IMPACT OF PHOSPHINE ON QUALITY PARAMETERS OF STORED PERISHABLE COMMODITIES

A Thesis Submitted
In Partial Fulfillment of the Requirements
for the Degree of

DOCTOR OF PHILOSOPHY

by

ANISHA KATHPALIA
(Roll no. 2K18/PHD/BT/16)

Under the Supervision of

Prof. Jai Gopal Sharma
Professor
Department of Biotechnology
Delhi Technological University

Dr. Sumitra Arora
Principal Scientist
ICAR-NCIPM, Delhi

Department of Biotechnology

DELHI TECHNOLOGICAL UNIVERSITY
(Formerly Delhi College of Engineering)
Shahbad Daulatpur, Main Bawana Road, Delhi-110042, India

2025

Dedicated to My Beloved Grandfather, Sh. V.K. Khattar, whose Love and Wisdom Continue to Guide Me, Even Though He Is No Longer with Us

ACKNOWLEDGEMENT

The satisfaction and euphoria that accompany the successful completion of any task would be incomplete without acknowledging the people who made it possible. Their constant guidance, encouragement, and unwavering support served as a beacon of light, guiding me toward success and crowning my efforts.

I consider it my privilege to express my gratitude to Dr. Jai Gopal Sharma, my research supervisor in the Department of Biotechnology at Delhi Technological University. His insightful mentorship, profound expertise, and consistent encouragement have been critical in the successful completion of this work. His support has enabled me to carry out my research with confidence and efficiency.

I am deeply thankful to Dr. Sumitra Arora, my co-supervisor, for being a constant source of inspiration and motivation. Her unwavering support and patience in solving all my doubts and challenges were crucial in shaping my research. She encouraged me at every step, offering valuable insights that guided me through difficult phases of my work and kept me focused on my goal. I am sincerely grateful to the Director, NCIPM-ICAR, for granting me the opportunity to work and access the resources at NCIPM, which were invaluable in completing my research.

I would also like to express my sincere thanks to all the faculty members of the Department of Biotechnology, DTU, Delhi, for their support, and to Mr. C.B. Singh and Mr. Jitendra for providing me with the necessary resources and information throughout my PhD journey.

A special acknowledgment goes to Dr. Rajendran S., Consultant (Fumigants) at UPL Limited, for being a continuous source of guidance. His immense knowledge of Phosphine Fumigation, expertise in experimental procedures, and encouragement throughout my research, especially with the compilation of my research paper, have been invaluable.

I extend my thanks to Dr. D. Raghavendra, Scientist at ICAR-NCIPM, for his support during the Phosphine dosage application and his patience in guiding me through the entomology-related aspects of my work. His presence in the lab and consistent assistance in resolving doubts were pivotal in advancing my research. I also wish to acknowledge Mr. Dev, Mr. Vinay, and Mr. Rajendra Shah for their kind help and cooperation during the laboratory work, which greatly contributed to the smooth execution of the experiments.

I would also like to express my gratitude to Dr. Shalini Gaur Rudra for her assistance in conducting all my experiments at the Food Science and Post-Harvest Technology, IARI, Delhi. Her generous provision of lab facilities, help with result analysis, and the compilation of my work were crucial to my research progress. I am sincerely thankful to Ms. Priya Pal for being an incredible support throughout the experiments and ensuring their timely completion at the Post Harvest Technology Division, IARI, Delhi. I am grateful to Dr. Namita, Scientist at Floriculture &

Landscaping, IARI Delhi, for providing the flower samples and guiding me through the analysis of Rose and Chrysanthemum.

I extend my sincere appreciation to UPL Pvt. Ltd., Vapi, for assisting with the residue analysis using Gas Chromatography, with special mention to Mr. Montu and Ms. Falguni, for comprehensive support during this process.

I owe my deepest gratitude to my parents, Dr. Virender Kathpalia and Mrs. Sunita Kathpalia, whose unwavering support and belief in me were my pillars of strength throughout this journey. Their love and motivation kept me going even during the toughest times of my PhD. My heartfelt thanks to my sister, Dr. Ankita Kathpalia, and brother-in-law, Dr. Aman Rajpal, for always standing by me, offering support, and encouraging me despite the physical distance. A special mention to my niece, Ayana Rajpal, for cheering me on during times of distress and bringing a smile to my face when I needed it the most. I gratefully acknowledge the blessings of my late grandmother, Smt. Krishna Khattar, whose memory remains a source of comfort and guidance. I am also grateful to my cousin, Ms. Vibhuti Kathpalia, for her continuous support throughout my PhD journey. She has always been there to help me with compiling my thesis, offering motivation, and keeping me focused during difficult times. I would also like to thank my cousin, Ms. Yashika Diwan, for her timely help with the last-minute compilation of my thesis.

I would like to express my gratitude to Dr. Narender, my uncle, for believing in me and encouraging me to pursue a PhD. Mrs. Ranjana Sethi, my aunt, deserves my sincere thanks for always being a constant motivator and having faith in my abilities.
I am forever grateful to my friends, Vishwadeep, Paridhi, Nitya, Anshita, Ram, Shelly, Meenakshi, Lt. Deepika Masabathula (whom I lost in 2020), Meghna, Dimple Saini, Pranav Sethi, Ankur Mudgal, Vivek Chopra, Ashish Gupta, Dheerender Pandey and Sweeti for being my steadfast support throughout this journey. Their love, encouragement, and friendship have been invaluable.

Above all, I bow my head in reverence to the Almighty God and seek His blessings in every endeavor I undertake.

Anisha Kathpalia

Date: 03/12/2024
Place: Delhi

DELHI TECHNOLOGICAL UNIVERSITY

(Formerly Delhi College of Engineering)
Shahbad Daulatpur, Main Bawana Road, Delhi-42

CANDIDATE'S DECLARATION

I, **Anisha Kathpalia**, hereby certify that the work which is being presented in the thesis entitled **"Impact of Phosphine on Quality Parameters of Stored Perishable Commodities"** in partial fulfillment of the requirements for the award of the Degree of Doctor of Philosophy, submitted in the Department of Biotechnology, Delhi Technological University is an authentic record of my work carried out during the period from **August 2018 to December 2024** under the supervision of **Prof. Jai Gopal Sharma, Department of Biotechnology, Delhi Technological University, Delhi and Co Supervision of Dr. Sumitra Arora, Principal Scientist, ICAR-NCIPM, Delhi, India.**

The matter presented in the thesis has not been submitted by me for the award of any other degree of this or any other Institute.

Candidate's Signature

Anisha Kathpalia

2K18/PHD/BT/16

This is to certify that the thesis has incorporated all the corrections suggested by the examiners in the thesis and the statement made by the candidate is correct to the best of the knowledge.

Signature of Supervisor(s) **Signature of External Examiner**

DELHI TECHNOLOGICAL UNIVERSITY
(Formerly Delhi College of Engineering)
Shahbad Daulatpur, Main Bawana Road, Delhi-42

CERTIFICATE BY THE SUPERVISOR(s)

Certified that **Anisha Kathpalia** (Roll no. 2K18/PHD/BT/16) has carried out their search work presented in this thesis entitled **"Impact of Phosphine on Quality Parameters of Stored Perishable Commodities"** for the award of **Doctor of Philosophy** from Department of Biotechnology, Delhi Technological University, Delhi, under our supervision. The thesis embodies results of original work, and studies are carried out by the student herself and the contents of the thesis do not form the basis for the award of any other degree to the candidate or to anybody else from this or any other University/Institution.

Prof. Jai Gopal Sharma
Professor
Department of Biotechnology
Delhi Technological University

Dr. Sumitra Arora
Principal Scientist
ICAR-NCIPM
Delhi

Date: 03/12/24

03.12.24

Prof. Yasha Hasija
HoD & DRC Chairperson,
Department of Biotechnology,
Delhi Technological University,
Delhi-110042

ABSTRACT

Phosphine fumigation is commonly used worldwide for managing storage pests in food grains, with documented applications for pest control in export-oriented perishable commodities such as fruits, vegetables, and flowers. This study aimed to evaluate the impact of phosphine fumigation on the nutrient and physical quality parameters of key perishable commodities, while also investigating sorption and residue levels. The perishables under investigation included Mango and Pomegranate (fruits), Bitter Gourd and Green Chilli (vegetables), and Rose and Chrysanthemum (flowers). The research was conducted over two consecutive years for the perishables to assess the reliability and reproducibility of the results.

The results demonstrated that phosphine fumigation did not significantly alter the key quality parameters, including firmness, moisture content, total soluble solids (TSS), ascorbic acid, total phenolic content, antioxidant capacity, and total carotenoid/anthocyanin content for all the treated commodities. These are essential indicators of both the texture and nutritional value of perishable goods. The statistical analysis showed that the p-values for all these parameters were greater than 0.05, which indicates that the differences observed in the quality attributes were not statistically significant. This suggests that, despite varying concentrations of phosphine and different exposure times, the fumigation process did not cause any measurable changes in the physical characteristics or nutritional composition of the commodities. The lack of significant effect on these quality parameters indicates that phosphine fumigation, when applied under the specific conditions (such as phosphine concentrations, exposure durations, and environmental conditions), effectively preserved the overall quality of the produce. These results are important because they suggest that phosphine fumigation can be used as a treatment method without negatively impacting the marketability or nutritional quality of the perishable commodities.

Sorption analysis revealed varying results among the commodities. Mango exhibited minimal sorption of phosphine, with values consistently ranging between 10-12%. Bitter gourd displayed a more variable sorption pattern, peaking at 20% after 8 hours and decreasing to 5-7% after 15 hours. Chilli, on the other hand, showed the highest sorption levels, reaching up to 60% after 8 hours of exposure, before declining to 30-34% after 10 hours. Chrysanthemum exhibited slightly higher sorption and residue levels compared to Rose, although the differences were not statistically significant. Chrysanthemum sorption levels varied, with a wider range of 10-15%, suggesting a higher level of fumigant uptake. Despite these differences, statistical analysis (ANOVA and regression) revealed no significant effect of exposure period on sorption levels ($p > 0.05$), suggesting that factors other than the exposure period, such as the

structural characteristics, and type of commodity, may influence sorption and residue accumulation.

Residue analysis using gas chromatography with an FPD detector indicated low levels of phosphine residues across all commodities. Mango residues ranged from 0.009 to 0.01 µL/L, which is well within the permissible limits (0.01 ppm) for food safety. Chilli samples exhibited negligible phosphine residues after aeration, further confirming the safety of using phosphine. Bitter gourd, while exhibiting slightly higher residues after shorter aeration times, remained within the Maximum residual limits (MRL) prescribed by regulatory bodies, supporting phosphine's suitability for use in food exports.

In conclusion, this study demonstrates that phosphine fumigation, when applied under controlled conditions, is an effective method for maintaining the quality of export-oriented perishable commodities while minimising residue accumulation. The findings suggest that phosphine can serve as a safe and viable alternative to other fumigants such as methyl bromide. However, the variation in sorption patterns across commodities indicates the need for further optimisation of fumigation protocols, particularly for exposure periods and concentrations, to ensure both effective pest control and the preservation of product quality.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

1.	FAO	The Food and Agriculture Organization
2.	APEDA	Agricultural and Processed Food Export Development Authority
3.	NHM	National Horticulture Mission
4.	PMKSY	Pradhan Mantri Kisan Sampada Yojana
5.	MT	Metric Ton
6.	WTO	World Trade Organisation
7.	MRL	Maximum Residue Limits
8.	PFS	Plants, Fruits, Seeds
9.	GDP	Gross Domestic Product
10.	UV-C	Ultra Violet-C
11.	QPS	Quarantine and Pre-ship Treatment
12.	°C	Degree Celsius
13.	®	Registered
14.	MAS	Modified Atmospheric Storage
15.	LPS	Low Pressure Storage
16.	MeBr	Methyl Bromide
17.	HCN	Hydrogen Cyanide
18.	CO_2	Carbon Dioxide
19.	O_2	Dioxygen
20.	MAP	Modified Atmosphere Packaging
21.	USDA	United State Department Of Agriculture
22.	APHIS	Animal and Plant health Inspection Service
23.	VHT	Vapor heat treatment
24.	RF	Radiofrequency
25.	MHz	Megahertz
26.	GHz	Gigahertz
27.	G/m^3	Gram Per cubic Meter
28.	H	Hour
29.	EF	Ethyl Formate
30.	MB	Methyl bromide
31.	HDS	Horn Diluphos System
32.	AQA	Agricultural Quarantine Agency
33.	BIOTROP	Tropical Biology Institute
34.	ARIAQ	The Indonesian Applied Research Institute of Agricultural Quarantine
35.	PPM	Parts per Million
36.	FWL	Fresh Weight Loss
37.	MDA	Malondialdehyde
38.	EL	Electrolyte leakage
39.	DI	Damage Indices
40.	IARI	Indian Agricultural Research Institute

41.	ICAR	Indian Council of Agricultural Research
42.	NCIPM	National Research Centre for Integrated Pest Management
43.	ICMR	Indian Council of Medical Research
44.	CIPHET	Central Institute of Post-Harvest Engineering and Technology
45.	DMSO	Dimethyl sulfoxide
46.	L	Liter
47.	ML	Milli liter
48.	TSS	Total Soluble Solids
49.	Mm	Milli Metre
50.	N	Newton
51.	g	Gram
52.	MC	Moisture content
53.	HPO_3	Metaphosphoric acid
54.	Mg	Milli Gram
55.	nm	Nano Metre
56.	cm	Centimetre
57.	µL	Micro Liter
58.	N	Normal
59.	Na_2CO_3	Sodium carbonate
60.	GAE	Gallic acid equivalents
61.	CUPRAC	CUPric Reducing Antioxidant Capacity
62.	µ molTrolox	Micro mol Trolox
63.	NaOH	Sodium hydroxide
64.	TC	Total Carotenoid
65.	DMSO	Dimethylsulfoxide
66.	F.W	Fresh Weight
67.	RPM	Revolutions per minute
68.	KCL	Potassium Chloride
69.	HCL	Hydrogen Chloride
70.	OD	Optical Density
71.	DF	Dilution Factor
72.	M	Molecular weight
73.	µL/L	Micro liter/Liter
74.	nL/L	Nano liter/Liter
75.	GLC	Gas-Liquid Chromatography
76.	PLW	Physiological Loss in Weight
77.	µg	Micro gram
78.	Hg	Mercury
79.	GC	Gas Chromatography
80.	ID	Inner Diameter
81.	DAP	Days after Planting
82.	ZECC	Zero Energy Cool Chamber

CHAPTER 1

INTRODUCTION

India has been accorded a climate that is conducive to the growth of fruits, vegetables, and sensitive and delicate floriculture products. Hence, it is the world's second-largest fruit and vegetable producer after China, accounting for 10.9% and 8.6% of the world's fruit and vegetable production, respectively FAO (2023). Unfortunately, only a small fraction of fruits and vegetables is utilized for processing (< 1%) and export (Fruits – 0.5% and Vegetables – 1.7%) as compared to other countries (Bala et al.,2020). Despite being one of the world's largest producers of these perishable commodities, India faces substantial post-harvest losses at various stages of the supply chain, from farm to market. Post-harvest loss refers to the measurable reduction in both the quality and quantity of a commodity as it moves through the supply chain, from the moment of harvest until it is consumed or utilized for other purposes (Hegazy, 2016).

Floriculture is another emerging high-growth industry in India. The Indian government has acknowledged floriculture as a rising industry and accorded it a 100% export-oriented status. This sector has witnessed a transition from traditional flowers to cut flowers, primarily for export purposes. As the demand for flowers continues to grow steadily, floriculture has evolved into a significant commercial sector within agriculture (APEDA,2024)

Post-harvest losses in fruits, vegetables, and flowers continue to be a pressing issue in India, affecting food security, economic sustainability, and the floriculture industry. Estimates suggest that these losses can range from 30% to 40% of the entire production (Hodges et al.,2011). These losses are often attributed to various factors like pest infestations, inadequate storage facilities, and poor handling and post-harvest practices.

1.1 Major Causes of Post-Harvest Losses:

1. **Inadequate Storage and Handling Facilities:** Lack of modern storage and transportation infrastructure and improper handling practices expose produce to physical damage and deterioration. (Hegazy,2016), (Sharma and Singh 2011) reported total post-harvest losses in tomatoes at 15.16% in Uttarakhand, mainly due to inadequate storage and poor handling during harvesting, transport, and marketing (Sharma and Singh 2011). In India, there are approximately 7,600 cold storage with a total capacity of 34.9 million metric tonnes. However, this capacity

is unevenly distributed among states. Four states—Punjab, Uttar Pradesh, Madhya Pradesh, and Gujarat—hold 59% of the storage capacity, totaling 21 million metric tonnes. About 75% of these cold storage facilities are exclusively designated for potatoes, emphasizing the limited availability of other products. Additionally, around 5,000 older cold stores lack integrated pack houses or auxiliary units for food storage support (TIWARI et al.,2021). Moreover, The Ministry of Food Processing Industries (MOFPI) is executing the Scheme for Integrated Cold Chain, Value Addition, and Preservation Infrastructure as part of the **Pradhan Mantri Kisan Sampada Yojana**. This 6000 crore initiative aims to reduce post-harvest losses of both horticultural and non-horticultural produce and to ensure that farmers receive fair prices for their produce (Ministry of Agriculture & Farmers Welfare , 2023).

2. **Pest Infestations & and Inadequate Pest Management:** Pest infestations are a significant cause of post-harvest losses, affecting the quality and shelf life of produce**.** Favorable environmental conditions in storage and transportation facilities can promote the proliferation of pests (Hodges et al., 2011). Also, incorrect application of pesticides can lead to pesticide resistance in pests, making control more challenging (Abhishek et al.,2014).

   For instance, fruit fly incidence not only reduces yield and quality but also restricts the export of fruits to many countries (Patel et al .,2013). In the highly humid and heavy rainfall zone of South Gujarat, fruit flies cause direct damage to 16-40% of mangoes and 2-4% of sapota fruits (Bana et al.,2023). Similarly, in the Palakkad district of Kerala, post-harvest losses due to biotic factors, including pests, were found to be around 35.59% in bitter gourd and 39.16% in snake gourd (Kalpana et al.,2023). Another study in Karnataka indicated total post-harvest losses in tomatoes are around 19%, with 9.43% occurring in the field, 4-5% in the market, and about 5% at the retail level (Rai and Singh 2022). In roses, insect and pest infestations can cause damage ranging from 28% to 95%, affecting both field- and polyhouse-grown plants (Hegde et al., 2020).

3. **Improper Post-Harvest Handling:** Mishandling during post-harvest stages, including harvesting, grading, and packaging, can cause physical damage to perishables and reduce their shelf life (Arah et al.,2016). It contributes to 20-30% of losses during different stages, including storage, grading, packaging, shipping, and ultimately marketing. The estimated loss of some fruits and vegetables is provided in table 1.1.

Table 1.1 Shows an estimated loss in fruits & vegetables

S.No	Commodity	% Loss
1.	Grapes	27%
2.	Banana	20-28%
3.	Citrus	20-95%
4.	Avocado	43%
5.	Apple	14%
6.	Onion	25-40%
7.	Carrot	5-9%
8.	Garlic	08-22%
9.	Potato	30-40%
10.	Tomato	5-34%
11.	Cabbage & cauliflower	7-25%
12.	Chilli	4-35%
13.	Radish	3-5%

By implementing stringent phytosanitary measures, embracing modern pest management practices, and investing in research and development, India can mitigate the risks associated with pest infestations and maintain its position as a leading exporter of perishable agricultural products in the global market.

1.2 Post-Harvest Losses in Fruits and Vegetables

Post-harvest losses in fruits and vegetables not only affect food security and economic sustainability but also hinder the country's ability to meet the nutritional needs of its growing population. A significant quantity of fruits and vegetables produced in India goes to waste because of inadequate post-harvest processes. Consequently, there exists a substantial disparity between the gross production and the actual availability of these products (Bala et al., 2020).

Table 1.2 shows the comparative details of area, production, and productivity of various horticulture crops during 2021-22 (3rd Adv. Est) and 2004-05 DA&FW (2023)

Crop	**Area(** '000 Ha)			**Production (**'000 MT)			**Productivity(**MT/Ha)		
	2004 - 05	**2020-21**	**2021-22**	**2004-05**	**2020-21**	**2021-22**	**2004-05**	**2020-21**	**2021-22**
Fruits	5049	6930	7049	50867	102481	107242	10.07	14.79	15.2
Vegetables	6744	10859	11348	101246	200445	204835	15.01	18.46	18.1
Flowers	118	322	283	659	2980	3128	5.58	9.25	11.1

Despite impressive production growth, the availability of fresh fruits, vegetables, and flowers in the market remains inadequate due to the inefficiencies in handling and distribution. The losses incurred in the horticulture sector pose a significant issue for India's horticulture sector. Fruits and Vegetables, being highly perishable commodities, suffer post-harvest losses due to various factors such as inadequate harvesting methods, decay, over-ripening, mechanical damage, weight loss, trimming, and sprouting. Therefore, it is crucial to critically assess these aspects to make improvements in processing and marketing practices (Bala et al., 2020).

Fruits and vegetables are inherently more prone to deterioration due to their high moisture content, suppleness, and susceptibility to climatic conditions (Jha et al,2016). Pests pose a severe threat to perishables during the post-harvest phase. Their presence leads to both quantitative as well as qualitative losses. Infestations accelerate the spoilage and deterioration of produce, reducing its shelf life. Therefore, pest infestation remains a critical driver of post-harvest losses in perishables, with far-reaching consequences for food security, economies, and sustainability (Abhishek et al.,2014).

1.3 Post-Harvest Losses in Flowers

Flowers are an important horticultural commodity in India, valued for their beauty and economic significance. However, the post-harvest period presents challenges in preserving the freshness and quality of cut flowers, resulting in significant losses. Due to their highly perishable nature, huge post-harvest loss occurs, ranging from 30-40% (Kumar 2012). These losses not only affect the income of flower growers but also have implications for the floriculture industry and international trade. Therefore, they need special care during harvesting, handling, storage, and transport.

Inadequate cooling and storage facilities, as well as poor transportation networks, can lead to premature wilting, pest infestation, and deterioration of flower quality. Mishandling during post-harvest stages, including harvesting, grading, and packaging, can cause physical damage to the flowers and reduce their vase life (Hegazy 2016)**.** Limited knowledge of Integrated Pest Management (IPM) practices among flower growers can result in ineffective pest control (Ramasamy et al.,2020)**.** Cut flowers are highly sensitive to temperature and humidity fluctuations, and the absence of control measures can accelerate wilting and spoilage (Navarro et al.,2015).

Initiatives should be made to mitigate these losses through the adoption of IPM practices, improved handling & infrastructure, and research and innovation. Addressing pest-related post-harvest losses is essential not only for the economic sustainability of the sector but also for ensuring that consumers can enjoy high-quality, pest-free cut flowers. It should be also ensured that cut flowers meet phytosanitary requirements for export and domestic trade.

1.4 Status of Perishables in India

The abundance of perishables in India reflects the country's rich agricultural diversity and its prominent role as a global producer of fruits, vegetables, and flowers. India's agricultural landscape boasts a wide variety of perishable crops, including tropical fruits like mangoes and bananas, an array of vegetables, and a rich tapestry of vibrant flowers (Hodges et al.,2011). Efforts to improve the status of perishables in India are ongoing, with a focus on reducing post-harvest losses and enhancing their economic value. The government has recognized the need for substantial investments in cold chain infrastructure, pest management practices, and modern storage facilities to extend the shelf life of perishable products (FAO 2019). Additionally, initiatives like the National Horticulture Mission (NHM) and the Pradhan Mantri Kisan Sampada Yojana (PMKSY) aim to bolster the entire supply chain, from production to marketing, to ensure that perishable crops reach consumers with minimal losses and at competitive prices (Nath and Jha 2020).

1.4.1 Fruits & Vegetables

India ranks first in the production of mangoes (41%), papaya (30%) and banana (28%). Among vegetables, India is the largest producer of peas (30%); and second largest of brinjal (29%), cauliflower (29%), onion (18%), and cabbage (8%) (Gajanana et al.,2011). While onions, potatoes, tomatoes, and green chillies make up the majority of the vegetable export basket; grapes, pomegranates, mangoes, bananas, and oranges make up the majority of the country's exports of fruits. Bangladesh, the United Arab Emirates, the Netherlands, Nepal, Malaysia, the United Kingdom, Europe, Singapore, Sri Lanka, Oman, and Qatar are the primary destinations for Indian

fruits and vegetables (APEDA 2024). Table 1 depicts the value and quantities of perishables exported to various destinations over the last three years.

