydration and maintain juice recovery (Bisen *et al.*, 2020; Wills *et al.*, 1980).

Across all storage intervals, juice recovery decreased progressively, a normal physiological phenomenon associated with moisture loss, respiration, and conversion of insoluble to soluble solids. The control treatment showed relatively higher TSS but lower juice recovery in later stages, consistent with accelerated tissue dehydration and concentration of solutes (Hazrati *et al.*, 2012; Wills *et al.*, 1980). In contrast, fruits treated with microbial consortia plus organic amendments retained higher juice content, suggesting enhanced cellular turgor and delayed breakdown of membranes. This agrees with previous reports indicating that biofertilizers and organic amendments, can slow postharvest deterioration and improve internal water status of citrus fruits (Mitra *et al.*, 2018; Saikia and Pathak, 2020). T₁₀ (microbial consortium + vermicompost) consistently outperformed all other treatments in preserving juice content during storage, followed by T₄ and T₉, whereas the control exhibited the fastest decline. These findings support the hypothesis that integrated microbial and organic management not only improves preharvest plant nutrition but also extends postharvest storability and juice retention in Khasi mandarin fruits.

Table 4.14 Effect of microbial consortium with organic amendments on juice recovery (%) during storage

Treatments	5			10			15			20		
	DAS											
	2023	2024	Pooled	2023	2024	Pooled	2023	2024	Pooled	2023	2024	Pooled
T ₁	45.93	47.32	46.62	43.13	44.53	43.83	40.33	41.73	41.03	36.62	38.47	37.54
T ₂	46.19	47.89	47.04	43.32	44.75	44.04	40.46	41.89	41.17	36.76	38.61	37.68
T ₃	48.66	50.12	49.39	44.57	46.61	45.59	40.48	42.52	41.50	36.85	38.66	37.75
T ₄	49.74	51.09	50.41	45.32	47.53	46.42	40.90	43.11	42.00	37.20	39.05	38.12
T ₅	46.49	48.45	47.47	43.44	44.96	44.20	40.39	41.91	41.15	36.68	38.53	37.60
T ₆	47.36	49.54	48.45	44.00	45.68	44.84	40.65	42.32	41.48	36.96	38.80	37.88
T ₇	46.96	48.88	47.92	43.74	45.35	44.54	40.53	42.13	41.33	36.83	38.68	37.75
T ₈	48.05	50.44	49.24	44.57	46.31	45.44	41.10	42.83	41.96	37.40	39.25	38.32
T ₉	49.76	51.23	50.49	45.32	47.54	46.43	40.89	43.10	41.99	37.19	39.04	38.11
T ₁₀	50.23	53.64	51.93	45.82	48.03	46.92	41.42	43.62	42.52	37.72	39.57	38.64
S Em±	0.74	0.60	0.67	0.55	0.69	0.67	0.47	0.39	0.60	0.49	0.58	0.63
CD at 5%	2.15	1.73	1.93	1.58	2.00	1.93	1.37	1.14	1.74	1.42	1.69	1.83

Continue.....

Treatments	25			30			35			40			45		
	DAS														
	2023	2024	Pooled	2023	2024	Pooled	2023	2024	Pooled	2023	2024	Pooled	2023	2024	Pooled
T ₁	33.18	34.90	34.04	28.70	30.94	29.82	25.54	27.12	26.33	23.64	24.59	24.11	21.89	22.76	22.32
T ₂	33.31	35.03	34.17	29.31	31.31	30.31	26.54	27.92	27.23	24.32	25.43	24.87	22.60	23.46	23.03
T ₃	33.40	35.12	34.26	29.74	31.57	30.65	26.58	28.16	27.37	24.43	25.50	24.96	22.68	23.55	23.11
T ₄	33.75	35.47	34.61	30.11	31.93	31.02	26.82	28.46	27.64	25.00	25.91	25.45	23.37	24.18	23.77
T ₅	33.23	34.95	34.09	29.24	31.23	30.23	26.07	27.65	26.86	23.71	24.89	24.30	21.96	22.83	22.39
T ₆	33.50	35.23	34.36	29.51	31.50	30.50	26.34	27.92	27.13	24.13	25.23	24.68	22.36	23.24	22.80
T ₇	33.35	35.09	34.22	29.34	31.34	30.34	26.17	27.75	26.96	23.84	25.00	24.42	22.16	23.00	22.58
T ₈	33.96	35.68	34.82	29.85	31.90	30.87	26.68	28.26	27.47	24.90	25.79	25.34	23.16	24.03	23.59
T ₉	33.73	35.46	34.59	29.62	31.67	30.64	26.45	28.03	27.24	24.25	25.35	24.80	22.60	23.42	23.01
T ₁₀	34.28	36.00	35.14	30.32	32.30	31.31	27.11	28.71	27.91	25.66	26.38	26.02	24.11	24.88	24.49
S Em±	0.57	0.54	0.49	0.35	0.59	0.40	0.40	0.36	0.41	0.30	0.34	0.43	0.37	0.42	0.48
CD at 5%	1.64	1.55	1.43	1.01	1.71	1.17	1.16	1.05	1.18	0.86	0.97	1.25	1.08	1.20	1.37

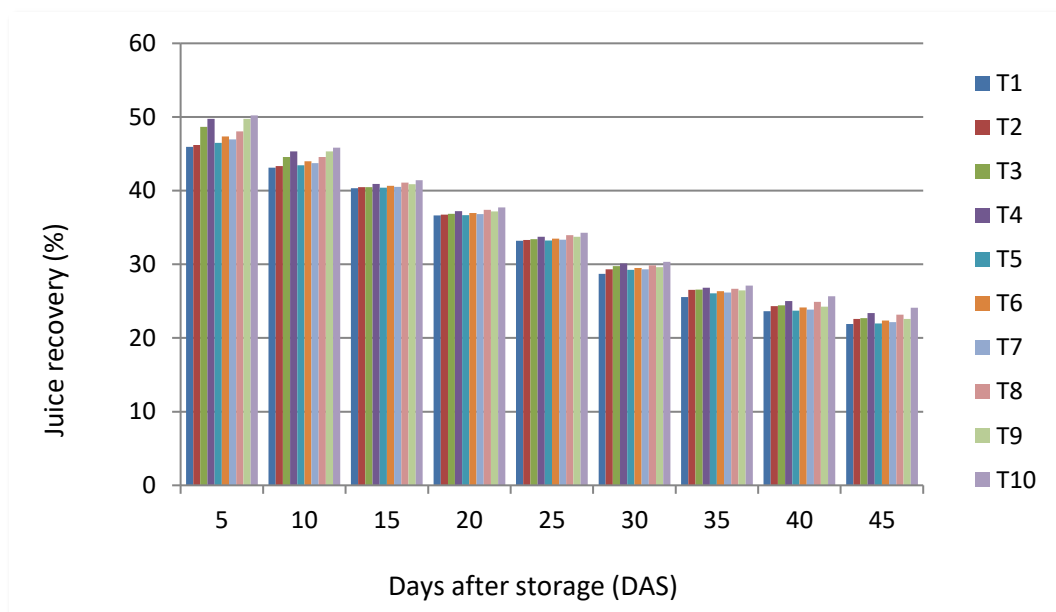


Fig 4.30 Juice recovery (%) of fruits during storage as influenced by microbial consortium and organic amendments during 2023

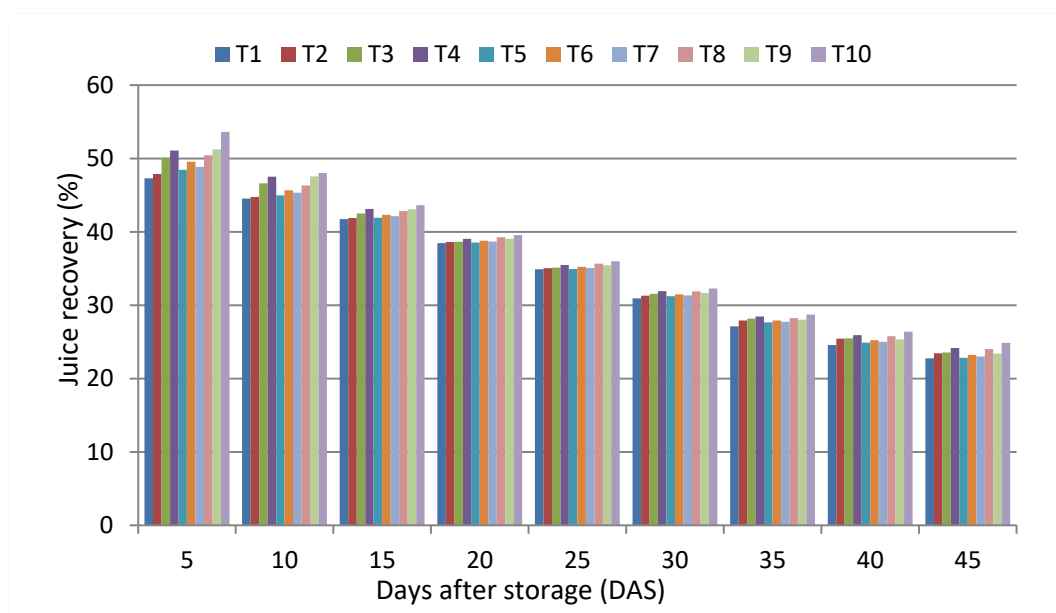


Fig 4.31 Juice recovery (%) of fruits during storage as influenced by microbial consortium and organic amendments during 2024

4.3.13.3 Total soluble solids in fruits (° Brix)

Table 4.15 and Figs 4.32, 4.33 clearly shows the total soluble solids of Khasi mandarin fruits as influenced by the various treatments in the first and second year of investigation and the pooled data. A close scrutiny of the table reveals that there was significant variation amongst the treatments. At the initial stage of storage (5 DAS), TSS values were relatively low and did not vary significantly across treatments, ranging from 8.09 °Brix (T₁) to 9.05 °Brix (T₁₀). This indicates that the initial TSS was fairly uniform among all fruits, reflecting minimal postharvest changes at this early stage.

By 10 DAS, gradual increases in TSS were observed in all treatments. T₁₀ (9.29%) consistently maintained higher TSS, whereas the T₁(8.18%) showed comparatively lower values. This suggests that the microbial consortium and organic amendments may help preserve sugar content during early storage. At 15 DAS, T₁₀ continued to demonstrate the highest TSS (9.61 °Brix). By 20 DAS, a clear divergence in TSS trends appeared especially T₁₀ retained higher and more stable TSS (9.71 °Brix), whereas T₁ (8.77%) and T₂(8.97%) exhibited relatively slower increments. This indicates the positive effect of treatments in moderating ripening and preserving sugar metabolism.

During the mid-storage period (25-35 DAS), an interesting trend emerged. T₁ began exhibiting higher TSS than many other treatments. For instance, at 30 DAS, T₁ reached 9.97 °Brix, surpassing several microbial and organic amendment treatments

However, this apparent superiority is not indicative of better quality. Rapid moisture loss through respiration and transpiration in control T₁ fruits led to the concentration of soluble solids, artificially elevating TSS. Additionally, uncontrolled ripening accelerated the hydrolysis of polysaccharides into simple sugars, further contributing to higher readings (Wills *et al.*, 1980; Hazrati *et al.*, 2012).

At advanced storage stages (40-45 DAS), TSS increased across all treatments, with control T₁ fruits showing the highest values (11.95 °Brix at 45 DAS) compared to other treatments. This trend is consistent with observations in papaya and plum,

where untreated fruits displayed higher TSS due to rapid water loss and substrate breakdown, whereas treated fruits maintained relatively lower but more stable TSS as a result of delayed metabolic activity (Lam, 1990; Hazrati *et al.*, 2012; Wills *et al.*, 1980).

Although control T₁ fruits recorded higher TSS at later stages, this reflects faster senescence and reduced storability, not superior eating quality. Treatments such as T₁₀, T₄, and T₆ were more effective in maintaining optimal TSS and prolonging fruit freshness by slowing degradation and preserving sugar stability.

Table 4.15 TSS (° Brix) during storage as affected by microbial consortium and organic amendment

Treatments	5			10			15			20		
	DAS											
	2023	2024	Pooled	2023	2024	Pooled	2023	2024	Pooled	2023	2024	Pooled
T ₁	8.09	8.10	8.09	8.11	8.25	8.18	8.40	8.55	8.47	8.70	8.85	8.77
T ₂	8.16	8.17	8.16	8.19	8.39	8.29	8.59	8.74	8.66	8.89	9.04	8.97
T ₃	8.20	8.34	8.27	8.49	8.69	8.59	8.90	8.97	8.93	9.05	9.12	9.08
T ₄	8.39	8.64	8.51	8.89	9.14	9.01	9.39	9.44	9.41	9.49	9.54	9.52
T ₅	8.23	8.36	8.29	8.50	8.69	8.59	8.89	8.96	8.92	9.04	9.12	9.08
T ₆	8.39	8.69	8.54	9.00	9.19	9.09	9.39	9.44	9.41	9.49	9.54	9.51
T ₇	8.29	8.44	8.36	8.60	8.80	8.70	9.00	9.09	9.04	9.19	9.29	9.24
T ₈	8.80	8.90	8.85	9.00	9.09	9.04	9.19	9.24	9.21	9.29	9.34	9.31
T ₉	8.80	8.90	8.85	9.00	9.09	9.04	9.19	9.24	9.21	9.29	9.34	9.31
T ₁₀	9.00	9.10	9.05	9.20	9.39	9.29	9.59	9.64	9.61	9.69	9.74	9.71
S Em±	0.12	0.14	0.11	0.14	0.16	0.14	0.17	0.12	0.12	0.14	0.09	0.14
CD at 5%	0.36	0.41	0.32	0.40	0.46	0.40	0.49	0.33	0.36	0.41	0.27	0.39

Continue.....

Treatments	25			30			35			40			45		
	DAS														
	2023	2024	Pooled	2023	2024	Pooled	2023	2024	Pooled	2023	2024	Pooled	2023	2024	Pooled
T ₁	9.00	9.40	9.20	9.80	10.14	9.97	10.49	10.84	10.66	11.19	11.49	11.34	11.80	12.10	11.95
T ₂	9.20	9.60	9.40	10.00	10.20	10.10	10.40	10.60	10.50	10.80	11.10	10.95	11.40	11.7	11.55
T ₃	9.20	9.29	9.24	9.39	9.54	9.46	9.69	9.84	9.77	10.00	10.4	10.2	10.80	11.2	11.00
T ₄	9.60	9.80	9.70	10.00	10.25	10.12	10.5	10.65	10.57	10.80	10.97	10.88	11.15	11.32	11.23
T ₅	9.20	9.39	9.29	9.59	9.79	9.69	9.99	10.24	10.12	10.50	10.85	10.67	11.20	11.55	11.37
T ₆	9.59	9.79	9.69	10.00	10.10	10.05	10.2	10.3	10.25	10.40	10.8	10.6	11.20	11.5	11.35
T ₇	9.39	9.59	9.49	9.79	9.89	9.84	9.99	10.09	10.04	10.19	10.62	10.40	11.05	11.48	11.26
T ₈	9.39	9.59	9.49	9.79	9.89	9.84	9.99	10.09	10.04	10.19	10.62	10.40	11.05	11.40	11.22
T ₉	9.39	9.49	9.44	9.59	9.84	9.71	10.0	10.24	10.17	10.40	10.70	10.55	11.00	11.3	11.15
T ₁₀	9.79	9.89	9.84	10.00	10.10	10.05	10.20	10.30	10.25	10.40	10.64	10.52	10.89	11.13	11.01
S Em±	0.16	0.14	0.15	0.11	0.12	0.12	0.21	0.20	0.16	0.15	0.08	0.18	0.16	0.19	0.14
CD at 5%	0.46	0.41	0.44	0.33	0.34	0.35	0.60	0.57	0.46	0.45	0.24	0.51	0.48	0.54	0.42

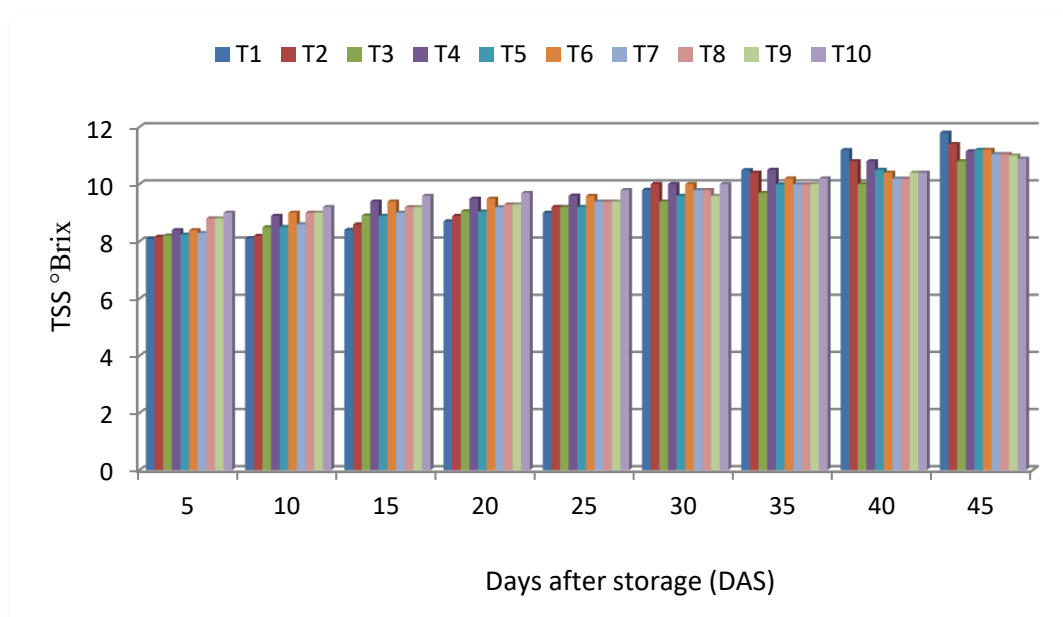


Fig 4.32 Total soluble solids (° Brix) of fruits during storage as influenced by microbial consortium and organic amendments during 2023

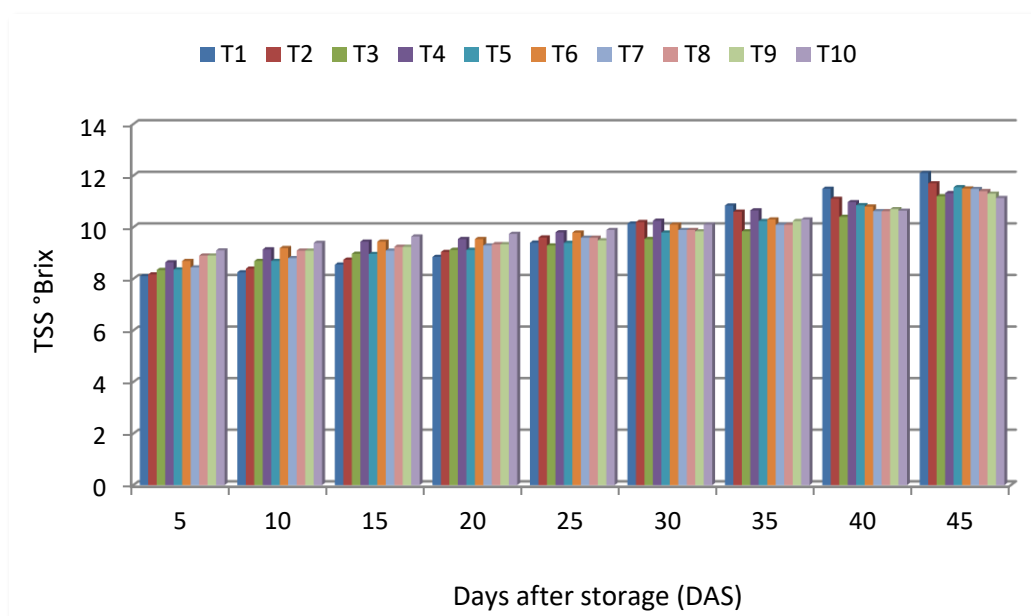


Fig 4.33 Total soluble solids (° Brix) of fruits during storage as influenced by microbial consortium and organic amendments during 2024

4.3.13.4 Titrable acidity in fruits (%)

Table 4.16 and Figs 4.34, 4.35 shows that Titrable acidity (TA) of Khasi mandarin fruits as influenced by the various treatments in the first and second year of investigation and the pooled data. A close scrutiny of the table reveals that there was significant variation amongst the treatments. Data clearly indicate progressive decline in TA from 5 to 45 DAS across all treatments, which aligns with the natural ripening and metabolic processes where organic acids are utilized as substrates for respiration and energy production (Kader, 2002; Wills *et al.*, 1980).

At 5 DAS, initial TA values ranged between 0.80% (T₁₀) and 0.89% (T₁). By 10 DAS, TA declined slightly in all treatments, with T₁₀ retaining 0.79% pooled, whereas T₁ recorded 0.87%. At 15 DAS, T₁₀ again exhibited better retention of acidity (0.78%) compared to T₁, which continued faster decline (0.85%). This trend suggests that microbial consortia in combination with organic amendments may help delay acid degradation by moderating respiration and enzymatic activity (Hazrati *et al.*, 2012). During 20-25 DAS, the decline in TA became more evident. At 20 DAS, T₁ had 0.82% TA, while T₁₀ retained 0.75%. By 25 DAS, T₁₀ continued to exhibit lower acidity (0.72%), whereas T₁ fruits registered higher acidity (0.80%). At 30 DAS, T₁₀ recorded only 0.68% whereas T₁ registered 0.77%. At 35-40 DAS, decline in TA was observed across all treatments, as expected during late ripening. T₁₀ consistently had lower acidity (0.65-0.61%) compared to T₁ (0.74-0.67%). By 45 DAS, T₁₀ maintained 0.56% TA, whereas T₇ fruits had higher acidity of 0.63%. The higher value in T₇ fruits suggests that pig manure helped in maintaining acid balance, likely through enhanced antioxidant activity and reduced metabolic stress (Kader, 2002; Rosenfeld *et al.*, 2013).