Table 1.3: Indian Export numbers for fruits and Vegetables. (APEDA 2024)

Year	Fruits Quantity (in MT)	Fruits value in Crores(₹)	Vegetable Quantity (in MT)	Vegetables value in Crores (₹)	Total Quantity (in MT)	Total value in Crores(₹)
2021-22	1,051,979.59	5,530.31	2,307,730.07	5,592.90	3,359,709.66	11,123.21
2022-23	965,204.85	5,658.90	3,352,546.40	6,965.83	4,317,752.25	12,624.73
2023-24	1,263,509.85	7,715.11	2635546.98	6,861.055	3,899,056.83	14,576.17
2024-25 (April-October)	508,741.04	2,583.38	1,335,577.43	3,343.96	1,844,318.47	5,927.34

1.4.2 Flowers

Floriculture is emerging as a high-potential growth sector in India. The United States, the Netherlands, the United Arab Emirates, the United Kingdom, Germany, and Malaysia are the main importers of Indian floricultural products (APEDA 2024). The floriculture products exported by India primarily include cut flowers, pot plants, cut foliage, seeds, bulbs, tubers, embedded cuttings, and dried flowers or leaves. The rose, carnation, tuberose, chrysanthemum, gerbera, gladiolus, gypsophila, nerine, Liatris, orchid, carnations, marigold, anthurium, tulip, and lilies are significant floricultural crops in the global cut flower trade (Palanisingh and Vijayalakshmi 2022). Table 2 presents the export figures for floriculture products from India to various countries over the past three years.

Table 1.4: Indian Export numbers for Floriculture APEDA (2024).

Year	Floriculture (in MT)	Floriculture value in crores(₹)
2021-22	23597.22	771.41
2022-23	21024.41	707.81
2023-24	19677.89	717.83
2024-25 (April-October)	11093.65	383.41

1.5 Pests Affecting Export-Oriented Fruits, Vegetables, and Flowers

India is a significant exporter of various fruits, vegetables, and flowers. Different species of pests infest these perishables during storage depending upon the type of host and storage conditions.

1.5.1 Mango

Major pests include fruit flies (*Bactrocera dorsalis, B. zonata, B. correcta*), seed weevil (*Sternochetus mangiferae*), mango pulp weevil (*Sternochetus frigidus*), Mango seed borer (*Deanolis albizonalis*) and mango fruit borer (*Citripestis eutraphera*). These pests affect mango quality and quantity, reducing export potential due to their ability to evade detection during packaging and inspection processes (Reddy et al.,2018).

1.5.2 Pomegranate

India is the world's largest producer of pomegranates, mainly exporting to the Middle East and European countries Apeda (2012). Pests such as the pomegranate butterfly (*Deudorix isocrates*), Mediterranean fruit fly (*Ceratitis capitata*), thrips (*Rhipiphorothrips cruentatus*), and mealybugs (*Planococcus lilacinus*) significantly reduce the quality and export potential of pomegranates by damaging the fruits (Ananda et al.,2009).

1.5.3 Bitter Gourd

Major pests affecting bitter gourd include fruit flies (*Bactrocera cucurbitae and Bactrocera dorsalis*), cucumber moth (*Diaphania indica*), and melon thrips (*Thrips palmi*). These pests damage the fruits, leading to substantial yield losses and reduced export quality (Dhillon et al. 2005).

1.5.4 Chilli

Chilli faces significant pest challenges, with 293 species of insects and mites affecting the crop in field and storage (Reddy et al., 2011). Notable pests include chilli thrips (*Scirtothrips dorsalis*), melon-cotton aphids (*Aphis gossypii*), and green peach aphids (*Myzus persicae*). The chilli thrips, originally from South Asia, are widespread and cause severe damage by feeding on tender plant tissues, resulting in necrosis Kumar et al (2013).

1.5.5 Rose

Rose faces significant threats from insects, mites, diseases, and nematodes, with sucking pests like thrips, aphids, leafhoppers, whiteflies, and mites being particularly problematic in polyhouse conditions. These pests cluster on the undersides of leaves, shoots, buds, and flowers, causing damage that reduces plant health and aesthetic value. On roses, both nymph and adult thrips (***Rhipiphorothrips cruentatus*)** feed primarily on the flowers, causing silvery or bleached patches on petals that later turn brown and dry. Severe infestations reduce the aesthetic value and can prevent bud opening. (Hedge et al.,2020).

1.5.6 Chrysanthemum

Chrysanthemum, a significant crop in floriculture known for its high cut flower production, faces substantial declines in productivity and marketability due to damage caused by insect pests, resulting in considerable economic losses for growers. It is susceptible to various pests, including aphids, caterpillars, mites, whiteflies, thrips, and leaf miners. Among these, the Chrysanthemum aphid (*Macrosiphoniella sanborni*), a major pest of the crop, is particularly widespread on cultivated Chrysanthemum globally (Raghuteja, Rao, & Rao, 2023).

1.6 Post-harvest Pest Management

India produces a lot of perishables, but despite this, the country's products do not have a significant impact on the export-focused global market e.g. Fruits & Vegetable crops, suffer a 25–30% yield loss as a result of pest infestation, which may be worth several crores a year (Sardana et al.,2017). Insect pests from orders such as Heteroptera, Homoptera, Diptera, Coleoptera, and Lepidoptera pose a threat to fruits and vegetables. Mango, guava, papaya, peach, pear, and cucurbits in India face significant threats from *Bactrocera spp*. Fresh produce in storage is primarily affected by fruit flies, stone weevil, codling moth, potato tuber moth, sweet potato weevil, almond moth, red flour beetle, and khapra beetle (Ansari et al.,2019).

Post-harvest pest management is a critical aspect of ensuring the quality and safety of agricultural produce during the storage and distribution phases. The presence of pests poses a significant threat to the quantity and quality of harvested crops, potentially leading to substantial economic losses. Moreover, the prestige of the country is also at stake when exporting countries reject the consignments due to quality issues. Addressing post-harvest pest management issues is not only essential for minimizing losses but also for preserving food security and meeting the growing demand for safe and high-quality food products in both domestic and international markets (Navarro 2019).

Knowledge of control strategies, pest biology, and pest ecology within agroecosystems forms the foundation of effective pest management. (Arif et al .,2017). Pest infestations and unfavorable storage practices not only cut short their postharvest life but also reduce quality and consumer acceptability. Post-harvest techniques, including controlled ripening, temperature control, and chemical treatments, are effective tools for reducing post-harvest losses in fruits and vegetables, improving nutrition and food security, and reducing poverty. Post-harvest technology in fruits and vegetables focuses on developing methods to reduce losses, prevent spoilage, and ensure maximum utilisation of produce in a nutritious and safe manner. (Poonam et al.,2022).

The main objectives of using postharvest technology for harvested fruits and vegetables are:

1. To maintain quality (appearance, texture, flavor, and nutritive value)
2. To protect food safety.
3. To reduce losses between harvest and consumption
4. To promote the global trade of fruits and vegetables (Poonam et al.,2022).

1.6.1 Post-harvest Pest Management Techniques for Perishables in India

India has seen a surge in the export of horticultural products, particularly fresh fruits and vegetables. Pre- and post-harvest pest management techniques are increasingly recognised and adopted, enhancing production, quality, and shelf life while complying with WTO regulations. Several nations forbid imports from India due to the presence of quarantine pests. Therefore, once a complete disinfestation technique has been approved and established, import will be permitted (Gupta and Khetarpal 2005)

A successful disinfestation procedure has to conform to the phytosanitary standards for a particular pest without significantly affecting the product's quality. Every country has different standards for the requisite efficacy to meet the phytosanitary requirements. For example, for the USA, the required efficacy has typically been 99.9968% (probit 9) with no survivors from 100,000 treated insects, demonstrated at the 95% confidence level (Gupta and Khetarpal 2005).

Japan uses a Probit 9 concept variant that requires no survivors from a treated population of 30,000 target pests (Jacobi et al.,2001). The Maximum Pest Limit in New Zealand presently allows five surviving flies per 1,000000 pieces of fruit for critical fruit fly species, including *C. capitata* and *B. Tryoni*. (Gupta and Khetarpal 2005). The Indian government has imposed several rules and regulations on the export/import of perishables.

Table 1.5: Regulations regarding import/export of fruits and vegetables.

S.No	Regulations for Import/Export	Details	References
1.	Agricultural and Processed Food Products Export Development Authority (APEDA) act, 1985	Formation of APEDA, whose major functions include the development of industries for scheduled export products, including financial assistance, surveys, and feasibility studies, registration of exporters, fixing of standards and specifications for export, inspection of meat and meat products, and improving packaging and marketing of export.	(apeda.gov.in, 2022)
2.	Plant Quarantine Order, 2003	Stipulating Phytosanitary conditions on plants and plant products being imported to India.	(https://biosafety.icar.gov.in/)
3.	Food Safety and Standards (Contaminants, Toxins and Residues) Regulations, 2011	ICAR provides essential field data on pesticide residues through its research, while ICMR conducts health risk assessments and toxicological evaluations. The Central Insecticides Board and Registration Committee (CIBRC) reviews these inputs, guiding the Food Safety and Standards Authority of India (FSSAI) in setting MRLs for fruits and vegetables.	(https://www.fssai.gov.in/)
4.	Food Safety and Standards (Import) Regulations, 2017	• Restricting import of any food article without an import license from the Central Licensing Authority following the provisions of the Food Safety and Standards (Licensing and Registration of Food Businesses) Regulations, 2011. • Registering the Food Importer with the Directorate General of Foreign Trade and obtaining a valid Import Export Code • Regulating standards for packaging, labeling, and storage under optimal conditions of temperature and hygiene. • Analysing the food quality by the laboratories notified by the Food Authority.	(https://www.fssai.gov.in/)

		• Prohibiting or restricting the import of any food based on the risk involved or outbreak of disease	
5.	Plants, Fruits, Seeds (Regulation of Import into India) Order{PFS} Order, 1989 issued under the Destructive Insects & Pests Act, 1914.	Preventing the introduction of exotic pests and diseases into the country	https://www.fssai.gov.in/).

A variety of postharvest physical (low/high temperatures, vapour heat, high-frequency waves, irradiation, etc., chemical (fumigants, fungicides, insecticides, chemical sprays, dipping, etc.), treatments may be used to preserve the fresh-like quality, high nutritional content, and compliance with fresh produce safety regulations (Mahajan et al.,2014).

1.6.2 Pest Management Techniques for Fruits & Vegetables

Horticulture is important to Indian agriculture. 8.5% of the land is cultivated, which generates 30.4% of the country's GDP (Poonam et al.,2022). Physical treatments usually include physical means such as low or high temperature, vapour heat, irradiation, high-frequency waves, high pressure, etc. These often demand a wide range of specially made facilities and equipment, as well as a lot of energy (Gupta and Khetarpal 2005).

Due to the complete absence of residues in the treated product and the low environmental impact, physical treatments have attracted a lot of attention in recent years as a means of controlling several postharvest diseases in fruits and vegetables (Usall et al.,2016). Traditional methods of application included hot water dips, hot water rinsing and brushing, hot air, vapour, and curing (Fallik 2004; Porat and Ben-Yehoshua 2005)**.**

Also, there has been a rise in interest in the heat treatment of fruits using radio frequency or microwave energy (Sisquella et al., 2014). Hypobaric and hyperbaric pressure and far ultraviolet radiation (UV-C light) are treated as promising control means, and controlled and modified atmospheres as complementary physical tools essential to reduce or delay the development of postharvest pathogens (Usall et al.,2016).

Table 1.6: Showing comparison of heat treatments (Hansen and Johnson 2007) and different combination treatments available.

Treatment	**Commodity**	**Advantages**	**Disadvantages**
Hot water	Fruits, bulbs, ornamentals, seeds	Simple & efficient	Surface heating first, high fuel costs
Vapor heat	Fruits & vegetables	Simple	Expensive facilities required; surface heating first; slow
Forced Hot Air	Fruits & vegetables	Product quality retained	Expensive facilities required; surface heating first; slow
Controlled Atmosphere /Temperature Treatment System (CATTS)	Experimental fresh produce	Faster than other air methods	Surface heating first; complicated, expensive facilities are required
Electromagnetic Energy	Experimental fresh produce, grains, seeds, nuts	Very fast; internal heating first	Expensive facilities required; variable effects (due to orientation of the target)
Combination Treatments			
Fumigation combined with Refrigeration	Fruits , Vegetables & Flowers	Fast, Simple & effective; inexpensive Product quality retained; no /little residue after proper aeration.	Chances of developing resistance due to sub lethal dosages and exposure periods.
Fumigation combined with Heat	Stone Fruits	Decreased fumigant concentration and treatment time	Expensive facilities are required for uniform heating.
Combination of Heat and Cold treatment	Fruits & vegetables	Reduced Chilling injury and decay control	If the Temperature/Time combination is not optimum, will result in fruit decay.

Modified and Controlled Atmosphere combined with high temperatures	Fruits & vegetables	Faster Killing Time at elevated temperatures and reduced treatment time.	It can cause changes in color, texture, and quality of the fruit. It can be lethal to humans if not handled properly.
Irradiation combined with heat	Fruits & vegetables	Reduced Radiation dose and duration of treatment; Less expensive.	Reduces the shelf life and renders the fruit unacceptable after two weeks of storage.
Radiofrequency and Hot Water Dip Method	Fruits & vegetables	Effective and uniform heating.	It can cause loss of firmness and color of the fruit.

Chemical treatments include fumigation with Methyl bromide, Phosphine, Hydrogen cyanide, and carbon dioxide. Fumigation is always carried out by a predetermined standard technique, which has been determined for the specific pest/commodity combination in terms of dosage, duration, and temperature. A thorough understanding of the fumigant's physical and chemical qualities, the sensitivity of pests, the application method, etc., is required to use fumigation effectively (Gupta and Khetarpal, 2005)**.**

Protocols for phosphine gas fumigation have been established as an alternative to methyl bromide for the quarantine and pre-ship treatment (QPS) of certain fruits, vegetables, and cut flowers (Tumambing et al.,2018). Many nations are exploring the use of pure phosphine gas (free of ammonia) for post-harvest fumigation of perishables. It was found that using pure phosphine in cooled fumigation chambers between -1.5°C and 15°C can effectively kill the majority of insects that infest fresh fruits and vegetables (Liu ,2018).

Phosphine in the form of two formulations namely ECO2FUME® and VAPORPH3OS® is found to be non –phytotoxic and does not damage perishables commodities such as cut flowers, fruits, and vegetables during fumigation (Tumambing et al.,2018). A combination of fumigation and low temperature/thermal treatment is found to be effective against pests infesting perishables (Armstrong, 1992).

For a nation like India, where numerous species of the *B. dorsalis* complex exist and *B. cucurbitae* has been documented from several agro-ecological areas, eradicating the target pest from the infested area is not practical. Hence, the most logical solution for the eradication of pests and promotion of export will be the development of a method for complete disinfestation (Gupta and Khetarpal,2005)**.**

1.6.3 Pest Management Techniques for Flowers

India has numerous agro-climatic zones that are ideal for producing delicate and sensitive floriculture products (Palanisingh et al.,2022). Commercial floriculture has grown in importance in terms of agricultural diversification and national economic development. With the global expansion of the floriculture sector, producing high-quality flowers that meet international standards has become a major challenge in commercial floriculture. Diseases and pests are among the most important factors influencing flower output quality and require continual monitoring and timely implementation of effective control methods (Singh et al.,2015).

Irradiation, Temperature treatments (Cold Storage, Hot Water Baths, Vapour Heat), Controlled atmospheres, Modified Atmospheric Storage (MAS) and Hypobaric Storage or Low-Pressure Storage (LPS), Fumigation (Methyl Bromide/Phosphine/HCN), insecticidal dips & sprays, treating with biocides, and the application of biological control agents (use of pathogens of insects to eliminate pests) are currently used postharvest methods to rid cut flowers of infestations (Mitra et al.,2019) and (Hansen and Hara,1994).

In this study, we have treated the perishables with effective pure phosphine concentrations, which resulted in 100% insect mortality, and evaluated the effect of the particular dosage on the Physical, Nutritional, and Quality parameters of the commodity. Additionally, this study investigated sorption and residue levels of phosphine in perishables to optimize fumigation protocols and enhance the export competitiveness of the horticultural sector.

1.7 Quality Parameters of Perishables

Quality is not a singular, well-defined attribute but encompasses multiple features or properties. The quality of fresh fruits and vegetables is typically assessed based on their chemical composition, physical characteristics, or a combination of both. Key components of quality include appearance, texture, flavor, and nutritional value (Dubey and Anchal, 2020). Attributes that interest consumers include visual appearance, texture and firmness, sensory qualities, nutritional value, and food safety (Watada, 1995). Consumers are unlikely to accept a product unless it meets their expectations for these quality attributes, which can significantly impact the marketing chain, especially in exports (Dubey and Anchal, 2020).

In the increasingly competitive global market for flowers, quality and reliability are paramount. Ensuring a longer post-harvest life of flowers guarantees customer, retailer, and consumer satisfaction (Gupta and Dubey, 2018). Like other horticultural crops, flowers require proper post-harvest management operations. This

is crucial because vase life is one of the most important post-harvest issues in the flower industry in both domestic and export markets. Flowers are assessed based on their water uptake, transpiration rate, water balance, changes in fresh weight, vase life, and anatomical traits (Patel et al.,2018).

Ensuring the quality of perishable commodities post-harvest is crucial for consumer acceptance and marketability. Quality parameters are typically categorized into physical and nutritional attributes.

1.7.1 Physical Quality Attributes

These quality attributes are assessed using principles of physics to measure the fruit's response to various factors such as light, weight, force, time, and spatial dimensions. The measurements typically include Texture (such as firmness), juice yield, Physiological Loss in Weight, pH, Moisture Content, water uptake, etc. (Ladaniy,2008). The various physical quality attributes that are a part of this study are discussed below.

1.7.1.1 Texture

Texture is one of the key factors defining fruit or vegetable quality, along with appearance, flavor, and nutritional properties. It plays a critical role in determining consumer acceptability (Abbott, 2004). It is typically measured using texture analysers, which assess attributes such as ripeness, firmness, skin rupture force (or 'bioyield point'), crust crispness, flexibility or rigidity, consistency, stickiness, and bruising potential. The quality of fruits and vegetables depends on various criteria, with firmness being a key factor as it changes significantly during ripening. Assessing firmness is essential for determining the optimal maturity and ripeness of fruits and vegetables. The bioyield point measures the initial rupture of cells in the whole fruit and indicates the maximum load the sample can handle without visible damage. It marks the point at which the fruit or vegetable starts to change shape or sustain damage under pressure (Stable Micro Systems ,2024).

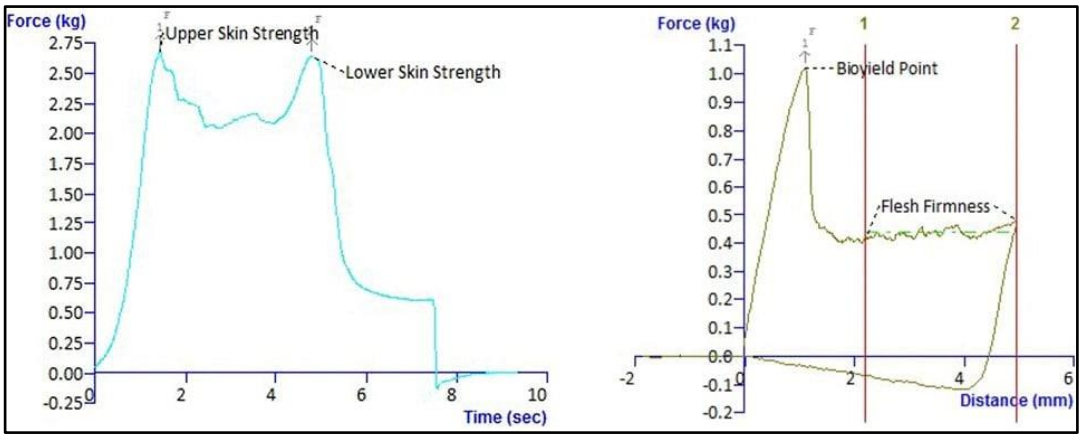


Figure 1.1: Typical Texture Analyser graphs with annotated properties illustrating ripeness (Stable Micro Systems ,2024).

Pink Lady apples were treated with ethyl formate (reagent grade, 97% purity) at dosages of 10, 20, 30, 40, and 80 g/m³ for 24 hours at 22–24°C. Even after 1, 2, and 3 weeks' post-treatment, no morphological differences were observed between treated and untreated apples in terms of color, texture, or firmness (Agarwal et al.,2015).

1.7.1.2 Juice Yield

The juice yield is an important physical parameter in assessing fruit processing efficiency, referring to the amount of juice extracted from a given quantity of fruit. It plays a significant role in both the economic and quality aspects of production. A higher juice yield ensures better utilisation of the fruit, impacting profitability, and serves as an indicator of fruit quality, with fresher, more mature fruits typically producing more juice (Tarantino et al.,2022). Juice yield was measured to determine if phosphine treatment affected extraction, ensuring that changes in yield were attributed to the treatment or natural factors like fruit variety and maturity.

Klementz et al. (2005) investigated the quality of table grapes treated with pure phosphine (VAPORPH3OS) at a concentration of 2 g/m³ for 48 hours at 0°C. Their findings showed no significant differences in quality parameters, including color, texture, sugar/acid ratio, and juice yield, between treated and untreated samples (Klementz, et al.,2005).

1.7.1.3 pH

Measuring the pH of fruit juices is crucial for ensuring their quality, as it influences taste, preservation, nutrient stability, and safety. Here, we measured the pH of pomegranate juice to determine if there was any change due to treatment with phosphine. pH level affects the taste and plays a key role in extending shelf life by preventing microbial growth, which reduces spoilage and the need for preservatives.

Additionally, pH control helps maintain nutrient stability, particularly for sensitive vitamins like vitamin C (Miguel et al.,2004).

1.7.1.4 Physiological Loss in Weight (PLW)

Physiological Loss in Weight (PLW) refers to the reduction in a fruit's weight over time due to natural processes like respiration and transpiration. After harvest, fruits continue to respire, leading to the loss of water and other volatile compounds, which causes a decrease in their overall mass. Factors such as temperature, humidity, and the condition of the fruit's skin influence the rate of PLW. This weight loss can impact the fruit's appearance, texture, and marketability, often resulting in shriveling and a less fresh look (Kader, 2002). In this study, we have tried to understand if the loss in weight is due to the treatment with phosphine or the natural factors influencing weight loss, such as temperature, humidity, and the condition of the fruit's skin. This is crucial for evaluating the impact of phosphine on fruit quality, particularly in terms of appearance, texture, and marketability.

1.7.1.5 Moisture Content

Measuring moisture content in fresh produce using the drying method is crucial for assessing their quality, shelf life, and overall condition. This method, which removes water through heat, provides precise moisture levels that indicate freshness and influence spoilage risk. Understanding moisture content helps in making informed decisions about processing and storage, as it directly affects the shelf life, weight, and nutrient density of the vegetables (Zambrano et al.,2019).

1.7.1.6 Water Uptake

Water uptake is an essential physical parameter for flowers, particularly concerning postharvest handling and vase life. It describes the flowers' capacity to absorb water through their stems after harvest (Prabawati et al.,2023). In this study, flowers were placed in a measured amount of water to assess whether water uptake was influenced by environmental factors such as temperature and humidity, or by treatment with phosphine.

1.7.2 Nutritional/Chemical Attributes

These quality attributes are assessed using principles of chemistry, focusing on the fruit's internal composition and its response to chemical reactions. These may include total Titratable acidity, Total Soluble Solids (TSS), Ascorbic acid content, Antioxidants, Phenols, etc. These parameters can offer valuable insights into the freshness and quality of the fruit (Ladaniya ,2008).

1.7.2.1 Titratable acidity

Titratable Acidity (TA) is an important factor that reflects fruit storage characteristics and quality, as it directly influences the taste, with higher acidity levels imparting a tart flavor and lower levels producing a milder taste. A pronounced reduction in TA can accelerate the senescence of fruits, leading to faster degradation and reduced shelf life (Cha et al .,2019).
Banana fruits treated with nitric oxide exhibited delayed peel colour changes, along with increased firmness, titratable acidity (TA), and total soluble sugar (TSS) content in the pulp (Wang et al.,2015).

1.7.2.2 Total soluble solids (TSS)

Total soluble solids (TSS) are a key indicator of the taste quality of produce and serve as a measure of ripeness, reflecting the concentration of soluble minerals and sugars in fresh produce. TSS levels in juice are typically assessed using a refractometer, which determines the refractive index of a solution to quantify the dissolved solids present. The level of soluble solids in a solution is measured in degrees Brix (°Bx). (Al-Dairi et al., 2021). As TSS significantly influences consumer preference, it is one of the most critical attributes in evaluating produce quality.