Table 4.16 Effect of microbial consortium with organic amendments on titrable acidity (%) in fruits during storage

Treatments	5			10			15			20		
	DAS											
	2023	2024	Pooled	2023	2024	Pooled	2023	2024	Pooled	2023	2024	Pooled
T ₁	0.90	0.89	0.89	0.88	0.87	0.87	0.86	0.84	0.85	0.83	0.82	0.82
T ₂	0.89	0.88	0.88	0.87	0.86	0.86	0.85	0.83	0.84	0.82	0.80	0.81
T ₃	0.83	0.82	0.82	0.82	0.81	0.81	0.81	0.79	0.80	0.78	0.77	0.77
T ₄	0.82	0.81	0.81	0.81	0.80	0.80	0.80	0.78	0.79	0.77	0.76	0.76
T ₅	0.84	0.83	0.83	0.82	0.81	0.81	0.80	0.78	0.79	0.77	0.75	0.76
T ₆	0.83	0.82	0.82	0.82	0.82	0.82	0.82	0.80	0.81	0.79	0.77	0.78
T ₇	0.87	0.86	0.86	0.86	0.85	0.85	0.85	0.83	0.84	0.82	0.80	0.81
T ₈	0.84	0.83	0.83	0.83	0.82	0.82	0.82	0.81	0.81	0.80	0.79	0.80
T ₉	0.84	0.83	0.83	0.82	0.81	0.81	0.80	0.78	0.79	0.77	0.76	0.76
T ₁₀	0.81	0.80	0.80	0.80	0.79	0.79	0.79	0.77	0.78	0.76	0.74	0.75
S Em±	0.01	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.02	0.01	0.01	0.01
CD at 5%	0.04	0.03	0.04	0.04	0.03	0.03	0.03	0.04	0.04	0.03	0.03	0.03

Continue.....

Treatments	25			30			35			40			45		
	DAS														
	2023	2024	Pooled	2023	2024	Pooled	2023	2024	Pooled	2023	2024	Pooled	2023	2024	Pooled
T ₁	0.81	0.79	0.80	0.78	0.77	0.77	0.76	0.72	0.74	0.69	0.66	0.67	0.63	0.59	0.61
T ₂	0.79	0.76	0.77	0.74	0.72	0.73	0.70	0.68	0.69	0.66	0.63	0.64	0.61	0.58	0.59
T ₃	0.76	0.74	0.75	0.72	0.70	0.71	0.69	0.66	0.67	0.64	0.62	0.63	0.60	0.57	0.58
T ₄	0.75	0.73	0.74	0.72	0.71	0.71	0.70	0.68	0.69	0.66	0.64	0.65	0.62	0.58	0.6
T ₅	0.74	0.72	0.73	0.71	0.69	0.70	0.68	0.65	0.66	0.63	0.61	0.62	0.59	0.55	0.57
T ₆	0.76	0.74	0.75	0.73	0.72	0.72	0.71	0.68	0.69	0.66	0.63	0.64	0.61	0.59	0.60
T ₇	0.79	0.77	0.78	0.76	0.74	0.75	0.73	0.71	0.72	0.69	0.67	0.68	0.65	0.62	0.63
T ₈	0.79	0.77	0.78	0.75	0.73	0.74	0.72	0.67	0.69	0.62	0.59	0.60	0.57	0.53	0.55
T ₉	0.75	0.73	0.74	0.72	0.71	0.71	0.70	0.68	0.69	0.67	0.64	0.65	0.61	0.58	0.59
T ₁₀	0.73	0.71	0.72	0.69	0.67	0.68	0.66	0.64	0.65	0.62	0.60	0.61	0.58	0.54	0.56
S Em±	0.01	0.01	0.02	0.01	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
CD at 5%	0.04	0.02	0.04	0.04	0.03	0.04	0.04	0.03	0.04	0.02	0.03	0.03	0.02	0.03	0.03

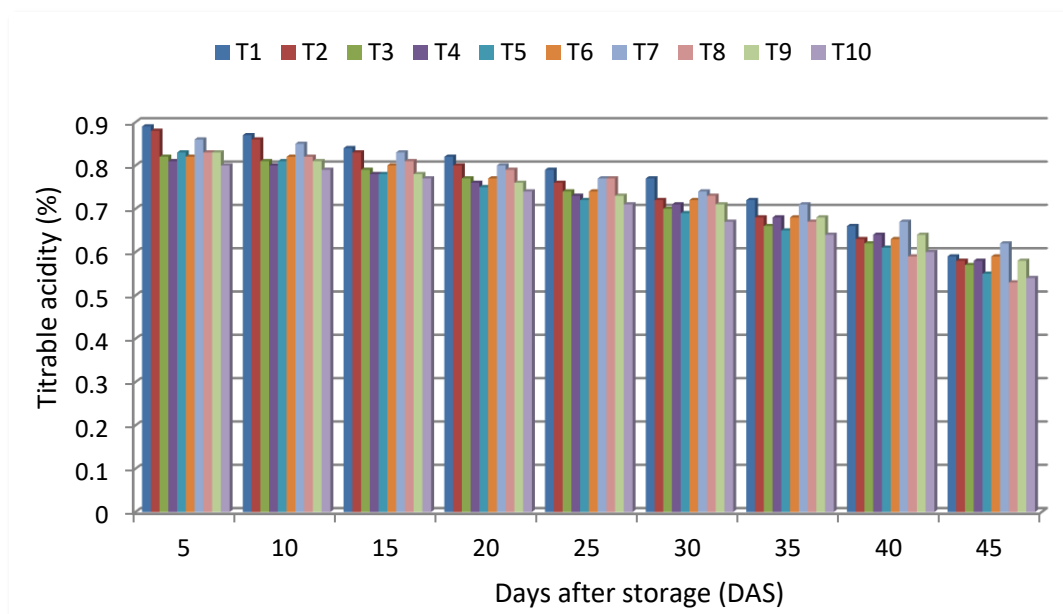


Fig 4.34 Titration acidity (%) of fruits during storage as influenced by microbial consortium and organic amendments during 2023

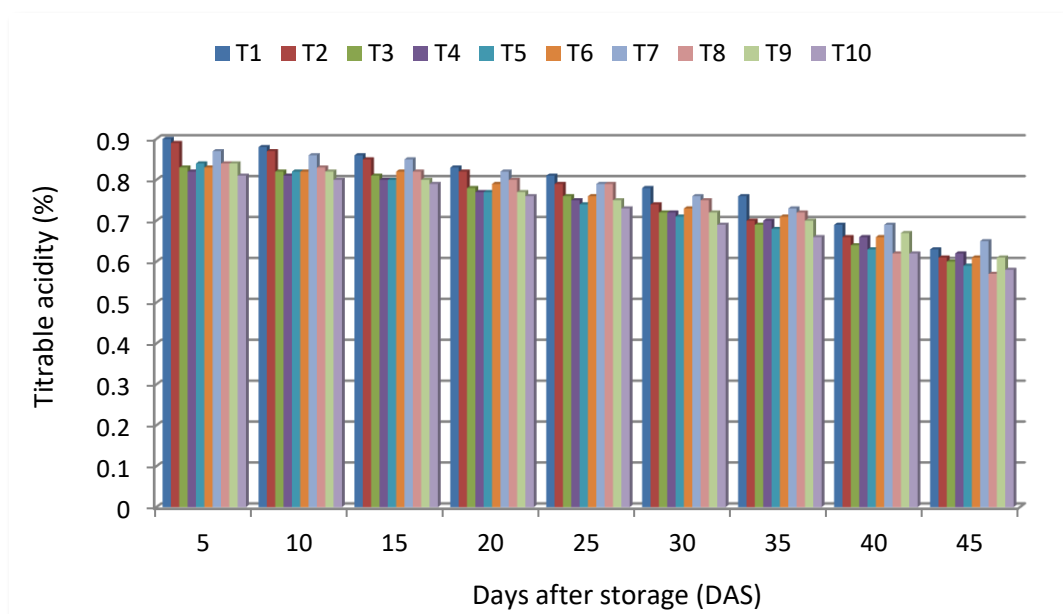


Fig 4.35 Titration acidity (%) of fruits during storage as influenced by microbial consortium and organic amendments during 2024

4.3.13.5 Total sugar in fruits (%)

Table 4.17 and Figs 4.36, 4.37 shows the total sugar of Khasi mandarin fruits as influenced by the various treatments in the first and second year of investigation and the pooled data. A close scrutiny of the table reveals that there was significant variation amongst the treatments. At 5 DAS, total sugar content in Khasi mandarin fruits ranged from 5.54% in T₁ (control) to 6.67% in T₁₀. Among all treatments, T₁₀ recorded the highest total sugar, followed closely by T₈ (6.43%) and T₇ (6.22%), while the control had the lowest. This superiority of T₁₀ continued at 10 DAS (6.74%) and 15 DAS (6.81%), showing significantly higher levels than the control (5.60%). Such early increases in total sugars under microbial and organic amendments can be attributed to enhanced photosynthate accumulation and improved carbohydrate translocation into fruits before harvest (Kumar *et al.*, 2019; Saikia and Pathak, 2020).

Between 20 and 30 DAS, a gradual increase in total sugar content was evident in all treatments, though the rate was faster in T₁₀ and T₈. At 20 DAS, T₁₀ maintained 6.84% total sugar compared to 5.63% in the control. By 25 DAS, T₁₀ registered 6.87%, whereas the control remained at 5.65%. At 30 DAS, T₁₀ reached 6.89% whereas 5.68% in the control. This consistent superiority indicates that microbial consortia with organic amendments helped sustain enzymatic conversion of starches into soluble sugars while slowing degradation and respiration losses (Bisen *et al.*, 2020; Hazrati *et al.*, 2012). The better nutritional status under these treatments likely delayed senescence and supported a steady increase in sweetness. During the later storage stages, total sugar content continued to rise slightly across all treatments but began stabilizing in the control fruits, reflecting their advanced senescence. At 35 DAS, T₁₀ recorded 6.92% total sugar against 5.71% in the control. By 40 DAS, T₁₀ retained 6.95% compared with 5.74% in T₁. At 45 DAS, T₁₀ peaked at 7.05%, the highest among all treatments, while the control showed 5.81%. The continued sugar accumulation in treated fruits can be linked to delayed metabolic breakdown and better preservation of soluble carbohydrates (Sharma *et al.*, 2019). In contrast, control fruits underwent faster moisture loss and oxidative degradation, leading to relatively lower total sugars by the end of storage (Wills *et al.*, 1980).

Across all storage intervals, total sugars exhibited a progressive increase, more pronounced in T₁₀, T₈, and T₇ than in the control. This trend aligns with the typical postharvest physiology of citrus fruits, where starch reserves are gradually hydrolyzed to soluble sugars and organic acids decline, increasing perceived sweetness (Hazrati *et al.*, 2012). Treatments combining microbial consortium and organic amendments appear to modulate enzyme activity (invertases, amylases) and slow oxidative losses, thereby prolonging the rise in sugars while maintaining fruit firmness and storability (Bhattacharya and Chandra, 2017; Mitra *et al.*, 2018).

T₁₀ consistently maintained the highest total sugar content from the beginning to the end of storage, followed by T₈ and T₇. The control fruits (T₁) showed the lowest values throughout. This demonstrates that microbial consortium with organic amendments not only improve preharvest carbohydrate accumulation but also enhance postharvest sugar stability, leading to superior fruit quality and consumer acceptability.

Table 4.17 Effect of microbial consortium with organic amendments on total sugar content (%) in fruits during storage

Treatments	5			10			15			20		
	DAS											
	2023	2024	Pooled	2023	2024	Pooled	2023	2024	Pooled	2023	2024	Pooled
T ₁	5.53	5.55	5.54	5.57	5.58	5.57	5.60	5.61	5.60	5.62	5.63	5.63
T ₂	5.82	5.84	5.83	5.85	5.86	5.86	5.88	5.89	5.88	5.90	5.91	5.91
T ₃	5.93	5.95	5.94	5.97	5.99	5.98	6.01	6.02	6.01	6.03	6.05	6.04
T ₄	6.00	6.02	6.01	6.04	6.06	6.05	6.08	6.09	6.08	6.10	6.12	6.11
T ₅	5.79	5.80	5.79	5.82	5.84	5.83	5.87	5.88	5.87	5.90	5.92	5.91
T ₆	6.02	6.04	6.03	6.06	6.09	6.08	6.13	6.14	6.13	6.15	6.17	6.16
T ₇	6.21	6.23	6.22	6.26	6.30	6.28	6.35	6.36	6.35	6.37	6.39	6.38
T ₈	6.42	6.44	6.43	6.47	6.51	6.49	6.55	6.56	6.55	6.58	6.59	6.58
T ₉	6.05	6.06	6.05	6.08	6.10	6.09	6.13	6.14	6.13	6.15	6.17	6.16
T ₁₀	6.66	6.69	6.67	6.72	6.76	6.74	6.81	6.82	6.81	6.83	6.85	6.84
S Em±	0.09	0.10	0.09	0.09	0.09	0.10	0.09	0.07	0.08	0.10	0.08	0.13
CD at 5%	0.25	0.30	0.27	0.25	0.25	0.29	0.27	0.20	0.24	0.28	0.24	0.38

Continue....

Treatments	25			30			35			40			45		
	DAS														
	2023	2024	Pooled	2023	2024	Pooled	2023	2024	Pooled	2023	2024	Pooled	2023	2024	Pooled
T ₁	5.65	5.66	5.65	5.67	5.69	5.68	5.70	5.72	5.71	5.73	5.75	5.74	5.77	5.83	5.81
T ₂	5.93	5.94	5.93	5.95	5.97	5.96	5.98	5.97	5.98	6.01	6.03	6.02	6.04	6.09	6.06
T ₃	6.06	6.07	6.07	6.09	6.10	6.09	6.11	6.13	6.12	6.14	6.16	6.15	6.18	6.21	6.19
T ₄	6.13	6.14	6.14	6.16	6.17	6.16	6.18	6.20	6.19	6.21	6.23	6.22	6.25	6.29	6.27
T ₅	5.93	5.94	5.94	5.95	5.97	5.96	5.98	6.00	5.98	6.01	6.03	6.02	6.04	6.12	6.08
T ₆	6.18	6.19	6.19	6.21	6.22	6.21	6.23	6.25	6.24	6.26	6.28	6.27	6.29	6.33	6.31
T ₇	6.40	6.41	6.41	6.42	6.44	6.43	6.45	6.47	6.46	6.48	6.50	6.49	6.51	6.54	6.53
T ₈	6.60	6.61	6.61	6.63	6.64	6.63	6.65	6.67	6.66	6.68	6.70	6.697	6.72	6.76	6.74
T ₉	6.18	6.19	6.18	6.20	6.22	6.21	6.23	6.25	6.24	6.26	6.28	6.27	6.31	6.34	6.32
T ₁₀	6.86	6.87	6.87	6.89	6.90	6.89	6.91	6.93	6.92	6.94	6.96	6.95	6.98	7.12	7.05
S Em±	0.12	0.08	0.09	0.10	0.09	0.10	0.08	0.10	0.09	0.07	0.09	0.09	0.07	0.09	0.09
CD at 5%	0.34	0.24	0.25	0.28	0.27	0.29	0.24	0.28	0.26	0.20	0.26	0.27	0.21	0.27	0.26

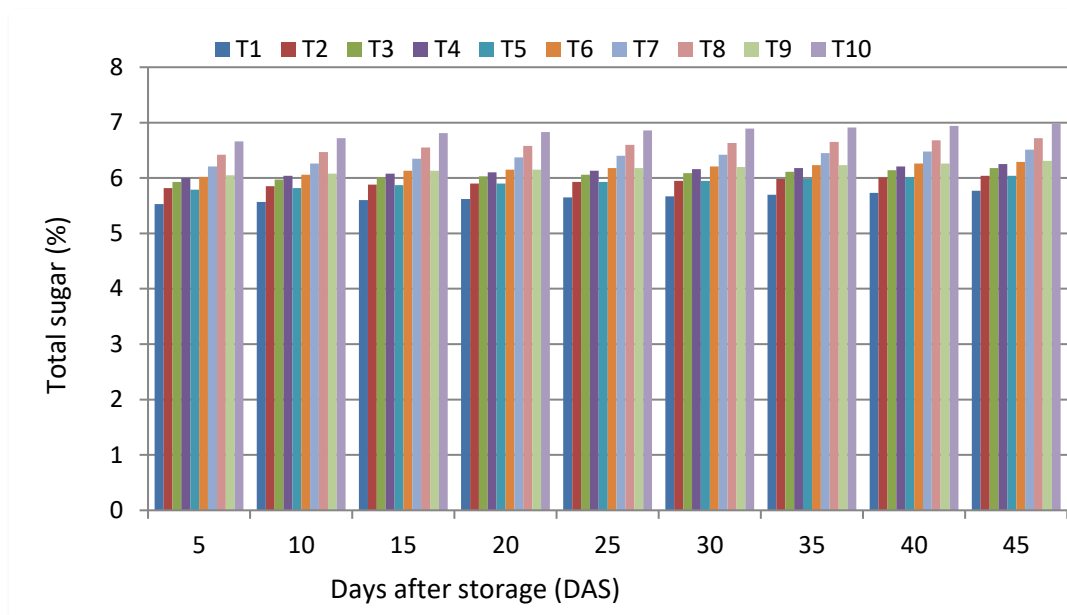


Fig 4.36 Total sugar (%) of fruits during storage as influenced by microbial consortium and organic amendments during 2023

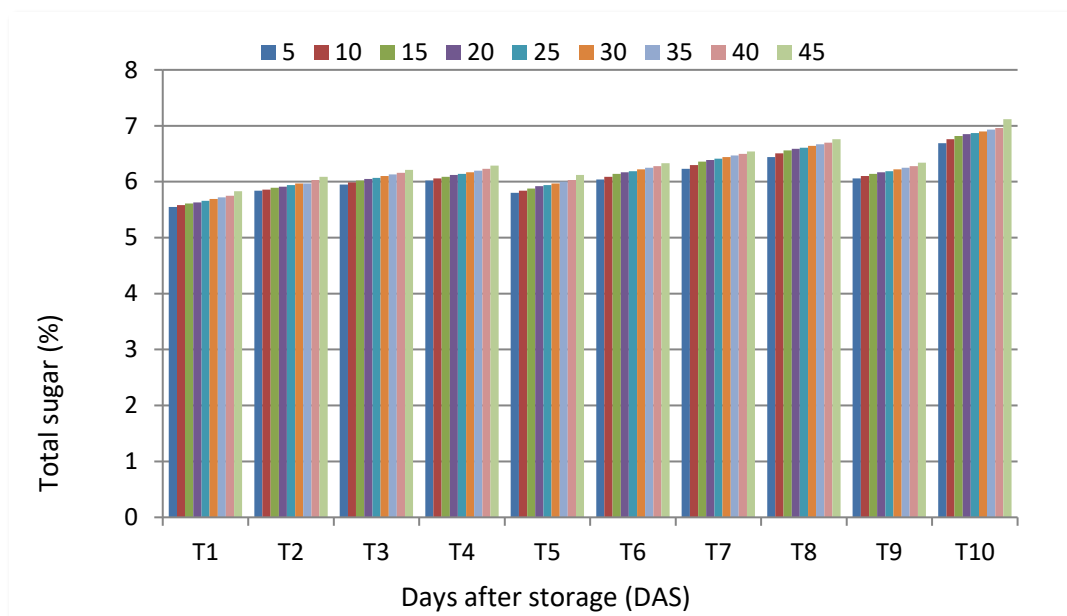


Fig 4.37 Total sugar (%) of fruits during storage as influenced by microbial consortium and organic amendments during 2024

4.3.13.6 Reducing sugar in fruits (%)

Table 4.18 and Figs 4.38, 4.39 shows the reducing sugar of Khasi mandarin fruits as influenced by the various treatments in the first and second year of investigation and the pooled data. A close scrutiny of the table reveals that there was significant variation amongst the treatments. At 5 DAS, reducing sugar content in Khasi mandarin fruits ranged from 3.81% in T₁ (control) to 4.05% in T₁₀. T₁₀ was significantly superior to all other treatments, followed by T₈ (3.98%) and T₇ (3.95%), whereas the control fruits exhibited the lowest reducing sugar content. A similar trend continued at 10 and 15 DAS, with T₁₀ maintaining the highest values (4.09% and 4.12%, respectively) compared to the control (3.83% and 3.86%, respectively). This pattern suggests that microbial consortium enhanced carbohydrate metabolism and sugar accumulation in the early stages of fruit maturity. Previous studies have reported that biofertilizers and organic amendments improve photosynthetic efficiency and translocation of assimilates into the fruit, thereby elevating reducing sugars during early maturation (Kumar *et al.*, 2019; Mitra *et al.*, 2018).

From 20 to 30 DAS, reducing sugar content continued to rise across all treatments, though the rate of increase was highest in T₁₀. At 20 DAS, T₁₀ recorded 4.15% compared to 3.90% in the control. By 25 DAS, T₁₀ increased to 4.18%, while the control reached only 3.93%. At 30 DAS, the highest reducing sugar was again observed in T₁₀ (4.22%), followed by T₈ (4.15%) and T₇ (4.12%), whereas T₁ recorded only 3.97%. This consistent superiority of microbial treatments could be attributed to enhanced enzymatic activity, especially invertases and amylases, which convert non-reducing sugars and starches into reducing sugars (Bhattacharya and Chandra, 2017). Moreover, the microbial consortium may have delayed respiration-driven degradation of sugars, thereby maintaining higher sweetness levels for longer periods (Bisen *et al.*, 2020).

In the later stages of fruit development (35-45 DAS), reducing sugars continued their upward trend but began to stabilize in the control fruits. At 35 DAS, T₁₀ recorded 4.25%, compared with 4.01% in T₁. By 40 DAS, T₁₀ reached 4.28% and

peaked at 4.32% and at 45 DAS the highest among all treatments while T₁ reached only 4.10%. This final stage pattern indicates that the microbial consortium delayed senescence and promoted the retention of reducing sugars. According to Wills *et al.* (1980), postharvest respiration accelerates sugar breakdown, but microbial and organic amendments likely buffered this effect by maintaining membrane integrity and antioxidant enzyme systems, thus slowing degradation (Sharma *et al.*, 2019).

Reducing sugar content showed a steady rise from 5 to 45 DAS across all treatments, with the highest values consistently recorded in T₁₀, followed by T₈ and T₇. Control fruits displayed the lowest values at all stages. This trend reflects normal fruit ripening physiology, where polysaccharides are progressively broken down to reducing sugars, enhancing sweetness (Hazrati *et al.*, 2012). Microbial consortium with organic amendments appear to stimulate this process early while also delaying postharvest senescence, leading to higher reducing sugar retention even in later stages (Saikia and Pathak, 2020).