Loquat fruits were fumigated with nitric oxide gas (99.5% pure) at concentrations of 5, 15, 25, 35, and 45 μL/L for 2 hours at 25°C, followed by storage at 5°C. The treatment effectively delayed the reduction in titratable acidity (TA) and total soluble solids (TSS). Additionally, nitric oxide fumigation inhibited the increase in fruit firmness and the decline in juice percentage (Mei-zi et al.,2014).

1.7.2.3 Ascorbic Acid

Ascorbic acid is one of the most significant nutritional quality factors in many horticultural crops due to its essential biological activities in the human body. It serves as a potent antioxidant and plays a vital role in protecting produce from oxidative damage and enhancing its nutritional profile. Several factors, including genetic variations, preharvest climatic conditions, agricultural practices, the stage of maturity at harvest, and postharvest handling methods can influence the ascorbic acid content in fruits and vegetables (Lee and Kader,2000). In an experiment conducted by Nolpradubphan and Lichanporn (2016), lime fruits treated with sodium nitroprusside (SNP) solution at a concentration of 5 μg/L exhibited increased levels of total soluble solids (TSS) and ascorbic acid.

1.7.2.4 Antioxidants

Antioxidants are a vital parameter in fruits and vegetables, significantly contributing to their health benefits and overall quality. The high antioxidant content is often associated with the freshness and nutritional value of fruits and vegetables, as they play a key role in preventing spoilage by slowing down oxidation processes that lead to deterioration (Kalt, 2005). Monitoring antioxidant levels is crucial for estimating the quality of fresh produce, as it helps ensure its nutritional value and freshness and appeal to consumers.

In a study on Pomegranate, it was found that pomegranate fruits when dipped in sodium nitroprusside (SNP) solutions at concentrations of 30, 100, 300, and 1000 μM for 2 minutes before storage at 5°C. Treatment with 1000 μM nitric oxide significantly reduced electrolyte leakage and total soluble solids (TSS) while preserving antioxidant activity and total anthocyanin levels. However, nitric oxide treatment had no significant effect on titratable acidity (TA), pH of the juice, or the chilling injury index (Ranjbari et al.,2016).

1.7.2.5 Carotenoids

Carotenoid composition in fruits and vegetables is influenced by various factors, including the cultivar or variety, the part of the plant consumed, the stage of maturity, climate or geographic origin, and postharvest handling, processing, and storage conditions (Britton, 1995). Among these, the stage of maturity at harvest is the most decisive factor affecting carotenoid content when the produce is offered for consumption. Carotenoids such as beta-carotene, the most widespread carotenoid in foods, not only impart vibrant colors but also contribute to the nutritional value by serving as precursors to vitamin A (Rodriguez-Amaya, 2001)**.**

1.7.2.6 Anthocyanins

Anthocyanins are naturally occurring compound responsible for the vibrant colors in fruits, vegetables, and flowers, making them one of the most significant groups of visible plant pigments (Winefield et al.,2009). These pigments are part of the broader class of flavonoids, a type of phenolic compound, and are glycosides of polyhydroxy and polymethoxy derivatives of 2-phenylbenzopyrylium or flavylium salts. Anthocyanins play a crucial role in attracting animals for pollination and seed dispersal, which is essential for the co-evolution of plant-animal interactions. Their presence not only enhances the visual appeal of plants but also supports their reproductive processes, underscoring their ecological and evolutionary importance (Kong et al.,2003).

Pomegranate fruits were treated with 300 μM nitric oxide (NO) solution by dipping for 2 minutes, followed by wrapping treatments using cellophane (wrapped or unwrapped), and stored at either 1°C or 5°C for 90 days. The application of 300 μM NO enhanced the antioxidant activity, total anthocyanin content, and the a* value (redness) of the aril color (Ranjbari et al.,2018).

1.7.2.7 Phenols

Phenolic components are crucial secondary metabolites that significantly influence the color, texture, hardness, and flavor of fruits. They serve as important indicators of the nutritional value of produce, reflecting not only its sensory attributes but also its overall quality and health benefits (Chen et al.,2023). The levels of phenolic compounds are influenced by factors such as plant variety, growing conditions, ripeness, and postharvest handling (Eseberri et al.,2022). In an experiment, blueberries were fumigated with sulphur dioxide (SO_2) at a concentration of 28 nL s^{-1} L^{-1} (>99% purity), followed by storage under controlled atmosphere conditions (3% O_2 with either 6% or 12% CO_2). This treatment effectively reduced decay without compromising fruit quality. No significant differences were observed in soluble solids content, titratable acidity (TA), polyphenolic content, or total antioxidant activity across all treatments (Cantin et al.,2012).

1.8 Sorption

The effectiveness of phosphine fumigation largely depends on the sorption behavior, type, and variety of the target food commodity. Sorption refers to the interaction of phosphine gas with the treated commodity, either by absorption into or adsorption onto its surface, significantly influencing the fumigant concentration within the commodity and potentially affecting pest control efficacy. Commodities with high sorption capacity may necessitate extended fumigation periods or increased phosphine concentrations to ensure complete insect mortality (Meenatchi et al.,2016). Factors such as temperature, moisture content, fumigation dosage, air tightness, and potential leakages also affect the sorption of phosphine (PH_3) by commodities (Meenatchi et al.,2016).

Sorption behavior plays a crucial role in determining fumigation success or failure, as it impacts the residual fumigant amount, the concentration of active material in the gas phase during treatment, and the rate at which the fumigant dissipates post-treatment (Banks, 1992).

During fumigation, gas concentration decreases due to leakage and sorption by the product. Sorption includes both “physisorption” (reversible) and “chemisorption” (irreversible) processes. Factors such as the nature of the commodity, particle size and composition, fumigation history, moisture content, fumigant dosage,

temperature, and exposure time impact sorption (Reddy et al.,2007). During fumigation, gas concentration decreases due to leakage and sorption by the product. Since food commodities have varying sorptive capacities, sorption can significantly influence whether a lethal fumigant concentration is reached under airtight conditions. Repeated fumigation may reduce sorption rates as fewer binding sites become available for phosphine (Reed and Pan, 2000).

Sorption significantly impacts various fumigation characteristics, including the concentration achieved and, consequently, the effectiveness of the fumigant dosage. It also influences the rate at which the fumigant disperses through the bulk of the commodity, the extent and rate of fixed residue formation, and the time required to ventilate the fumigant from the treated product (Reddy et al.,2007). Here, we also examine phosphine sorption and residue levels in perishables to optimize fumigation protocols to enhance pest control while minimizing phosphine residues and meeting international food safety standards.

1.9 Research Objectives

This research is focused on understanding Phosphine as a fumigant for the treatment of export-oriented fresh fruits, vegetables, and flowers.
The objectives of this study are listed below:

1. To evaluate the effect of different concentrations of Phosphine on the nutrient quality of Perishable commodities.
2. To examine and compare the physical parameters of perishable commodities after treatment with phosphine.
3. To study the Sorption and residues of different concentrations of Phosphine on Perishable commodities.

CHAPTER 2

REVIEW OF LITERATURE

To prevent the transmission of agricultural pests from one nation to another, different treatments are available to control pests for the export and import of perishables before shipment and after they are received in the port of destination. Among the traditional methods used for this purpose, the use of methyl bromide fumigation, thermal treatments, or prolonged storage at low temperatures are the most common. The use of traditional post-harvest treatments like Methyl Bromide may pose environmental concerns such as ozone depletion. Therefore, advanced techniques such as refrigerated storage and transportation, controlled and modified atmosphere storage, irradiation, thermal processing, drying, and Phosphine Fumigation are being implemented to improve the post-harvest shelf life of perishable goods.

Harvested perishables are commonly subjected to low temperatures to slow down respiration, postpone ripening, and delay the aging process of fruits and vegetables. Storing perishable items such as fruits at low temperatures and controlled humidity levels aids in preserving various quality characteristics such as texture, nutritional content, aroma, and flavor (Yahia et al.,2011). However, this approach comes with a significant expense related to maintaining the cooling system, facilities, and equipment (Armstrong, 1992).

Insecticidal atmosphere, utilizing elevated CO_2 or low O_2 levels within the treatment enclosure, is employed as a quarantine treatment. This method decreases ethylene production in fruits and vegetables, thereby decelerating the ripening process and reducing issues like enzymatic browning, chilling injury, and chlorophyll breakdown (Bodbodak and Moshfeghifar,2016). However, only fruits capable of enduring prolonged refrigeration and controlled atmosphere storage can withstand this treatment (Armstrong,1992). Modified Atmosphere Packaging (MAP) entails sealing commodities in polymeric film packages to adjust the levels of oxygen and carbon dioxide within the package. However, the potential of MAP for storing and treating many fruits and vegetables has not been fully explored (Sandarani et al.,2018).

Insecticide sprays, immersions, and fruit waxes have demonstrated effectiveness against fruit flies. For instance, the combination of Methoprene with fruit wax, when applied to infested papayas and peaches, resulted in high mortality rates of the Mediterranean fruit fly. However, many insecticides are linked to concerns regarding their residues and potential risks to operators. Additionally, insecticides that are approved for immersion or spray treatments in one country may not have the same

registration status in other countries for the same application. This disparity could restrict the marketing of insecticide-treated fruits across different regions (Armstrong,1992). Food irradiation involves sterilizing or killing storage pests by exposing food products to ionizing radiation. This radiation can take the form of Gamma rays (from Cobalt-60 or Cesium-137 sources), electron beams, or X-rays. Gamma rays are often preferred due to their ability to penetrate deeply into food products. In 1989, the North American Plant Protection Organization (NAPPO) recognized irradiation as a broad-spectrum quarantine treatment for fresh fruits and vegetables (Satin and Loaharanu, 1997). However, it's an expensive technology that requires a significant initial investment. Irradiation doses render insects sterile or developmentally incompetent, but they do not kill them outright because the doses needed to kill insects are higher than those tolerated by perishables (Yahia et al.,2011).

Hot water immersion is a widely recognized quarantine treatment used in several countries for mangoes and papayas to control fruit flies. The USDA APHIS approved this treatment for *Tephritidae* fruit flies in mangoes in 1987. It involves immersing fruits in hot water at temperatures ranging from 46.1 to 46.5°C for 65 to 120 minutes, depending on fruit weight and variety. However, it's not effective against all quarantine pests; for instance, Mango seed weevils in Alfonso Mango from India were not killed. Hydro-cooling is recommended after at least a 30-minute waiting period after hot water treatment to reduce heat damage to the fruit as it returns to ambient temperature (not below 21.1°C) (Yahia et al.,2011).

Vapor heat treatment (VHT) involves exposing fruit surfaces to hot air saturated with water vapor, typically at temperatures between 40°C and 50°C. As the fruit's surface is cooler, the air condenses on it, transferring heat energy from the surface to the fruit's core. The condensation of vapor releases latent heat, uniformly and rapidly raising the pulp temperature, effectively killing the insect pests (Gaffney et al.,1990). Vapor Heat Treatment (VHT) is more complex and expensive, demanding additional engineering and computer programs to monitor treatment parameters and equipment (Yahia et al.,2011).

Radiofrequency(RF) and Microwave heating involves electromagnetic waves to rapidly raise the interior temperature of commodities without affecting the surface (Tang et al.,2000). Radio frequency (RF) waves, with frequencies of 10 to 50 MHz, penetrate deep into food, heating it uniformly (Jiao et al.,2018). This high-temperature-short-time treatment minimizes the adverse thermal impact on treated commodities (Tang et al.,2000). Unlike microwaves (with frequencies ranging from 1 to 100 GHz), RF's longer wavelengths enable deep penetration into food products, resulting in uniform heating (Jiao et al.,2018). RF and microwave treatments have a minimal environmental impact and leave no chemical residues on food (Tang et

al.,2000). However, uneven heat distribution in fruits poses a challenge for microwave technology, making RF more suitable for dried products than fresh produce. While effective, RF technology remains experimental and awaits further development (Tang et al.,2000).

Fumigation for fruits and vegetables is a common method used to control pests and pathogens, ensuring the safety and quality of produce during storage and transportation. This process involves the application of fumigants, such as methyl bromide or phosphine gas, in sealed environments to eliminate pests at various stages of their life cycle. Methyl Bromide treatment is rapid and effective; it has several drawbacks. Its use contributes to ozone layer depletion, and fumigation must be conducted at high temperatures (above 15°C), which can lead to fruit heating and reduced shelf life. Moreover, the gas is phytotoxic and harmful to the fruit. The treated fruit has also been found to develop a different flavor in some cases (The USA Patent No. US 7,740,890 B2 , 2010).

Extensive research on Phosphine fumigation is being carried out as a potential replacement for Methyl Bromide in quarantine protocols, due to its minimal impact on fresh commodities (Erturk et al .,2018). Phosphine gas, primarily known for its efficacy in controlling pests, has become a widely used fumigant for the preservation of perishable produce. Understanding its impact on different types of crops, however, is crucial for optimizing its application and ensuring the safety and quality of these commodities.

2.1 Phosphine Fumigation for Fruits & Vegetables

In Australia, Methyl Bromide is the only fumigant that has been approved for use in citrus pest control. The sole alternative to a 2-hour Methyl Bromide fumigation is a 16-day cold treatment at 1°C, thus a quicker substitute such as Phosphine fumigation would be preferred. The phosphine cylinder gas composition ECO2FUME® (2% Phosphine +98% CO_2 w/w) served as the foundation for experimental fumigations on oranges that were contaminated with Queensland fruit fly larvae, *Bactrocera tryoni*. Uninfected oranges were fumigated and tested for any negative effects. Fly larvae died in 96.4% of cases after a 16-hour fumigation at 20°C with an initial phosphine concentration of 0.98 g/m^3. Although it was a positive outcome, the mortality attained did not match the threshold for interstate trade (99.5%) or export trade (99.9%) (Williams et al.,2000).

In subsequent fumigation rounds, exposure periods, temperatures, and phosphine concentrations were progressively increased. The exposure period was 48 hours during the final round of fumigations using export-grade Washington navel oranges at 23-25°C. The initial phosphine concentrations were 1.67 g/m^3, and topped

up to 0.7 g/m^3 after 24 hours. No adverse impacts on the oranges were noticed, mortality rate of 99.998% was achieved for >48000 exposed larvae (Williams et al.,2000).

Another formulation consisting of a phosphine generator that produces pure phosphine without ammonia, such as QuickPHlo® has a potential to be used to conduct low-temperature phosphine fumigation treatment on fresh commodities for post-harvest pest control under the normal atmospheric oxygen level or an oxygen-enriched atmosphere. To control western flower thrips (*Frankliniella occidentalis* (Pergande) (Thysanoptera: *Thripidae*) and lettuce aphid (*Nasonovia ribisnigri* (Mosely) (Homoptera: *Aphididae*), vacuum-cooled Iceberg and Romaine lettuce were fumigated at 2°C for 24 and 72 hours. Iceberg and romaine lettuce were subjected to an oxygenated phosphine fumigation for 48 hours at 2°C under 60% O_2 to control lettuce aphids. The control of Western flower thrips was achieved in just 24 hours, while lettuce aphid was completely eradicated in 72 hours and in 48 hours in case of oxygenated fumigation (Liu Y.-B., 2018).

When the quality was assessed 14 days after fumigation, it was found that longer (≥48 hours) treatments of fumigated iceberg lettuce had a higher incidence of brown stains. Despite increased brown stain incidence on fumigated iceberg lettuce in the 48-hours treatment and significantly different quality scores in both Iceberg and Romaine lettuce in the 72-hours treatment, both treatments and controls of lettuce showed good visual quality. The brown stains were probably due to the high sensitivity of lettuce to carbon dioxide. The study concluded that QuiPHlo® phosphine generator has the potential for low-temperature phosphine fumigation due to its speedy establishment of desired phosphine levels, effectiveness in pest control, and reasonable safety to product quality (Liu Y.-B., 2018).

In order to facilitate the export of apples, including the "Fuji" apple (*Malus pumila var. "Fuji")* in South Korea, maintaining the quality of apples during postharvest storage and eradicating quarantine pests is quite important. For the control of peach fruit moth larvae (*Carposina sasakii*), which had infested Fuji apples, phosphine fumigation as an alternative to Methyl Bromide was found to be more successful at a high temperature (25^0C) than at a low temperature (5^0C) as Methyl bromide fumigation of apples significantly reduced fruit quality and caused phytotoxic damage to the fruits (Kim B.-S. et al.,2022).

Phosphine fumigation at a concentration of 2.0 g/m³ for 72 hours at low temperatures (5 ± 1°C), followed by cold treatment at 3 ± 2°C for 2 or 4 weeks, significantly improved pest control efficacy compared to fumigation alone. Furthermore, this method preserved apple quality parameters, including firmness, sugar content, and color, without causing notable phytotoxic effects. The study

highlights this treatment as a promising alternative to methyl bromide fumigation, addressing both quarantine regulations and the need for maintaining fruit quality (Kim B.-S. et al.,2022).

Turkey exports a number of major agricultural goods, including fresh vegetables like tomatoes and green peppers. The presence of *F. occidentalis* on tomatoes and green peppers has a detrimental effect on the international trade of fresh vegetables. Tomatoes and green peppers get rejected from time to time due to infestations of western flower thrips, *F. occidentalis*, in exported products; this is especially true for nations with strict quarantine rules (Erturk et al.,2018) ECO2FUME® formulation of phosphine was found to be a suitable fumigant for *F. occidentalis* disinfestation of tomatoes and green peppers at low temperatures before shipment. Physical, chemical, and sensory examination of treated green pepper and tomato fruit for 24 hours at 500, 1000, and 2000 ppm revealed no adverse impacts on fruit quality, storage, or shelf life (Erturk et al.,2018).

In South Korea, a known quarantine pest, Citrus mealybug, *Planococcus citri*, is difficult to eradicate in Pineapple with phosphine or Ethyl Formate (EF) alone, especially at low temperatures. As Methyl bromide is scheduled to be phased out in South Korea over the next decade, the effect of EF alone and when combined with PH3 as an alternative to MB for the control of *P. citri* adults, nymphs, and eggs revealed that EF combined with Phosphine caused high toxicity to all *P. citri* life stages. The nymphs and adults were less tolerant than the eggs. At dosages of 25.1 g/m³ ethyl formate (EF) mixed with 1.0 g/m³ phosphine (PH_3) at 8^0C for 4 hours, the combination treatment completely controlled eggs infesting pineapples with less damage to the treated perishable commodities at low temperatures **(**Yang et al.,2016**).** Apples infested with codling moth fifth instar larvae and eggs were fumigated for two lengths of time (48 or 72 h) at two temperatures (0.5 or 12^0C) using concentrations of 500, 1000, 2000 & 3500 ppm phosphine (1.39% phosphine gas in nitrogen). Larval mortality was assessed three days after fumigation at 0.5^0C, showing a dose-dependent increase, with little difference between 48 and 72 hours. In contrast, larvae fumigated at 12^0C did not exhibit a dose-dependent increase in mortality; instead, they showed higher overall mortality compared to those at 0.5^0C. Eggs of the codling moth were more susceptible to fumigation at 0.5^0C than at 12^0C. Moreover, phosphine fumigation at 12^0C for 72 h may have an adverse effect on the fruit quality (Rogers et al.,2013).

In New Zealand, phosphine is approved as a post-harvest fumigant on kiwifruit. As a replacement to methyl bromide and availability of better formulations, ECO2FUME® and VAPORPH3OS®, the usage of phosphine as a fumigant has expanded globally (Jamieson et al.,2012). A variety of phosphine treatments were applied to scale insects, mealybugs, and diapausing two spotted spider mites All life

stages of the oleander scale insect were completely eradicated after a 48-hour fumigation at low temperatures (1.7–4.6°C). Similarly, fumigating with phosphine at concentrations of 6408–3311 ppm for 12 hours effectively eliminated all life stages of the long-tailed mealybug. A 36-hour treatment at 2.5-3.3^{0}C with 4332-2712 ppm resulted in 100% mortality of all stages of the hungry scale insect. Meanwhile, a 48–96-hour treatment at 1–15^{0}C with 3600–1200 ppm achieved 91.3–100% mortality of diapausing two-spotted spider mite adults. VAPORPH3OS® along with Horn Diluphos System (HDS) has been registered for treatment of cut flowers, apples, and kiwifruit in New Zealand against pests (Jamieson et al.,2012).

The Indonesia Agricultural Quarantine Agency (AQA) had recognized ECO2FUME® phosphine fumigant as a major option to replace methyl bromide for quarantine and pre-shipment purposes. In cooperation with Cytec and the Tropical Biology Institute (BIOTROP), the Indonesian Applied Research Institute of Agricultural Quarantine (ARIAQ) has established phosphine fumigation protocols using ECO2FUME for QPS treatment of major commodities such as rice and other stored grains, coffee, cacao, tobacco, pineapple, and mangosteen (Tumambing and Dikin, 2013)**.**

In South America, TK-Gas or F-Gas (commercial name for the VAPORPH3OS®), used in conjunction with the Horn Diluphos System (HDS) fumigation equipment can be used commercially for Postharvest treatment of exported fresh fruits and vegetables against insect pests. Chile exports pure phosphine-treated fruits including kiwifruit, apples, grapes, oranges, and plums to over 25 developed and developing nations. Fruits shipped from Chile to Mexico or Iran have to go through mandatory pure phosphine fumigation treatment as a condition of shipment (Horn P. et al.,2010).

Following a 24-hour exposure to 1500 ppm of phosphine, (Castro et al.,2009) from Chile discovered that no harm was caused to various types of orange and lemons. (Kulczycki et al.,2008) in Argentina determined that after being fumigated with phosphine, blueberries showed no signs of damage, and less fungus was discovered (Horn P. et al.,2010).

When table grapes were treated with pure phosphine at a concentration of 1500 ppm for 48 hours at 0^{0}C, Klementz et al (2005), in Germany discovered no appreciable difference in the quality characteristics (color, texture, sugar/acid ratio, and juice yield) between the treated and untreated samples.

Apples were treated post-harvest with pure cylinderized phosphine TK-GAS (VAPORPHOS® in USA) at 1500 ppm at -0.5^{0}C and +1^{0}C with HDS. When

compared to untreated fruit, there were no differences in the fruit's condition, color, and level of maturity. The fruit showed no organoleptic changes after 6 days but had a slight metallic taste before day 6, however, this taste subsided during storage. As a result, it is not recommended to eat the fruit before six days of ventilation (The USA Patent No. US 7,740,890 B2, 2010).

When the three phosphine treatments evaluated—1.5 g/m³ applied for 12 or 24 hours at 5°C, and for 12 hours at 12°C, the quality of the lemons, grapefruit, navel, and Valencia oranges, and mandarins were unaffected. Sensory analysis revealed no reduction in flavor or visual quality (Obenland et al.,2021).

Hass' avocado fruit infested with greenhouse thrips (*Heliothrips haemorrhoidalis*) was treated with ECO2FUME® at 500, 750, and 1500 ppm for 24, 48, and 72 hours at 5-6^{0}C and internal & external quality was assessed after ripening at 20^{0}C. External fruit quality and skin coloration were unaffected by Phosphine treatments, and only a slight increase in softening was observed at 24 hours but not at 48 or 72 hours. Thrips were completely (100%) killed after 48 hours at all concentrations (Pidakala et al.,2022).

2.2 Phosphine Fumigation for Cut Flowers

'Dabaiju', a widely known cultivar of White chrysanthemum (*Dendranthema morifolium* Tzvel.) in China is found to be sensitive to methyl bromide (MB) fumigation, so was fumigated with three phosphine dosages of 0.76, 1.52, 3.04 g/m^3 for 2, 5, 8, and 11 days at 2^{0}C. Fumigation for less than 5 days with all phosphine dosages showed no significant changes in flower appearance and physiological indices such as fresh weight loss (FWL), vase life, flower diameter, respiration, soluble protein, malondialdehyde (MDA), proline, and electrolyte leakage (EL). However, exposure to 1.52 and 3.04 g/m^3 of phosphine for 11 days significantly reduced vase life and flower diameter, increased respiration, decreased soluble protein, accelerated the accumulation of MDA and proline, and enhanced EL for fumigation periods exceeding 5 days (Zhang et al.,2012).

Four important species of cut flowers that China exports to other countries are the Chrysanthemum, Carnation, Rose, and Chinese rose. Phytosanitary elimination of insects like western flower thrips (*Franklintella occidentalis*), Pea leafminer (*Liriomyza huidobrensis* Blanchard), Melon aphid (*Aphis gossypii* Glover), and two-spotted spider mite (*Tetranychus urticae* Koch) require methyl bromide (MB) fumigation before export and even then, some were rejected on arrival (Wang and Lin, 1984 ;Jiang et al.,2006). Pure Phosphine (without ammonia) fumigation for 6 hours at a dosage as high as 12.2 g/m^3 at 24^{0}C and 8d with 3.04 g/m^3 at 2^{0}C had no negative impacts on flower colour, diameter, vase life, or other damage indices (DI) for all

cultivars. However, during a 12-day treatment, flower diameter and vase life for White chrysanthemums significantly decreased at concentrations of 1.52 and 3.04 g/m^3 (Zhang et al.,2013).

Oxygenated phosphine (1.6% pure phosphine) fumigation treatments under 70% oxygen was applied on different cut flower species namely roses, lilies, tulips, gerbera daisy, and pompon chrysanthemum in separate groups with 2,500 ppm phosphine for 72h at 5^0**C**. The cut flower species attained egg mortalities of 99.7–100%. Except for gerbera daisies, all cut flowers were safe during the treatment. However, a 96-hour fumigation treatment with 2200 ppm phosphine on cut chrysanthemum flowers failed to completely eradicate the eggs. Thus oxygenated phosphine treatment was found to be safe for most of the cut flowers (Liu et al.,2015). In Turkey, QuickPHlo-R® aluminium phosphide formulation (77.5%; pure phosphine) with doses of 1.1, 2.2, and 3.3 g/m^3 were employed for ~~a~~ 48-hour exposure period at a low temperature of 6^0C. Phosphine at 3.3 g/m^3 for 48 h resulted in 100% mortality of all stages of *F. occidentalis*. This technology can be conveniently applied to meet quarantine requirements of the exporter country of the cut flowers without affecting the quality of the treated commodity**. (**Erturk and Alkan, 2022**).**

Phosphine has the potential to be a safe and effective insect disinfestation fumigant for King protea, tulip, and kangaroo paw at 4000 ppm for 6 hours without affecting vase life or causing damage. Geraldton wax flower was relatively sensitive to phosphine as it was damaged by 4000 ppm for 6 hours Karunaratne et al (1997). ECO2FUME® was used to disinfest cut flowers including Roses (Bordo and Grasia varieties), Chrysanthemums (Baksun and Ford varieties) and lily (Orgast variety). *T. urticae* eggs and adults, as well as adults and larvae of *A. gossypii* and *F. occidentalis*, were all killed by the mixture gas at 100 g/m3 at 8^0C. There was no damage in flowers when exposed to a gas mixture at concentrations of 100 and 200 g/m^3 at 8^0C during storage for 1 day at 8^0C, followed by 6 days at 20^0C post-fumigation. However, Bordo roses at 100 and 200g/m^3 and lilies at 200g/m^3 had delayed flowering (Park et al.,2010).

Phosphine was found to be the most promising fumigant for cut flowers after evaluation of numerous options due to its higher efficacy and minimal phytotoxicity. Commercial fumigation trials on a large scale were conducted using Pestigas® (comprising Pyrethrum at 0.4% and Carbon Dioxide at 87.6%), followed by Phosfume® (ECO2FUME®). Nearly all stages of *M. persicae* and *S. ejectana* were eliminated with a 0.3–1.4 g/m^3 phosphine dose given for 4.5–6 hours. Most flowers showed no damage and remained in good condition after 7 days, except for carnations, which wilted and developed brown petal edges when exposed to concentrations >0.4 g/m^3 of both the fumigants. Additionally, the leaves of *Protea neriifola*, *Protea longifolia*, and *Protea 'Pink Ice'* changed color more rapidly and turned brown when

fumigated compared to unfumigated flowers over 7 days. *Leucadendron* leaves also showed some browning after 7 days when fumigated with phosphine concentrations of 0.9 g/m^3 and above (Williams and Muhunthan,1998).

Kawakami et al. (1996) fumigated cut flowers of six chrysanthemum cultivars and four orchid cultivars using a gas mixture comprising methyl bromide (10 g/m^3), phosphine (3 g/m^3), and 5% carbon dioxide for 3, 4, and 6 hours at temperatures of 15^0C and 20^0C When orchid and chrysanthemum cultivars were fumigated at 15^0C for 4 hours, they exhibited no signs of damage. Fumigating both types of cut flowers at 20^0C for 3 hours, followed by storage at 15^0C or higher, did result in some damage in the form of chlorosis of buds and leaves, discoloration of tiny young petals etc. in some cultivars of both the cut flowers. However, the level of injury observed remained within acceptable commercial standards.

Protea 'Pink Ice' fumigation with 1 and 2 g/m^3 phosphine for 5 hours did not affect product quality, however, vase life was shortened at higher dosages and treatment durations. Weller and Graver (1998) suggested a combination of phosphine with other pest management techniques like cold treatment and insecticides to shorten the treatment period and increase insect mortality while minimizing potential phosphine-related phytotoxicity damage.

This review of the literature thus provides a comprehensive overview of the impact of phosphine fumigation on fruits, vegetables, and flowers. It is evident from the studies discussed that phosphine fumigation offers a versatile and effective method for pest control and preservation in various horticultural products. The success of phosphine treatment is influenced by factors such as dosage, exposure duration, temperature, and the type of produce. While the method is generally well-received for its minimal effect on product quality, it is essential to carefully consider the parameters to optimize its efficacy and minimize any potential negative effects. The findings from these studies collectively contribute to our understanding of the potential benefits and limitations of phosphine fumigation, aiding in the development of improved post-harvest pest management strategies and ensuring the safety and quality of horticultural products.

CHAPTER 3

MATERIALS AND METHODS

The present research entitled **"Impact of Phosphine on Quality & Nutritional Parameters of Stored Perishable Commodities"** was undertaken at the ICAR-NCIPM, New Delhi. The Sorption and the residue analysis was carried out at a Lab facility at UPL Pvt. Ltd., Vapi, Gujarat. The materials & methodology details of the research are presented in this chapter.

3.1 Materials

The perishable samples, including fruits (Mango), Vegetables (Bitter gourd & Chilli), and Flowers (Rose & Chrysanthemum) as per their seasonal availability and requirement for the analysis were harvested from untreated Horticulture & Floriculture fields at the Indian Agricultural Research Institute (IARI), New Delhi. Pomegranate samples were taken from CIPHET Abohar Campus, Punjab. The variety of perishables chosen are as follows:

1) Mango - Amrapalli
2) Pomegranate - Mridula
3) Bitter gourd – S-2
4) Chilli- NS 1101
5) Rose - Pusa Viranga
6) Chrysanthemum- Jaya

Figure 3.1 shows the Floriculture and Horticulture fields of Chrysanthemum, Rose and Mango respectively at IARI, New Delhi.

The reagents and chemicals included Sulphuric acid (97 %) Ethanol (99.9%), Metaphosphoric acid (Glacial stick), Dichlorophenol indophenol dye, NaOH, Sodium bicarbonate, Sodium carbonate, Sodium sulphate, Potassium chloride, Hydrochloric acid, Petroleum ether (99%), Acetone (95%), Folin-Ciocalteu's Phenol reagent, Copper Chloride, Ammonium Acetate buffer, Phenolphthalein indicator, Neocuproine, Dimethyl sulfoxide(DMSO) were from Fischer Scientific Ltd, SRL, Mumbai and Merck, India. QUICKPHLO-R® Granules (UPL, Ltd.), 2-3 L Gastight glass desiccators (local manufacturer, Delhi), gastight syringes manufactured by Hamilton, USA.

3.2 Phosphine Gas Generation

QUICKPHLO-R® Granules (UPL, Ltd.), which contain 77.5% Aluminium Phosphide, were employed to produce pure Phosphine (93%, free of Ammonia) by employing a 5% (v/v) aqueous sulphuric acid solution following the FAO (1975) method. The gas generation apparatus comprised two glass containers: an upper vessel for collecting the trapped phosphine and a lower vessel containing the Sulphuric acid solution. The QUICKPHLO-R® Granules were wrapped in a thin cloth and securely immersed into the solution, positioned carefully beneath an inverted glass funnel. The gas produced during the reaction was collected in the upper vessel through the neck of the inverted funnel. A septum was used to seal the opening of the upper vessel to prevent any gas from escaping. For the experimental process, the gas was extracted using gastight syringes manufactured by Hamilton, USA.

Figure 3.2 Apparatus for Phosphine Gas Generation & QUICKPHLO-R® Granules for Gas Generation

3.2.1 Fumigation Chamber

Fumigation was carried out in 2-3 L Gastight glass desiccators. The lid was sealed over the desiccator after placing the perishable samples by applying a thin layer of silicon grease to prevent gas leakage. Additionally, a glass tube, a center tube with a septum for injecting the gas besides an inlet and outlet tubes (with valves) for circulation and monitoring of the phosphine gas were attached to the lid, allowing for continuous gas monitoring throughout the experiment. Samples to be treated are put in the desiccators and treated with a Specified dosage calculated as per the volume of the desiccators of Phosphine for a particular exposure period followed by Quality Analysis.

Figure 3.3: (Left) shows Chilli fumigation in Gastight Glass Desiccators and

Figure 3.4: (Right) Shows the Temperature-controlled fumigation of mango in a refrigerator.

3.2.2 Phosphine Treatment

The untreated perishable commodities used in this study were treated with different concentrations of phosphine, which were calculated based on the volume of the desiccator used for fumigation. The volumes of phosphine injected were adjusted according to the specific desiccator volume to ensure accurate and consistent exposure across all samples. Table 3.1 below shows the volume of phosphine (PH_3) injected, calculated based on the desiccator's volume.

Table 3.1: Showing the volume of phosphine (PH_3) injected based on the desiccator's volume.

S.No	Volume of the Dessicator	PH3 volume to be injected (mL)												
	Litre	PH3 dosage in ppm												
		50	75	100	150	200	300	400	750	900	1500	3000	4000	5000
1	2.250	0.1197	0.1795	0.2394	0.3590	0.4787	0.7181	0.9574	1.7952	2.1543	3.590	7.181	9.574	11.968
2	2.870	0.1527	0.2290	0.3053	0.4580	0.6106	0.9160	1.2213	2.2899	2.7479	4.580	9.160	12.213	15.266
3	2.752	0.1464	0.2196	0.2928	0.4391	0.5855	0.8783	1.1711	2.1957	2.6349	4.391	8.783	11.711	14.638
4	2.850	0.1516	0.2274	0.3032	0.4548	0.6064	0.9096	1.2128	2.2739	2.7287	4.548	9.096	12.128	15.160
5	2.840	0.1511	0.2266	0.3021	0.4532	0.6043	0.9064	1.2085	2.2660	2.7191	4.532	9.064	12.085	15.106
6	2.850	0.1516	0.2274	0.3032	0.4548	0.6064	0.9096	1.2128	2.2739	2.7287	4.548	9.096	12.128	15.160
7	2.250	0.1197	0.1795	0.2394	0.3590	0.4787	0.7181	0.9574	1.7952	2.1543	3.590	7.181	9.574	11.968
8	2.050	0.1090	0.1636	0.2181	0.3271	0.4362	0.6543	0.8723	1.6356	1.9628	3.271	6.543	8.723	10.904
9	2.850	0.1516	0.2274	0.3032	0.4548	0.6064	0.9096	1.2128	2.2739	2.7287	4.548	9.096	12.128	15.160
10	2.420	0.1287	0.1931	0.2574	0.3862	0.5149	0.7723	1.0298	1.9309	2.3170	3.862	7.723	10.298	12.872
11	2.400	0.1277	0.1915	0.2553	0.3830	0.5106	0.7660	1.0213	1.9149	2.2979	3.830	7.660	10.213	12.766
12	2.850	0.1516	0.2274	0.3032	0.4548	0.6064	0.9096	1.2128	2.2739	2.7287	4.548	9.096	12.128	15.160
13	2.332	0.1240	0.1861	0.2481	0.3721	0.4962	0.7443	0.9923	1.8606	2.2328	3.721	7.443	9.923	12.404
14	2.850	0.1516	0.2274	0.3032	0.4548	0.6064	0.9096	1.2128	2.2739	2.7287	4.548	9.096	12.128	15.160
15	2.870	0.1527	0.2290	0.3053	0.4580	0.6106	0.9160	1.2213	2.2899	2.7479	4.580	9.160	12.213	15.266

3.3 Quality evaluation studies

The perishables treated with Phosphine were subjected to physio-chemical evaluation for parameters like firmness, moisture content, Titratable acidity, Total Soluble Solids (TSS), Ascorbic acid, Total Carotenoids, Anthocyanin, Total Phenolic content, Chlorophyll content, Water Uptake and Antioxidants. After the desired exposure period, the treated commodities were removed from the fumigation chambers and taken for Quality Analysis following an aeration period of 2 hours.

Table 3.2:Shows the list of the commodities along with the tested Quality parameters

Name of commodity	**Quality Parameters Tested**	
	Physical	**Biochemical/Nutritional**
Bitter gourd	Moisture Content, Colour, Texture	Chlorophyll content, Ascorbic Acid (AA), and Total Soluble Solids (TSS)
Chilli	Moisture Content, Colour, Texture	Chlorophyll content Ascorbic Acid, TSS, and Antioxidants
Mango	Texture, and Physiological loss in weight (PLW)	Titratable Acidity (TA), Carotenoids
Pomegranate	PLW, Juice Yield, and Juice pH	TSS, AA, Total phenolic content, TA, Antioxidants, Anthocyanin
Chrysanthemum	Water uptake, Moisture Content	Anthocyanin content
Rose	Water uptake, Moisture Content	Anthocyanin content

3.3.1 Firmness

Firmness represents a crucial consideration, given that virtually all fruits and vegetables undergo a significant alteration in their firmness as they ripen. Due to the varying nature of the ripening process across different types of produce, there can be a significant divergence in firmness levels among individual items within the same batch or those harvested concurrently. These variations in outward characteristics can significantly impact consumer satisfaction with the product, as they are closely associated with the 'eating maturity' and overall texture of the product.

Firmness of fruits and vegetables were determined by a Texture Analyzer (TAXT2,Stable microsystems, UK) using a 2 mm P/2 cylindrical SS Needle probe with a pre-test of 5 mm/s, test speed of 0.5 mm/s and post-test speed of 10 mm/s till a distance of 10 mm (5 mm in case of chilli). Maximum force during the puncture was expressed in Newton (N) and was used to denote the fruit firmness using Exponent Texture Analyzer software**.** The typical measurements included: Bioyield Point, Skin Elasticity, Stiffness, Work to Penetrate Skin, Flesh Firmness, and Work to Penetrate Flesh.

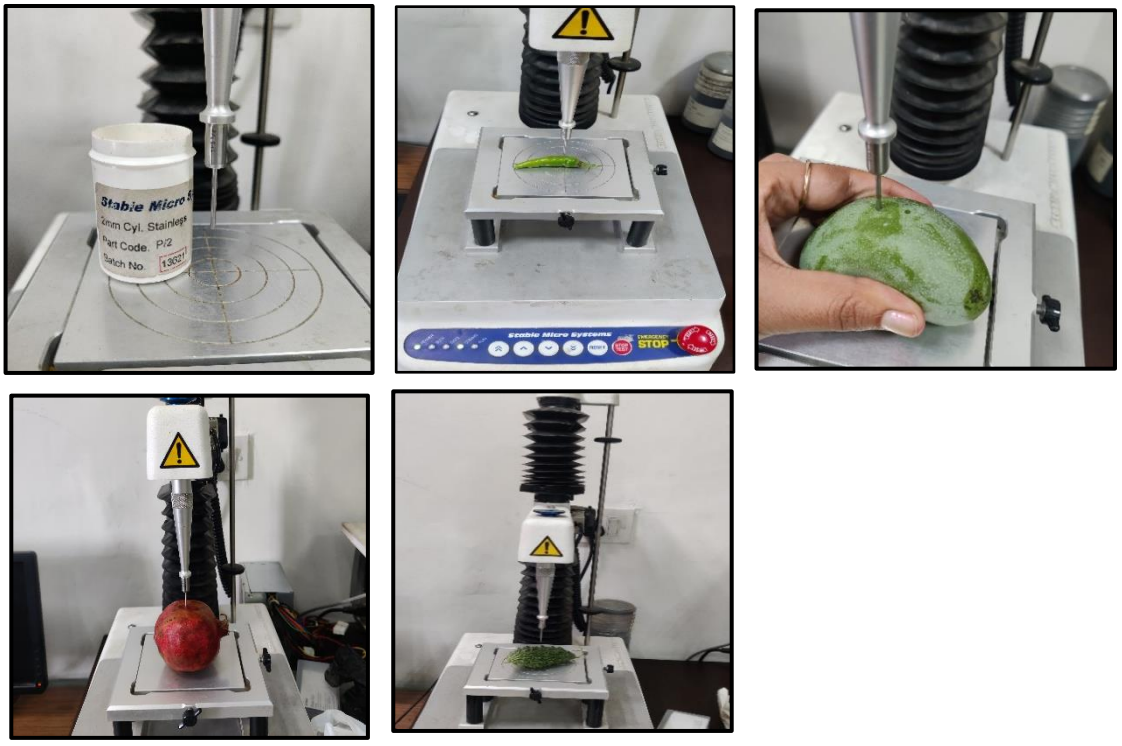


Figure 3.5 (clockwise): 1. Texture Analyzer with attached P/2 probe, Texture Analysis of 2. Chilli, 3. Mango, 4. Pomegranate, 5. Bitter gourd.

3.3.2 Moisture Content

This was carried out for Bitter gourd and Chilli. The moisture content of samples was estimated as per the method given by (Obi et al., 2016). Dry and clean aluminium petri dishes were pre-weighed and 5 g (Bitter gourd) & 2g (Chilli) samples were weighed again and kept at 90ºC for 12-15 hours/till completely dry in a hot air oven. The dishes were taken out from the hot air oven. The weight of Petri-dishes dishes was measured.

Figure 3.6: Petri dishes with fresh (left) and dry (right) Bitter gourd

The moisture content of the Bitter gourd and Chilli was measured on a wet basis and readings were expressed in percentage using the formula:

$$\textbf{M.C. (\%)} = \frac{\mathbf{W_2 - W_3}}{\mathbf{W_2 - W_1}} \times \mathbf{100}$$

where,
MC = Moisture content of the sample in % wet basis.
W_1= weight of empty petri dish (g)
W_2= weight of petri dish + sample (g) before drying
W_3= weight of petri dish + sample (g) after drying

Figure 3.7**:** Fresh and Dry Chilli (Left) and Fresh and Dry Bitter Gourd (Right)

3.3.3 Total soluble solids (TSS)

TSS is the amount of sugar and the soluble minerals present in fruits and vegetables. It is determined using a handheld refractometer based on the principle of refraction of light. Total soluble solids (TSS) of Bitter gourd, Chilli, Mango, and pomegranate were determined using a handheld refractometer (ATAGO Co. Ltd.,

Tokyo) with a range from 0 to 50 °Brix (Ranganna, 1999). A drop of sample (juice) is placed on the prism, and the reading is noted at the demarcation line while holding the refractometer towards the light. The readings are expressed in Degrees Brix or °Brix (Brix).

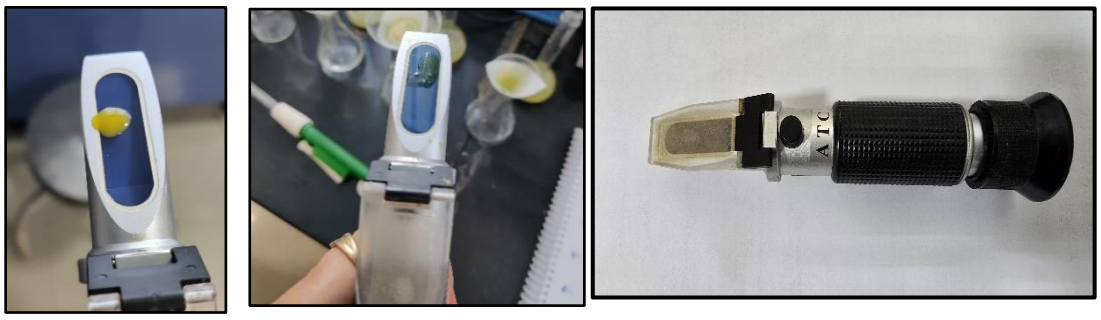


Figure 3.8: Showing TSS measurement using the handheld Refractometer in Mango and Bitter gourd.

3.3.4 Ascorbic acid

The ascorbic acid content was measured by using the visual titrimetric method (AOAC, 2000) and a solution of 2,6-dichlorophenol indophenol dye. Ascorbic acid reduces the 2,6-dichlorophenol indophenol dye to a colourless leuco-base and the ascorbic acid itself gets oxidized to dehydro-ascorbic acid. The endpoint is the appearance of pink colour.

3.3.4.1 Dye Preparation

For the preparation of 200 mL of dye solution, 42 mg of sodium bicarbonate was dissolved in 150 mL of hot distilled water. 50 mg of 2,6-dichlorophenol indophenol was dissolved in it and the volume was made up to 200 mL with distilled water. This dye solution was stored in the refrigerator and standardized on the day of use. 3% Metaphosphoric acid (HPO_3) was prepared in distilled water. Standard (stock) ascorbic acid solution was prepared by dissolving 50 mg of L-ascorbic acid in a 50 mL volumetric flask with 3% metaphosphoric acid. For the preparation of a working solution, 10 mL of stock solution in a 50 mL volumetric flask and a volume made up to 50 mL by 3% metaphosphoric acid. For standardization of dye, 5 mL of working ascorbic acid solution and 5 mL of HPO_3 were taken in a conical flask and titrated against the dye till the pink colour persisted for at least 30 seconds.

Dye factor was calculated by using the following formula:

$$\textbf{Dye factor} = \frac{\textbf{0.5}}{\textbf{Titre Value}}$$

In the case of Fruits and vegetable parts, 5g (3g in the case of Chilli) of the sample was crushed/ground in a pestle and mortar by using 20 to 30 mL of 3% metaphosphoric acid and then transferred in 100 mL volumetric flask and volume made up to 100 mL with the help of 3% metaphosphoric acid.

Figure 3.8: Estimation of Ascorbic Acid Content using Titration

In the case of fruit Juice, 5 mL of juice was taken and volume made up to 100 mL with the help of 3% metaphosphoric acid. The samples were filtered with Whatman No. 1 filter paper and then 10 mL aliquot was taken in a conical flask. It was titrated against the dye solution to a pink endpoint. The estimated ascorbic acid was expressed in mg/ 100g.

$$\textbf{Ascorbic acid (mg/100 g)} = \frac{\textbf{Titre value} \times \textbf{Dye factor} \times \textbf{Volume made up (mL)} \times \textbf{100}}{\textbf{Aliquot taken(mL)} \times \textbf{Weight/volume of sample taken}}$$

3.3.5 Total phenolic content

Total phenolic content was estimated using the Folin-Ciocalteau reagent (Singleton et al., 1999). The clear supernatant was used for the estimation of total phenol. In the case of Pomegranate, 5mL of juice was taken and mixed with 20 mL 80% ethanol. 100 µL of supernatant was taken in a test tube and 2.9 mL of distilled water was also added to this followed by the addition of 0.5 mL of Folin-Ciocalteau (1N) and then kept for 3 minutes. After that 2 mL of 20% Na_2CO_3 was added and the

final volume was made up to 10 mL by adding 4.5 mL Distilled water. The absorbance was taken at 750 nm using a 1 cm cuvette in a Spectrophotometer. For the standard calibration curve, Gallic acid was used. The estimated total phenol was expressed in mg of Gallic acid equivalents (GAE) /100g of extract.

$$\textbf{Total phenol (GAE mg/100 g)} = \frac{\textbf{Absorbance} \times \textbf{volume made up} \times 100}{0.02 \times \textbf{weight of sample taken} \times \textbf{aliquot} \times 1000}$$

3.3.6 Antioxidant capacity

Antioxidant activity in fresh fruits was determined using the CUPRAC (**CUPric Reducing Antioxidant Capacity**) method as explained by (Apak et al., 2004) . As explained in section 3.3.5, the supernatant obtained was used to estimate antioxidant capacity with a 2 g sample (Chilli) and 2 mL juice (Pomegranate). A 2 g sample (Chilli) was crushed in 15 mL of 80% ethanol and centrifuged at 10,000 rpm for 15 minutes at 4ºC. Two mL juice (Pomegranate) was mixed with 20 mL 80% ethanol and centrifuged at 10,000 rpm for 15 minutes at 4ºC. One mL each of Copper chloride, neocuprine, and ammonium acetate buffer were pipetted in a test tube. Following this, 0.1 mL of extracted supernatant of the sample was added to this mixture along with 1 mL of distilled water. The volume was made up to 4 mL in the test tube, capped, and kept for 30 minutes in a dark place. Now, the absorbance of samples was measured at 460 nm against blank. It was expressed in µ mol Trolox equivalents/g

$$\textbf{Antioxidant activity (µ mol TE/g.)} = \frac{\textbf{Absorbance} \times 4.1 \times \textbf{volume made up}}{1.67 \times 10000 \times \textbf{aliquot taken} \times \textbf{wt.of sample}}$$

3.3.7 Titratable Acidity

Mango and Pomegranate samples were taken in this analysis. Juice (10 mL) was extracted from the fruit by squeezing or using a suitable extraction method and mixed with distilled water and volume made up to 100mL in a volumetric flask. An aliquot (10 mL) was then taken from the above solution in a conical flask. Phenolphthalein indicator (2-3 drops) was added. It is then titrated against 0.1N NaOH taken in a burette till the liquid turns colourless to pink (AOAC, 1990). The indicator will change colour as the acidity of the juice is neutralized. NaOH solution is added until the colour change is permanent. The endpoint is reached when the indicator colour changes permanently. The volume of NaOH consumed during the titration is noted. The titratable acidity was calculated using the following formula:

$$\textbf{\% Acidity} = \frac{\textbf{Titre Value} \times \textbf{N NaOH} \times \textbf{Volume made up} \times \textbf{Equivalent weight of acid}}{\textbf{Weight.of sample} \times \textbf{Volume of aliquot} \times 1000}$$

3.3.8 Total Carotenoids

The total carotenoid (TC) content of Mango was determined as per the method by Roy (1973). Approximately 5 g of the mango sample was weighed in a mortar on a digital balance. For the carotenoid extraction, successive additions of 5 mL of acetone were made and the extract was decanted until the sample became colourless. The extract obtained was transferred to a 500 mL separating funnel. 5mL of 5 % Sodium sulphate solution and 10mL of petroleum ether were added to the separating funnel. The funnel was gently shaken; 2 layers of liquid will be visible in the funnel in some time. The bottom layer is discarded and the top layer is then transferred to a 25mL Amber flask. The volume of the amber flask is made up to 25mL of petroleum ether.