T₁₀ was the most effective treatment for maintaining and enhancing reducing sugars throughout storage, followed by T₈ and T₇. Control fruits recorded the lowest values, underscoring the benefits of microbial consortium plus organic amendment in improving and sustaining fruit sweetness during storage.

Table 4.18 Effect of microbial consortium with organic amendments on reducing sugar content (%) in fruits during storage

Treatments	5			10			15			20		
	DAS											
	2023	2024	Pooled	2023	2024	Pooled	2023	2024	Pooled	2023	2024	Pooled
T ₁	3.79	3.81	3.81	3.83	3.84	3.83	3.86	3.87	3.86	3.89	3.91	3.90
T ₂	3.87	3.89	3.88	3.91	3.93	3.92	3.94	3.96	3.95	3.97	3.99	3.98
T ₃	3.83	3.85	3.84	3.86	3.88	3.87	3.90	3.92	3.91	3.93	3.95	3.94
T ₄	3.90	3.91	3.91	3.93	3.95	3.94	3.97	3.98	3.97	4.00	4.01	4.01
T ₅	3.81	3.82	3.8	3.84	3.85	3.84	3.87	3.89	3.88	3.90	3.92	3.91
T ₆	3.89	3.91	3.90	3.92	3.94	3.93	3.96	3.97	3.96	3.99	4.01	4.00
T ₇	3.95	3.96	3.95	3.98	3.90	3.98	4.01	4.03	4.02	4.04	4.06	4.05
T ₈	3.97	3.99	3.98	4.01	4.02	4.01	4.03	4.05	4.05	4.07	4.09	4.08
T ₉	3.87	3.89	3.88	3.92	3.93	3.93	3.95	3.96	3.96	3.98	4.00	4.00
T ₁₀	4.04	4.06	4.05	4.08	4.09	4.09	4.11	4.12	4.12	4.14	4.16	4.15
S Em±	0.05	0.05	0.07	0.05	0.06	0.06	0.05	0.05	0.05	0.06	0.06	0.06
CD at 5%	0.15	0.15	0.20	0.16	0.17	0.17	0.15	0.15	0.15	0.19	0.17	0.16

Continue.....

Treatments	25			30			35			40			45		
DAS															
	2023	2024	Pooled	2023	2024	Pooled	2023	2024	Pooled	2023	2024	Pooled	2023	2024	Pooled
T ₁	3.92	3.94	3.93	3.96	3.98	3.97	4.00	4.02	4.01	4.04	4.07	4.05	4.09	4.12	4.10
T ₂	4.01	4.02	4.02	4.04	4.06	4.05	4.08	4.10	4.09	4.12	4.14	4.13	4.16	4.19	4.17
T ₃	3.97	3.99	3.98	4.01	4.02	4.01	4.04	4.06	4.05	4.08	4.09	4.09	4.11	4.14	4.13
T ₄	4.03	4.05	4.04	4.07	4.09	4.08	4.11	4.13	4.12	4.14	4.16	4.15	4.18	4.21	4.19
T ₅	3.94	3.96	3.95	3.97	3.99	3.98	4.01	4.03	4.02	4.05	4.07	4.06	4.08	4.11	4.10
T ₆	4.03	4.04	4.04	4.06	4.08	4.07	4.10	4.12	4.11	4.14	4.16	4.15	4.17	4.21	4.19
T ₇	4.07	4.09	4.08	4.11	4.13	4.12	4.15	4.17	4.16	4.19	4.21	4.19	4.22	4.26	4.24
T ₈	4.11	4.12	4.11	4.14	4.16	4.15	4.17	4.19	4.18	4.21	4.22	4.22	4.24	4.28	4.26
T ₉	4.01	4.03	4.02	4.05	4.06	4.06	4.08	4.10	4.09	4.12	4.13	4.13	4.15	4.19	4.17
T ₁₀	4.18	4.19	4.18	4.21	4.23	4.22	4.24	4.26	4.25	4.28	4.29	4.28	4.31	4.34	4.32
S Em±	0.06	0.06	0.05	0.07	0.06	0.07	0.07	0.04	0.05	0.06	0.06	0.07	0.07	0.03	0.06
CD at 5%	0.18	0.17	0.15	0.20	0.19	0.20	0.20	0.13	0.16	0.18	0.17	0.21	0.20	0.10	0.18

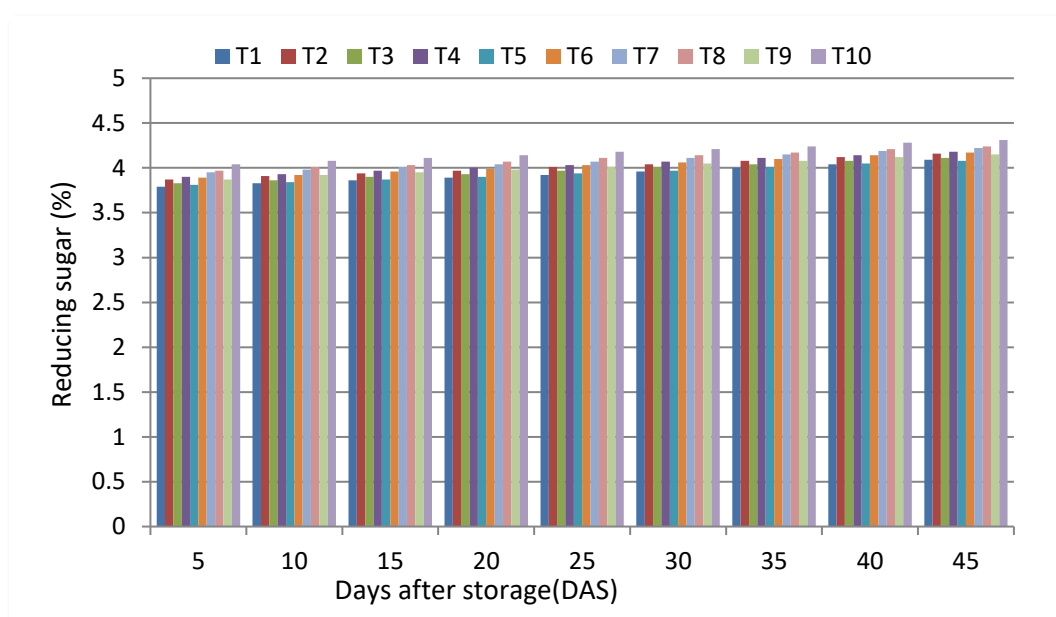


Fig 4.38 Reducing sugar (%) of fruits during storage as influenced by microbial consortium and organic amendments during 2023

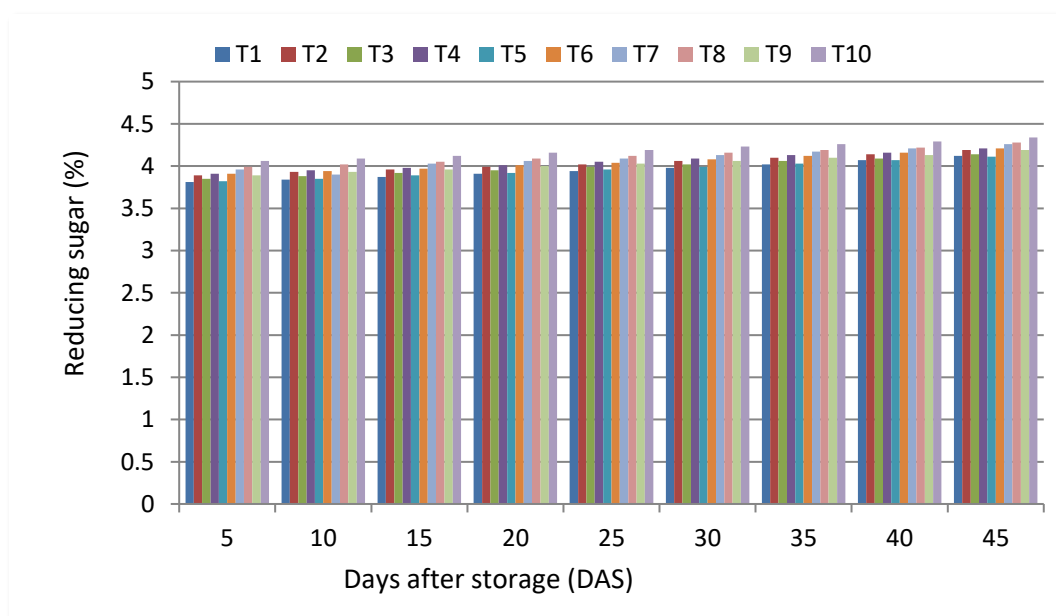


Fig 4.39 Reducing sugar (%) of fruits during storage as influenced by microbial consortium and organic amendments during 2024

4.3.13.7 Ascorbic acid content in fruits (mg/ 100ml)

Table 4.19 and Figs 4.40, 4.41 shows the ascorbic acid content of Khasi mandarin fruits as influenced by the various treatments in the first and second year of investigation and the pooled data. A close scrutiny of the table reveals that there was significant variation amongst the treatments. The data revealed a gradual decline in ascorbic acid content with the advancement of storage/maturity (from 5 to 45 DAS), irrespective of treatment, which is consistent with the well-established trend of vitamin C degradation during fruit ripening due to enzymatic oxidation and metabolic utilization (Lee and Kader, 2000; Davey *et al.*, 2000). However, significant differences were observed among treatments at each stage, highlighting the beneficial effect of microbial and organic amendments in retaining vitamin C.

At 5 DAS, the highest ascorbic acid content was recorded in T₁₀ (33.25 mg/100g), which was significantly superior to all other treatments, followed by T₄ (31.91 mg/100g) and T₈ (31.71 mg/100g). The lowest value was observed in T₁ (28.80 mg/100g). This trend continued at 10 and 15 DAS, where T₁₀ maintained its superiority (31.91 and 29.88 mg/100g, respectively), while control treatments T₁ and T₂ consistently recorded the lowest values. These observations suggest that microbial consortia combined with organic amendments promoted early accumulation and stabilization of vitamin C in developing fruits, likely by enhancing nutrient absorption, stimulating antioxidant enzyme activity, and protecting cellular structures from oxidative stress (Rosenfeld *et al.*, 2013; Sharma *et al.*, 2020).

As fruits matured, a gradual decline in ascorbic acid content was observed across all treatments. At 20 DAS, T₁₀ retained the highest pooled content (27.95 mg/100g), followed by T₈ (27.44 mg/100g) and T₄ (27.29 mg/100g), whereas T₁ recorded the lowest (24.40 mg/100g). This trend persisted at 25 and 30 DAS, with T₁₀ maintaining superiority (26.12 and 24.58 mg/100g, respectively) and T₈ and T₄ performing consistently better than other treatments. Treatments T₁ exhibited the lowest vitamin C content (21.04 mg/100g). The decline in ascorbic acid at this stage is attributed to increased enzymatic oxidation (ascorbate oxidase activity) and

utilization of vitamin C as a cofactor in metabolic processes during ripening (Davey *et al.*, 2000; Lee and Kader, 2000).

During the later stages of fruit maturity, a sharper decline in ascorbic acid was evident. At 35 DAS, T₁₀ retained the highest value (23.14 mg/100g), significantly superior to all other treatments, followed by T₈ (22.64 mg/100g) and T₄ (22.50 mg/100g). T₁ remained the lowest (19.61 mg/100g). At 40 DAS, T₁₀ recorded 21.82 mg/100g and T₁ the lowest (18.26 mg/100g). By 45 DAS, the minimum ascorbic acid content was recorded across all treatments, yet T₁₀ still maintained the highest (21.04 mg/100g), followed by T₄ (19.85 mg/100g) and T₈ (19.65 mg/100g), with T₁ at the lowest (16.56 mg/100g). These results indicate that microbial consortium applications delayed oxidative degradation of vitamin C, preserving higher concentrations for a longer period (Sharma *et al.*, 2020; Rosenfeld *et al.*, 2013).

The study clearly demonstrates that ascorbic acid content declines progressively with fruit maturation, but treatments T₁₀, T₄, and T₈ consistently maintained higher levels throughout storage. The vermicompost and microbial consortium, particularly in T₁₀, enhanced vitamin C retention, possibly by improving nutrient uptake, increasing antioxidant activity, and slowing enzymatic degradation. T₁ consistently exhibited the lowest vitamin C content at all stages, indicating faster oxidative degradation and lower postharvest quality.

Table 4.19 Influence of microbial consortium with organic amendments on ascorbic acid content (mg/ 100ml) in fruits during storage

Treatments	5			10			15			20		
	DAS											
	2023	2024	Pooled	2023	2024	Pooled	2023	2024	Pooled	2023	2024	Pooled
T ₁	28.57	29.04	28.80	27.59	28.08	27.83	25.78	26.68	26.23	23.95	24.86	24.40
T ₂	29.31	29.67	29.49	28.64	28.97	28.81	26.97	27.80	27.38	25.14	26.05	25.60
T ₃	30.43	30.82	30.62	29.68	30.05	29.86	27.90	28.79	28.34	26.07	26.98	26.53
T ₄	31.73	32.09	31.91	30.59	31.16	30.87	28.65	29.62	29.13	26.85	27.74	27.29
T ₅	30.03	30.55	30.29	28.86	29.44	29.15	26.86	27.86	27.36	25.04	25.95	25.49
T ₆	30.76	31.47	31.11	29.26	30.01	29.63	27.11	28.18	27.64	25.28	26.19	25.74
T ₇	30.68	31.17	30.92	29.70	30.19	29.94	27.53	28.61	28.07	25.70	26.61	26.16
T ₈	31.50	31.92	31.71	30.65	31.07	30.86	28.81	29.73	29.27	26.98	27.89	27.44
T ₉	30.90	31.42	31.16	29.90	30.40	30.15	27.84	28.87	28.35	26.06	26.95	26.50
T ₁₀	32.92	33.59	33.25	31.58	32.25	31.91	29.32	30.45	29.88	27.49	28.41	27.95
S Em±	0.58	0.60	0.48	0.39	0.47	0.40	0.41	0.40	0.42	0.36	0.42	0.38
CD at 5%	1.67	1.74	1.37	1.13	1.36	1.16	1.19	1.15	1.22	1.03	1.22	1.10

Continue.....

Treatments	25			30			35			40			45		
	DAS														
	2023	2024	Pooled	2023	2024	Pooled	2023	2024	Pooled	2023	2024	Pooled	2023	2024	Pooled
T ₁	22.12	23.03	22.57	20.68	21.4	21.04	19.24	19.96	19.61	17.94	18.59	18.26	16.10	17.02	16.56
T ₂	23.32	24.23	23.77	21.87	22.59	22.23	20.43	21.15	20.79	19.14	19.78	19.46	17.76	18.45	18.10
T ₃	24.25	25.16	24.70	22.81	23.53	23.17	21.37	22.09	21.73	20.07	20.72	20.39	19.17	19.62	19.39
T ₄	25.04	25.94	25.49	23.59	24.31	23.95	22.14	22.86	22.50	20.85	21.49	21.17	19.52	20.18	19.85
T ₅	23.22	24.13	23.67	21.77	22.49	22.13	20.32	21.04	20.68	19.03	19.67	19.35	17.87	18.45	18.16
T ₆	23.46	24.37	23.91	22.01	22.73	22.37	20.56	21.28	20.92	19.27	19.91	19.59	18.10	18.68	18.39
T ₇	23.88	24.79	24.33	22.44	23.16	22.80	21.00	21.72	21.36	19.70	20.35	20.02	18.88	19.29	19.08
T ₈	25.16	26.07	25.61	23.72	24.44	24.08	22.28	23.00	22.64	20.99	21.63	21.31	19.21	20.10	19.65
T ₉	24.29	25.17	24.73	22.84	23.56	23.20	21.39	22.11	21.75	20.11	20.75	20.43	18.99	19.55	19.27
T ₁₀	25.67	26.58	26.12	24.22	24.94	24.58	22.78	23.50	23.14	21.50	22.14	21.82	20.89	21.19	21.04
S Em±	0.26	0.26	0.32	0.34	0.30	0.32	0.28	0.39	0.40	0.39	0.27	0.26	0.32	0.28	0.24
CD at 5%	0.76	0.76	0.91	0.97	0.88	0.91	0.80	1.14	1.17	1.12	0.78	0.76	0.93	0.82	0.71

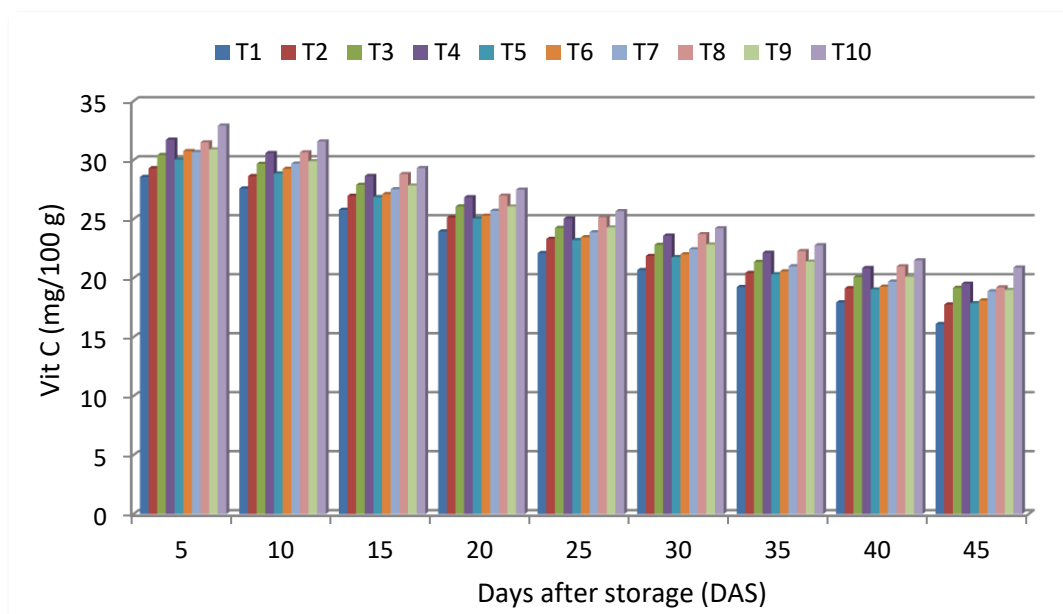


Fig 4.40 Ascorbic acid content (mg/100ml) of fruits during storage as influenced by microbial consortium and organic amendments during 2023

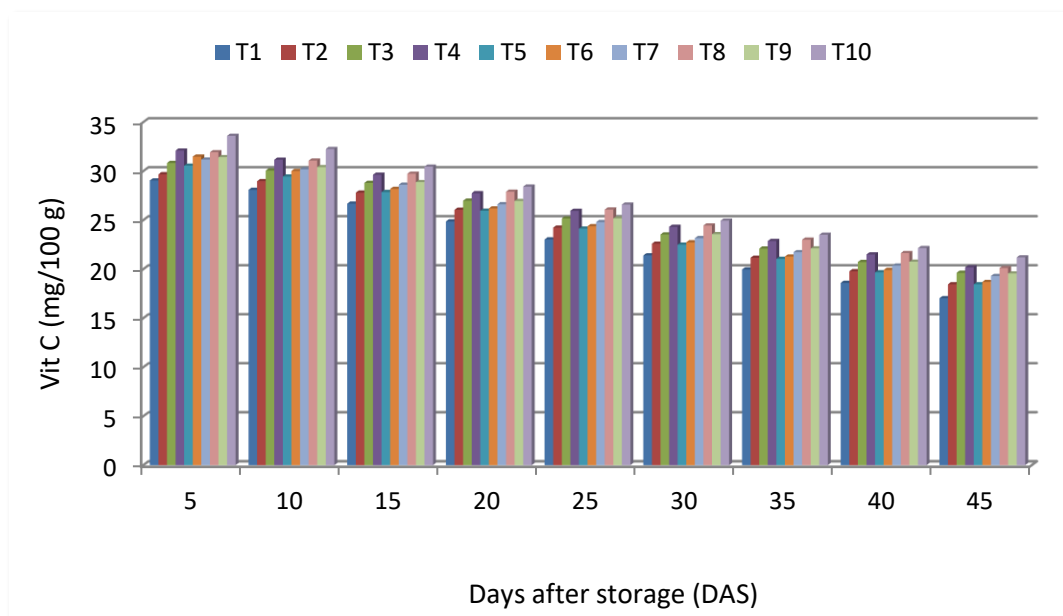


Fig 4.41 Ascorbic acid content (mg/100ml) of fruits during storage as influenced by microbial consortium and organic amendments during 2024



T₁



T₂



T₃



T₄



T₅



T₆



T₇



T₈



T₉



T₁₀

Plate 4.4 Harvested fruits from various treatments

4.3.14 Soil Characteristics

4.3.14.1 Soil pH

Soil pH is a key indicator of soil chemical health and strongly influences nutrient availability and microbial activity in the rhizosphere. The data presented in Table 4.20 and Fig 4.42, show that soil pH values exhibited slight variation among the treatments during both years of the study. During the first year, soil pH ranged from 6.10 (T₁, T₂, T₅, T₆) to 6.40 (T₉ and T₁₀), while in second year, it varied between 6.10 (T₅, T₆) and 6.44 (T₁₀). The pooled mean followed a similar pattern, with pH values ranging from 6.10 to 6.42. The highest soil pH was recorded under T₁₀ (6.42), which was statistically at par with T₉ (6.40) and T₇ (6.33), whereas the lowest values were observed in T₁, T₂, T₅ and T₆ (6.10-6.12). Treatments T₉ and T₁₀, which included vermicompost and microbial consortium applications, likely enhanced buffering capacity through increased soil organic matter and microbial metabolites that neutralize acidity. The observed near-neutral pH values (6.3-6.4) under these treatments suggest improved soil conditions conducive to nutrient availability, especially for nitrogen, phosphorus, and micronutrients such as Fe and Zn (Brady and Weil, 2017). Overall pH values across treatments remained within the optimal range (6.0-6.5) for Khasi mandarin cultivation, implying that none of the treatments caused harmful acidification or alkalization of the soil.