Figure 3.9: Showing the separating funnel with 2 layers for total carotenoid content.

The OD reading is then taken using a spectrophotometer at 452 nm using Petroleum ether as a blank. The total carotenoid content was calculated using the following formula:

$$\textbf{Total Carotenoids (mg/100g)} = \frac{\textbf{3.87}\times\textbf{OD Value}\times\textbf{Volume made up}\times\textbf{100}}{\textbf{Weight of sample taken}\times\textbf{1000}}$$

3.3.9 Chlorophyll extraction

The chlorophyll extraction was performed using DMSO as a solvent (Manolopoulou et al., 2016). Chilli and Bitter Gourd samples (0.1 g) were placed in separate test tubes containing 10 mL of DMSO. The test tubes were incubated in a water bath at 60°C for one hour to achieve complete discoloration of the sample tissue. After incubation, the tubes were allowed to cool to room temperature, and the contents were filtered. The resulting extract's OD was then measured at 648 nm and 655 nm using DMSO as the blank.

Total Chlorophyll (mg/g F.W) = (7.49 A_{665} + 20.34 A_{648})

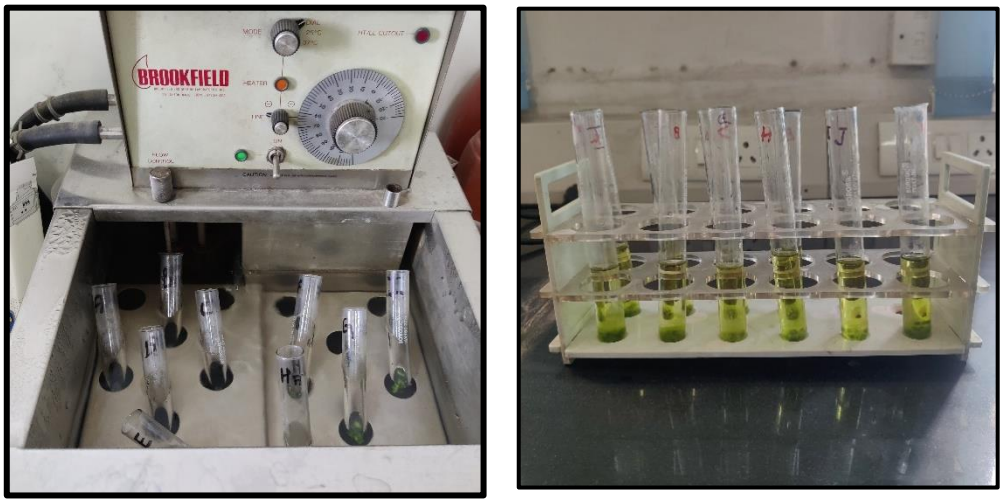


Figure 3.10: Test tubes incubated in a water bath (Left) and kept for cooling down at room temperature (Right) for Chlorophyll estimation.

3.3.10 Anthocyanin content

Rose & Chrysanthemum sample (0.5g) and 4mL Pomegranate Juice was taken. It was then mixed with 80% ethanol and crushed properly. The volume was made up to 15/20ml in a centrifuge tube. Tubes were centrifuged at 10,000 rpm for 15 minutes. In 2 separate test tubes, 4 ml of each of the following two buffers was taken:

a) **pH 1**:
   - 0.2 N KCl was prepared by dissolving 7.45g in 500 mL of distilled water.
   - 0.2N HCl was prepared by dissolving 8.3mL in 500mL of distilled water.
   - 125 mL of 0.2 N KCl solution with 385 mL of 0.2 N HCl solution were combined to make a pH 1 buffer solution.

b) **pH 4.5**:
   - 68 g of sodium acetate was taken and dissolved in 500 mL of distilled water.
   - 83 mL of concentrated HCl was taken and dissolved in 500 mL of distilled water
   - Combine 200 mL of sodium acetate solution with 60 mL of 1 N HCl solution
   - Add 240 mL of distilled water to the above to make up the volume to 500 mL to make a pH 4.5 buffer solution.

The supernatant (2 mL) was taken, with 1 mL added to each of the two test tubes containing the buffers mentioned above. The tubes were kept for 15 minutes in the dark and then OD reading was taken in a spectrophotometer at 510 & 700 nm (Lee et al., 2005).

$$\mathbf{A = (A_{510} - A_{700})\ pH1.0 - (A_{510} - A_{700})}$$

The content of total anthocyanin was calculated as follows:

$$\textbf{Total Anthocyanin (mg/100g fresh weight)} = \frac{\mathbf{A \times M \times DF \times 1000}}{\boldsymbol{\varepsilon \times \lambda \times m}}$$

DF is the dilution factor,
M is the molecular weight of cyanidin-3-glucoside
ε is the molar absorption coefficient = 26,900 L mol^{-1} cm^{-1} for cyanidin-3-glucoside
λ is the cuvette optical path length (1 cm) and
m is the weight of the sample (g)

Figure 3.11: Rose flower was crushed in 80% ethanol (Left) and the supernatant was put in two buffers for Anthocyanin estimation (Right).

3.3.11 Water uptake for flowers

Rose & Chrysanthemum flowers each with stems measuring 5 or 6 inches in length for water uptake after fumigation were taken and kept in test tubes containing 50mL distilled water. This was monitored until the flowers reached the end of their shelf life at room temperature. Flowers were then taken out and the remaining water was measured using a measuring cylinder. The water uptake can be calculated using the final and initial water in the test tube.

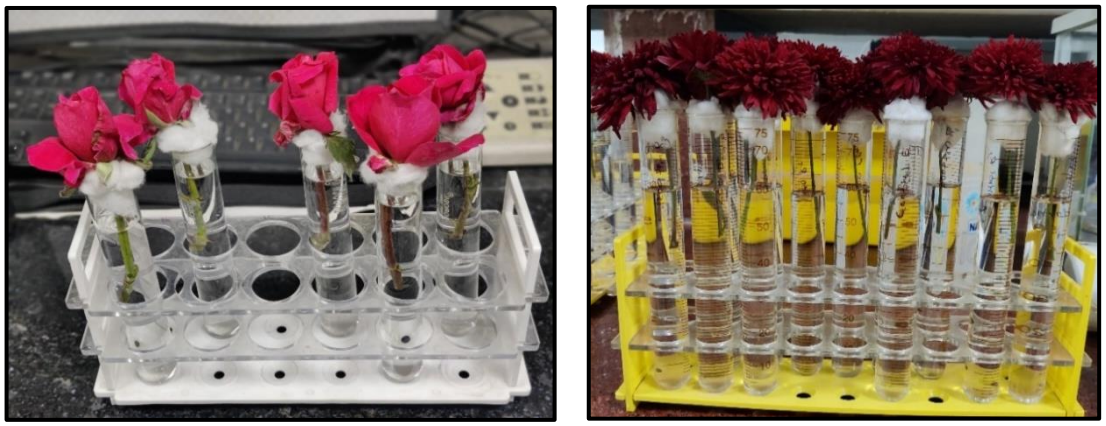


Figure 3.12: Rose and Chrysanthemum flowers kept for calculating the water uptake.

3.3.12 Moisture Loss (%)

Rose & Chrysanthemum samples were weighed and kept in a paper envelope for drying at **60-65** °C in a hot air oven (Obi et al., 2016). The final weight is taken after the samples are completely dry.

Figure 3.13: Showing the Fresh and Dried Rose flowers for calculating the Moisture Loss (%)

3.4 Phosphine Fumigation & Gas Concentration Monitoring

The sorption study was carried out at a lab facility at UPL, Vapi, Gujarat, India. All the commodities under the study were taken to UPL, Vapi, Gujarat, India for Sorption studies. The samples were treated with Phosphine with concentrations & exposure period at which 100% mortality was observed. Three replicates for each concentration (with control) & exposure period were taken. After the desired exposure period, the desiccators were aerated for around 2 hours to free the samples from Phosphine residues.

3.4.1 Phosphine Sorption

To evaluate the sorption of phosphine by each commodity, terminal phosphine concentrations within the commodity chambers were meticulously measured. The FumiSense Pro PH_3 Gas Monitor, developed by Uniphos Envirotronic Pvt Ltd, was employed for this purpose. This advanced handheld device features a gas inlet, a digital display for real-time readings, and a gas outlet for expelling sampled gas, with a measurement range spanning from 0 to 2000 µL/L. Measurements of phosphine concentrations were taken at two critical points: the beginning (A) and the end (B) of the exposure period, across all treatment conditions. To ensure the integrity and accuracy of these measurements, the desiccators used in the experiments were meticulously sealed to create and maintain airtight conditions. This was crucial to prevent any gas leakage that could compromise the readings.

All connections to the gas monitor, including the inlets and outlets, were rigorously checked and made leak-proof. Additionally, to further ensure the reliability of the setup, the Uniphos KwikAlert device was used. This device is specifically designed to detect and alert users to any potential gas leaks, operating with a measuring range of 0-20 µL/L and offering a high resolution of 0.01 µL/L. The use of KwikAlert provided an extra layer of security, ensuring that any minute leaks were promptly identified and addressed, thereby preserving the accuracy of the phosphine concentration measurements throughout the experiment (Uniphos 2024).

Figure 3.14: Phosphine fumigation of roses with Gas Monitoring for Sorption.

Gas concentrations were also evaluated in untreated control chambers to account for any potential interfering volatiles emitted by the commodities (Reddy et al. 2007). The difference between the initial phosphine concentration and the desiccator concentration after fumigation was used to determine the sorption. The sorption was calculated using the following formula:

$$\textbf{Sorption (\%)} = [(A-B)/A] \times 100$$

Where: A represents the phosphine concentration at 0 hours.
B represents the phosphine concentration at the end of the fumigation period.

Empty desiccators served as "blanks" to validate that the observed decrease in phosphine concentration was due to adsorption by the commodity. Phosphine concentrations in these empty desiccators remained relatively stable throughout the exposure period, indicating that the reduced phosphine levels in the treated samples were due to gas sorption by the commodity. After the designated exposure period, the desiccators were aerated for 2 hours. Following this aeration period, the samples in the desiccators were evaluated for residual phosphine concentration.

3.4.2 Calibration Curve Preparation

Pure phosphine was generated by hydrolyzing aluminium phosphide granules in water. To ensure uniform diffusion, the flask containing the mixture was vigorously shaken and then allowed to settle undisturbed. Various concentrations of phosphine were prepared by performing a series of dilutions in flasks of different capacities. For the calibration curve, phosphine concentrations ranging from 10 to 100 nL/L were used. The mean peak area was plotted against the concentration in µL/L, and linear regression analysis was performed to determine the regression constants. The slope, intercept, and coefficient of correlation were found to be 1237.9, 91.1, and 0.998, respectively.

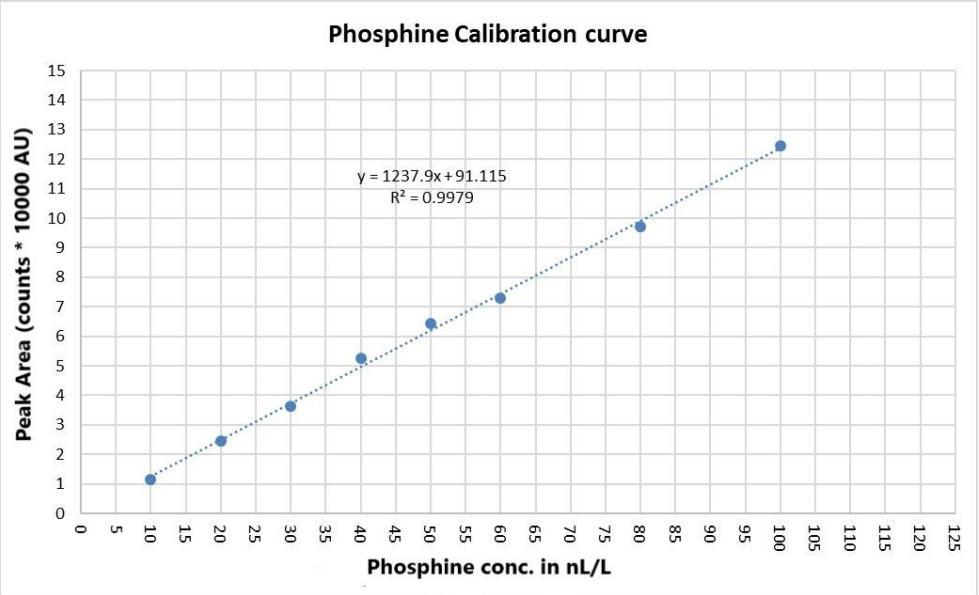


Figure 3.15: Phosphine Calibration Curve

3.4.3 Recovery of phosphine from different commodities

The phosphine residues in the treated samples were estimated using the method described by Nowicki (1978). A 250 mL round-bottom extraction flask, equipped with three necks and a stopper, was utilized to extract phosphine from the sample. One of the flask's necks was outfitted with a 250 mL dropping funnel for the addition of 5 N Sulphuric acid, while the other neck had a water condenser for cooling purposes. The flask was vigorously shaken for 5 minutes and then purged with nitrogen before introducing the sample into the reaction flask. This reaction flask was subsequently connected to the receiver flask. Before the experiment, it was ensured that the samples were free from any traces of phosphine.

A specific quantity of phosphine gas was introduced into the flask containing a fixed weight of samples. The extraction apparatus was spiked, before the addition of dilute sulphuric acid, with 44 or 440 µL of phosphine gas in nitrogen (0.934µg/mL), equivalent to about 0.001 and 0.01 mg/kg of phosphine residue in a sample. After fortification, the extraction flask was connected to the assembly as described earlier. For each spike level, three replicates were extracted, and two replicate injections were performed at each spike level.

After dispensing approximately 150 mL of 5 N sulphuric acid from the dropping funnel into the sample, while retaining 20 to 25 mL of acid as a liquid seal in the funnel, the mixture was heated for a duration of 25 to 30 minutes using a heating mantle set at a temperature range of 60 to 70°C. During this process, phosphine vapours were collected in the receiver flask. The remaining sulphuric acid in the

dropping funnel was then allowed to blend with the sample to balance the pressure inside the receiver flask with the external atmosphere. Following this, the reaction flask was cooled to room temperature, shaken, and the phosphine content was subsequently analyzed using Gas-Liquid Chromatography (GLC) using a Flame Photometric Detector with Phosphorus Filter.

Figure 3.16: Residue Analysis of Rose at UPL, Vapi

Phosphine concentration in the receiver flask is calculated as:

$$\frac{(\textbf{Area Counts} - \textbf{intercept}) \times \textbf{\textit{total volume of flask}}}{\textbf{Slope of calibration curve} \times \textbf{Injection volume in GLC}}$$

An equivalent amount of phosphine gas was injected into the empty receiver flask for the untreated control sample.

The conversion of phosphine (PH_3) volume into mass can be done using the following formula:

$$\textbf{Phosphine (µg)} = \frac{\text{Phoshine injected (µl) x 33.99 x P1 x T0}}{\text{22.4 x Po x T1}}$$

Po = One atmospheric pressure (760 mm Hg)
P1 = Pressure at ambient temperature
T1 = ambient temperature in K
T0 = 273 K
Molar mass of Phosphine = 33.99 g/mol
Quantity of PH_3 = PH_3 injected in the dilution flask (µg) × injection volume (ml) per injection volume (µg) Volume of dilution flask (ml)

3.4.4 Gas Liquid Chromatography

The analysis of phosphine residues in the food samples was conducted at a lab facility at UPL Pvt. Ltd. in Vapi, Gujarat, India, using Gas Chromatography.

Table 3.3: Gas Chromatography Specifications

Gas Chromatograph	Shimadzu GC – 2010 plus
Column	(DB-1), capillary column, Length: 30.0 m, Inner Diameter (ID) : 0.25 mm. Film Thickness: 0.32 µm
Detector	Flame Photometric Detector with Phosphorus Filter
Column Temperature	100°C
Injection Temperature	250°C
Detector Temperature	280°C
Carrier Gas	Nitrogen
Carrier Gas flow rate	30 ml/min
Oxygen Flow rate	90 ml/min
Hydrogen Flow rate	62.5 ml/min

CHAPTER 4

RESULTS

The impact of phosphine fumigation on the quality of export-oriented perishable commodities, including fruits, vegetables, and flowers, was studied. The research aimed to evaluate how different concentrations of phosphine influence both the nutrient and physical quality parameters of these commodities. The experiments were conducted for two consecutive years to see the reproducibility of the results, while the findings were validated in the second year. However, due to the limited availability of both infested and fresh samples, the experiments were conducted only for one year for pomegranate. By investigating these quality attributes, the study provides insights into the suitability of phosphine fumigation for maintaining the overall quality and marketability of perishable commodities during storage and transportation.

The data was analyzed using IBM SPSS Statistics version 20, employing Univariate Analysis of Variance (ANOVA). In this analysis, dosage was treated as a fixed factor to determine its effect on various quality parameters of the commodities. Post-hoc comparisons were conducted using Tukey's B test to identify specific dosage levels that caused significant differences between groups. The significance level for all tests was set at $p < 0.05$, allowing us to assess whether the differences in the measured parameters across different dosages were statistically significant. Parameters with p-values greater than 0.05 are considered not statistically significant, implying that phosphine dosage did not have a discernible impact on these quality traits during the exposure period.

4.1 Bitter Gourd

Bitter Gourd samples were treated with varying phosphine concentrations over 4/6/8/10/15-hour exposure period. The temperature was maintained between 22-25°C, and the relative humidity (RH) was kept at 65-70%. The results present the effects of phosphine on both the nutrient and physical quality parameters, including total soluble solids (TSS), total chlorophyll, ascorbic acid content, moisture content, and various physical characteristics like bioyield point, skin elasticity, stiffness, work to penetrate the skin and flesh, and flesh firmness.

4.1.1 4-Hour Exposure Period

(a) Quality Parameters

Table 4.1: Quality Parameters of Bitter Gourd Treated with Varying Phosphine Dosages over two Consecutive Years (4-Hour)

Year 2021										
Dosage (in ppm)	**TSS(°Brix)**	**Total Chlorophyll (mg/g)**	**Ascorbic Acid (mg/100g)**	**Moisture Content (%)**	**Bioyield Point**	**Skin Elasticity**	**Stiffness**	**Work to Penetrate Skin**	**Flesh Firmness**	**Work to Penetrate Flesh**
0	5	0.837	53.125	91.520	19.829	6.763	5.066	39.499	9.351	47.153
0	5	0.605	50.000	91.137	21.098	6.294	5.36	39.478	9.961	50.173
0	5	0.771	57.500	91.926	20.791	6.425	4.765	38.781	9.207	47.595
600	5	0.939	56.250	91.998	20.363	6.459	5.149	34.313	8.085	41.792
600	5	0.874	67.500	92.879	21.43	6.424	5.273	38.187	9.524	49.232
600	5	0.784	42.500	91.265	21.36	6.617	5.197	39.157	9.584	47.267
800	5	0.744	55.000	91.749	21.744	6.831	5.385	40.461	9.379	48.482
800	5	0.786	66.250	92.019	20.107	6.537	5.034	39.268	9.651	49.881
800	5	0.715	68.750	91.742	21.291	6.535	5.027	38.817	9.475	48.979
1000	5	0.700	47.500	91.704	21.471	6.512	5.491	40.491	9.483	46.708
1000	5	1.058	57.500	92.248	20.284	6.656	5.408	39.109	9.579	47.618
1000	5	0.637	55.000	91.657	19.391	6.045	4.379	38.01	7.367	38.076
1200	5	0.905	56.250	91.980	20.993	6.386	5.02	39.15	10.46	50.311
1200	5	1.110	62.500	92.050	22.551	6.356	5.169	37.226	9.258	44.666
1200	5	0.799	58.750	91.453	20.234	6.498	5.106	41.386	9.362	44.706

Year 2022										
0	3	1.541	72.5	87.600	17.398	9.699	2.658	45.811	8.852	45.743
0	3	0.912	75	88.917	18.792	9.726	3.172	48.248	9.142	47.228
0	4	1.283	85	88.987	19.111	9.368	2.849	42.437	9.264	45.071
1200	3	1.355	93.75	88.916	16.3	9.928	2.657	44.029	8.797	41.827
1200	4	1.423	65	88.048	17.121	9.552	2.66	42.876	8.765	43.956
1200	3	0.877	90	88.457	17.016	9.201	2.754	42.813	8.209	45.254
1400	3	1.591	77.5	87.054	19.178	9.314	3.182	41.188	8.894	45.954
1400	3	1.566	93.75	88.540	17.038	9.79	2.763	46.648	8.793	45.436
1400	4	1.318	92.5	87.254	16.845	8.641	2.964	42.503	9.304	47.215

a) Statistical Analysis: Univariate Analysis of Variance (ANOVA) was conducted for each nutrient and physical quality parameter. The analysis focused on determining whether variations in phosphine dosage resulted in statistically significant changes to parameters.