These findings are consistent with reports by Saha *et al.* (2021) and Mishra *et al.* (2019), who observed that the incorporation of organic manures and microbial inoculants stabilized soil pH near neutral levels by enhancing cation exchange and base saturation. Thus, it can be inferred that treatments T₉ and T₁₀ maintained a more favorable soil reaction, contributing to better nutrient dynamics and microbial activity in the Khasi mandarin rhizosphere.

Table 4.20 Effect of microbial consortium with organic amendments on soil characteristics

	Soil pH			C (%)			N(kg/ha)			P(kg/ha)			K(kg/ha)		
Treatments	2023	2024	Pooled	2023	2024	Pooled	2023	2024	Pooled	2023	2024	Pooled	2023	2024	Pooled
T ₁	6.10	6.14	6.12	1.04	1.09	1.06	356.20	364.50	360.35	33.15	34.12	33.63	200.36	203.61	201.98
T ₂	6.10	6.12	6.11	1.10	1.10	1.10	401.40	409.10	405.25	38.88	38.96	38.92	209.55	214.65	212.10
T ₃	6.30	6.33	6.31	1.37	1.39	1.38	326.14	329.21	327.67	28.14	30.12	29.13	184.48	190.45	187.46
T ₄	6.30	6.33	6.31	1.34	1.36	1.35	342.10	350.95	346.52	35.71	37.62	36.66	189.16	196.18	192.67
T ₅	6.10	6.10	6.10	1.15	1.17	1.16	301.05	309.08	305.06	23.67	26.67	25.17	179.13	183.19	181.16
T ₆	6.10	6.10	6.10	1.10	1.14	1.12	316.00	321.54	318.77	25.71	27.51	26.61	181.41	184.11	182.76
T ₇	6.30	6.35	6.32	1.20	1.23	1.21	313.60	319.54	316.57	30.21	32.11	31.16	183.42	186.43	184.92
T ₈	6.30	6.31	6.30	1.13	1.15	1.14	325.00	330.52	327.76	33.54	35.45	34.49	188.56	191.80	190.18
T ₉	6.40	6.40	6.40	1.34	1.37	1.35	320.50	322.04	321.27	32.11	33.44	32.77	185.61	187.54	186.57
T ₁₀	6.40	6.44	6.42	1.30	1.33	1.31	337.20	341.12	339.16	36.41	39.66	38.03	191.44	195.61	193.52
S Em±	0.08	0.09	0.08	0.02	0.02	0.02	5.14	3.45	3.23	0.41	0.42	0.47	3.02	2.70	2.29
CD at 5%	0.24	0.25	0.24	0.06	0.06	0.07	14.88	9.90	9.33	1.18	1.20	1.35	8.74	7.80	6.61

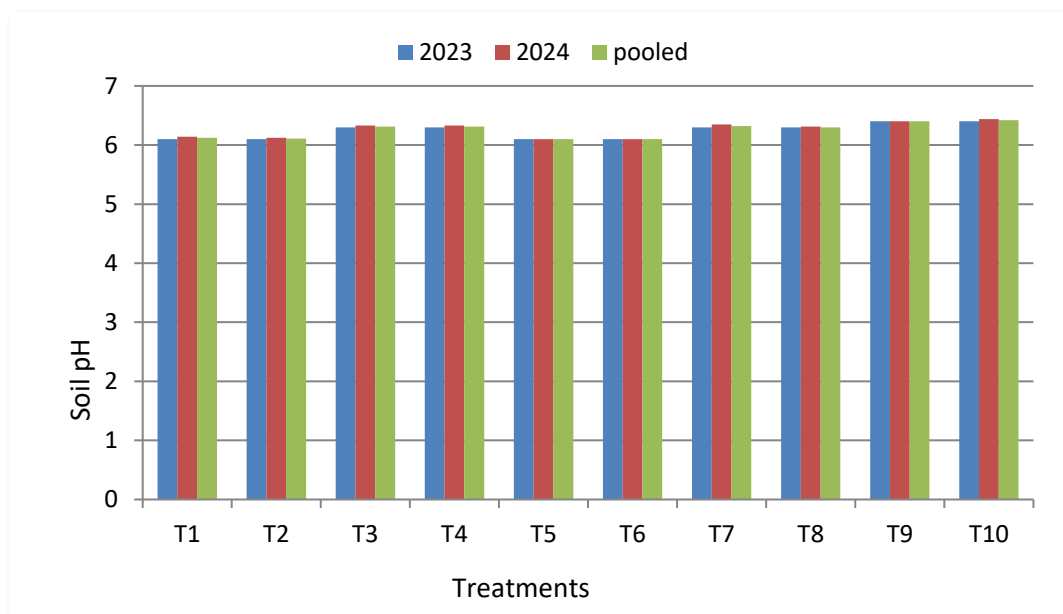


Fig 4.42 Influence of microbial consortium with organic inputs on soil pH in two years of study

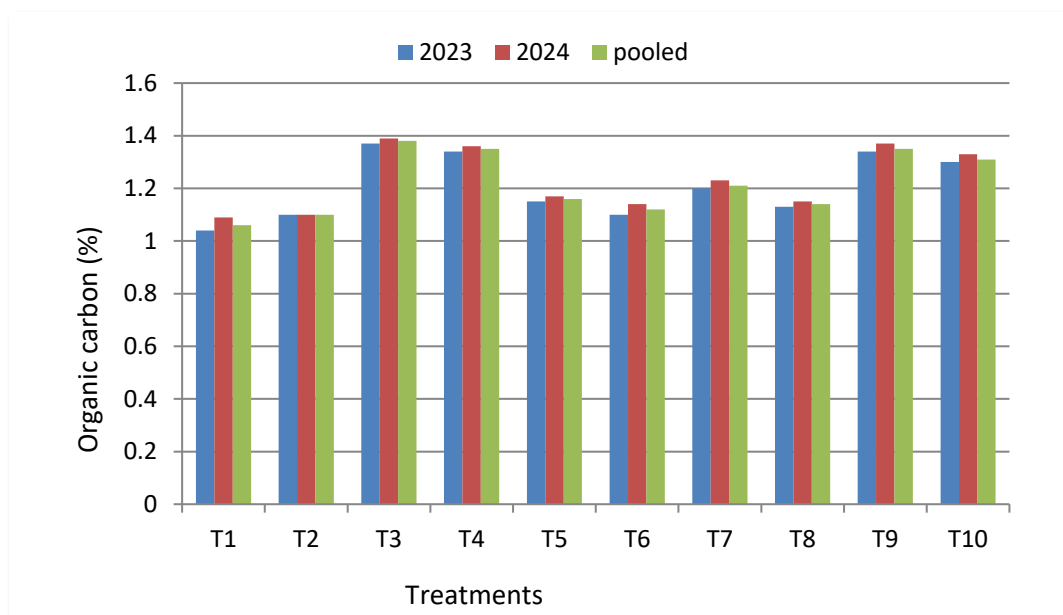


Fig 4.43 Influence of microbial consortium with organic inputs on soil organic carbon (%) in two years of study

4.3.14.2 Soil organic carbon (%)

The organic carbon content of soil is a key indicator of soil fertility, influencing nutrient availability, microbial activity, and overall soil structure. The data presented in Table: 4.20 and Fig 4.43 reveal a marked variation in organic carbon (C) percentage among different treatments during both years of the studies. During first year, soil organic carbon ranged from 1.04% in the control treatment (T₁) to 1.37 % in T₃, while in second year, values varied between 1.09% (T₁) and 1.39% (T₃). The pooled data followed a similar trend, with organic carbon content ranging from 1.06% to 1.38%. The highest organic carbon was consistently observed in T₃ (1.38%), followed closely by T₄ (1.35%) and T₉ (1.35%), while the lowest values occurred in T₁ (1.065%) and T₂ (1.10%).

The significant increase in soil organic carbon under treatments T₃, T₄, and T₉ may be attributed to the application of organic manures and microbial consortium that promote decomposition of organic residues and stabilization of soil organic matter. The microbial inoculants likely enhanced the formation of humic substances through microbial transformation of root exudates and organic amendments. Similar findings were reported by Mishra *et al.* (2019) and Saha *et al.* (2021), who observed that incorporation of microbial and organic inputs significantly, increased organic carbon in citrus rhizospheric soils. Conversely, the relatively lower organic carbon observed in T₁ and T₂ may be due to limited addition of organic matter and reduced microbial activity, leading to lower carbon sequestration in the soil. Nevertheless, all treatments maintained organic carbon above 1%, indicating overall fertile soil conditions suitable for Khasi mandarin cultivation.

4.3.14.3 Available soil nitrogen (kg ha⁻¹)

Table 4.20 and Fig 4.44 show the total available nitrogen in Khasi mandarin orchard as influenced by the various treatments in the first and second year of investigation and the pooled data. A close scrutiny of the table reveals that there was significant variation amongst the treatments. During the first year, the available

nitrogen content ranged from 301.05 kg ha⁻¹ (T₅) to 401.40 kg ha⁻¹ (T₂). In the second year it ranged from 309.08 kg ha⁻¹ (T₅) to 409.10 kg ha⁻¹ (T₂). The pooled data followed a similar pattern, with nitrogen content varying from 305.07 kg ha⁻¹ (T₅) to 405.25 kg ha⁻¹ (T₂).

The maximum available nitrogen recorded in T₂ was statistically superior to all other treatments, followed by T₁ (360.35 kg ha⁻¹) and T₄ (346.53 kg ha⁻¹), while the lowest was observed under T₅. The significant improvement in nitrogen availability under T₂ could be attributed to the application of microbial consortium along with the fertilizers that enhance nitrogen mineralization and biological nitrogen fixation thereby increasing soil N content in plant-available forms. Enhanced nitrogen mineralization through microbial action has been well documented by Chakraborty *et al.* (2016b) and Sarma *et al.* (2018b) in citrus-based systems. Overall, the results demonstrate that T₂ was most effective in enhancing available nitrogen, followed by T₁ and T₄, while T₅ recorded the lowest value. The consistent improvement in available nitrogen across treatments highlights the role of microbial inoculants and organic materials in maintaining soil fertility and supporting nutrient supply in the Khasi mandarin rhizosphere.

4.3.14.4 Available soil phosphorus (kg ha⁻¹)

Table 4.20 and Fig 4.45 show the total available phosphorus (P) of Khasi mandarin orchard as influenced by the various treatments in the first and second year of investigation and the pooled data. A close scrutiny of the table reveals that there was significant variation amongst the treatments. In first year, soil phosphorus ranged from 23.67 kg ha⁻¹ (T₅) to 38.88 kg ha⁻¹ (T₂), while in second year, it varied between 26.67 kg ha⁻¹ (T₅) and 39.66 kg ha⁻¹ (T₁₀). The pooled data followed a similar pattern, with values ranging from 25.17 kg ha⁻¹ in T₅ to a maximum of 38.92 kg ha⁻¹ in T₂, closely followed by T₁₀ (38.04 kg ha⁻¹) and T₄ (36.67 kg ha⁻¹).

The highest phosphorus availability under T₂ was statistically superior to the rest of the treatments and can be attributed to application of fertilizer which increased its total availability and enhanced phosphorus solubilization and mobilization through

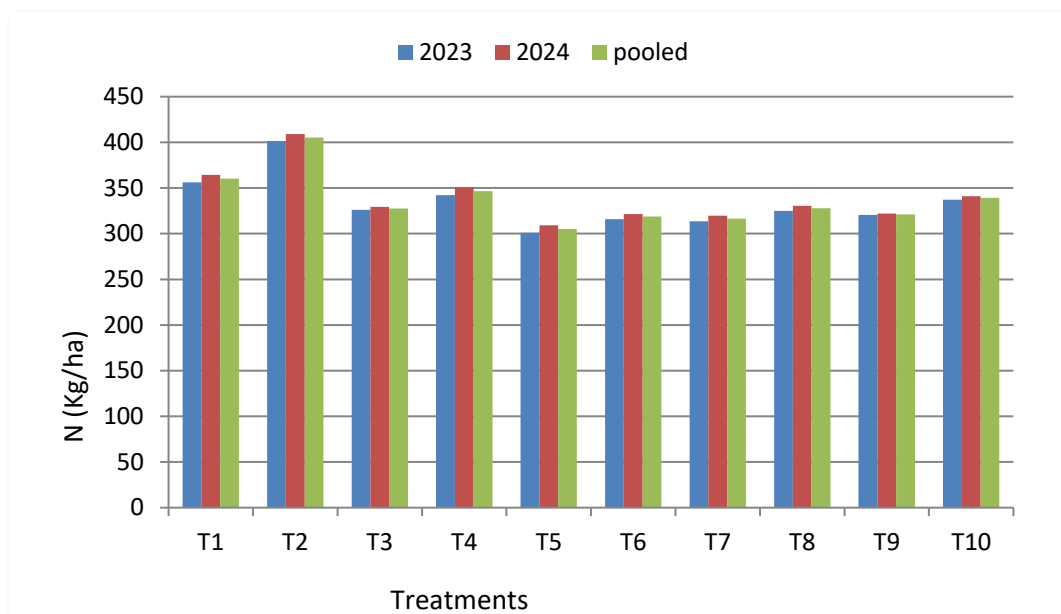


Fig 4.44 Influence of microbial consortium with organic inputs on available soil nitrogen (kg ha^{-1}) in two years of study

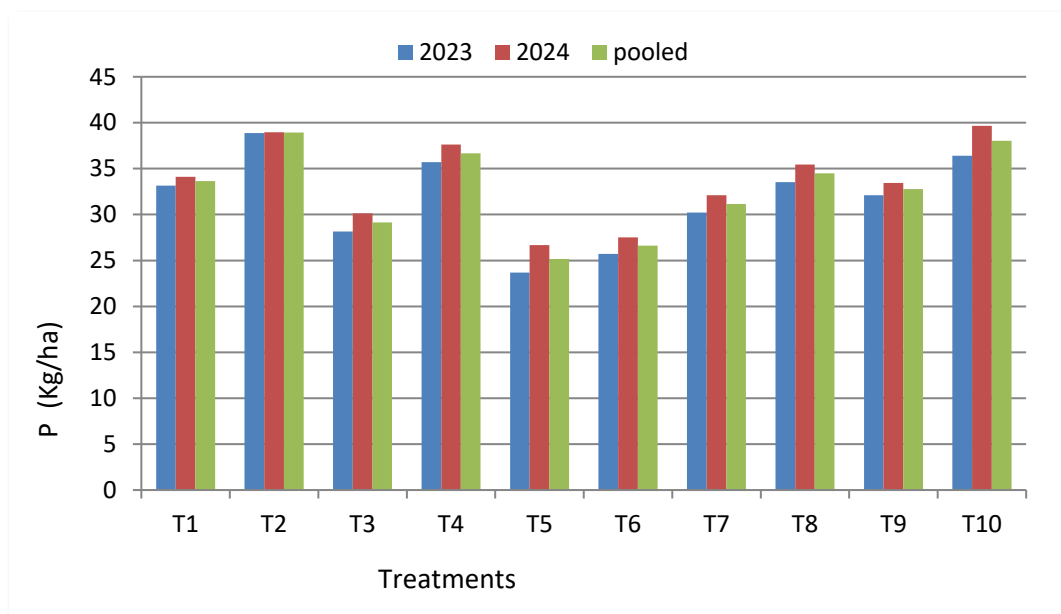


Fig 4.45 Influence of microbial consortium with organic inputs on available soil Phosphorous (kg ha^{-1}) in two years of study

microbial consortium. Microbial consortium likely released organic acids, phosphatases, and chelating agents that convert insoluble inorganic phosphates into plant-available forms, thereby increasing the soil P pool. The improvement observed under T₄ and T₁₀ could similarly be linked to the synergistic effects of organic manure decomposition and microbial activity, which maintain a favorable rhizosphere pH and support sustained phosphorus availability. Conversely, T₅ consistently recorded the lowest phosphorus content across both years and pooled data, indicating limited nutrient mineralization and reduced microbial activity in the absence of bio-organic enrichment. However, the overall phosphorus levels across all treatments remained within the medium to high fertility range, suggesting adequate P status for Khasi mandarin growth.

These findings corroborate earlier reports by Patel *et al.* (2020) and Saha *et al.* (2021), who observed that integrated application of organic manures and microbial inoculants significantly increased available phosphorus through enhanced solubilization and reduced fixation in citrus rhizosphere soils. Therefore, it can be inferred that T₂ and T₁₀ were most effective in maintaining high soil phosphorus availability, contributing to improved nutrient balance and sustainable soil fertility in Khasi mandarin cultivation.

4.3.14.5 Available soil potassium (kg ha⁻¹)

Table 4.20 and Fig 4.46 show the total available potassium (K) of Khasi mandarin orchard as influenced by the various treatments in the first and second year of investigation and the pooled data. A close scrutiny of the table reveals that there was significant variation amongst the treatments. In the first year, available soil K ranged from 179.13 kg ha⁻¹ (T₅) to 209.55 kg ha⁻¹ (T₂), while in second year, the values varied between 183.19 kg ha⁻¹ (T₅) and 214.65 kg ha⁻¹ (T₂). The pooled mean followed a similar trend, ranging from 181.16 kg ha⁻¹ (T₅) to a maximum of 212.10 kg ha⁻¹ (T₂).

The highest potassium availability observed in T₂ was statistically superior to all other treatments, followed by T₁ (201.99 kg ha⁻¹) and T₄ (192.67 kg ha⁻¹), whereas

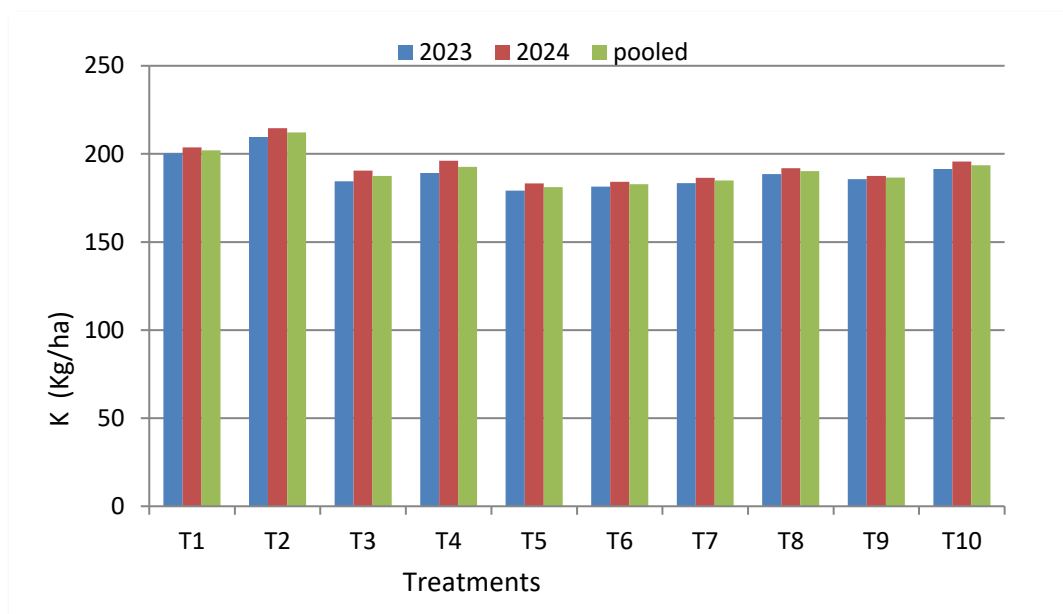


Fig 4.46 Influence of microbial consortium with organic inputs on available soil Potassium (kg ha^{-1}) in two years of study

T₅ recorded the lowest K content. The improved potassium status under T₂ can be attributed to fertilizer application and enhanced microbial-mediated solubilization and mineral weathering processes. Microorganisms, particularly potassium-solubilizing bacteria (KSB), release organic acids and chelators that mobilize potassium from insoluble minerals into available forms, thus increasing soil K concentration (Meena *et al.*, 2014).

Treatments receiving a combination of organic manures and microbial inoculants (T₄, T₈ and T₁₀) also exhibited moderate improvement in soil K availability. This can be ascribed to increased cation exchange capacity (CEC), improved soil structure, and enhanced nutrient retention due to the buildup of organic matter and humic substances. The relatively lower potassium content in T₅ and T₆ may be due to the absence of such bioactive inputs and possible nutrient depletion under continuous crop uptake. However, all treatments maintained K levels within the medium fertility range (180-220 kg ha⁻¹), suitable for sustaining Khasi mandarin growth.

4.3.15 Economic attributes

4.3.15.1 Influence of soil treatments on fruit yield (t ha⁻¹)

Significant variation in fruit yield of Khasi mandarin was observed among the different treatments during both years of studies shown in Table 4.21. The yield data revealed a clear positive response to the application of organic and microbial treatments compared to the control.

In first year, fruit yield ranged from 3.232 t ha⁻¹ (T₁) to 3.928 t ha⁻¹ (T₄), while in second year, yield varied between 4.568 t ha⁻¹ (T₅) and 5.112 t ha⁻¹ (T₁₀). The highest yield in first year was recorded under T₄ (3.928 t ha⁻¹), closely followed by T₁₀ (3.760 t ha⁻¹) and T₈ (3.688 t ha⁻¹). Similarly, in second year, T₁₀ achieved the maximum yield (5.112 t ha⁻¹), followed by T₈ (5.008 t ha⁻¹) and T₉ (4.988 t ha⁻¹).

The consistent superiority of T₁₀ across both years indicates the strong positive influence of vermicompost and microbial inputs on fruit production. Treatments T₈ and T₉ also produced comparable yields, highlighting the effectiveness of bio-organic combinations in sustaining soil fertility and improving nutrient uptake efficiency. The substantial yield enhancement under these treatments can be attributed to improved soil physicochemical properties, higher organic carbon, and enhanced availability of nitrogen, phosphorus, and potassium conditions that favour better root growth, nutrient absorption, and fruit development. Lower yields in T₁ and T₅ may be due to nutrient limitations, poorer soil structure, and reduced microbial activity, which limit the plant's physiological and reproductive potential. The progressive increase in yield from first year to second year across all treatments reflects the residual and cumulative effects of organic and microbial amendments, which improve soil fertility and plant vigour over time.

These findings are in agreement with the observations of Sarma *et al.* (2018b) and Saha *et al.* (2021), who reported that the integration of organic manures with microbial inoculants significantly enhanced fruit yield in citrus by improving soil biological activity and nutrient cycling. Hence, it can be inferred that T₁₀, followed by T₈ and T₉, was most effective in improving fruit yield, underscoring the potential of

integrated nutrient management strategies for achieving higher productivity and sustainability in Khasi mandarin cultivation.

4.3.15.2 Influence of soil treatments on Cost of cultivation (₹ ha⁻¹)

The total cost of cultivation of Khasi mandarin varied appreciably among the different treatments during both years of experimentation due to variations in input use, organic materials, and microbial consortium as shown in Table: 4.21. The total cost in first year ranged from ₹70,646 ha⁻¹ (T₅) to ₹1,20,486 ha⁻¹ (T₃), while in second year it varied between ₹70,576 ha⁻¹ (T₅) and ₹1,20,427 ha⁻¹ (T₃).

The highest cost incurred in T₃ was mainly due to higher expenditure on organic inputs and bio-inoculants, which generally require more labour and material handling. This was followed by T₄ (₹1,06,486 ha⁻¹) and T₂ (₹82,486 ha⁻¹). In contrast, the lowest cost of cultivation was recorded in T₅ (₹70,646 ha⁻¹) and T₁ (₹72,486 ha⁻¹), which received minimal or no organic and microbial additions. Although the cost of cultivation was relatively higher under treatments incorporating organic and microbial amendments, the corresponding increases in fruit yield and net returns justified these investments. Treatments T₈, T₉, and T₁₀, which recorded the highest yields, maintained moderate total costs (₹72,646–₹75,446 ha⁻¹), thereby achieving the most favorable benefit–cost ratio. This indicates that strategic integration of bio-organic inputs enhances productivity without proportionally increasing cultivation expenses. The relatively low variation in cost between years (less than 1% difference) suggests stable input pricing and management consistency throughout the experimental period. These findings are consistent with the observations of Patel *et al.* (2020) and Sarma *et al.* (2018b), who reported that moderate input-based organic modules optimize resource utilization and improve profitability in citrus cultivation systems.

Overall, it can be inferred that while T₃ involved the highest investment, treatments T₈, T₉ and T₁₀ offered the best economic efficiency due to their balanced input costs and significantly higher yields, making them the most economically viable modules for sustainable Khasi mandarin production.

4.3.15.3 Influence of soil treatments on Gross return (₹ ha⁻¹)

As shown in Table 4.21, the gross return of Khasi mandarin varied notably among different treatments during both years of studies, reflecting the combined influence of yield performance and prevailing market prices. In first year, gross return ranged from ₹1,93,920 ha⁻¹ (T₁) to ₹2,35,680 ha⁻¹ (T₄), whereas in second year, it varied between ₹2,74,080 ha⁻¹ (T₅) and ₹3,06,720 ha⁻¹ (T₁₀). The results clearly indicate that higher yields obtained from treatments integrating microbial and organic inputs directly translated into greater economic returns.

The maximum gross return was achieved under T₁₀, closely followed by T₈ and T₉, corresponding to their superior fruit yield performance in both years. Treatments T₂, T₄, and T₆ also produced comparatively high returns, reflecting the beneficial effects of treatments in improving fruit productivity. On the other hand T₁ and T₅ recorded the lowest gross returns due to relatively lower yields.

The overall increase in gross returns from first year to second year across all treatments demonstrates the residual and cumulative effects of organic and microbial applications in enhancing soil fertility and sustaining productivity over time. This trend aligns with the findings of Sarma *et al.* (2018b) and Patel *et al.* (2020), who reported that organic and microbial integration in citrus cultivation significantly improved gross returns by enhancing nutrient availability, soil health, and fruit quality. Although the total cost of cultivation was marginally higher in treatments with organic and microbial inputs, the proportionate increase in yield and gross return ensured higher profitability. Therefore, T₁₀ followed by T₈ and T₉, proved to be the most economically efficient treatments, offering the highest gross returns while maintaining moderate input costs. This highlights the economic sustainability of integrated nutrient management modules for Khasi mandarin cultivation.

4.3.15.4 Influence of soil treatments on net return (₹ ha⁻¹)

The net return from Khasi mandarin cultivation varied markedly among different treatments during both years of the study as shown in Table 4.21. The differences in net return correspond closely with variations in yield and total cost,

clearly demonstrating the economic advantage of bio-organic and microbial interventions.

In first year, net returns ranged from ₹83994 ha⁻¹ (T₃) to ₹152154 ha⁻¹ (T₁₀), whereas in second year, the values varied between ₹161514 ha⁻¹ (T₃) and ₹233274ha⁻¹ (T₁₀).The highest net return was consistently recorded under T₁₀, followed by T₈ (₹148634 and ₹227834 ha⁻¹) and T₉ (₹144634 and ₹223834 ha⁻¹)for 2023 and 2024, respectively. Conversely, T₃ recorded the lowest net return in both years, owing to its high cost of cultivation and moderate yield. The markedly superior net returns under T₁₀ indicate that this treatment combination effectively optimized input use and yield efficiency, leading to maximum profitability. Treatments T₈ and T₉ also demonstrated high economic viability, showing that the integration of organic manures with microbial consortia creates a favorable soil plant microbe interaction, which enhances nutrient availability and fruit yield, thereby improving net income.

The progressive increase in net returns from first year to second year across all treatments reflects the cumulative effects of organic and microbial applications on soil fertility and plant performance. This sustained improvement over time underscores the long-term benefits of integrated nutrient management for perennial fruit crops like Khasi mandarin. These findings are in agreement with the reports of Saha *et al.* (2021) and Sarma *et al.* (2018b), who observed that the use of microbial inoculants in combination with organic fertilizers not only increased yield but also improved profitability in citrus orchards by reducing chemical fertilizer dependency and improving soil biological health. Hence, based on the two-year average, T₁₀ recorded the highest economic return, followed by T₈ and T₉, confirming these as the most profitable and sustainable treatments for Khasi mandarin cultivation under the given agro-climatic conditions.

4.3.15.5 Influence of soil treatments on Benefit: Cost ratio

The Benefit: Cost (B: C) ratio is an important economic indicator used to assess the profitability and efficiency of different production modules. The data presented in Table: 4.21 show that considerable variations were observed among the

treatments across both years of study. During first year, the B:C ratio ranged from 0.69 to 2.072, while in second year, it ranged from 1.341 to 3.176, indicating an overall improvement in the economic return over the years.

Among the treatments, the highest B:C ratio was recorded in T₁₀ (2.072 in first year and 3.176 in second year), followed closely by T₆ (2.03 and 3.152) and T₈ (2.046 and 3.126). These treatments exhibited superior profitability, suggesting that the combination of organic inputs with microbial inoculants substantially enhanced yield and return per unit cost of production. The lowest B:C ratio was noted in T₃ (0.69 in 2023 and 1.341 in 2024), reflecting poor cost-effectiveness, possibly due to lower fruit yield or higher input costs.

A marked improvement in B:C ratio was observed in all treatments during 2024 compared to 2023, with percentage increases ranging from 42.1 % to 94.3 %. This positive trend could be attributed to the residual effects of organic and microbial amendments, which likely improved soil fertility and plant performance over time. Similar findings were reported by Sharma *et al.* (2020) and Gogoi and Barbora (2022), who observed higher benefit: cost ratios under integrated nutrient management in citrus due to cumulative improvement in yield and input-use efficiency. Overall, the results clearly indicated that treatments integrating organic sources such as compost or manure along with microbial consortium were economically more viable and sustainable for Khasi mandarin cultivation, providing maximum benefit per unit investment compared to sole chemical control.

Table 4.21 Economics in cultivation in organic mediated Khasi mandarin plants

	Yield (t/ha)		Total cost		Gross return		Net return		Benefit: cost ratio	
Treatments	2023	2024	2023	2024	2023	2024	2023	2024	2023	2024
T ₁	3.232	4.592	72486	72365	193920	275520	121434	203034	1.675	2.801
T ₂	3.564	4.920	82486	82408	213840	295200	131354	212714	1.592	2.578
T ₃	3.408	4.700	120486	120427	204480	282000	83994	161514	0.690	1.341
T ₄	3.928	4.852	106486	106438	235680	291120	129194	184634	1.220	1.734
T ₅	3.248	4.568	70646	70576	194880	274080	124234	203434	1.758	2.879
T ₆	3.576	4.916	71046	71005	214560	294960	143514	223914	2.030	3.152
T ₇	3.540	4.848	73846	73773	212400	300576	138554	226730	1.876	3.070
T ₈	3.688	5.008	72646	72802	221280	300480	148634	227834	2.046	3.126
T ₉	3.668	4.988	75446	75391	220080	299280	144634	223834	1.917	2.966
T ₁₀	3.760	5.112	73446	73398	225600	306720	152154	233274	2.072	3.176

CHAPTER V

SUMMARY AND CONCLUSIONS

SUMMARY AND CONCLUSIONS

The study entitled “**Study on Microbes mediated Organic Production for Khasi Mandarin**” was carried out at Farmer Laseng Umbon’s Orchard, Pangna Gaon, Tinsukia and also at School of Agricultural Sciences, Nagaland University, Medziphema during the years 2023 and 2024. The experimental orchard, located at 27°21’N latitude and 95°44’E longitude with an altitude of 141 m above MSL, experiences a humid subtropical climate with 2500 mm annual rainfall and moderately acidic soil containing moderate organic carbon, moderate nitrogen, phosphorus, and potassium respectively.

Seedling studies

. The first experiment was laid out in a Completely Randomized Design (CRD) with four replications and five treatments representing rhizospheric soils from elite Khasi mandarin trees. Rhizospheric soils were collected from vigorous, high-yielding trees and used as growth media for seedling studies in polybags. Growth parameters such as seedling height, girth, and number of leaves were recorded at day intervals up to 180 days of seedling age, and leaf samples were analyzed for macro- and micronutrients following standard methods.

Seedling studies showed that rhizospheric treatments significantly affected growth and nutrient status: seedling height increased with age under all treatments, with T₂ giving the greatest early height but T₄ producing the tallest seedlings by 180 days, indicating stronger sustained growth under those soils; stem girth increased progressively in all treatments with T₂ recording the largest girth throughout and T₅ the smallest, leaf number was highest under T₄ by 180 days, while T₂ generally produced fewer leaves. Leaf nutrient analysis revealed treatment dependent differences (P being non-significant): T₂ had the highest leaf N closely followed by T₁, K was highest in T₁ and T₄, Ca peaked in T₁, Mg and several micronutrients such as Cu, Fe were highest in T₄, while Mn and Zn tended to be higher in T₁. Overall, T₄ promoted greater final height, leaf production and improved Ca, Mg, Cu and Fe accumulation whereas T₂ favoured early height, stem thickening and nitrogen uptake,

showing that different rhizospheric soils distinctly influence vegetative performance and nutrient uptake in Khasi mandarin seedlings.

Soil microbial studies

The treatment showing superior growth and nutrient uptake was selected for metagenomic analysis of soil microbial diversity. DNA extraction, PCR amplification of 16S rRNA/ITS regions, and high-throughput Illumina sequencing were conducted to determine microbial community composition, processed using DADA2 and analyzed for alpha diversity (Shannon, Simpson indices) and functional pathway distribution, providing insights into the rhizosphere microbial structure influencing Khasi mandarin seedling growth.

The metagenomic analysis of Khasi mandarin rhizosphere soil, derived from the combined T₁ and T₄ rhizospheric samples, revealed a high-quality sequencing dataset with excellent read integrity, minimal duplication, and balanced GC content, confirming the reliability of downstream microbial profiling. DADA2 based processing produced 96,094 high-confidence, non-chimeric reads, ensuring accurate identification of Amplicon Sequence Variants (ASVs). Taxonomic analysis showed a strong dominance of the Firmicutes phylum, followed by Proteobacteria, Actinobacteria, and Bacteroidetes, reflecting a metabolically versatile and stress-tolerant microbial community. At the genus level, *Clostridium*, *Lysinibacillus* and *Bacillus* were most abundant, indicating active participation in nutrient cycling, organic matter decomposition, and plant growth promotion. Dominant species such as *Clostridium sartagoforme*, *C. perfringens*, *Terrisporobacter glycolicus* and *Bacillus thuringiensis* were associated with cellulose degradation, nitrogen transformation and pathogen suppression, contributing to soil fertility and plant vigor. The coexistence of aerobic (e.g., *Bacillus*, *Lysinibacillus*) and anaerobic (e.g., *Clostridium*, *Paraclostridium*) taxa suggests a functionally complementary and ecologically balanced rhizosphere supporting diverse metabolic activities. Rarefaction and alpha diversity analyses confirmed sufficient sequencing depth and high microbial richness and evenness, signifying a stable, biologically active, and functionally diverse microbial ecosystem. Overall, the Khasi mandarin rhizosphere harbours a robust consortium of beneficial microorganisms that enhance nutrient availability, promote

growth, and sustain soil health—hallmarks of a productive and sustainable citrus ecosystem.

Studies with organic inputs and microbial consortium

The second experiment to study the effect of organic manures and microbial consortium on growth, yield, quality and post-harvest changes in Khasi Mandarin was conducted in a 35-year-old Khasi mandarin orchard at Pangna Gaon, Tinsukia, using a Randomized Complete Block Design (RBD) with ten treatments, four replications, and two trees per replication at 5 × 5 m spacing. Treatments included control, microbial consortium, and combinations of FYM, poultry manure, pig manure, and vermicompost at different rates with or without microbial consortium. Organic inputs were applied twice annually using the ring method, while irrigation and weeding were carried out as per crop requirements. The microbial consortium (IIFCO, India) contained *Rhizobium*, *Azotobacter*, *Acetobacter*, *Phosphobacteria*, *Pseudomonas*, and Potassium Solubilizing *Bacillus*. Growth parameters such as tree height, spread, canopy volume, stem girth, flowering intensity, fruit set, fruit drop, yield, and fruit number were recorded using standard procedures. Fruit quality attributes including juice content, total soluble solids (°Brix), titratable acidity, TSS:acid ratio, ascorbic acid, total and reducing sugars, peel oil content, and physiological loss in weight were analyzed following Association of Official Analytical Collaboration methods, while sensory evaluation was conducted using a 9-point hedonic scale with a trained panel. Soil samples were analyzed for pH, organic carbon, available nitrogen, phosphorus, and potassium (ammonium acetate extraction) following standard analytical protocols. Economic analysis included cost of inputs, labour, gross and net returns, and benefit-cost (B:C) ratio. Data were statistically analyzed using ANOVA for RBD and treatment means were compared using the Critical Difference (CD) test at 5% significance level.

The two-year field study revealed significant effects of organic manures and microbial consortium on the vegetative, reproductive, and postharvest performance of Khasi mandarin. Treatments integrating vermicompost and microbial consortium (T₁₀) and FYM + microbial consortium (T₄) consistently outperformed others across most parameters. T₂ (microbial consortium + fertilizer) also promoted vigorous

vegetative growth, recording the highest tree height, stem girth, and flower intensity, while T₁₀ produced the largest canopy volume and tree spread. Fruit yield attributes followed a similar trend T₁₀ recorded the highest number of fruits per tree and yield, followed closely by T₄ and T₈, demonstrating the synergistic benefits of combining organic and microbial inputs. Enhanced fruit growth traits such as fruit length, diameter, volume, and weight were consistently observed in T₄, reflecting improved nutrient uptake and physiological efficiency. Quality parameters including juice content, TSS, ascorbic acid, total sugars, and TSS: acid ratio were highest under T₁₀, indicating superior sweetness, flavor, and nutritional value. Postharvest studies revealed that T₁₀ markedly reduced physiological loss in weight (PLW), retained higher juice recovery and maintained elevated vitamin C and sugar levels, confirming better storability and delayed senescence. Soil analysis showed improved fertility under integrated treatments T₁₀ and T₉ enhanced soil pH, organic carbon, and available NPK levels, sustaining long-term soil health. Economically, T₁₀ achieved the highest net return and benefit–cost ratio, followed by T₈ and T₉, proving its superior profitability and sustainability.

Based on the above summary of the results, the following conclusions may be drawn from the present investigation:

1. Rhizospheric soils from elite Khasi mandarin trees significantly influenced seedling growth and nutrient status. Among the treatments, T₄ promoted maximum seedling height, leaf number, and enhanced Ca, Mg, Cu, and Fe accumulation, whereas T₂ recorded higher early height growth, stem girth, and nitrogen uptake. The results indicated that distinct rhizospheric microbial compositions differentially affect vegetative performance and nutrient assimilation in seedlings.
2. Metagenomic analysis revealed a highly diverse and balanced microbial community dominated by the phyla Firmicutes, Proteobacteria, Actinobacteria, and Bacteroidetes. The dominant genera, *Clostridium*, *Bacillus*, and *Lysinibacillus*, were associated with nutrient mineralization, organic matter decomposition, and pathogen suppression. High alpha diversity indices confirmed a stable and functionally active microbial ecosystem supporting healthy rhizosphere dynamics in Khasi mandarin.

3. The two-year field experiment demonstrated significant effects of organic manures and microbial consortium on vegetative growth, yield, and quality of Khasi mandarin. Integrated treatments, particularly vermicompost + microbial consortium (T₁₀) and FYM + microbial consortium (T₄), consistently recorded superior performance across parameters. T₂ (microbial consortium + control) favored vegetative growth, while T₁₀ resulted in the highest canopy volume, fruit yield, and overall productivity.
4. Fruits from T₁₀ treatment exhibited higher juice content, total soluble solids, ascorbic acid, total sugars, and TSS: Acidity ratio, contributing to enhanced flavour and nutritional quality. The lowest physiological loss in weight (PLW) observed in T₁₀ indicated delayed senescence, better moisture retention, and improved storability compared to control.
5. Vermicompost-consortium combination and vermicompost alone treatments (T₁₀ and T₉) significantly improved soil reaction, organic carbon, and available nitrogen, phosphorus, and potassium contents. This demonstrated the positive influence of microbial and vermicompost integration in maintaining soil fertility and sustaining long-term productivity.
6. The treatment T₁₀ (vermicompost + microbial consortium) achieved the highest net return and benefit–cost ratio, establishing it as the most economically viable and sustainable nutrient management module for Khasi mandarin.
7. The study concludes that the integration of microbial consortium with organic manures, particularly vermicompost, enhances plant growth, fruit yield, quality, storability, soil health, and profitability. This approach represents a sustainable and eco-friendly nutrient management strategy for improving productivity and longevity of Khasi mandarin orchards.

Future thrust

Integrated nutrient management using vermicompost or FYM with the microbial consortium is recommended, as it enhanced yield, fruit quality, storability, and profitability, whereas excessive poultry manure alone should be avoided. Long-term, multi-location studies are needed to validate the sustainability and optimize the dosage of these modules. Further research should focus on understanding microbial–plant interactions through metagenomics and enzyme assays and on isolating key beneficial strains like *Clostridium*, *Bacillus*, and *Lysinibacillus* for bioinoculant development. Environmental benefits such as improved soil carbon, reduced fertilizer use, and lower greenhouse emissions should also be evaluated.

REFERENCES

REFERENCES

- Abobatta, W. F. 2020. Sustainable agriculture: Integrated nutrient management strategies for enhancing productivity and quality of horticultural crops. *HortScience*. **55**(11):1801-1808.
- Agustí, M. and V. Almela. 1991. The role of nitrogen in fruit set and fruit drop of citrus. *Scientia Horticulturae*. **47**(3-4):239-247.
- Agustí, J., Alquézar, J.M., Mesejo, A.C.A., Soler, A.C., Carrera, M.F., Alós, M. A. F., G. Mesejo, C. and Guardiola, M. A. F. 2022. Physiological control of flowering in citrus: a complex interplay of nutrients, carbohydrates and hormones. *Scientia Horticulturae*. **301**:111166.
- Ahmad, S., Ahmad, S., Mahmood, S., Khan, A. S. and Wajid, M. I. 2017. Integrated Use of Compost and Chemical Fertilizers Improves Fruit Quality and Nutritional Status of Kinnow Mandarin (*Citrus nobilis* x *Citrus deliciosa*). *Journal of Plant Nutrition*. **40**(12):1794-1804.
- Akdemir, B., Özer, A. Y. and Arslan, M. I. 2012. Economic analysis of organic and conventional apple production systems in Turkey. *African Journal of Agricultural Research*. **7**(28):4038-4045.
- Anon. 2009. Citrus: Nutritional and Health Benefits. *Fact Sheet*. University of California Cooperative Extension.
- Anon. 2014. Citrus Cultivation: General Guidelines. *Technical Bulletin*. Central Citrus Research Institute (CCRI), Nagpur.
- Anwar, T., Sahid, M. A., Butt, A. U. R. and Ahmad, I. 2022. Integrated use of growth hormones and nutrients for managing premature fruit drop in citrus orchards of Pakistan. *Journal of Plant Nutrition*. **45**(16):2588-2601.
- Arancon, N.Q., Edwards, C.A., Atiyeh, R. and Metzger, J.D. 2004. Effects of vermicomposts produced from food waste on the growth and yields of greenhouse peppers. *Bioresource Technology*. **93**(2): 139-44.
- Aslantaş, R., Cakmakci, R. and Şahin, F. 2007. Effect of plant growth promoting rhizobacteria on young apple tree growth and fruit yield under orchard conditions. *Scientia Horticulturae*. **111**(4):371-377.
- Assam Agricultural University (AAU). 2021. Package of Practices for Horticultural Crops in Assam. *Directorate of Research (Agriculture)*, Jorhat.
- Association of Official Analytical Chemists (AOAC). 2000. *Official Methods of Analysis of AOAC International* (17th ed.). AOAC International, Gaithersburg, MD.