Table 4.2: Analysis of quality parameter data of the phosphine-bitter gourd using univariate ANOVA ($\alpha = 0.05$)(04-Hour)

Year 2021				
Quality Parameters	**Dosages**	**F Value**	**p-value**	**Significance**
TSS	0, 400, 600, 800, 1000,1200	-	-	Not Significant
Total Chlorophyll	0, 400, 600, 800, 1000,1200	1.083	0.415	Not Significant
Ascorbic Acid	0, 400, 600, 800, 1000,1200	1.042	0.433	Not Significant
Moisture Content	0, 400, 600, 800, 1000,1200	0.501	0.736	Not Significant
Bioyield Point	0, 400, 600, 800, 1000,1200	0.509	0.731	Not Significant
Skin Elasticity	0, 400, 600, 800, 1000,1200	0.623	0.657	Not Significant
Stiffness	0, 400, 600, 800, 1000,1200	0.091	0.983	Not Significant

Work to Penetrate Skin	0, 400, 600, 800, 1000,1200	0.997	0.453	Not Significant
Flesh Firmness	0, 400, 600, 800, 1000,1200	0.687	0.617	Not Significant
Work to Penetrate Flesh	0, 400, 600, 800, 1000,1200	1.017	0.444	Not Significant
Year 2022				
TSS	0, 1200,1400	0.00	1.000	Not Significant
Total Chlorophyll	0, 1200,1400	0.968	0.432	Not Significant
Ascorbic Acid	0, 1200,1400	0.661	0.550	Not Significant
Moisture Content	0, 1200,1400	1.573	0.282	Not Significant
Bioyield Point	0, 1200,1400	2.190	0.193	Not Significant
Skin Elasticity	0, 1200,1400	0.655	0.553	Not Significant
Stiffness	0, 1200,1400	1.638	0.271	Not Significant
Work to Penetrate Skin	0, 1200,1400	0.821	0.484	Not Significant
Flesh Firmness	0, 1200,1400	2.764	0.141	Not Significant
Work to Penetrate Flesh	0, 1200,1400	3.521	0.097	Not Significant

4.1.2 6-Hour Exposure Period

a) Quality Parameters

Table 4.3**:** Quality Parameters of Bitter Gourd Treated with Varying Phosphine Dosages over two Consecutive Years (6-Hour)

Year 2021										
Dosage (in ppm)	**TSS (°Brix)**	**Total Chlorophyll (mg/g)**	**Ascorbic Acid (mg/100g)**	**Moisture Content (%)**	**Bioyield Point (N)**	**Skin Elasticity (mm)**	**Stiffness (N/s)**	**Work to Penetrate Skin (N second)**	**Flesh Firmness (N)**	**Work to Penetrate Flesh N.sec**
0	5	0.895	76.250	92.725	21.988	6.202	8.207	37.813	8.207	48.884
0	5	0.636	78.750	91.925	17.813	5.921	8.394	28.805	8.394	43.382
0	5	0.602	72.500	92.549	17.19	4.756	7.77	33.02	8.163	39.826
400	5	0.823	61.250	90.441	24.636	6.028	9.174	38.079	9.176	47.423
400	5	0.906	83.750	92.520	19.962	6.659	8.813	37.734	8.572	44.31
400	5	0.895	81.250	92.561	21.548	6.166	8.712	36.556	8.524	44.108
600	5	0.801	66.250	92.862	20.365	5.846	8.053	38.572	8.053	39.826
600	5	0.685	81.250	93.027	21.864	6.164	8.786	34.888	8.786	44.535
600	5	0.749	67.500	91.744	19.165	5.553	8.014	36.202	8.014	44.182
800	5	0.835	75.000	92.666	18.695	6.145	8.359	35.907	8.044	43.21
800	5	0.712	80.000	92.724	21.448	6.436	8.81	36.231	8.81	47.883
800	5	0.798	75.000	92.928	21.305	6.14	8.433	37.954	8.768	45.322
1000	5	0.720	63.750	92.372	16.839	6.042	7.441	32.199	7.468	38.601
1000	5	0.656	72.500	92.175	20.656	6.401	8.268	37.344	8.711	46.512
1000	5	0.935	70.000	92.317	18.446	6.008	8.218	36.074	8.218	42.463

Year 2022										
0	5	0.658	65	92.2915	9.489	4.361	4.04	19.091	6.866	12.588
0	4	0.599	87.5	92.0411	10.769	4.236	4.309	19.319	7.818	15.479
0	4	0.587	75	92.1508	9.987	4.358	4.207	19.078	8.093	15.262
1100	5	0.704	87.5	91.0313	9.197	4.195	3.834	17.935	6.178	11.782
1100	4	0.560	81.25	92.6298	10.487	4.868	3.064	18.616	6.656	12.199
1100	5	0.735	75	92.8625	10.395	4.599	3.752	19.139	7.295	12.922
1300	5	0.622	90	92.6714	10.416	4.255	3.71	18.306	8.552	14.947
1300	4	1.109	87.5	92.1098	9.831	4.525	3.519	19.561	6.706	14.419
1300	4	0.781	81.25	91.7739	11.025	4.963	3.982	18.439	7.666	13.508

b) **Statistical Analysis**

Table 4.4 Analysis of quality parameter data of the phosphine-bitter gourd using univariate ANOVA ($\alpha = 0.05$)(6-Hour)

Year 2021				
Quality Parameters	**Dosages**	**F Value**	**p-value**	**Significance**
TSS	0, 400, 600, 800, 1000	-	-	Not Significant
Total Chlorophyll	0, 400, 600, 800, 1000	0.996	0.454	Not Significant
Ascorbic Acid	0, 400, 600, 800, 1000	0.648	0.641	Not Significant
Moisture Content	0, 400, 600, 800, 1000	0.969	0.466	Not Significant
Bioyield Point	0, 400, 600, 800, 1000	1.363	0.314	Not Significant
Skin Elasticity	0, 400, 600, 800, 1000	1.371	0.311	Not Significant
Stiffness	0, 400, 600, 800, 1000	3.189	0.062	Not Significant
Work to Penetrate Skin	0, 400, 600, 800, 1000	1.275	0.343	Not Significant
Flesh Firmness	0, 400, 600, 800, 1000	1.040	0.434	Not Significant

Work to Penetrate Flesh	0, 400, 600, 800, 1000	0.524	0.721	Not Significant
Year 2022				
TSS	0, 1100,1300	0.333	0.729	Not Significant
Total Chlorophyll	0, 1100,1300	1.689	0.260	Not Significant
Ascorbic Acid	0, 1100,1300	1.310	0.337	Not Significant
Moisture Content	0, 1100,1300	0.001	0.999	Not Significant
Bioyield Point	0, 1100,1300	0.324	0.735	Not Significant
Skin Elasticity	0, 1100,1300	0.759	0.508	Not Significant
Stiffness	0, 1100,1300	3.816	0.085	Not Significant
Work to Penetrate Skin	0, 1100,1300	0.973	0.431	Not Significant
Flesh Firmness	0, 1100,1300	1.565	0.284	Not Significant
Work to Penetrate Flesh	0, 1100,1300	3.722	0.089	Not Significant

4.1.3 8 h Exposure Period

a) Quality Parameters

Table 4.5 Quality Parameters of Bitter Gourd Treated with Varying Phosphine Dosages over two Consecutive Years (8-Hour)

Year 2021										
Dosage (in ppm)	**TSS (°Brix)**	**Total Chlorophyll (mg/g)**	**Ascorbic Acid (mg/100g)**	**Moisture Content (%)**	**Bioyield Point (N)**	**Skin Elasticity (mm)**	**Stiffness (N/s)**	**Work to Penetrate Skin (N second)**	**Flesh Firmness (N)**	**Work to Penetrate Flesh N.sec**
0	6	0.666	60	91.764	21.627	6.772	4.157	40.272	8.653	44.73
0	6	0.674	53.75	91.730	20.679	6.689	4.631	40.911	8.289	42.846
0	5	0.791	51.25	92.152	23.495	6.972	5.166	43.876	9.309	48.179

400	5	0.688	36.25	92.521	20.441	6.275	4.973	33.706	7.987	44.184
400	5	0.684	37.5	92.004	21.828	6.822	4.865	39.612	8.372	45.956
400	5	0.661	42.5	92.253	21.886	6.508	4.45	39.472	7.877	45.815
600	6	0.618	48.75	92.161	20.661	6.219	4.685	38.451	7.539	41.44
600	5	0.763	52.5	91.852	19.676	6.173	4.899	38.291	7.786	44.01
600	6	0.766	50	96.078	21.74	6.835	4.625	38.129	8.098	43.767
800	5	0.748	60	91.366	21.449	6.491	4.766	38.952	8.206	45.533
800	6	0.654	56.25	91.915	21.698	7.074	4.931	39.384	8.077	46.805
800	5	0.741	57.5	92.672	24.993	6.758	5.737	38.859	9.293	51.907
1000	5	0.614	61.25	91.785	17.457	5.954	4.793	35.558	7.772	44.413
1000	5	0.767	63.75	91.421	23.917	6.392	5.343	39.643	7.655	44.548
1000	5	0.776	50	92.237	22.736	6.747	5.011	38.989	8.596	44.434
Year 2022										
0	3	1.665	48.75	91.0771	18.385	9.570	2.746	45.270	8.594	44.410
0	3	1.028	40	94.3743	22.255	9.252	3.669	46.466	9.446	48.821
0	4	1.258	43.75	91.2568	19.763	8.849	3.320	44.887	9.171	45.501
1000	3	1.325	37.5	92.5187	23.06	9.224	3.948	51.079	9.905	51.186
1000	4	1.409	47.5	89.2674	21.633	8.58	3.310	42.684	9.235	47.737
1000	3	1.198	47.5	91.2589	18.947	9.859	2.859	44.738	8.753	45.018
1100	3	1.246	43.75	91.5427	18.715	9.784	2.647	45.876	8.14	47.418
1100	3	1.401	40	91.3714	20.103	8.928	3.355	48.310	9.483	44.997
1100	4	1.171	37.5	90.2356	17.965	9.116	2.261	40.282	7.135	40.620

b) **Statistical Analysis**

Table 4.6 Analysis of quality parameter data of the phosphine-bitter gourd using univariate ANOVA ($\alpha = 0.05$)(8-Hour)

Year 2021				
Quality Parameters	**Dosages**	**F Value**	**p-value**	**Significance**
TSS	0, 400, 600, 800, 1000	1.667	0.233	Not Significant
Total Chlorophyll	0, 400, 600, 800, 1000	0.184	0.941	Not Significant
Ascorbic Acid	0, 400, 600, 800, 1000	1.654	0.236	Not Significant
Moisture Content	0, 400, 600, 800, 1000	0.978	0.461	Not Significant
Bioyield Point	0, 400, 600, 800, 1000	0.436	0.780	Not Significant
Skin Elasticity	0, 400, 600, 800, 1000	1.330	0.324	Not Significant
Stiffness	0, 400, 600, 800, 1000	0.992	0.455	Not Significant
Work to Penetrate Skin	0, 400, 600, 800, 1000	1.981	0.174	Not Significant
Flesh Firmness	0, 400, 600, 800, 1000	2.033	0.165	Not Significant
Work to Penetrate Flesh	0, 400, 600, 800, 1000	2.314	0.129	Not Significant
Year 2022				
TSS	0, 1000,1100	0.00	1.00	Not Significant
Total Chlorophyll	0, 1000,1100	0.04	0.961	Not Significant
Ascorbic Acid	0, 1000,1100	0.675	0.544	Not Significant
Moisture Content	0, 1000,1100	0.656	0.553	Not Significant
Bioyield Point	0, 1000,1100	1.254	0.351	Not Significant
Skin Elasticity	0, 1000,1100	0.012	0.988	Not Significant
Stiffness	0, 1000,1100	1.162	0.374	Not Significant
Work to Penetrate Skin	0, 1000,1100	0.111	0.897	Not Significant
Flesh Firmness	0, 1000,1100	1.422	0.312	Not Significant
Work to Penetrate Flesh	0, 1000,1100	1.114	0.388	Not Significant

4.1.4 10 h Exposure Period

a) Quality Parameters

Table 4.7 Quality Parameters of Bitter Gourd Treated with Varying Phosphine Dosages over two Consecutive Years (10-Hour)

Year 2021										
Dosage (in ppm)	**TSS (°Brix)**	**Total Chlorophyll (mg/g)**	**Ascorbic Acid (mg/100g)**	**Moisture Content (%)**	**Bioyield Point (N)**	**Skin Elasticity (mm)**	**Stiffness (N/s)**	**Work to Penetrate Skin (N second)**	**Flesh Firmness (N)**	**Work to Penetrate Flesh N.sec**
0	5	0.650	40	91.875	15.489	6.524	3.529	33.045	8.718	45.062
0	5	0.789	43.75	91.764	13.856	5.566	4.319	28.632	7.444	38.481
0	5	0.785	38.75	91.730	16.781	6.479	4.192	33.631	10.932	46.666
200	5	0.603	37.5	92.481	16.844	6.424	4.194	33.589	9.246	46.719
200	5	0.613	38.75	91.915	17.481	6.579	4.281	34.162	9.527	47.407
200	5	0.737	40	90.306	16.284	6.369	4.946	33.689	9.878	47.327
400	5	0.756	36.25	92.424	15.878	6.194	4.137	32.609	9.113	42.475
400	5	0.763	37.5	92.493	15.859	6.233	4.154	33.038	8.659	42.126
400	5	0.771	42.5	91.174	17.165	6.318	4.608	34.038	10.508	46.764
600	5	0.783	41.25	91.366	15.928	6.159	4.451	33.405	9.016	46.599
600	5	0.773	37.5	91.915	15.859	6.364	4.047	32.31	9.366	44.956
600	5	0.684	40	92.672	16.517	6.424	4.371	34.449	9.686	46.109
800	5	0.601	36.25	91.785	15.135	5.978	4.124	33.638	9.223	46.357
800	5	0.668	38.75	91.421	15.420	6.115	4.444	32.474	9.16	46.422
800	5	0.696	41.25	92.228	15.461	6.367	4.302	34.069	9.097	47.026

Year 2022										
0	4	0.659	42.5	91.4550	13.613	5.707	3.867	32.471	8.244	36.642
0	4	0.770	35	91.9384	13.876	5.293	4.282	31.085	8.112	35.065
0	4	1.619	46.5	91.8841	13.074	5.64	4.168	32.723	8.433	38.075
800	5	0.916	34	91.9881	13.897	5.749	3.698	31.643	7.108	36.743
800	7	0.908	57.5	92.4933	13.936	5.866	3.63	32.897	7.232	36.125
800	4	1.353	50	91.7608	16.256	5.869	4.387	33.624	8.856	38.751
1000	4	0.991	52.5	91.6770	14.89	5.297	4.239	33.492	8.675	35.884
1000	4	1.165	43	91.4048	13.409	6.206	4.008	33.914	8.883	35.418
1000	5	1.004	40	91.4498	15.841	5.818	4.987	34.461	8.817	42.356

b) **Statistical Analysis**

Table 4.8 Analysis of quality parameter data of the phosphine-bitter gourd using univariate ANOVA ($\alpha = 0.05$)(10-Hour)

Year 2021				
Quality Parameters	**Dosages**	**F Value**	**p-value**	**Significance**
TSS	0, 200,400, 600, 800	-	-	Not Significant
Total Chlorophyll	0, 200,400, 600, 800	2.537	0.106	Not Significant
Ascorbic Acid	0, 200,400, 600, 800	0.429	0.785	Not Significant
Moisture Content	0, 200,400, 600, 800	0.208	0.928	Not Significant
Bioyield Point	0, 200,400, 600, 800	1.956	0.178	Not Significant
Skin Elasticity	0, 200,400, 600, 800	0.590	0.677	Not Significant
Stiffness	0, 200,400, 600, 800	0.831	0.535	Not Significant
Work to Penetrate Skin	0, 200,400, 600, 800	0.931	0.484	Not Significant

Flesh Firmness	0, 200,400, 600, 800	0.153	0.957	Not Significant
Work to Penetrate Flesh	0, 200,400, 600, 800	1.605	0.248	Not Significant
Year 2022				
TSS	0, 800,1000	1.625	0.273	Not Significant
Total Chlorophyll	0, 800,1000	0.014	0.986	Not Significant
Ascorbic Acid	0, 800,1000	0.358	0.713	Not Significant
Moisture Content	0, 800,1000	3.171	0.115	Not Significant
Bioyield Point	0, 800,1000	1.203	0.364	Not Significant
Skin Elasticity	0, 800,1000	0.765	0.506	Not Significant
Stiffness	0, 800,1000	1.211	0.362	Not Significant
Work to Penetrate Skin	0, 800,1000	4.004	0.079	Not Significant
Flesh Firmness	0, 800,1000	2.555	0.157	Not Significant
Work to Penetrate Flesh	0, 800,1000	0.196	0.827	Not Significant

4.1.5 15 h Exposure Period

a) Quality Parameters

Table 4.9: Quality Parameters of Bitter Gourd Treated with Varying Phosphine Dosages over two Consecutive Years (15-Hour)

Year 2021										
Dosage (in ppm)	**TSS (°Brix)**	**Total Chlorophyll (mg/g)**	**Ascorbic Acid (mg/100g)**	**Moisture Content (%)**	**Bioyield Point (N)**	**Skin Elasticity (mm)**	**Stiffness (N/s)**	**Work to Penetrate Skin (N second)**	**Flesh Firmness (N)**	**Work to Penetrate Flesh N.sec**
0	4	0.647	41.25	93.656	19.292	6.809	3.394	35.931	8.285	42.827
0	5	0.675	43.75	93.337	18.458	7.286	4.651	34.219	7.405	38.821
0	5	0.795	40	93.530	17.832	6.408	3.457	37.226	8.009	40.491

200	5	0.830	42.5	92.794	19.972	6.757	5.468	34.126	7.575	40.963
200	5	0.660	35	93.419	21.869	6.169	5.777	36.378	7.811	40.366
200	5	0.666	40	92.163	21.201	7.426	4.807	38.27	8.112	43.707
400	5	0.628	36.25	91.704	20.195	6.92	4.817	40.466	8.745	45.199
400	5	0.625	37.5	91.537	18.64	6.304	5.27	39.105	8.706	46.738
400	5	0.764	42.5	93.310	17.285	6.39	3.88	37.023	7.743	40.02
600	5	0.601	41.25	92.080	20.242	6.497	5.009	37.214	8.895	47.616
600	5	0.677	38.75	92.167	20.619	6.503	5.424	37.423	8.357	44.216
600	5	0.792	45	93.086	17.37	6.948	4.1	31.229	7.104	41.267
800	5	0.698	36.25	92.746	19.303	6.73	3.512	35.373	8.089	44.42
800	5	0.622	38.75	92.405	20.146	6.792	5.373	40.464	8.436	45.866
800	5	0.662	41.25	93.431	17.4	6.673	3.521	37.474	7.866	42.667
Year 2022										
0	4	0.969	87.5	90.873	16.594	5.639	4.503	31.263	8.595	43.815
0	4	0.805	87.5	90.861	17.763	5.999	4.576	33.799	8.839	43.291
0	4	0.803	75	90.821	17.698	5.606	4.168	31.005	8.792	44.216
600	5	1.403	75	91.033	16.106	5.076	4.336	30.186	8.162	42.189
600	5	0.906	83.75	91.432	16.772	5.612	4.5	31.653	8.162	42.189
600	4	0.901	60	90.772	17.309	5.673	4.703	31.787	8.835	43.428
800	4	0.874	76.25	90.643	17.876	5.942	4.524	33.534	9.127	43.815
800	4	1.638	87.5	91.325	16.974	5.258	4.184	31.274	8.445	43.291
800	5	0.896	87.5	90.878	18.729	5.911	4.975	33.792	8.183	44.216

b) **Statistical Analysis**

Table 4.10 Analysis of quality parameter data of the phosphine-bitter gourd using univariate ANOVA (α = 0.05)(15-Hour)

Year 2021				
Quality Parameters	**Dosages**	**F Value**	**p-value**	**Significance**
TSS	0, 200,400, 600, 800	1.000	0.452	Not Significant
Total Chlorophyll	0, 200,400, 600, 800	0.258	0.898	Not Significant
Ascorbic Acid	0, 200,400, 600, 800	0.776	0.565	Not Significant
Moisture Content	0, 200,400, 600, 800	1.915	0.185	Not Significant
Bioyield Point	0, 200,400, 600, 800	1.729	0.220	Not Significant
Skin Elasticity	0, 200,400, 600, 800	0.266	0.893	Not Significant
Stiffness	0, 200,400, 600, 800	1.867	0.193	Not Significant
Work to Penetrate Skin	0, 200,400, 600, 800	1.158	0.385	Not Significant
Flesh Firmness	0, 200,400, 600, 800	0.489	0.744	Not Significant
Work to Penetrate Flesh	0, 200,400, 600, 800	1.342	0.320	Not Significant
Year 2022				
TSS	0, 600, 800	1.50	0.296	Not Significant
Total Chlorophyll	0, 600, 800	0.667	0.547	Not Significant
Ascorbic Acid	0, 600, 800	1.412	0.312	Not Significant
Moisture Content	0, 600, 800	0.506	0.626	Not Significant
Bioyield Point	0, 600, 800	1.844	0.238	Not Significant
Skin Elasticity	0, 600, 800	0.744	0.514	Not Significant
Stiffness	0, 600, 800	0.207	0.819	Not Significant
Work to Penetrate Skin	0, 600, 800	1.215	0.361	Not Significant
Flesh Firmness	0, 600, 800	0.706	0.531	Not Significant
Work to Penetrate Flesh	0, 600, 800	4.374	0.067	Not Significant

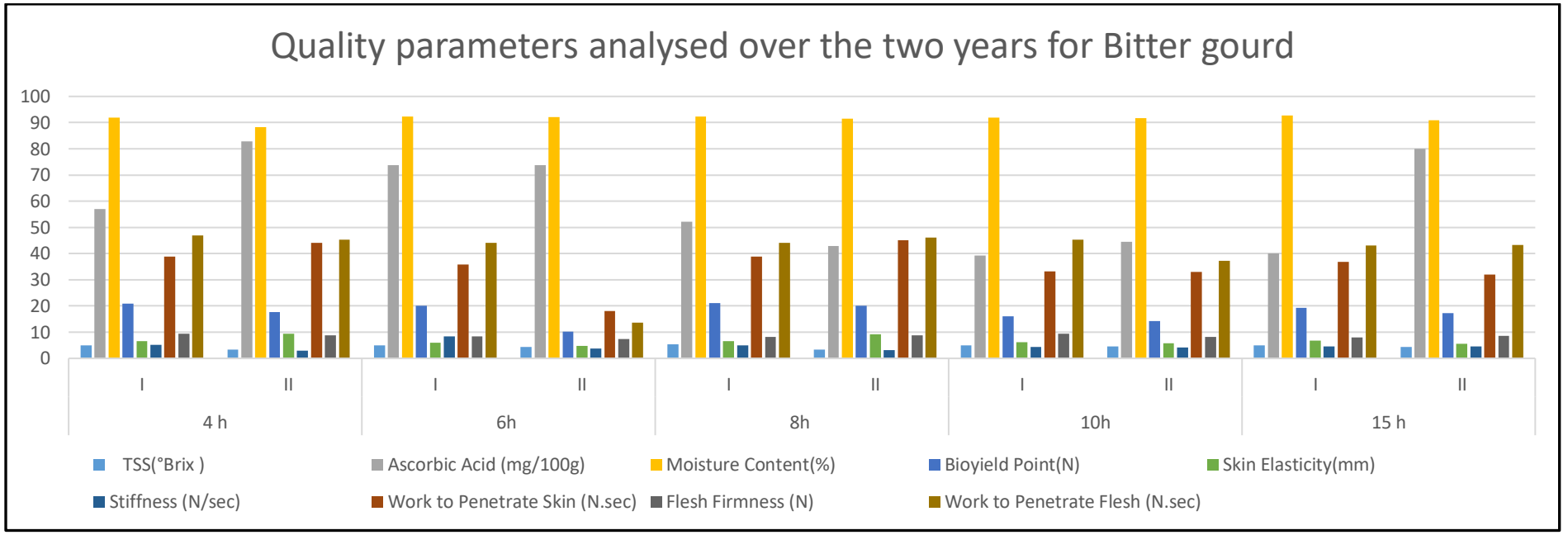


Figure 4.1 Showing the quality parameters tested over the two years for Bitter gourd.

4.2 Green Chilli

Green Chilli samples were treated with varying phosphine concentrations over 4/6/8/10-hour exposure. The temperature was maintained between 26-28°C, and the relative humidity (RH) was kept at 62-75%. The results detail the effects of phosphine on various nutrient and physical quality parameters, including moisture content, color, texture, chlorophyll content, ascorbic acid content, total soluble solids (TSS), and antioxidant activity. The analysis focused on how phosphine treatment influenced these characteristics, impacting the overall quality of the green chillies. The study on chilli was conducted for two consecutive years, with varying phosphine dosages. In the initial phase, dosages ranged from 0 to 1500 ppm. This higher dosage range was selected to thoroughly assess the effects of phosphine on the quality parameters of chilli. Interestingly, the results showed that even at higher dosages, there was no significant adverse impact on the quality of the commodity. However, based on the successful pest mortality results reported at NCIPM during the first year of lab experiments, and supported by literature findings, the confirmation phase focused on lower dosages (0-60 ppm). This refined range was selected because lower doses were sufficient to achieve the desired pest control without the need for higher concentrations. The effectiveness of lower dosages against pest management was confirmed by NCIPM scientists; moreover, these were more aligned with practical applications, ensuring minimal treatment while maintaining product quality.