- Association of Official Analytical Chemists (AOAC). 2016. *Official Methods of Analysis*. AOAC International, Gaithersburg, MD.
- ASTM. 1981. Standard Practice for Determination of Odor and Taste Thresholds by a Forced-Choice Ascending Concentration Series Method of Limits. *ASTM Standard E679-79*. American Society for Testing and Materials, Philadelphia, PA.
- Baker, R. A. 1994. Potential for citrus flavonoids and pectin as dietary supplements. *In:ACS Symposium Series 562:Flavor Chemistry:Industrial and Academic Perspectives*. American Chemical Society, Washington, D.C.
- Bakshi, M., Bakshi, P. V., Wali, K. and Jasrotia, A. 2018. Economic evaluation of integrated nutrient management in Kinnow mandarin (*Citrus nobilis* × *C. deliciosa*). *Journal of Applied and Natural Science*. **10**(4):1238-1243.
- Bakshi, M., Bakshi, P., Wali, V. K., Rai, P. K. and Jasrotia, A. 2017. Effect of inorganic and organic fertilizers along with *Azotobacter* on growth, yield and quality of Kinnow mandarin. *Indian Journal of Horticulture*. **74**(2):198-202.
- Baral, S. 2021. Comparative benefit-cost analysis and sensitivity testing of mandarin cultivation in India and Nepal. *Journal of Crop Science and Biotechnology*. **24**(2):205-212.
- Barbora, M. K., Sarkar, S. K. and Ghosh, P. K. 2019. Characterization and selection of elite Khasi mandarin (*Citrus reticulata* Blanco) genotypes. *International Journal of Current Microbiology and Applied Sciences*. **8**(3):1406-1413.
- Barthakur, I. K. 2018. Soil pH as a phenotype determinant in humans: Proposing a scientific hypothesis. *Open Journal of Soil Science*. **8**(1): 36–46.
- Baviskar, V. S., Kadu, P. P., Dod, V. N. and Raut, R. S. 2011. Effect of integrated nutrient management on growth, yield and quality of sapota (*Manilkara achras* L.). *Asian Journal of Horticulture*. **6**(2):345-348.
- Berendsen, R. L., Pieterse, C. M. J. and Bakker, P. A. H. M. 2012. The rhizosphere microbiome and plant health. *Trends in Plant Science*. **17**(8):478-486.
- Bhajan, V., Kumar, A.K.S.P., Kamble, V.G., Tumdam, S.M. and Kakade, P.J. 2024. Economic analysis of Nagpur mandarin (*Citrus reticulata* Blanco) in Nagpur district of Maharashtra. *The Pharma Innovation Journal*. **13**(1):1850-1854
- Bhalerao, P. P. and Patel, P. P. 2012. Effect of foliar application of Ca, Zn, Fe and B on growth, yield and quality of papaya (*Carica papaya* L.) var. ‘Taiwan Red Lady’. *International Journal of Horticulture*. **99**: 55-61.
- Bhalerao, P.P., Gondane, V.S., Rane, P. K., Kadam, P., Badgujar, A.N. and Kale, P.

- B. 2009. Integrated nutrient management in Nagpur mandarin (*Citrus reticulata* Blanco). *Journal of Soils and Crops*. **19**(1):18-24
- Bhargava, B. S. 2002. Leaf sampling and preparation for analysis of essential elements. In: Tandon, H. L. S. (Ed.), *Methods of Analysis of Soils, Plants, Waters and Fertilizers*. Fertilizer Development and Consultation Organization, New Delhi.
- Bhat, J.A., Wani, F.R., Liu, Z., Cai, L., Fu, L., Sun, L., Xu, L., Ni, Z., Fan, Z., Fan, J., Zhou, Z., Chen, L., Wu, Q., Sun, X., Dong, H., Hu, H., Li, C., Bi, B., Hu, L., Kang, J. and Chen, J. 2020. Role of PGPR in biosynthesis of essential oils and secondary metabolites in aromatic and medicinal plants. *Journal of Applied Microbiology*. **129**(4):745-758.
- Bhatnagar, P. and Singh, S. P. 2015. Response of Custard Apple cv. “Arka Sahan” Plants to Integrated Nutrient Management. *HortFlora Research Spectrum*. **4**(1):18-21.
- Bhattacharjee, H., Barua, P. K. and Darandale, R. V. 2024. Impact of integrated nutrient management on plant and soil nutrient status in sweet orange (*Citrus sinensis* L.) cv. Phule Mosambi. *The Pharma Innovation Journal*. **13**(1):1205-1210.
- Bhattacharya, P. and Chandra. R. 2017. Effect of biofertilizers on post-harvest quality and storage life of Khasi mandarin (*Citrus reticulata* Blanco). *Journal of Horticultural Sciences*. **12**(2):159-164.
- Bhattacharyya, P. N. and Jha, D. K. 2012. Plant growth-promoting rhizobacteria (PGPR): emergence in agriculture. *World Journal of Microbiology and Biotechnology*. **28**(4):1327-1350.
- Bhosale, N. A., Deshmukh, A. K. S. and Wankhede, S. G. 2015. Integrated nutrient management for improving flowering, fruit set and yield of Nagpur mandarin (*Citrus reticulata* Blanco). *The Asian Journal of Horticulture*. **10**(2):308-312.
- Bisen, A. L., Singh, R. K. and Singh, V. R. P. K. 2020. Effect of bio-inoculants and post-harvest treatments on biochemical changes and shelf life of Nagpur mandarin. *International Journal of Chemical Studies*. **8**(3):1205-1209.
- Bisen, A.L., Singh, D.K., Kumar, V.G., Kamble, S.M., Tumdam, P.J. and Kakade, G. B. L., 2011. Effect of biofertilizers on post-harvest quality and shelf life of Nagpur mandarin (*Citrus reticulata* Blanco). *Journal of Soils and Crops*. **21**(1):161-166.
- Blouin, M., Hodson, M.E., Delgado, E.A., Baker, G., Brussaard, L., Butt, K.R., Dai, J., Dendooven, L., Peres, G., Tondoh, J.E., Cluzeau, D. and Brun, J.J. 2019. A review of the role of earthworms in the soil system and their influence on

nutrient cycling. *Soil Biology and Biochemistry*. **138**:107592

- Bolyen, E., Rideout, J. R. and Dillon, M. R. 2019. Reproducible, interactive, scalable and extensible microbiome data science using QIIME 2. *Nature Biotechnology*. **37**(8):852-857.
- Bopanna, S. 2016. Economics and marketing of Coorg mandarin (*Citrus reticulata*) in Coorg (Kodagu) district of Karnataka. *International Journal of Agricultural Science and Research (IJASR)*. **6**(1):185-194.
- Borah, A., Deka, B. C., Bora, D. K. and Pathak, P. L. 2020. Effect of integrated organic nutrient management on fruit quality and storability of Khasi mandarin (*Citrus reticulata* Blanco). *Journal of Crop and Weed*. **16**(1):18-24.
- Brady, N.C. and Weil, R.R. 2017. *The Nature and Properties of Soils* (15th ed.). Pearson Education, Inc., New York.
- Brahma, K., Ray, M.A., Lahkar, K., Hazarika, S.K., Borthakur, D., Nath, P., Tamuli, K., Sarmah, M. K., Kakati, K. P., Nath, A. and Bora, P. K. 2024. Economic analysis of integrated organic-inorganic nutrient management in mandarin cultivation. *Indian Journal of Horticultural Research*. **45**(1):65-72.
- Bray, R. H. and Kurtz, L. T. 1945. Determination of total, organic and available forms of phosphorus in soils. *Soil Science*. **59**(1):39-45
- Callahan, B. J., McMurdie, P. J., Rosen, M. J., Han, A. W., Johnson, A. J. A. and Holmes, S. P. 2016. DADA2: High-resolution sample inference from Illumina amplicon data. *Nature Methods*. **13**(7):581-583.
- Caporaso, J. G., Kuczynski, J., Stombaugh, J., Bittinger, K., Bushman, F. D., Costello, E. K., Fierer, N., Gonzalez Peña, A., Goodrich, J. K., Gordon, J. I., Huttley, G. A., Kelley, S. T., Knights, D., Koenig, J. E., Ley, R. E., Lozupone, C. A., McDonald, D., Muegge, B. D., Pirrung, M., Reeder, J., Sevinsky, J. R., Turnbaugh, P. J., Walters, W. A., Widmann, J., Yatsunenko, T., Zaneveld, J. and Knight, R. 2010. QIIME allows analysis of high-throughput community sequencing data. *Nature Methods*. **7**(5):335-336.
- Castle, W. S. 1983. Canopy volume and tree size. *Proceedings of the Florida State Horticultural Society*. **96**:31-33.
- Chadha, K. L. 1995. *Handbook of Horticulture*. ICAR, New Delhi.
- Chakraborty, A., Sarkar, S.K. and Biswas, P. 2016a. Effect of Microbial Inoculants on Leaf Nutrient Concentration and Yield of Mandarin Orange (*Citrus reticulata* Blanco). *Journal of Crop and Weed*. **12**(2):108-112.
- Chakraborty, B., Sarkar, S. K. and Ghosh, P. K. 2016b. Effect of microbial consortia on soil health and nutrient availability in citrus orchards. *Indian Journal of*

Soil Conservation. **44**(2):159-165.

- Chandra, S., Singh, D. K. and Singh, D. K. 2018. Effect of bio-inoculants and organic manures on post-harvest quality and storability of guava (*Psidium guajava* L.). *Journal of Pharmacognosy and Phytochemistry*. **7**(6): 2697-2700.
- Cheke, S. S. and Patil, R. D. 2024. Effect of Rhizosphere Microbial Consortium on Yield, Quality and Soil Health of Sweet Orange. *The Pharma Innovation Journal*. **13**(1):1541-1547.
- Cheke, S. S., Singh, S. V. D. and Kadam, P. H. 2024. Response of Rhizosphere Microbial Consortium on Yield, Quality and Soil Health of Sweet orange. *Current Journal of Applied Science and Technology*. **43**(1):12-20.
- Chhetri, B. K., Sharma, B. P., Poudel, G. D. and Mainali, R. P. 2017. Effect of Integrated Plant Nutrient Management System (IPNMs) on Quality Parameters of Mandarin Orange (*Citrus reticulata* Blanco). *Journal of Agriculture and Natural Resources*. **1**(1):120-130.
- Chiu, C. Y., Wang, M. K. and King, H. B. 2002. Physical and chemical properties in rhizosphere and bulk soils of *Tsuga* and *Yushania* in a temperate rain forest. *Communications in Soil Science and Plant Analysis*. **33**(11-12):1729-1744.
- Clevenger, J. F. 1928. Apparatus for the determination of volatile oil. *Journal of the American Pharmaceutical Association*. **17**(4):346-349.
- Compant, S., Duffy, B., Nowak, J., Clément, C. and Ait Barka, E. 2005. Use of plant- growth-promoting bacteria for biocontrol of plant diseases: principles, mechanisms of action and future prospects. *Applied and Environmental Microbiology*. **71**(9):4951-4959.
- Dahal, B. 2023. Economic analysis of mandarin (*Citrus reticulata*) cultivation in Salyan district, Nepal. *Journal of Agriculture and Natural Resources*. **6**(1): 112-124.
- Das, S., Hazarika, B. N., Bora, D. K. and Hazarika, D. 2019. Effect of integrated organic modules on post-harvest quality and storability of Khasi mandarin (*Citrus reticulata* Blanco). *International Journal of Chemical Studies*. **7**(6): 1369-1373.
- Davey, M.W., VanMontagu, M., Inzé, D., Sanmartin, M., Kanellis, A., Smirnoff, N., Benzie, I. J. J., Strain, J. J., Favell, D. and Fletcher, J. 2000. Plant L- ascorbic acid: chemistry, function, metabolism, bioavailability and effects of processing. *Journal of the Science of Food and Agriculture*. **80**(7):825-860
- Devi, H. L., Mitra, S. K. and Poi, S. C. 2012. Effect of different organic and biofertilizer sources on guava (*Psidium guajava* L.) 'Sardar'. *Acta*

Horticulturae. **959**:201-208.

- Dhomane, P. A., Kadam, A. S., Lakade, S. K. and Gharage, V. R. 2011. Effect of different sources of nitrogen on growth and yield of guava (*Psidium guajava* L.) cv. sardar. *Asian Journal of Horticulture*. **6**(1):92-95
- Dong, R., Zhang, Y., Song, Q., Li, Y., Liu, L. and Chen, S. 2023. Optimizing Spring and Summer Fertilization Proportion to Improve Soil Nutrient Availability, Fruit Quality and Yield in 'Newhall' Orange Orchard. *HortScience*. **58**(2): 203-210.
- Dotaniya, M. and Meena, V. 2015. Rhizosphere effect on nutrient availability in soil and its uptake by plants: A Review. Proceedings of the National Academy of Sciences, India Section: *Biological Sciences*. **85**(1):1-12.
- Dubey, A. K. and Yadav, D. S. 2001. Effects of pig manure, nitrogen and phosphorus on fruit yield and quality of acid lime (*Citrus aurantifolia* Swingle). *Progressive Horticulture*. **33**(2):147-150.
- Durgapal, A., Pandey, A. and Palni, L. M. S. 2002. The Use of Rhizosphere Soil for Improved Establishment of Conifers at Nursery Stage for Application in Plantation Programmes. *Journal of Sustainable Forestry*. **15**(3):57-73.
- Dutta, P., Bora, D. K. and Hazarika, D. 2016. Effect of organic and inorganic fertilizers on soil properties, nutrient uptake and yield of Khasi mandarin (*Citrus reticulata*). *International Journal of Tropical Agriculture*. **34**(3):833-838.
- Dutta, P., Kundu, S., Hazarika, T. K. and Bora, P. 2009. Response of guava (*Psidium guajava* L.) cv. L-49 to biofertilizers and inorganic fertilizers on growth and productivity. *Indian Journal of Horticulture*. **66**(4):461-464.
- Dutta, S., Sarkar, M. and Roy, S. 2016. Effect of Integrated Nutrient Management on Growth, Yield and Quality of Mango (*Mangifera indica* L.) cv. Himsagar. *International Journal of Plant and Soil Science*. **10**(1):1-8.
- Dwivedi, N. 2013a. Economic analysis of integrated nutrient management practices in guava (*Psidium guajava* L.). *The Asian Journal of Horticulture*. **8**(2): 374-377.
- Dwivedi, V. 2013b. Effect of integrated nutrient management on yield, quality and economics of guava (*Psidium guajava* L.). *Annals of Plant and Soil Research*. **15**(2):149-151.
- Eissa, A. M., El-Mahdy, A. M. H. and Fikry, M. I. I. 2016. Effect of nitrogen fertilization levels on growth, flowering, yield and fruit quality of Washington Navel orange trees. *Middle East Journal of Agriculture Research*. **5**(2):134-142.

- El-Naby, S. K. M. 2000. Effect of banana compost as organic manure on growth, nutrient status, yield and fruit quality of Maghrabi banana. *Assiut Journal of Agricultural Science*. **31**(3):101-114.
- Ennab, H. (2016). Effect of organic manures, biofertilizers and NPK on vegetative growth, yield, fruit quality and soil fertility of Eureka lemon trees (*Citrus limon* (L.) Burm). *Journal of Soil Sciences and Agricultural Engineering*. **7**(10): 767–774.
- Ennab, H. A. A. 2016a. Impact of biofertilizers and organic manures on growth, yield and fruit quality of 'Valencia' orange trees. *Journal of Horticultural Science and Ornamental Plants*. **8**(3):146-154.
- Ennab, H. A. A. 2016b. Impact of Integrated Nutrient Management on Growth, Nutritional Status, Yield and Fruit Quality of Eureka Lemon Trees Grown in Sandy Soil. *Journal of Horticultural Science and Ornamental Plants*. **8**(3): 140-143.
- Ennab, H. A. A., Ahmed, R. E. M. El-Mahdy, A. M. H and. Fikry, M. I. I. 2019. Effect of organic nitrogen with different doses of mineral nitrogen on Washington navel orange trees grown in clay soil. *Horticultural Science*. **46**(1):11-20.
- Ezrari, S., Mhidra, O., Radouane, N., Tahiri, A., Polizzi, G., Lazraq, A. and Lahlali, R. 2021. Potential Role of Rhizobacteria Isolated from Citrus Rhizosphere for Biological Control of Citrus Dry Root Rot. *Microorganisms*. **9**(5):1060.
- Fikry, A. M., Ennab, H. A. A., El-Mahdy, A. M. H. and Ahmed, R. E. M. 2022. Effect of Inorganic and Organic Nitrogen Sources on 'Murcott' Mandarin. *Horticultural Science*. **49**(1): 1-11.
- Fikry, M. I. I., El-Mahdy, A. M. H. and Ennab, H. A. A. 2020. Using of Integrated Nutrient Management to Improve Growth, Yield and Nutritional Status of Murcott Tangerine Trees. *Horticultural Science*. **47**(1):1-10.
- Food and Agriculture Organization of the United Nations (FAO). 2017. *The Future of Food and Agriculture - Trends and Challenges*. Rome
- Ghosh, S. N. 2007. Diversity of citrus in North East India. *Indian Journal of Plant Genetic Resources*. **20**(2):101-105.
- Ghosh, S. N., Pradhan, B., Barman, P., Nath, T.K., Soren, K., Mazumdar, K., Kuila, K. K., Pal, A., Nayak, B., Pradhan, P. K. and Hazra, P. B. 2017. Effect of Integrated Nutrient Management on Post-Harvest Quality and Storage Life of Guava (*Psidium guajava* L.). *Horticultural Science*. **52**(1):112-117.
- Ghosh, S.P. 1977. Citrus cultivation in North Eastern Hill Region. *Indian Horticulture*. **22**(3):12-14.

- Gogoi, A. and Barbora, A. C. 2022. Integrated use of organic and inorganic fertilizers on yield, quality and nutrient content of Khasi mandarin (*Citrus reticulata*) in Assam. *Journal of Soils and Crops*. **32**(2): 358-361.
- Gogoi, D., Deka, M. and Das, B S. 2018. Integrated nutrient management in Khasi mandarin (*Citrus reticulata* Blanco): a study on yield, quality and soil fertility. *International Journal of Current Microbiology and Applied Sciences*. **7**(2): 2154-2162.
- Goramnagar, H. B., Gondane, S. U., Rafeekher, M., Sorte, P. N. and Murkute, A. A. 2000. Studies on integrated nutrient management in Nagpur oranges. *Journal of Soils and Crops*. **10**(2): 289-291.
- Goswami, A. K., Lal, S. and Misra, K. 2012. Integrated nutrient management improves growth and leaf nutrient status of guava cv. *Pant Prabhat*. *Indian Journal of Horticulture*. **69**(2):168-172.
- Govind, S. and Yadav I. S. 1999. Citrus germplasm collection and conservation in North Eastern India. *Indian Journal of Horticulture*. **56**(3):191-197.
- Grady, E. N., McDonald, T. R., Kallassy, K. M., Kloepper, J. W. and Trivedi, P. 2016. Genomic and metabolic traits of *Paenibacillus* spp. relevant to plant growth promotion and soil quality. *Applied Soil Ecology*. **97**:1-13.
- Hadole, D. M., Gite, J. G. and Chinchmalatpure, P. L. 2015. Effect of integrated nutrient management on soil fertility status and productivity of Nagpur Mandarin (*Citrus reticulata* Blanco). *The Bioscan*. **10**(1):317-320.
- Hameed, A., Ahmad, M. A. Wajid, H., Hameed, A. B. and Mahmood, K. (2018). Improving yield, quality and nutritional status of Kinnow Mandarin (*Citrus reticulata*) via integrated nutrient management. *HortScience*. **53**(1): 102-107.
- Handique, S., Bora, P., Ziogas, V., Srivastava, A.K., Jagannadham, P.T.K. and Das, A. K. 2024. Phytophthora infection reorients the composition of rhizospheric microbial assembly in Khasi Mandarin (*Citrus reticulata* Blanco). *Horticulturae*. **10**(4):304.
- Hangsing, L., Mathew, B. S. and Kalita, D. C. 2016. Evaluation of growth and yield performance of Khasi mandarin (*Citrus reticulata* Blanco) in Garo Hills of Meghalaya. *The Asian Journal of Horticulture*. **11**(2):308-312.
- Hasan, A., Ahmad, S., Islam, A. K. M. A. and Mannan, M. A. 2013. Integrated nutrient management in improving fruit quality of mango 'himsagar'. *International Journal of Agricultural Research, Innovation and Technology*, **3**(2), 52-55.
- Hazarika, N. K., Hazarika, L. K.H. K. Nath, H. K., Deka, S. K. and Gogoi, B. 2024.

Effect of biodynamics enriched organic amendments on yield attributing characters, yield, leaf and soil nutrition of Khasi mandarin (*Citrus reticulata* Blanco). *The Pharma Innovation Journal*. **13**(1):509-516.

Hazarika, P. 2012. Status of citrus in North-East India: Diversity, potential and constraints. *Journal of Crop and Weed*. **8**(2):183-189.

Hazarika, P., Hazarika, B.N., Deka, D.K., Singh, A.K., Maiti, R.K. and Pradhan, M. 2011. Impact of integrated nutrient management on growth, yield and quality of Khasi mandarin (*Citrus reticulata*). *Journal of Horticultural Sciences*. **6**(1):36-40.

Hazarika, T. K. and Malsawmkimi, M. 2023. Leaf nutrient status and soil properties in Khasi mandarin (*Citrus reticulata* Blanco) cultivation as influenced by bio-fertiliser enriched organic amendments. *Biological Agriculture and Horticulture*. **39**(2): 269-286.

Hazrati, M., Alizadeh, M., Ramezani, A. and Keshavarz, B. 2012. Effect of postharvest treatments on quality and shelflife of plum fruit. *African Journal of Agricultural Research*. **7**(22):3280-3286.

Hsieh, T. C. and Wu, J. M. 1995. Inhibition of prostate cancer cell proliferation by citrus pectin. *Biochemical and Biophysical Research Communications*. **214**(3):840-848.

Huang, M. S., Li, H. H., Li, A. C. and Chen, T. S. 2008. Studies on the chemical constituents and pharmacological activities of the genus *Citrus* (Rutaceae). *Chinese Journal of Integrated Traditional and Western Medicine*. **14**(3):199-204.

Huang, M., Barua, P. K. and Darandale, R. V. 2024. Microbial and organic manure fertilization alters fruit characteristics in ‘Orah’ Citrus. *International Journal of Plant and Soil Science*. **18**(2):45-53.

Jackson, M. L. 1973. *Soil Chemical Analysis*. Prentice Hall of India Pvt. Ltd., New Delhi.

Johnsen, K., Jacobsen, C. S., Torsvik, V. and Sorensen, J. 2001. Pesticide effects on bacterial diversity in agricultural soils: a review. *Microbial Ecology*. **41**(3): 331-343.

Kader, A. A. 2002. Postharvest biology and technology: an overview. *Acta Horticulturae*. **596**:15-22.

Kadlag, S.P., Srivastava, A.K., Deshmukh, S. and Singh, V. R.P.K. 2025. Effect of beneficial bacterial inoculants on productivity and quality of citrus: a sustainable approach. *Journal of Horticultural Science and Biotechnology*. **100**(1):12-20.

- Kakoti, B., Deka, B.C. and Sarmah, B.C. 2019. Assessment of variability in growth and fruit quality traits of Khasi mandarin (*Citrus reticulata* Blanco) in three districts of Manipur. *Journal of Pharmacognosy and Phytochemistry*. **8**(3): 4467-4470.
- Kaur, A. and Kaundal, G. 2017. Effect of organic and inorganic nutrient sources on physico-chemical characteristics and shelf life of Kinnow mandarin (*Citrus nobilis* × *C. deliciosa*). *International Journal of Pure and Applied Bioscience*. **5**(6):1341-1345.
- Kirankumar, H. K., 2022. Studies on integrated nutrient management in relation to growth and yield characters in Mrig bahar season. *The Pharma Innovation Journal*. **11**(4):2087-2090.
- Kirankumar, K. H., Shivakumara, B. S., Madaiah, D., and Sarvjna, B. S. 2022. Effect of integrated nutrient management on economics of pomegranate cv. bhagwa under central dry zone of Karnataka. *Journal of Agriculture Research and Technology*. **47**(3).
- Kour, K., Wali, V. K. Bakshi, P., Kumar, S. and Jasrotia, A. 2019. Effect of integrated nutrient management on growth and yield of Aonla (*Emblica officinalis* Gaertn.) cv. NA-7. *International Journal of Chemical Studies*. **7**(1):1205-1209.
- Kuczynski, J., Stombaugh, J., Walters, W. A., González, A., Caporaso, J. G. and Knight, R. 2012. Using 16S rRNA gene sequencing for microbial community analysis. *Current Protocols in Bioinformatics*. **39**(1):1731-1732.
- Kumar, N., Singh, H. K. and Mishra, P. K. 2015. Impact of organic manures and biofertilizers on growth and quality parameters of strawberry cv. Chandler. *Indian Journal of Science and Technology*. **8**(15):1-6.
- Kumar, P., Bakshi, M. A., Kour, S. and V. R. 2024. Integrated nutrient management for sustainable and economic apricot production. *International Journal of Plant and Soil Science*. **18**(3): 101-108.
- Kumar, P., Singh, M. S., Singh, R. K. and Kumar. L. G. 2012. Biocontrol potential and plant growth promotion by *Bacillus thuringiensis* and other rhizobacteria. *African Journal of Microbiology Research*. **6**(39): 6868-6874.
- Kumar, R., Singh, S. K., Singh, V. K. and Singh, M. P. 2014. Effect of organic and inorganic nutrient sources on physico-chemical characteristics and shelf life of Kinnow mandarin (*Citrus reticulata*). *The Asian Journal of Horticulture*. **9**(1):180-184.
- Kumar, R., Singh, S. K., Singh, V. K. and Singh, M. P. 2019. Influence of integrated nutrient management on growth, yield and quality of sweet orange (*Citrus sinensis* L.). *Indian Journal of Horticulture*. **76**(4):635-641.

- Kumar, S. 2022. Role of microbial consortium in enhancing nutrient use efficiency and reproductive performance in fruit crops. *Journal of Horticultural Sciences*. **17**(1):1-10.
- Kuttimani, R., Velayudham, K., and Somasundaram, E. 2013a. Growth and yield parameters and nutrient uptake of banana as influenced by integrated nutrient management practices. *International Journal of Recent Scientific Research*. **4**(5): 680-686.
- Kuttimani, R., Velayudham, K., and Somasundaram, E. 2013b. Physiological and biochemical parameters and quality of banana as influenced by integrated nutrient management practices. *International Journal of Recent Scientific Research*. **4**(6): 856-860.
- Kuttimani, R., Velayudham, K., Somasundaram, E. and Jagath Jothi, N. 2013. Effect of integrated nutrient management on corm and root growth and physiological parameters of banana. *International Journal of Advanced Research*. **1**(8):46-55.
- Lakkineni, K. C. and Abrol. Y. P. 1994. Effect of farmyard manure and inorganic fertilizers on soil properties and yield of rice-wheat system. *Journal of Plant Nutrition*. **17**(9):1461-1476.
- Lakra, R., Singh, P. K., Singh, A. K. and Singh, S. V. D. 2019. Effect of integrated nutrient management on vegetative growth and nutrient status of sweet orange (*Citrus sinensis* Osbeck). *Journal of Pharmacognosy and Phytochemistry*. **8**(3):3324-3327.
- Lal, B. 2017. Enhanced microbial activity in organically managed citrus orchards increases the synthesis of terpenoid compounds. *Journal of Essential Oil Research*. **29**(4):307-315.
- Lam, P. F. 1990. Postharvest handling of papaya. *ASEAN Food Journal*, **5**(2):47-53.
- Lane, J. H. and Eynon, L. (1923). Determination of reducing sugars by Fehling's solution with methylene blue indicator. *Journal of the Society of Chemical Industry*. **42**:32-37.
- Larsen, J., Jaramillo-López, P., Rudolph, S. and Jakobsen, I. (2015). Biotic interactions in the rhizosphere in relation to plant and soil nutrient dynamics. *Advances in Agronomy*, 130, 45-77.
- Larsen, J., Pablo, J. L., Miguel, N. and Carlos, G. E. 2014. Biotic interactions in the rhizosphere in relation to plant and soil nutrient dynamics. *Journal Of Soil Science and Plant Nutrition*. **15**(2):449-463.
- Lawrence, B.M. 1992. Progress in essential oils. *Perfumery and Flavorist*. **17**(5): 55-66.

- Lee, S. K. and A. A. Kader. 2000. Preharvest and postharvest factors influencing vitamin C content of horticultural crops. *Horticultural Reviews*. **24**:1-17.
- Lemanceau, P., Blouin, M., Buscot, F., Muller, D. and Moëgne-Loccoz, Y. 2017. The soil microbiome: a major driver of plant health. *Current Opinion in Microbiology*. **37**: 107-116.
- Lenka, J. and P. C. Lenka. 2014. Effect of integrated nutrient management on growth and yield of banana (*Musa* spp.) variety Grand Naine. *Journal of Crop and Weed*. **10**(1):182-185.
- Li, S., Zhang, Y., Dong, J., Li, Y., Wu, G., Ren, G., Luan, H. and Zhou, Z. 2020. *Clostridium sartagoforme*: A novel bacterium with strong cellulolytic and fermentative ability isolated from soil. *Applied Microbiology and Biotechnology*. **104**(12):5427-5438.
- Li, S., Zhang, Y., Dong, X., Han, R., Liu, M., Zhang, Y. and Songwei, D. 2021. The effects of phosphorus on plant growth, yield and fruit quality of tomato. *Horticulturae*. **7**(10): 386.
- Li, Y., Liang, P., Shen, G., Zhou, J., Li, Z. and Zhang, Z. 2019. Soil management practices alter citrus rhizosphere microbial communities: a review. *Journal of Integrative Agriculture*. **18**(1):1-11.
- Lima, H. S., Coletta-Filho, H. D., Coletta, V. O. J., Trivedi, P. and Wang, N. 2024. Global citrus root microbiota unravels assembly cues and core members. *Scientific Data*. **11**:671.
- Liu, G., Z. Sun, J. Yang, J., Yu, M., Wu, H. and Tian, D. 2019. Long-term organic fertilization improves kiwifruit (*Actinidia chinensis* Planch.) productivity through increasing rhizosphere microbial diversity and network complexity. *Applied Soil Ecology*. **137**:153-162.
- Manjare, M. A., Waghmare, P. N. and Chobhe, R. P. 2018. Influence of *Azotobacter* in combination with chemical fertilizers on growth and yield of sapota (*Manilkara achras* L.). *International Journal of Chemical Studies*. **6**(3):3154-3157.
- Marathe, R. A. and Bharambe, P. R. 2007. Integrated nutrient management for sustainable citrus production. *Indian Journal of Horticulture*. **64**(4): 371-378.
- Marschner, P. 2012. Marschner's mineral nutrition of higher plants (3rd ed.). Academic press.
- Mditshwa, A., Caleb, J. S., Fawole, A. S. and Opara, W.O. H. B. 2017. The effect of organic and conventional production on postharvest quality and nutritional value of fruits: A review. *International Journal of Postharvest Technology*

and Innovation. **6**(2):134-150.

- Meena, V. S., Maurya, B. R. and Verma, J. P. 2014. Potassium solubilizing microorganisms: a critical review. *Journal of Crop Science and Biotechnology*. **17**(1):1-10.
- Mendes, R., Kruijt, M. and de Bruijn, I. 2011. Deciphering the rhizosphere microbiome for disease suppressive soils. *Science*. **332**(6032):1097-1100.
- MinhTu, N. T., Thanh, L.X., Une, A., Ukeda, H. and Sawamura, M. 2002. Chemical composition of Vietnamese mandarin (*Citrus reticulata*) peel oil. *Journal of Essential Oil Research*. **14**(4):278-281.
- Mishra, R., Singh, S. V. D., Singh, P. K. and Deka, S. K. 2019. Analysis of bacterial diversity in the rhizosphere of *Citrus reticulata* and its correlation with soil enzymatic activity and nutrient availability. *Environmental Microbiology Reports*. **11**(5):709-718.
- Mitra, P., Das, S. K., Mitra, S. K. and Maity, S. 2018. Integrated nutrient management enhances post-harvest quality and shelf life of sweet orange (*Citrus sinensis* Osbeck). *International Journal of Chemical Studies*. **6**(1): 1862-1867.
- Mohanty, C., Dash, D. K. and Dash, A. K. 2015. Effect of bio-inoculants on post-harvest quality and storage life of acid lime (*Citrus aurantifolia* Swingle). *The Ecoscan*. **9**(3):1081-1085.
- Morton, J. F. 1987. *Fruits of Warm Climates*. Creative Resources Systems, Inc., Winterville, NC
- Muhr, G. R., Datta, N. P., Sankarasubramoney, H., Lelley, V. K., and Donahue, R. L. 1965. *Soil Testing in India*. United States Agency for International Development (USAID) Mission to India.
- Naik, B. H., Janhavi, M. H. and Anjaneya, M. 2015. Standardization of optimum nutrient dose for superior growth and yield of banana cv. Sugandham (AAB) under integrated nutrient management. *The Bioscan*. **10**(3):1183-1187.
- Naik, L. B. and M. D. Babu. 2007. Effect of organic manures and biofertilizers on soil physico-chemical properties, yield and quality of sweet orange (*Citrus sinensis* Osbeck). *Orissa Journal of Horticulture*. **35**(2):112-117.
- Nakade, A. B., Srivastava, A. K. and Deshmukh, S. 2021. Effect of integrated nutrient management on growth, yield and fertility status of Nagpur mandarin. *The Pharma Innovation Journal*. **10**(7):822-827.
- Nannipieri, P., Ascher, J., Ceccherini, M.T., Landi, L., Pietramellara, G. and Renella, G. 2003. Microbial diversity and soil functioning. *European Journal of Soil*

Science. **54**(4):655-670.

- National Horticulture Board. 2018. Horticultural Statistics at a Glance 2017-18. *NHB Annual Report*. Ministry of Agriculture & Farmers Welfare, Government of India.
- Ngoc, B. N., Son, L. X., Long, D. T. and Ngu, L. V. 2021. Long-term application of organic amendments impacts soil quality and productivity of pomelo (*Citrus maxima*) orchards. *Soil Science and Plant Nutrition*. **67**(5):590- 598.
- Olsen, S. R., Cole, C. V., Watanabe, F. S. and Dean, L. A. 1954. Estimation of available phosphorus in soils by extraction with sodium bicarbonate. *United States Department of Agriculture Circular*. **939**:1-19.
- Omar, A. K. and Belal, B. E. A. 2008. Effect of bio-, organic and mineral fertilization on growth, yield and fruit quality of mango (*Mangifera indica* L.) cv. Sukari. *Research Journal of Agriculture and Biological Sciences*. **4**(5):451-457.
- Panse, V. G. and Sukhatme, P.V. 1967. Statistical methods for agricultural workers (2nd ed.). Indian Council of Agricultural Research (ICAR), New Delhi.
- Patel, C. R., Patel, N. L., Patel, V. K., Rymbai, H. and Joshi, A. 2012. Effect of integrated nutrient management on growth and yield of banana cv. Grand Naine. *Research/extension bulletin* (pp. 445-448).
- Patel, P., Gorakh, R.S. and Singh, V.R.P.K. 2020. Influence of microbial consortia and organic amendments on leaf nutritional status and yield of mandarin orange. *International Journal of Chemical Studies*. **8**(3):837-841.
- Pathak, A., Singh, D. K. and Singh, D. K. 2018. Effect of organic nutrient management on post-harvest quality of mandarin (*Citrus reticulata*). *Journal of Pharmacognosy and Phytochemistry*. **7**(6):2697-2700.
- Patil, B., Singh, S. M. K. K. P and Singh, P. K. 2017. Post-harvest quality and shelf-life of organically and conventionally produced mango (*Mangifera indica* L.) fruits. *Indian Journal of Horticulture*. **74**(3):334-338.
- Patil, R.D., Kulkarni, G. P., Patil, V. R., Singh, P. K. and Patil M. A. R. 2012. Effect of biofertilizers and organic manures on biochemical properties and sugar content of sweet orange (*Citrus sinensis* Osbeck) fruits. *The Asian Journal of Horticulture*. **7**(1):180-184.
- Patil, V. K. and Shinde, B. N. 2013. Studies on integrated nutrient management on growth and yield of banana cv. *Ardhपुरी* (Musa AAA). *Journal of Horticulture and Forestry*. **5**(9):130-138.
- Phawa, B., Deka, B. K., Nath, M., Singh, L. N., Pathak, B., Kumar, A., Singh, H. and Sharma, T. S. 2024. Value chain analysis of Khasi mandarin (*Citrus*

reticulata Blanco) in North East India. *International Journal of Tropical Agriculture*. 42(1):145-152.

Piper, C. S. 1966. *Soil and Plant Analysis*. Hans Publishers, Bombay.

Ram, R. B. and M. K. Verma. 2015. Economic evaluation of organic mango (*Mangifera indica* cv. Dashehari) cultivation. *Indian Journal of Agricultural Sciences*. **85**(11):1403-1406.

Ram, R. B., Yadav, R. S. S., Singh, P. K., Singh, V. K. and Singh, M. P. 2017. Effect of integrated nutrient management on fruit yield and quality of Mango (*Mangifera indica* L.) cv. Mallika. *International Journal of Pure and Applied Bioscience*. **5**(2):1004-1008.

Ramezani, M., Madvar, A., Khaleghi, M. and Hemmati, R. 2015. Isolation and identification of new beneficial bacterial strains from rhizosphere of *Citrus sinensis* orchards. *Progress in Biological Sciences*. **5**:75-84.

Rana, M. S., Thakur, K. S., Sood, S. K. and Thakur, P. 2020. Effect of integrated nutrient management on physico-chemical characteristics of Sweet Orange (*Citrus sinensis* Osbeck) Fruits. *International Journal of Chemical Studies*. **8**(3):833-836

Ranganna, S. 2019. Handbook of analysis and quality control for fruit and vegetable products. Tata McGraw-Hill, New Delhi.

Rathore, B. L., Singh, P. L. and Gupta, G. P. 2007. Effect of organic and inorganic nutrition on post-harvest quality and storage life of Kinnow mandarin (*Citrus reticulata*). *Indian Journal of Horticulture*. **64**(4): 386-390.

Rawat, P., Wali, V. K., Jasrotia, A. and Raina, N. 2020. Effect of fym, npk and biofertilizers on flowering, fruit set and yield of Kinnow (*Citrus nobilis* × *C. deliciosa*). *Journal of Pharmacognosy and Phytochemistry*. **9**(3):1083-1087.

Ray, P.K. and Deka, B.C. 2000. Citrus genetic resources in North-East India: Exploration and conservation. *Journal of Non-Timber Forest Products*. **7**(1/2):30-38.

Reddy, Y. T. N., Kurian, R. M., Ganeshamurthy, A. N. and Pannerselvam, P. 2010. Effect of organic nutrition practices on papaya (cv. Surya) fruit yield, quality and soil health. *Journal of Horticultural Sciences*. **5**(2):124-127.

Reganold, J. P. and J. M. Wachter. 2016. Organic agriculture in the twenty-first century. *Nature Plants*. **2**:15221.

Rengel, Z. and Marschner, P. 2005. Nutrient availability and management in the rhizosphere: Exploiting genotypic differences. *New Phytologist*. **168**(2):305-312.

- Romanazzi, G., Sanzani, S. M. and Linsalata, F. 2016. Induced resistance as an eco-friendly strategy to manage postharvest decay of fruit and vegetables. *Postharvest Biology and Technology*. **119**: 147-153.
- Rosenfeld, D., Eshel, Y. and Rabinowitch, H. D. 2013. Enhanced retention of ascorbic acid and reduced oxidative stress in tomato fruit grown with beneficial microorganisms. *Postharvest Biology and Technology*. **85**:20-26.
- Rouseff, R. L. and Nagy, S. 1994. The role of orange and grapefruit juices in health and disease. *In: Citrus Processing: Quality Evaluation and Technology*. VCH Publishers, New York.
- Rymbai, H., Singh, K., Jha, A. K., Talang, H. D., Touthang, H. T. and Chhetri, P. 2022. Productivity and profitability of Khasi mandarin (*Citrus reticulata* Blanco) as influenced by age of the tree. *Indian Journal of Horticulture*. **79**(3):120-125.
- Saha, S., Hazarika, B. N., Bora, D. K. and Hazarika, D. 2021. Microbial community structure and functional attributes in the rhizosphere of Khasi mandarin (*Citrus reticulata*): effect of organic nutrient management. *Applied Soil Ecology*. **161**:103859.
- Saikia, B. and H. L. Pathak. 2020. Effect of integrated nutrient management on post-harvest quality and shelf life of Khasi mandarin (*Citrus reticulata* Blanco). *Journal of Crop and Weed*. **16**(1):112-117.
- Sarma, D., Bora, D. K., Hazarika, L. K. and Pathak, P. L. 2018a. Effect of integrated nutrient management on leaf nutrient status and fruit quality of Khasi mandarin (*Citrus reticulata* Blanco). *Journal of Crop and Weed*. **14**(1): 180-185.
- Sarma, J., Borah, D. K. and Hazarika, D. 2018b. Effect of integrated nutrient management on soil chemical properties and nutrient availability in Khasi mandarin (*Citrus reticulata*). *Journal of Crop and Weed*. **14**(2):161-165.
- Sgroi, F., Candela, M., Di Trapani, A. M., Foderà, M., Squatrito, R., Testa, R. and Tudisca, S. 2015. Economic evaluation of the organic and conventional production of lemon in Sicily. *Journal of Agricultural Sciences - Belgrade*. **60**(4):471-483.
- Shaheen, M. A., Abd El Wahab, S. M., El-Morsy, F. M. and Ahmed, A. S. S. 2013. Effect of organic and bio-fertilizers as a partial substitute for NPK mineral fertilizer on vegetative growth, leaf mineral content, yield and fruit quality of *Superior* grapevine. *Journal of Horticultural Science & Ornamental Plants*. **5**(3):151-159.
- Shannon, C. E. 1948. A mathematical theory of communication. *Bell System Technical Journal*. **27**(3):379-423.