4.2.1 4-Hour Exposure Period

a) Quality Parameters

Table 4.11 Quality Parameters of Green Chilli Treated with Varying Phosphine Dosages over two Consecutive Years (04-Hour)

Year 2021											
Dosage (in ppm)	**TSS (°Brix)**	**Total Chlorophyll (mg/g)**	**Ascorbic Acid (mg/100g)**	**Antioxidant capcity (micro mol TE/g)**	**Moisture Content (%)**	**Bioyield Point (N)**	**Skin Elasticity (mm)**	**Stiffness (N/s)**	**Work to Penetrate Skin (N second)**	**Flesh Firmness (N)**	**Work to Penetrate Flesh N.sec**
0	5	0.563	50.00	8.81	89.61649	8.569	3.024	4.254	10.655	5.469	10.483
0	5	0.514	38.33	9.24	88.29048	8.123	3.026	4.097	9.687	5.089	10.721
0	6	0.513	28.33	10.00	88.88922	8.102	2.937	3.939	9.891	5.177	10.059
500	5	0.543	51.67	10.49	89.53772	7.736	3.254	4.036	10.087	5.205	9.776
500	6	0.492	36.67	11.22	88.24693	8.583	3.183	4.079	10.838	5.73	10.512
500	6	0.557	38.33	8.30	88.79951	8.015	3.544	4.091	10.272	5.541	10.214
750	4	0.558	40.00	9.02	90.72904	8.497	2.689	4.72	10.209	5.109	10.101
750	5	0.538	31.67	9.19	89.64706	8.328	3.045	4.028	10.151	5.117	10.287
750	5	0.530	46.67	9.18	89.58941	8.395	2.989	3.953	10.003	5.315	9.985
1000	5	0.591	35.00	10.88	89.50839	8.303	2.833	4.626	10.038	5.048	10.115
1000	5	0.511	50.00	9.54	88.85909	8.868	3.237	4.233	11.99	5.534	10.153
1000	5	0.528	33.33	10.11	89.39137	8.322	3.026	3.977	9.094	5.189	10.015
1250	4	0.562	35.00	9.09	90.01309	8.577	3.568	3.752	10.761	5.315	10.49
1250	5	0.522	33.33	9.97	89.15774	8.303	2.82	3.876	10.054	5.187	10.575
1250	5	0.552	46.67	10.84	89.12263	8.413	3.261	4.271	9.847	5.204	10.114

Year 2022											
0	5	0.532	75.000	13.663	83.146	8.814	3.419	3.676	10.457	4.798	8.417
0	6	0.552	58.333	11.195	80.378	8.123	3.323	3.812	9.658	4.458	8.407
0	5	0.619	66.667	9.869	86.836	8.399	3.396	3.736	9.732	4.76	8.731
50	6	0.532	66.667	15.265	87.976	8.269	3.296	3.852	9.385	4.349	8.19
50	6	0.552	95.833	15.080	83.471	8.964	3.553	3.775	9.431	4.736	8.687
50	5	0.619	62.500	10.054	84.279	8.744	3.562	3.832	9.386	4.452	8.511
60	5	0.629	93.750	13.939	84.899	8.621	3.416	3.815	10.055	4.532	8.748
60	5	0.611	75.000	9.207	84.962	8.737	3.546	3.565	9.943	4.766	8.744
60	**5**	0.550	87.500	10.661	86.738	8.413	3.461	3.671	9.569	4.576	8.965

c) **Statistical Analysis**

Table 4.12 Analysis of quality parameter data of the phosphine-treated green chilli using univariate ANOVA ($\alpha = 0.05$)(04-Hour)

Year 2021				
Quality Parameters	**Dosages**	**F Value**	**p-value**	**Significance**
TSS	0,500,750,1000,1250	2.125	0.152	Not Significant
Total Chlorophyll	0,500,750,1000,1250	0.184	0.942	Not Significant
Ascorbic Acid	0,500,750,1000,1250	0.089	0.984	Not Significant
Antioxidant	0,500,750,1000,1250	0.803	0.551	Not Significant
Moisture Content	0,500,750,1000,1250	1.870	0.192	Not Significant
Bioyield Point	0,500,750,1000,1250	0.930	0.484	Not Significant
Skin Elasticity	0,500,750,1000,1250	1.707	0.224	Not Significant
Stiffness	0,500,750,1000,1250	0.629	0.653	Not Significant
Work to Penetrate Skin	0,500,750,1000,1250	0.111	0.976	Not Significant
Flesh Firmness	0,500,750,1000,1250	1.149	0.389	Not Significant
Work to Penetrate Flesh	0,500,750,1000,1250	1.066	0.423	Not Significant

Year 2022				
TSS	0, 50, 60	1.50	0.296	Not Significant
Total Chlorophyll	0, 50, 60	0.430	0.669	Not Significant
Ascorbic Acid	0, 50, 60	1.619	0.274	Not Significant
Antioxidant	0, 50, 60	0.696	0.535	Not Significant
Moisture Content	0, 50, 60	0.658	0.552	Not Significant
Bioyield Point	0, 50, 60	0.391	0.693	Not Significant
Skin Elasticity	0, 50, 60	0.875	0.464	Not Significant
Stiffness	0, 50, 60	1.907	0.228	Not Significant
Work to Penetrate Skin	0, 50, 60	2.975	0.127	Not Significant
Flesh Firmness	0, 50, 60	0.670	0.546	Not Significant
Work to Penetrate Flesh	0, 50, 60	2.915	0.130	Not Significant

4.2.2 6-Hour Exposure Period

a) Quality Parameters

Table 4.13 Quality Parameters of Green Chilli Treated with Varying Phosphine Dosages over two Consecutive Years (06-Hour)

Year 2021											
Dosage (in ppm)	**TSS (°Brix)**	**Total Chlorophyll (mg/g)**	**Ascorbic Acid (mg/100g)**	**Antioxidant capcity (micro mol TE/g)**	**Moisture Content (%)**	**Bioyield Point (N)**	**Skin Elasticity (mm)**	**Stiffness (N/s)**	**Work to Penetrate Skin (N second)**	**Flesh Firmness (N)**	**Work to Penetrate Flesh N.sec**
0	5	0.605	26.67	11.85	89.079	7.996	2.889	4.555	7.124	5.206	9.549
0	7	0.620	32.00	10.06	90.228	7.495	2.621	4.750	8.021	4.621	9.111
0	6	0.591	24.00	9.49	90.263	7.617	2.543	4.229	7.871	4.418	8.991

400	6	0.685	29.33	12.69	89.421	7.430	2.648	4.293	7.796	4.307	9.367
400	6	0.671	24.00	12.15	89.054	7.535	2.568	4.338	7.090	4.127	8.772
400	6	0.545	21.33	10.71	89.313	7.697	2.857	4.273	8.050	4.831	9.817
600	6	0.596	32.00	10.22	89.700	7.777	2.545	4.492	7.370	4.778	9.647
600	6	0.616	34.67	11.52	89.682	7.372	2.678	4.400	7.069	4.297	9.177
600	6	0.561	26.67	11.93	89.314	7.961	2.819	4.342	8.109	5.195	9.528
800	6	0.678	26.67	11.51	87.668	7.661	2.538	4.776	7.719	4.696	9.462
800	6	0.653	37.33	11.93	88.631	7.658	2.847	4.154	8.175	4.879	9.461
800	6	0.633	26.67	10.32	89.693	7.975	2.745	4.665	7.242	4.449	9.645
1000	6	0.582	21.33	10.84	90.507	7.771	2.421	4.449	7.978	4.622	9.479
1000	6	0.664	34.67	11.02	89.409	7.983	2.956	4.395	7.015	4.908	9.443
1000	6	0.634	26.67	10.84	88.300	7.891	2.564	4.807	7.869	4.544	9.11
Year 2022											
0	8	0.817	62.500	16.075	84.886	9.024	3.32	3.906	9.695	5.388	9.338
0	6	0.734	68.750	14.731	82.444	9.67	3.119	3.866	9.87	5.272	9.865
0	6	0.814	75.000	15.099	84.416	9.177	3.614	3.749	9.571	5.685	9.384
40	8	0.771	62.500	17.548	83.879	9.43	3.138	3.851	9.202	5.749	9.568
40	7	0.624	77.083	18.192	82.966	8.953	3.035	3.836	9.244	5.702	9.59
40	8	0.789	41.667	16.112	84.724	9.64	3.241	3.61	9.738	5.85	9.901
50	7	0.830	79.167	14.454	83.722	9.743	3.609	3.804	9.134	5.437	9.422
50	7	0.781	89.583	16.369	81.378	9.154	3.594	3.606	9.848	5.685	9.618
50	7	0.887	70.833	15.927	82.446	9.258	3.153	3.603	9.956	5.359	9.363

b) **Statistical Analysis**

Table 4.14 Analysis of quality parameter data of the phosphine-treated perishables using univariate ANOVA ($\alpha = 0.05$)(06-Hour)

Year 2021				
Quality Parameters	**Dosages**	**F Value**	**p-value**	**Significance**
TSS	0,400,600,800,1000	0.00	1.00	Not Significant
Total Chlorophyll	0,400,600,800,1000	1.008	0.448	Not Significant
Ascorbic Acid	0,400,600,800,1000	0.688	0.616	Not Significant
Antioxidant	0,400,600,800,1000	0.954	0.473	Not Significant
Moisture Content	0,400,600,800,1000	1.058	0.426	Not Significant
Bioyield Point	0,400,600,800,1000	0.952	0.474	Not Significant
Skin Elasticity	0,400,600,800,1000	0.045	0.996	Not Significant
Stiffness	0,400,600,800,1000	0.690	0.615	Not Significant
Work to Penetrate Skin	0,400,600,800,1000	0.065	0.991	Not Significant
Flesh Firmness	0,400,600,800,1000	0.480	0.750	Not Significant
Work to Penetrate Flesh	0,400,600,800,1000	0.448	0.772	Not Significant
Year 2022				
TSS	0, 40, 50	1.400	0.317	Not Significant
Total Chlorophyll	0, 40, 50	1.879	0.233	Not Significant
Ascorbic Acid	0, 40, 50	1.928	0.226	Not Significant
Antioxidant	0, 40, 50	3.949	0.080	Not Significant
Moisture Content	0, 40, 50	1.474	0.302	Not Significant
Bioyield Point	0, 40, 50	0.060	0.942	Not Significant
Skin Elasticity	0, 40, 50	1.655	0.268	Not Significant
Stiffness	0, 40, 50	1.699	0.260	Not Significant
Work to Penetrate Skin	0, 40, 50	0.812	0.488	Not Significant
Flesh Firmness	0, 40, 50	3.341	0.106	Not Significant
Work to Penetrate Flesh	0, 40, 50	0.831	0.480	Not Significant

4.2.3 8-Hour Exposure Period

a) Quality Parameters

Table 4.15 Quality Parameters of Green Chilli Treated with Varying Phosphine Dosages over two Consecutive Years (08-Hour)

Year 2021											
Dosage (in ppm)	**TSS (°Brix)**	**Total Chlorophyll (mg/g)**	**Ascorbic Acid (mg/100g)**	**Antioxidant capcity (micro mol TE/g)**	**Moisture Content (%)**	**Bioyield Point (N)**	**Skin Elasticity (mm)**	**Stiffness (N/s)**	**Work to Penetrate Skin (N second)**	**Flesh Firmness (N)**	**Work to Penetrate Flesh N.sec**
0	5	0.584	42.67	10.779	89.469	7.377	3.722	3.808	8.021	4.958	9.996
0	5	0.541	40.00	8.930	89.064	7.801	3.225	4.53	7.982	4.691	9.264
0	5	0.623	48.00	11.042	89.659	7.491	3.255	4.103	7.472	4.263	9.376
400	5	0.524	48.00	11.551	89.191	7.833	3.228	4.213	8.313	5.038	10.059
400	5	0.575	48.00	11.829	89.065	7.252	3.267	4.001	7.522	4.75	9.784
400	5	0.616	37.33	10.133	89.278	7.994	2.957	4.51	7.468	4.502	10.002
600	5	0.527	34.67	9.560	89.872	7.227	3.029	4.25	7.215	4.373	8.84
600	5	0.509	40.00	11.241	89.585	7.561	3.462	4.443	8.235	5.449	10.604
600	5	0.616	37.33	11.772	90.150	7.877	3.213	4.143	7.538	4.649	9.007
800	5	0.511	32.00	9.650	89.471	7.815	3.449	4.151	7.812	4.613	9.501
800	5	0.543	42.67	11.326	89.538	7.633	3.273	4.318	7.856	4.767	9.721
800	5	0.652	32.00	10.225	89.984	7.536	2.881	4.243	7.761	4.496	9.79
1000	5	0.571	37.33	10.838	90.334	7.083	3.065	3.971	7.555	4.501	9.115
1000	5	0.599	48.00	10.724	89.226	7.793	3.167	4.185	7.744	4.838	10.108
1000	5	0.547	40.00	10.519	89.571	8.283	3.15	4.24	7.368	4.799	10.504

Year 2022											
0	7	0.933	40.000	13.460	83.754	9.637	3.315	3.837	11.406	5.753	9.88
0	8	0.721	49.600	16.038	80.970	9.615	3.027	4.421	10.582	5.447	9.99
0	9	0.682	26.667	15.191	84.218	8.519	3.69	4.302	11.551	5.144	9.131
30	7	0.900	43.733	10.017	85.225	8.803	3.349	4.178	10.566	5.445	9.989
30	6	0.706	52.267	18.855	91.322	8.988	3.417	4.135	11.875	6.106	10.01
30	7	0.669	33.600	14.491	86.071	9.061	3.069	4.212	9.763	5.716	9.462
40	8	0.919	29.867	15.596	87.274	9.064	3.114	4.351	10.097	5.615	9.123
40	8	0.673	37.333	16.314	83.151	8.711	3.178	4.102	10.557	5.112	9.217
40	8	0.834	32.000	9.280	86.863	9.628	3.392	4.02	10.137	5.452	9.625

b) **Statistical Analysis**

Table 4.16 Analysis of quality parameter data of the phosphine-treated green chilli using univariate ANOVA ($\alpha = 0.05$)(08-Hour)

Year 2021				
Quality Parameters	**Dosages**	**F Value**	**p-value**	**Significance**
TSS	0,400,600,800,1000	----	-----	Not Significant
Total Chlorophyll	0,400,600,800,1000	0.153	0.957	Not Significant
Ascorbic Acid	0,400,600,800,1000	1.753	0.215	Not Significant
Antioxidant	0,400,600,800,1000	0.474	0.754	Not Significant
Moisture Content	0,400,600,800,1000	1.938	0.181	Not Significant
Bioyield Point	0,400,600,800,1000	0.129	0.968	Not Significant
Skin Elasticity	0,400,600,800,1000	0.725	0.595	Not Significant
Stiffness	0,400,600,800,1000	0.249	0.904	Not Significant
Work to Penetrate Skin	0,400,600,800,1000	0.308	0.866	Not Significant
Flesh Firmness	0,400,600,800,1000	0.189	0.939	Not Significant

Work to Penetrate Flesh	0,400,600,800,1000	0.398	0.806	Not Significant
Year 2022				
TSS	0,30, 40	4.00	0.079	Not Significant
Total Chlorophyll	0,30, 40	0.117	0.891	Not Significant
Ascorbic Acid	0,30, 40	0.989	0.425	Not Significant
Antioxidant	0,30, 40	0.086	0.919	Not Significant
Moisture Content	0,30, 40	2.481	0.164	Not Significant
Bioyield Point	0,30, 40	0.334	0.728	Not Significant
Skin Elasticity	0,30, 40	0.184	0.837	Not Significant
Stiffness	0,30, 40	0.015	0.985	Not Significant
Work to Penetrate Skin	0,30, 40	1.281	0.344	Not Significant
Flesh Firmness	0,30, 40	1.278	0.345	Not Significant
Work to Penetrate Flesh	0, 30, 40	1.521	0.292	Not Significant

4.2.4 10-Hour Exposure Period

a) Quality Parameters

Table 4.17 Quality Parameters of Green Chilli Treated with Varying Phosphine Dosages over two Consecutive Years (10-Hour)

Year 2021											
Dosage (in ppm)	**TSS (°Brix)**	**Total Chlorophyll (mg/g)**	**Ascorbic Acid (mg/100g)**	**Antioxidant capcity (micro mol TE/g)**	**Moisture Content (%)**	**Bioyield Point (N)**	**Skin Elasticity (mm)**	**Stiffness (N/s)**	**Work to Penetrate Skin (N second)**	**Flesh Firmness (N)**	**Work to Penetrate Flesh N.sec**
0	5	0.546	42.67	8.113	88.438	8.971	2.842	4.156	9.082	5.323	9.765
0	5	0.611	32.00	10.751	88.126	8.725	2.955	4.108	8.599	4.824	9.138
0	7	0.567	40.00	11.398	87.561	9.404	3.203	4.1	9.769	5.389	9.501
0	6	0.562	21.33	8.986	87.109	9.147	2.884	4.241	8.523	5.482	9.687

0	7	0.595	42.67	11.212	88.735	8.116	3.556	3.646	8.828	5.384	9.164
250	6	0.609	37.33	12.013	86.397	9.466	2.791	4.777	8.325	5.331	9.779
250	6	0.618	48.00	9.980	87.362	9.321	2.874	4.477	8.723	5.668	9.751
250	6	0.457	26.67	10.113	88.597	8.479	2.935	4.112	8.913	4.986	9.148
250	6	0.577	32.00	10.113	89.124	8.491	2.993	3.994	8.564	5.285	9.693
250	7	0.606	29.33	9.376	87.233	9.021	3.51	4.171	8.417	5.738	10.388
500	5	0.416	26.67	11.252	87.564	9.75	2.981	4.37	9.159	5.527	9.162
500	6	0.432	32.00	8.181	88.645	9.083	3.016	4.056	8.705	5.333	9.782
500	7	0.529	32.00	9.376	87.630	9.23	3.781	3.892	8.982	5.18	9.503
500	6	0.575	26.67	10.013	86.686	9.334	2.771	4.714	8.818	5.48	9.598
500	6	0.646	40.00	9.928	89.219	8.529	2.776	4.164	8.449	5.144	9.435
Year 2022											
0	7	0.285	93.750	12.337	82.094	8.017	3.545	3.663	9.976	5.236	9.604
0	8	0.542	114.583	14.289	85.020	9.47	3.775	3.865	12.106	5.522	9.778
0	7	0.273	110.417	12.024	82.087	8.713	3.474	3.603	10.692	5.077	9.313
25	9	0.411	104.167	13.644	80.575	8.473	3.593	3.464	10.061	5.218	9.244
25	8	0.412	72.917	12.779	86.017	8.47	3.242	3.823	9.886	5.081	9.322
25	8	0.268	72.917	11.011	82.888	8.732	3.238	3.784	9.898	5.207	9.551
30	7	0.292	110.417	13.386	82.985	8.315	3.643	3.764	10.45	5.318	9.337
30	7	0.311	106.250	12.484	83.140	8.687	3.6	3.764	10.557	5.317	9.502
30	8	0.338	83.333	14.123	78.720	8.776	3.487	3.596	10.845	5.319	9.718

b) Statistical Analysis

Table 4.18 Analysis of quality parameter data of the phosphine-treated green chilli using univariate ANOVA ($\alpha = 0.05$)(10-Hour)

Year 2021				
Quality Parameters	**Dosages**	**F Value**	**p-value**	**Significance**
TSS	0,250,500	0.118	0.890	Not Significant
Total Chlorophyll	0,250,500	1.049	0.380	Not Significant
Ascorbic Acid	0,250,500	0.400	0.679	Not Significant
Antioxidant	0,250,500	0.282	0.759	Not Significant
Moisture Content	0,250,500	0.102	0.904	Not Significant
Bioyield Point	0,250,500	0.608	0.560	Not Significant
Skin Elasticity	0,250,500	0.052	0.950	Not Significant
Stiffness	0,250,500	1.033	0.385	Not Significant
Work to Penetrate Skin	0,250,500	1.392	0.286	Not Significant
Flesh Firmness	0,250,500	0.289	0.754	Not Significant
Work to Penetrate Flesh	0,250,500	1.198	0.335	Not Significant
Year 2022				
TSS	0,25,30	3.00	0.125	Not Significant
Total Chlorophyll	0,25,30	0.262	0.778	Not Significant
Ascorbic Acid	0,25,30	1.914	0.227	Not Significant
Antioxidant	0,25,30	0.412	0.680	Not Significant
Moisture Content	0,25,30	0.407	0.683	Not Significant
Bioyield Point	0,25,30	0.127	0.883	Not Significant
Skin Elasticity	0,25,30	2.188	0.193	Not Significant
Stiffness	0,25,30	0.016	0.984	Not Significant
Work to Penetrate Skin	0,25,30	1.829	0.240	Not Significant
Flesh Firmness	0,25,30	0.951	0.438	Not Significant
Work to Penetrate Flesh	0,25,30	0.771	0.501	Not Significant

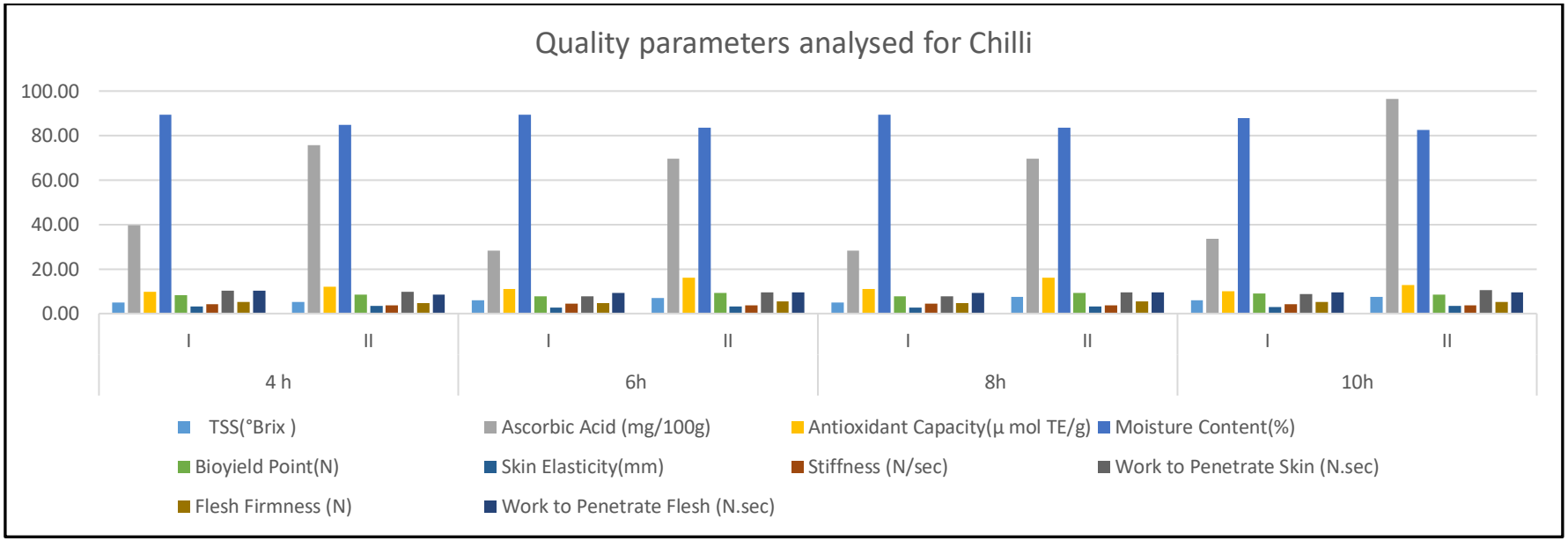


Figure 4.2 Showing the quality parameters tested over the two years for Chilli

4.3 Mango

Mango samples were exposed to varying phosphine concentrations over 4/6/8/10-hour periods, with the temperature controlled between 15-18°C and relative humidity (RH) maintained at 75-80%. The study in two consecutive years and the results were validated in the second year. In the initial phase, different doses were tested by NCIPM scientists to establish the efficacy of phosphine in terms of pest control and quality maintenance. Based on the results, the confirmation phase employed refined dosages sufficient to achieve effective treatment while minimizing potential impacts on quality. The study evaluated the effects of phosphine on both the nutritional and physical quality attributes of the mango fruits. The parameters assessed included total soluble solids (TSS), acidity, carotenoid content, bioyield point, skin elasticity, stiffness, work to penetrate the skin and flesh, flesh firmness, and physiological loss in weight over a storage period of 10 days. These factors were measured to determine the impact of phosphine treatment on the quality and shelf life of the mangoes.