- Sharma, A., S. R., Singh, S. R., Gite, S. D. and Gawai, V.B. 2014. Effect of integrated nutrient management on growth of custard apple (*Annona squamosa* L.) cv. Arka Sahan. *The Asian Journal of Horticulture*. **9**(1):165-167.
- Sharma, A., Wali, V. K., Bakshi, P. and Jasrotia, A. 2013. Effect of integrated nutrient management strategies on nutrient status, yield and quality of guava. *Indian Journal of Horticulture*. **70**(3):333-339.
- Sharma, H., Hazarika, S. and Deka, S. K. 2015. Effect of organic nutrient management on post-harvest quality of Khasi mandarin (*Citrus reticulata* Blanco) during ambient storage. *Journal of Krishi Vigyan*. **3**(2): 78-82.
- Sharma, R. R., Singh, R. and Singh, S. K. 2019. Integrated nutrient management enhances fruit quality and storability of sweet orange (*Citrus sinensis* Osbeck). *Journal of Food Science and Technology*. **56**(7): 3481-3489.
- Sharma, R., Hazarika, S. A. and Borah, B. K. 2015. Comparative efficacy of bio-organic nutrient sources on cropping behaviour and fruit quality of kiwifruit (*Actinidia deliciosa*). *International Journal of Tropical Agriculture*. **33**(3): 1081-1085.
- Sharma, V. K., Verma, M. K. and Singh, R. 2016. Effect of integrated nutrient management on the yield and economics of mango (*Mangifera indica* L.) cv. Amrapali. *The Asian Journal of Horticulture*. **11**(2):208-212
- Sharma, V. K., Verma, M. K. and Singh, R. 2020. Enhancing quality and yield of Kinnow mandarin through bio-organic nutrient management. *Journal of Crop and Weed*. **16**(2):106-110.
- Shaw, P. E. 1979. Review of quantitative analyses of citrus essential oils. *Journal of Agricultural and Food Chemistry*. **27**(2):246-257.
- Shen, T., Wu, Q. S. and Wu, D. L. 2018. Organic production enhances soil microbial activity and fruit storability in citrus orchards. *Ecology and Evolution*. **8**(23): 12411-12420.
- Shen, Z., Shi, S. M. and Zhang, Y. L. 2019. Integrated agricultural strategy to reconstruct the soil microbiome for suppressing banana Panama disease. *Applied Soil Ecology*. **137**:122-132.
- Shivakumar, B. S. 2010. *Integrated nutrient management studies in papaya (Carica papaya L.)* M.Sc. (Horticulture) Thesis, University of Agricultural Sciences, Dharwad, Karnataka, India.
- Simpson, E. H. 1949. Measurement of diversity. *Nature*. **163**(4148):688.
- Singh, A., Sharma, R. R. and Verma, S. C. 2016. Chemical composition, mineral content, dietary fibre, colour parameters, antioxidant activity and

- polyphenol profiles of various fruits and vegetables. *Food Chemistry*. **198**:81-89.
- Singh, H.P. and Chadha, K.L. 1993. Mandarin orange in India. *Indian Horticulture*. **38**(2):3-7.
- Singh, K. K. 1990. Taxonomy and distribution of citrus species in North Eastern India. *Indian Journal of Plant Genetic Resources*. **3**(1):1-10.
- Singh, R., Pandey, S. K., Ray, P. K. and Singh, H. K. 2010. Response of integrated nutrient management on growth and yield of papaya (*Carica papaya* L.) cv. Surya. *Indian Journal of Horticulture*. **67**(2):173-178.
- Singh, R., Sharma, R. R. and Chinchmalatpure, P. L. 2016a. Effect of organic and conventional farming on post-harvest quality and shelf-life of sweet orange (*Citrus sinensis* Osbeck). *Journal of Food Science and Technology*. **53**(1): 328-336.
- Singh, S. K., Ghosh, P. K. and Srivastava, A. K. 2016b. "Growth and yield of different citrus species under various rootstocks and scions. *Indian Journal of Agricultural Sciences*. **86**(8):1011-1017.
- Singh, S. P. and Nambi, V. A. 2017. Influence of integrated nutrient management on post-harvest quality and shelf life of Kinnow mandarin (*Citrus nobilis* × *C. deliciosa*). *Journal of Horticultural Sciences*. **12**(1):11- 16.
- Singh, S., Deshmukh, A. K. S. and Wankhede, S. G. 2018. Influence of integrated nutrient management on biochemical attributes and quality of Nagpur mandarin (*Citrus reticulata* Blanco). *Indian Journal of Horticultural Research*. **42**(1):112-117.
- Singh, S., Deshmukh, A. K. S. and Wankhede, S. G. 2020. Integrated nutrient management for enhancing yield attributes and fruit quality of Khasi mandarin (*Citrus reticulata* Blanco). *Journal of Crop and Weed*. **16**(2):101-105.
- Song, P., Li, Z., Wang, J., Yang, Y., Zhang, Y., Yan, Z. and Wei, F. 2023. Diversity and structural analysis of rhizosphere soil microbial communities in wild and cultivated *Rhizoma Atractylodis Macrocephalae* and their effects on accumulation of active components. *Frontiers in Microbiology*. **14**:1109405.
- Srivastava, A. K. (Ed.). 2012. *Advances in citrus nutrition*. Dordrecht, Netherlands: Springer. doi:10.1007/978-94-007-4171-3
- Srivastava, A. K. and Singh, S. (2009). Integrated nutrient management in citrus: frontier developments. *Indian Journal of Fertilisers*. **6**(11):34-44.
- Srivastava, A. K., Dass, H. C., Ram, L. and Singh, S. 1997. Flowering behaviour of Nagpur mandarin (*Citrus reticulata*) as affected by vertical variation in

- physico-chemical composition of black soils. *The Indian Journal of Agricultural Sciences*. **67**(10): 692-694.
- Srivastava, A. K., Paithankar, D. H., Chinchmalatpure, P. L. and Deshmukh, S. 2015. "Long term field evaluation of integrated nutrient management in Nagpur mandarin (*Citrus reticulata* Blanco) on Vertic Ustochrept. *Journal of Plant Nutrition*. **38**(11):1735-1748.
- Srivastava, A. K., Singh, S. and Marathe, R. A. 2002. Organic Citrus: Soil Fertility and Plant Nutrition. *Journal of Sustainable Agriculture*. **19**(3): 5-29.
- Srivastava, A.K. 2021. Integrated Soil Fertility Management (ISFM) in Citrus for long term: A review. *Journal of Plant Nutrition*. **44**(12):1731-1750.
- Srivastava, A.K. and Singh, R.K. 2008. Nutrient management and sink-source relationship in citrus: a key determinant of fruit set and abscission. *Indian Journal of Horticulture*. **65**(3):247-254.
- Suhag, M. 2016. Impact of chemical fertilizers on soil health and environment. *International Journal of Environmental Sciences*. **7**(2):208-213.
- Tanaka, T. 1958. Species problems in citrus (Revision of the system of classification of citrus species). *Journal of the Horticulture Association of Japan*. **27**:103-115.
- Tandel, M. K., S. K. Patel, P. R. Patel, S. A. Patel and B. G. Solanki. 2014. Effect of integrated nutrient management on growth and physiological parameters of guava (*Psidium guajava* L.) cv. Sardar. *International Journal of Agricultural Sciences*. **10**(1):122-125.
- Tandon, H. L. S. 2005. *Methods of Analysis of Soils, Plants, Waters and Fertilizers* (2nd ed.). Fertilizer Development and Consultation Organization, New Delhi.
- Thakur, N and Thakur, B. S. 2014. Studies on the effect of integrated nutrient management on growth and yield of plum cv. santa rosa. *Asian Journal of Horticulture*. **9**(1):112-115.
- Thakur, P., Thakur, K. S. and Rana, M. S. 2019. Impact of integrated nutrient management on biochemical quality traits and shelf life of mandarin (*Citrus reticulata* Blanco). *Journal of Pharmacognosy and Phytochemistry*. **8**(6): 2697-2700.
- Toor, R. K., Aftab, T. and Ahmad, P. 2021. Potassium: A vital element for enhancing quality and abiotic stress tolerance in fruit crops. InP. Ahmad & M.M.I. Khan (Eds.), *Plant Nutrition: Management of Crop Quality* (pp. 235-252). Springer.
- Turpault, M. P., Gobran, G. R. and Bonnaud, P. 2007. Temporal variations of rhizosphere and bulk soil chemistry in a Douglas fir stand. *Geoderma*.

137(3-4):490-496.

- Usha, K., Saxena, A. and Singh, B. 2004. Rhizosphere dynamics influenced by arbuscular mycorrhizal fungus (*Glomus deserticola*) and related changes in leaf nutrient status and yield of Kinnow mandarin [King (*Citrus nobilis*) × Willow Leaf (*Citrus deliciosa*)]. *Australian Journal of Agricultural Research*. **55**(5):571-576.
- Ventura, M., Canchaya, C., Tauch, A., Chandra, G., Fitzgerald, G. F., Chater, K. F., vanSinderen, D. 2007 Genomics of actinobacteria: tracing the evolutionary history of an ancient phylum. *Microbiology and Molecular Biology Review*. **71**(3):495-548.
- Verma, D., Gorakh, R. S. and Singh, P. K. 2014. Effect of biofertilizers and organic manures on growth and yield of Kinnow mandarin (*Citrus nobilis* × *C. deliciosa*). *The Asian Journal of Horticulture*. **9**(1): 112-116.
- Verma, J. and Rao, V. K. 2013. Impact of integrated nutrient management on soil properties, plant growth and yield parameters of strawberry cv. *Chandler*. *Journal of Hill Agriculture*. **4**(2):61-67.
- Walkley, A., and Black, I. A. 1934. An examination of the Degtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method. *Soil Science*. **37**(1), 29–38.
- Wang, J., Guo, C. and Zhang, H. 2016. Beneficial fungi: dual roles in plant disease suppression and stress tolerance. *Plant Ecology and Biodiversity*. **38**(4):101-115.
- Wang, N., Lu, P. and Trivedi, P. 2015. Rhizosphere microbiome engineering to combat citrus Huanglongbing: Is It Feasible? *Phytopathology*. **105**(11): 1407-1415.
- Whittaker, R.H. 1972. Evolution and measurement of species diversity. *Taxon*. **21**(2/3):213-251.
- Wills, R. B. 1980. *Postharvest: An Introduction to the Physiology and Handling of Fruit and Vegetables*. Springer.
- Wu, F., Schipper, S. A. J. and Vangronsveld, R. G. F. 2016. Effects of organic farming on decay and quality of citrus fruits during postharvest storage. *Scientia Horticulturae*. **213**:41-48
- Wu, X., Li, X.H., Srivastava, A.K., Tu, S.X., Zou, Y.N. and Liu, S.M. 2017. AMF diversity in citrus rhizosphere. *The Indian Journal of Agricultural Sciences*. **87**(5):653-659.
- Wu, Y., Wang, Y. P. and Wang, B. T. 2016. Organic and biological management strategies strengthen host resistance against common post-harvest fungal

- pathogens in citrus. *European Journal of Plant Pathology*. **146**(2):301-311.
- Xian, Y. 2007. The pharmacological activities of *Citrus reticulata* (Mandarin). *Journal of Traditional Chinese Medicine*. **27**(1):70-75.
- Xu, Q., Chen, L. L., Ruan, X., Chen, D., Zhu, A., Chen, C. and Deng, X. 2013. The draft genome of sweet orange (*Citrus sinensis*). *Nature Genetics*. **45**(1): 59-66
- Xu, X., Trivedi, P. and Wang, Y. 2020. The role of the rhizosphere microbiome in citrus health and productivity. *Current Opinion in Plant Biology*. **56**:120-127.
- Xu, J., Wei, Z., Wang, J., Huang, K. And Li, J. 2018. The structure and function of the global citrus rhizosphere microbiome. *Nature Communications*. **9**:4894.
- Yadav, A. L., Singh, R. S. and Yadav, D. K. 2011a. Effect of organic, inorganic and bio-fertilizers on growth and yield of papaya (*Carica papaya* L.) cv. Pusa Dwarf. *Annals of Horticulture*. **4**(1):79-83.
- Yadav, M., Singh, R., Singh, S. K. and Arya, M. P. S. 2013. Post-harvest performance of organically and conventionally produced kinnow mandarin (*Citrus reticulata*) fruits. *Progressive Horticulture*. **45**(1):180-185
- Yadav, P. K., Yadav, A. L., Yadav, A. S., Yadav, H. C. and Singh, Y. P. 2011b. Effect of integrated nutrient nourishment on yield attributes and economics of papaya (*Carica papaya* L.) cv. Pusa Dwarf. *Plant Archives*. **11**(1):327-329.
- Yadav, S. K., Khokhar, U. U., and Yadav, R. P. 2013a. Post-harvest behavior of organically and conventionally cultivated Kinnow mandarin. *Journal of Eco-Friendly Agriculture*. **8**(1): 63-65.
- Yadav, S. K., Khokhar, U. U., and Yadav, R. P. 2013b. Effect of organic and conventional nutrient management practices on post-harvest quality and shelf life of Kinnow mandarin. *Journal of Eco-Friendly Agriculture*. **8**(2), 162-165.
- Yadav, S. M., Singh, V. K., Dubey, R. K. and Singh, S. K. 2014. Effect of organic nutrient management on post-harvest quality and storage life of guava (*Psidium guajava* L.). *International Journal of Farm Sciences*. **4**(1):110-117.
- Yung-Sheng, L. 2010. Chemical composition and biological activities of the essential oil from dried peels of *Citrus reticulata* Blanco. *Molecules*. **15**(7):4672-4682.
- Zhang, M., Li, J. and Wang, X. 2019. Intercropping improved the richness and diversity of fungal communities in mulberry and modified the structure of

the fungal community. *Forests*. **10**:167-172.

Zhang, Z. F., Li, Y. Q., Zhao, H. R. and Liu, G. X. 2012. Antioxidant and antimicrobial activities of mandarin (*Citrus reticulata*) extracts. *International Journal of Food Science and Technology*. **47**(7):1533-1540.

Ziauddin, S. 2009. *Integrated nutrient management studies in Banana (cv. Ardhapuri)*. pp. 126-130.

Ziegler, L.W. and Wolfe., H.S. 1961. *Citrus Growing*. John Wiley & Sons, Inc., New York.

APPENDICES

APPENDIX- I

Meteorological data recorded during the experimental months

Month	Temperature		Relative humidity	Precipitation
	Min (°C)	Max (°C)	(%)	(mm)
January, 2023	10.837	22.187	74.754	0.1806
February,2023	14.1	25.621	74.1025	3.279
March,2023	16.629	27.979	73.53	4.4845
April,2023	19.78	32.128	67.444	4.5006
May,2023	20.924	33.223	69.283	6.6177
June,2023	24.621	34.703	76.524	12.944
July,2023	25.748	35.31	77.924	19.1554
August,2023	25.664	33.998	82.027	14.2112
September,2023	24.65	36.008	74.636	4.7386
October,2023	21.166	30.201	78.331	3.8845
November,2023	16.458	27.237	74.516	0.278
December,2023	14.34	24.618	76.465	0.6832
January, 2024	10.881	22.251	75.61	0.2158
February,2024	12.603	24.447	72.279	3.0562
March,2024	16.286	28.688	67.759	2.9458
April,2024	21.055	33.435	64.493	5.0633
May,2024	22.973	34.461	69.341	6.1867
June,2024	25.135	34.685	77.727	20.7686
July,2024	25.783	34.7	80.231	24.5839
August,2024	25.934	34.913	79.135	8.225
September,2024	25.437	36.08	76.113	4.0046
October,2024	21.415	30.908	82.716	10.8738

APPENDIX- II

Rating chart for soil NPK values

Particulars	(kg	Low	Medium	High
ha-1)				
Available N		<272.00	272.00-544.00	>544.00
Available P		<22.50	22.50-56.00	>56.00
Available K		<136.00	136.00-337.50	>337.50

Source: Muhr *et al.* (1965)

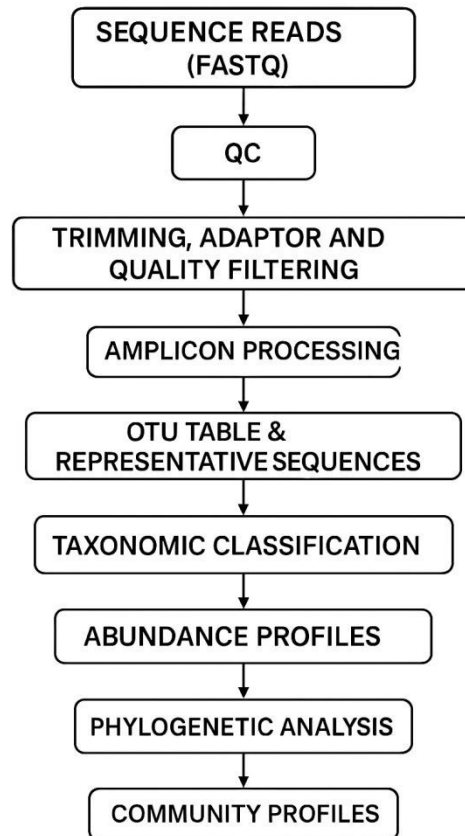
APPENDIX- III

Rating chart for soil of experimental field

Nutrient (kg/ha)	Rating
Available Nitrogen	Medium
Available phosphorus	Medium
Available potassium	Medium

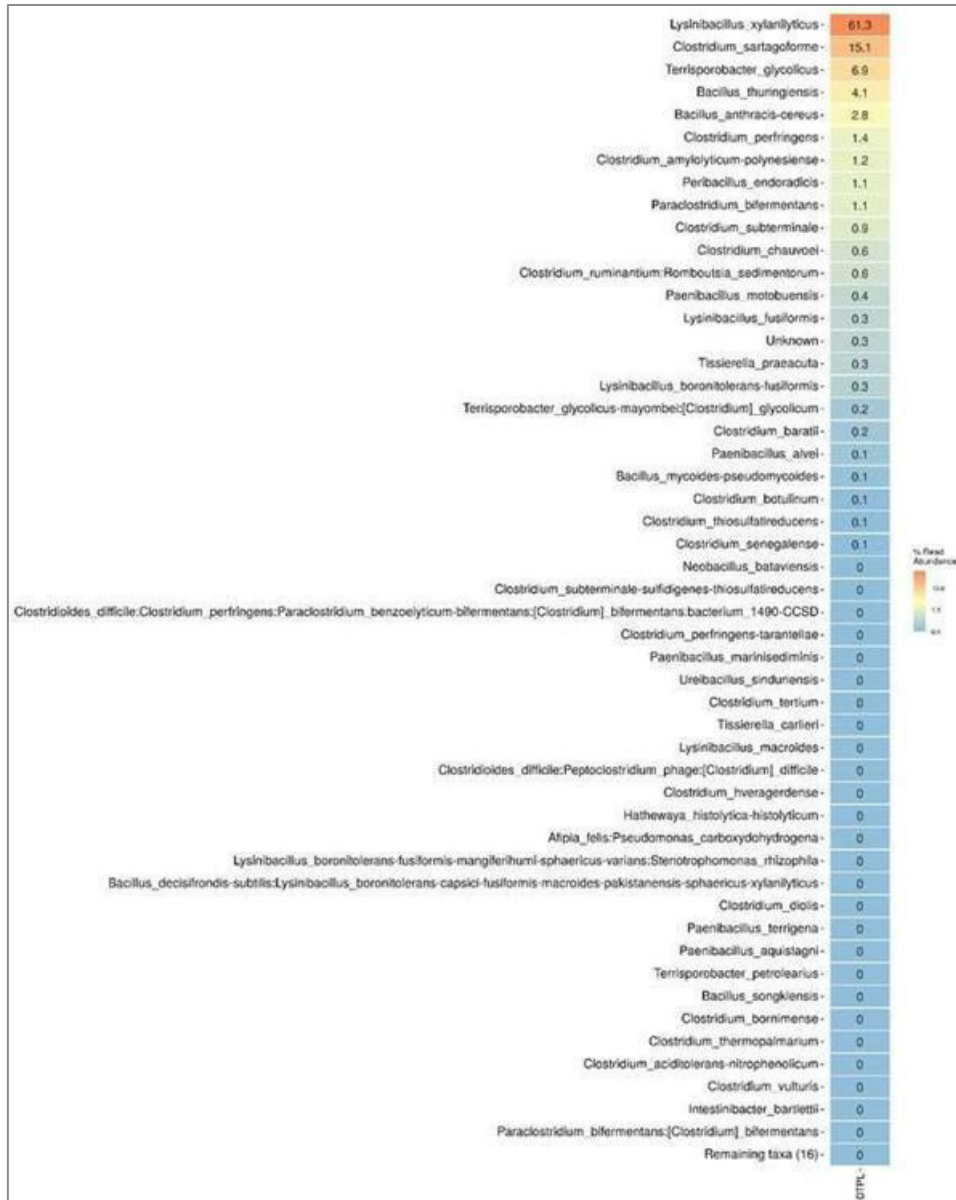
APPENDIX-IV

Workflow of amplicon sequencing data analysis



APPENDIX- V

Heatmap showing relative abundance of bacterial species based on amplicon sequencing data



APPENDIX- VI

Economic analysis of Khasi mandarin production under various organic and microbial nutrient management practices for the year 2023

Sl.	Particulars	Rate	Treatments									
no			T ₁	T ₂	T ₃	T ₄	T ₅	T ₆	T ₇	T ₈	T ₉	T ₁₀
1	Cost of manures, fertilizers and Microbial Consortium											
	FYM	5/kg		-	48000	24000						
	Vermicompost	15/kg		-							24000	12000
	Microbial Consortium	250/lts		10000		10000		10000		10000		10000
	Pig Manure	7/kg		-					22400	11200		
	Poultry Manure	12/kg		-			19200	9600				
	Nitrogen(in the form of Urea)	10/kg	5200	5200								
	P2O5(in the form of SSP)	12/kg	8640	8740								
	K2O(in the form of MOP)	20/kg	7200	7200								
2	Cost of cultural operations											
	Ring making and fertilizer application	262 Rs	10480	10480	10480	10480	10480	10480	10480	10480	10480	10480
	Weeding	262 Rs	18340	18340	18340	18340	18340	18340	18340	18340	18340	18340
	Irrigation	262 Rs	1572	1572	1572	1572	1572	1572	1572	1572	1572	1572
3	Harvesting	262 Rs	17554	17554	17554	17554	17554	17554	17554	17554	17554	17554
4	Transport and marketing		3000	3000	3000	3000	3000	3000	3000	3000	3000	3000
5	Miscellaneous		500	500	500	500	500	500	500	500	500	500
6	Total cost		72486	82486	1,20,486	106486	70646	71046	73846	72646	75446	73446
7	Yield(t/ha)		3.232	3.564	3.408	3.928	3.248	3.576	3.540	3.688	3.668	3.760
8	Gross returns		1,93920	213840	204480	235680	194880	214560	212400	221280	220080	225600
9	Net returns		121434	131354	83994	129194	124234	143514	138554	148634	144634	152154
10	Benefit-cost ratio		1.675	1.592	0.69	1.22	1.758	2.03	1.876	2.046	1.917	2.072

APPENDIX- VII

Economic analysis of Khasi mandarin production under various organic and microbial nutrient management practices for the year 2024

Sl.	Particulars	Rate	Treatments									
no			T ₁	T ₂	T ₃	T ₄	T ₅	T ₆	T ₇	T ₈	T ₉	T ₁₀
1	Cost of manures, fertilizers and Microbial Consortium											
	FYM	5/kg		-	48000	24000						
	Vermicompost	15/kg		-							24000	12000
	Microbial Consortium	250/lts		10000		10000		10000		10000		10000
	Pig Manure	7/kg		-					22400	11200		
	Poultry Manure	12/kg		-			19200	9600				
	Nitrogen(in the form of Urea)	10/kg	5200	5200								
	P2O5(in the form of SSP)	12/kg	8640	8740								
	K2O(in the form of MOP)	20/kg	7200	7200								
2	Cost of cultural operations											
	Ring making and fertilizer application	262 Rs	10480	10480	10480	10480	10480	10480	10480	10480	10480	10480
	Weeding	262 Rs	18340	18340	18340	18340	18340	18340	18340	18340	18340	18340
	Irrigation	262 Rs	1572	1572	1572	1572	1572	1572	1572	1572	1572	1572
3	Harvesting	262 Rs	17554	17554	17554	17554	17554	17554	17554	17554	17554	17554
4	Transport and marketing		3000	3000	3000	3000	3000	3000	3000	3000	3000	3000
5	Miscellaneous		500	500	500	500	500	500	500	500	500	500
6	Total cost		72486	82486	1,20,486	106486	70646	71046	73846	72646	75446	73446
7	Yield(t/ha)		4.592	4.920	4.700	4.852	4.568	4.916	4.848	5.008	4.988	5.112
8	Gross returns		275520	295200	282000	291120	274080	294960	300576	300480	299280	306720
9	Net returns		203034	212714	161514	184634	203434	223914	226730	227834	223834	233274
10	Benefit-cost ratio		2.801	2.578	1.341	1.734	2.879	3.152	3.070	3.126	2.966	3.176