4.3.1 4-Hour Exposure Period

a) Quality Parameters

Table 4.19 Quality Parameters of Mango Treated with Varying Phosphine Dosages in the year 2022 (04-Hour)

Year 2022									
Dosage (ppm)	**TSS(°Brix)**	**Titratable Acidity (%)**	**Carotenoids (mg/100g)**	**Bioyield Point (N)**	**Skin Elasticity (mm)**	**Stiffness (N/s)**	**Work to Penetrate Skin (N second)**	**Flesh Firmness (N)**	**Work to Penetrate Flesh N.sec**
0	13	0.768	7.798	22.708	3.385	13.240	23.309	8.224	35.067
0	15	0.512	7.527	24.276	3.163	14.300	21.890	8.702	38.582
0	14	0.640	7.547	24.310	3.302	12.121	24.816	7.912	38.545
1200	12	0.768	7.624	24.640	2.790	12.840	22.319	8.518	40.802
1200	15	0.512	6.618	23.640	3.606	13.672	23.522	8.485	39.529
1200	15	0.640	6.405	23.168	3.809	11.460	24.133	7.459	35.465

1500	15	0.640	6.386	23.415	3.960	12.768	27.478	8.459	36.867
1500	15	0.768	6.250	23.746	3.178	11.836	23.962	7.866	36.641
1500	10	0.768	7.005	24.257	2.837	12.737	22.558	9.074	42.512

Physiological Loss in Weight (PLW) (in percentage)					
Dosage	**Day 2**	**Day 4**	**Day 6**	**Day 8**	**Day 10**
0	2.357	2.691	4.410	5.341	7.400
0	1.832	3.241	4.680	6.052	8.403
0	1.594	3.104	4.715	6.113	8.595
1200	2.325	3.668	4.669	6.330	8.572
1200	1.780	3.016	4.497	5.563	7.707
1200	1.835	3.873	5.171	6.056	8.418
1500	1.226	3.613	4.077	5.252	7.252
1500	1.699	3.297	4.945	6.268	8.429
1500	1.338	2.875	4.118	5.217	7.196

b) Statistical Analysis

Table 4.20 Analysis of quality parameter data of the phosphine-treated Mango using univariate ANOVA ($\alpha = 0.05$)(04-Hour)

Year 2022				
Quality Parameters	**Dosages**	**F Value**	**p-value**	**Significance**
TSS	0, 1200,1500	2.375	0.174	Not Significant
TA	0, 1200,1500	2.167	0.196	Not Significant
Carotenoids	0, 1200,1500	4.491	0.064	Not Significant
Bioyield Point	0, 1200,1500	0.004	0.996	Not Significant
Skin Elasticity	0, 1200,1500	0.051	0.951	Not Significant
Stiffness	0, 1200,1500	0.53	0.614	Not Significant

Work to Penetrate Skin	0, 1200,1500	0.567	0.595	Not Significant
Flesh Firmness	0, 1200,1500	0.251	0.786	Not Significant
Work to Penetrate Flesh	0, 1200,1500	0.201	0.823	Not Significant
PLW 2 (%)	0, 1200,1500	2.826	0.137	Not Significant
PLW 4 (%)	0, 1200,1500	1.379	0.321	Not Significant
PLW 6 (%)	0, 1200,1500	0.921	0.448	Not Significant
PLW 8 (%)	0, 1200,1500	0.544	0.607	Not Significant
PLW 10 (%)	0, 1200,1500	0.859	0.470	Not Significant

4.3.2 6-Hour Exposure Period

a) Quality Parameters

Table 4.21 Quality Parameters of Mango Treated with Varying Phosphine Dosages over two Consecutive Years (06-Hour)

Year 2021									
Dosage (ppm)	**TSS(°Brix)**	**Titratable Acidity (%)**	**Carotenoids (mg/100g)**	**Bioyield Point (N)**	**Skin Elasticity (mm)**	**Stiffness (N/s)**	**Work to Penetrate Skin (N second)**	**Flesh Firmness (N)**	**Work to Penetrate Flesh N.sec**
0	19	0.512	15.623	12.847	7.519	4.837	22.822	4.527	22.135
0	19	0.384	15.422	12.064	7.853	4.605	21.626	3.812	22.211
0	18	0.256	15.523	12.287	7.242	4.847	22.953	4.358	23.154
250	19	0.384	16.037	12.155	7.078	4.560	22.774	4.095	21.169
250	19	0.256	15.807	12.891	7.179	3.807	26.566	6.050	21.784
250	17	0.384	15.261	12.547	7.896	5.295	22.142	4.128	22.036
400	20	0.384	15.749	11.639	7.180	4.064	22.020	4.023	21.382
400	19	0.256	14.356	12.328	7.218	4.477	22.599	4.504	22.760

400	19	0.512	16.486	11.830	6.958	5.297	21.529	4.537	21.670
500	20	0.256	16.061	12.744	8.306	4.671	23.347	5.290	22.346
500	19	0.384	14.420	11.878	8.011	4.729	21.476	3.926	22.571
500	17	0.256	14.629	11.969	7.037	4.645	23.654	3.750	22.876
750	20	0.256	14.286	12.034	6.897	4.615	23.195	4.398	21.288
750	18	0.384	15.855	12.749	7.814	4.405	22.385	4.088	21.873
750	20	0.256	14.675	12.879	8.327	4.432	22.789	4.231	22.758
900	19	0.512	14.656	12.835	7.308	4.687	22.373	4.665	22.392
900	20	0.256	13.481	11.077	7.325	4.712	23.067	4.494	22.752
900	18	0.384	14.342	12.217	7.485	4.258	22.114	4.917	21.412

Year 2022									
Dosage (ppm)	**TSS(**°Brix)	**Titratable Acidity (%)**	**Carotenoids (mg/100g)**	**Bioyield Point (N)**	**Skin Elasticity (mm)**	**Stiffness (N/s)**	**Work to Penetrate Skin (N second)**	**Flesh Firmness (N)**	**Work to Penetrate Flesh N.sec**
0	9	1.281	5.012	29.059	2.603	16.883	25.963	12.583	65.024
0	8	1.409	5.495	26.934	2.429	16.487	23.026	13.206	63.246
0	8	1.665	4.779	28.835	2.396	16.316	24.066	12.860	65.263
750	10	1.537	6.366	26.573	2.328	17.201	21.604	12.909	66.709
750	8	1.665	5.476	27.405	2.510	16.390	23.278	12.891	66.619
750	8	1.665	6.115	26.362	2.386	16.673	22.273	11.753	59.786
900	10	1.281	5.979	26.348	2.339	17.368	21.414	12.995	65.399
900	8	1.665	5.457	31.476	2.512	18.961	26.736	12.920	67.816
900	9	1.409	6.231	26.960	2.498	16.126	23.863	11.795	60.958

	Physiological Loss In Weight (PLW) (%)				
Dosage	**Day 2**	**Day 4**	**Day 6**	**Day 8**	**Day 10**
0	2.736	6.381	8.746	12.698	17.246
0	2.476	6.169	9.827	13.838	18.451
0	2.866	6.471	9.227	12.931	17.330
750	2.509	4.945	8.959	12.922	16.607
750	2.026	5.542	8.648	12.184	16.607
750	3.359	5.822	9.178	11.587	16.549
900	3.030	6.618	10.311	13.058	17.587
900	2.739	5.562	8.962	12.066	17.355
900	2.569	5.325	7.715	10.648	15.318

a) **Statistical Analysis**

Table 4.22 Analysis of quality parameter data of the phosphine-treated Mango using univariate ANOVA ($\alpha = 0.05$)(06-Hour)

Year 2021				
Quality Parameters	**Dosages**	**F Value**	**p-value**	**Significance**
TSS	0,250,400,500,750,900	0.440	0.812	Not Significant
TA	0,250,400,500,750,900	0.483	0.712	Not Significant
Carotenoids	0,250,400,500,750,900	1.844	0.179	Not Significant
Bioyield Point	0,250,400,500,750,900	0.732	0.613	Not Significant
Skin Elasticity	0,250,400,500,750,900	0.803	0.569	Not Significant
Stiffness	0,250,400,500,750,900	0.179	0.967	Not Significant
Work to Penetrate Skin	0,250,400,500,750,900	0.774	0.587	Not Significant
Flesh Firmness	0,250,400,500,750,900	0.429	0.820	Not Significant
Work to Penetrate Flesh	0,250,400,500,750,900	1.068	0.425	Not Significant

Year 2022				
TSS	0,750,900	0.375	0.702	Not Significant
TA	0,750,900	1.067	0.401	Not Significant
Carotenoids	0,750,900	4.298	0.069	Not Significant
Bioyield Point	0,750,900	0.699	0.533	Not Significant
Skin Elasticity	0,750,900	0.350	0.718	Not Significant
Stiffness	0,750,900	0.938	0.442	Not Significant
Work to Penetrate Skin	0,750,900	0.989	0.425	Not Significant
Flesh Firmness	0,750,900	0.356	0.715	Not Significant
Work to Penetrate Flesh	0,750,900	0.010	0.990	Not Significant
PLW 2 (%)	0,750,900	0.091	0.915	Not Significant
PLW 4 (%)	0,750,900	2.644	0.150	Not Significant
PLW 6 (%)	0,750,900	0.141	0.872	Not Significant
PLW 8 (%)	0,750,900	1.625	0.273	Not Significant
PLW 10 (%)	0,750,900	1.537	0.289	Not Significant

8-Hour Exposure Period

a) Quality Parameters

Table 4.23 Quality Parameters of Mango Treated with Varying Phosphine Dosages over two Consecutive Years (08-Hour)

Year 2021									
Dosage (ppm)	**TSS(°Brix)**	**Titratable Acidity (%)**	**Carotenoids (mg/100g)**	**Bioyield Point(N)**	**Skin Elasticity(mm)**	**Stiffness (N/sec)**	**Work to Penetrate Skin (N.sec)**	**Flesh Firmness (N)**	**Work to Penetrate Flesh (N.sec)**
0	19	0.640	12.655	10.425	4.837	4.837	20.345	3.921	20.931
0	17	0.512	12.132	10.189	4.929	4.605	18.957	3.804	21.859
0	18	0.512	13.820	11.891	3.942	4.847	19.987	4.258	21.479
50	20	0.640	12.554	11.864	4.275	4.560	18.851	3.702	21.220

50	18	0.512	13.913	11.040	4.699	3.807	18.325	3.478	19.072
50	17	0.640	11.842	12.995	4.052	5.295	20.898	4.294	23.812
100	21	0.512	11.010	10.647	4.064	4.064	19.361	4.504	22.943
100	19	0.512	14.900	12.792	4.477	4.477	19.705	4.075	21.568
100	16	0.768	12.094	11.725	5.897	5.297	18.599	3.737	22.782
200	16	0.640	13.971	10.129	4.671	4.671	18.905	4.438	20.819
200	19	0.640	12.657	11.949	4.729	4.729	20.706	3.952	22.907
200	17	0.512	13.862	12.015	5.037	4.645	20.761	4.234	21.889
300	19	0.512	12.152	11.565	4.615	4.615	19.581	3.895	20.048
300	16	0.640	9.528	10.584	4.358	4.405	19.906	4.198	21.992
300	19	0.640	12.076	11.751	4.432	4.432	19.755	3.770	21.489

Year 2022									
Dosage (ppm)	**TSS(°Brix)**	**Titratable Acidity (%)**	**Carotenoids (mg/100g)**	**Bioyield Point(N)**	**Skin Elasticity(mm)**	**Stiffness (N/sec)**	**Work to Penetrate Skin (N.sec)**	**Flesh Firmness (N)**	**Work to Penetrate Flesh (N.sec)**
0	14	1.537	3.967	26.618	2.198	15.702	22.417	11.615	60.018
0	12	1.537	4.838	25.333	2.442	15.791	27.601	11.334	58.579
0	15	1.665	3.580	28.154	2.725	15.817	26.339	12.381	63.980
300	14	1.537	5.774	25.647	2.662	14.445	23.751	14.815	60.810
300	12	1.409	3.638	27.651	2.468	16.831	25.197	12.471	63.910
300	14	1.409	4.760	25.423	2.458	15.844	24.821	12.857	66.441
400	14	1.665	5.070	27.529	2.622	15.944	22.417	13.471	69.613
400	15	1.665	4.257	25.760	2.588	15.854	27.601	12.400	60.748
400	16	1.537	4.044	27.160	2.806	15.395	26.339	12.349	63.819

	Physiological Loss In Weight (PLW) (%)				
Dosage	**Day 2**	**Day 4**	**Day 6**	**Day 8**	**Day 10**
0	1.584	3.761	6.645	8.194	11.816
0	1.469	3.922	6.427	9.132	12.938
0	1.417	3.921	6.934	8.675	12.278
300	1.536	3.357	6.442	8.901	12.679
300	1.414	4.737	6.692	9.140	12.856
300	1.169	3.797	4.818	6.667	11.274
400	1.563	3.851	5.075	8.371	11.869
400	1.229	4.135	7.541	10.212	12.798
400	1.117	3.592	6.479	9.405	12.211

b) Statistical Analysis

Table 4.24 Analysis of quality parameter data of the phosphine-treated Mango using univariate ANOVA ($\alpha = 0.05$)(08-Hour)

Year 2021				
Quality Parameters	**Dosages**	**F Value**	**p-value**	**Significance**
TSS	0,50,100,200,300	0.244	0.907	Not Significant
TA	0,50,100,200,300	0.125	0.970	Not Significant
Carotenoids	0,50,100,200,300	1.182	0.376	Not Significant
Bioyield Point	0,50,100,200,300	0.623	0.657	Not Significant
Skin Elasticity	0,50,100,200,300	0.474	0.754	Not Significant
Stiffness	0,50,100,200,300	0.180	0.943	Not Significant
Work to Penetrate Skin	0,50,100,200,300	0.504	0.734	Not Significant
Flesh Firmness	0,50,100,200,300	0.657	0.635	Not Significant

Work to Penetrate Flesh	0,50,100,200,300	0.446	0.773	Not Significant
Year 2022				
TSS	0,300,400	1.50	0.296	Not Significant
TA	0,300,400	4.333	0.068	Not Significant
Carotenoids	0,300,400	0.433	0.667	Not Significant
Bioyield Point	0,300,400	0.191	0.831	Not Significant
Skin Elasticity	0,300,400	1.134	0.382	Not Significant
Stiffness	0,300,400	0.006	0.994	Not Significant
Work to Penetrate Skin	0,300,400	0.147	0.866	Not Significant
Flesh Firmness	0,300,400	2.580	0.155	Not Significant
Work to Penetrate Flesh	0,300,400	1.005	0.420	Not Significant
PLW 2 (%)	0,300,400	0.836	0.478	Not Significant
PLW 4 (%)	0,300,400	0.052	0.950	Not Significant
PLW 6 (%)	0,300,400	0.403	0.685	Not Significant
PLW 8 (%)	0,300,400	0.931	0.445	Not Significant
PLW 10 (%)	0,300,400	0.010	0.990	Not Significant

4.3.3 10-Hour Exposure Period

a) Quality Parameters

Table 4.25 Quality Parameters of Mango Treated with Varying Phosphine Dosages over two Consecutive Years (10-Hour)

Year 2021									
Dosage (ppm)	**TSS(°Brix)**	**Titratable Acidity (%)**	**Carotenoids (mg/100g)**	**Bioyield Point(N)**	**Skin Elasticity(mm)**	**Stiffness (N/sec)**	**Work to Penetrate Skin (N.sec)**	**Flesh Firmness (N)**	**Work to Penetrate Flesh (N.sec)**
0	24	0.128	13.622	11.426	6.415	3.030	23.912	4.792	22.153
0	22	0.128	11.146	12.206	6.657	3.318	22.739	4.362	22.553
0	21	0.256	12.094	12.425	6.064	3.238	23.106	4.408	22.789
1500	24	0.128	11.765	11.155	6.194	2.881	23.846	4.495	23.237
1500	20	0.128	13.971	11.269	6.029	3.003	22.263	3.984	22.441
1500	24	0.256	11.784	12.764	6.269	2.245	22.431	4.178	21.599
2000	24	0.256	11.327	10.965	6.348	2.089	24.236	5.077	22.285
2000	20	0.128	11.300	11.186	6.853	2.866	22.816	3.989	22.847
2000	23	0.256	12.094	12.528	6.741	2.052	22.681	3.977	22.529
3000	20	0.128	12.0357	12.095	6.709	2.465	23.817	4.618	22.874
3000	22	0.128	11.8809	10.804	6.145	2.463	23.584	3.968	22.612
3000	23	0.256	10.3716	12.864	7.024	3.269	22.012	3.955	22.788

Year 2022									
Dosage (ppm)	**TSS(°Brix)**	**Titratable Acidity (%)**	**Carotenoids (mg/100g)**	**Bioyield Point(N)**	**Skin Elasticity(mm)**	**Stiffness (N/sec)**	**Work to Penetrate Skin (N.sec)**	**Flesh Firmness (N)**	**Work to Penetrate Flesh (N.sec)**
0	15	0.768	6.618	24.621	2.335	14.167	21.975	13.608	55.588
0	12	0.768	5.863	24.470	3.170	13.353	26.398	12.397	55.301
0	13	0.768	6.192	21.876	2.359	13.881	24.826	11.979	55.782
600	16	0.512	7.953	23.294	3.865	11.114	23.914	11.898	56.936
600	16	0.640	5.902	24.270	2.784	14.311	24.569	12.860	56.522
600	14	0.512	4.663	22.191	3.186	14.446	22.495	10.525	57.617
800	12	0.640	5.495	24.510	2.427	12.665	23.913	11.455	57.087
800	12	1.025	6.463	23.209	2.293	13.708	21.769	14.197	56.524
800	20	0.512	6.289	23.551	3.405	13.252	25.270	12.624	55.402

	Physiological Loss In Weight (PLW) (%)				
Dosage	**Day 2**	**Day 4**	**Day 6**	**Day 8**	**Day 10**
0	1.593	3.025	4.360	6.444	8.641
0	1.697	3.101	5.479	8.311	9.926
0	2.025	4.014	5.880	8.809	10.535
600	1.245	4.122	5.753	8.534	10.213
600	1.649	3.087	4.489	6.908	8.471
600	1.676	3.904	6.284	7.898	9.727
800	1.961	3.524	4.864	7.078	8.389
800	1.676	3.005	4.911	6.413	8.990
800	2.348	5.084	6.171	8.355	10.970

b) Statistical Analysis

Table 4.26 Analysis of quality parameter data of the phosphine-treated Mango using univariate ANOVA ($\alpha = 0.05$)(10-Hour)

Year 2021				
Quality Parameters	**Dosages**	**F Value**	**p-value**	**Significance**
TSS	0,1500,2000,3000	0.147	0.929	Not Significant
TA	0,1500,2000,3000	0.250	0.859	Not Significant
Carotenoids	0,1500,2000,3000	0.793	0.531	Not Significant
Bioyield Point	0,1500,2000,3000	1.682	0.247	Not Significant
Skin Elasticity	0,1500,2000,3000	0.474	0.754	Not Significant
Stiffness	0,1500,2000,3000	2.418	0.142	Not Significant
Work to Penetrate Skin	0,1500,2000,3000	0.153	0.925	Not Significant
Flesh Firmness	0,1500,2000,3000	0.425	0.740	Not Significant
Work to Penetrate Flesh	0,1500,2000,3000	0.280	0.838	Not Significant
Year 2022				
TSS	0,600,800	0.176	0.842	Not Significant
TA	0,600,800	0.6	0.579	Not Significant
Carotenoids	0,600,800	0.015	0.985	Not Significant
Bioyield Point	0,600,800	0.164	0.852	Not Significant
Skin Elasticity	0,600,800	1.284	0.344	Not Significant
Stiffness	0,600,800	0.231	0.800	Not Significant
Work to Penetrate Skin	0,600,800	0.180	0.840	Not Significant
Flesh Firmness	0,600,800	0.683	0.540	Not Significant
Work to Penetrate Flesh	0,600,800	4.144	0.066	Not Significant
PLW 2 (%)	0,600,800	2.248	0.187	Not Significant
PLW 4 (%)	0,600,800	0.317	0.740	Not Significant
PLW 6 (%)	0,600,800	0.086	0.919	Not Significant
PLW 8 (%)	0,600,800	0.273	0.770	Not Significant
PLW 10 (%)	0,600,800	0.049	0.953	Not Significant

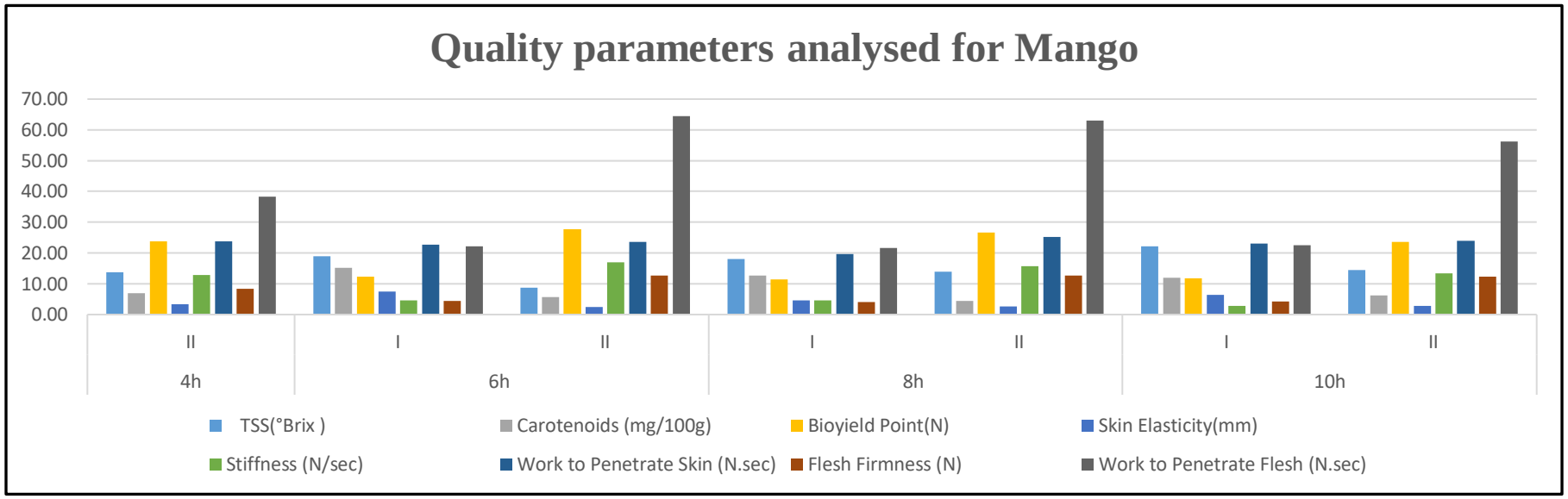


Figure 4.3 Figure showing the quality parameters tested over the two years for Mango.

4.4 Pomegranate

Due to the limited availability of samples, only a single phase of treatment was performed for the Pomegranate. Samples were exposed to phosphine fumigation for 10 and 24 hours at maximum concentrations, as infested samples were unavailable. For both exposure times, two sets of samples were taken to assess changes in quality parameters over time considering the shelf life of the samples. The fumigation was conducted at a temperature range of 25-28°C and relative humidity (RH) between 65-85%. Key quality parameters analysed included Total Soluble Solids (TSS), pH, Juice Yield, Total Phenolic Content, Total Anthocyanin Content, Titratable Acidity, Antioxidant Capacity, and Ascorbic Acid, providing a comprehensive evaluation of post-harvest quality following treatment.

4.4.1 10-Hour Exposure Period

a) Quality Parameters: I Sample Set

Table 4.27 Quality Parameters of Pomegranate for I Sample set Treated with Varying Phosphine Dosages (10-Hour)

I Sample Set														
Dosage (ppm)	**TSS (°Brix)**	**Juice Yield (%)**	**pH**	**Total Phenolic Content (mg/100g)**	**Total Anthocyanin (mg/100g)**	**Titratable acidity (%)**	**Antioxidant capcity (micro mol TE/g)**	**Ascorbic Acid (mg/100 g)**	**Bioyield Point(N)**	**Skin Elasticity (mm)**	**Stiffness (N/sec)**	**Work to Penetrate Skin (N.sec)**	**Flesh Firmness (N)**	**Work to Penetrate Flesh (N.sec)**
0	14	67.14	3.3	66.80	9.530	0.384	20.48	26.64	21.501	3.219	8.367	23.043	9.605	38.74
0	14	60.00	3.26	79.18	8.718	0.410	20.70	29.6	20.106	3.362	9.259	22.512	9.262	38.852
0	15	64.29	3.6	81.03	9.242	0.359	18.87	28.12	20.223	2.987	9.952	23.854	9.012	40.528
500	15	60.71	3.4	70.88	9.227	0.461	20.66	29.60	21.45	3.037	9.341	23.86	8.838	38.525
500	14	61.43	3.8	61.50	9.371	0.359	17.65	25.16	19.94	3.079	9.45	22.189	9.184	38.454
500	14	62.86	3.6	79.50	9.417	0.384	18.17	28.12	20.21	2.985	9.149	23.298	9.282	40.259
1000	16	62.86	3.58	84.10	8.430	0.461	18.35	23.68	20.686	3.43	9.415	23.862	8.688	39.198
1000	14	60.71	3.7	78.10	9.318	0.359	17.82	28.12	22.494	2.933	10.168	22.443	9.51	44.321
1000	13	60.00	3.2	74.68	8.354	0.410	18.81	31.08	18.89	2.857	9.116	23.658	8.854	40.258

2000	13	66.43	3.4	71.60	9.462	0.371	18.93	26.64	22.003	3.38	9.632	23.721	9.138	41.816
2000	13	62.86	3.7	70.28	8.013	0.333	20.46	31.08	22.924	3.308	9.719	23.159	9.363	42.79
2000	14	61.43	3.5	75.30	8.620	0.384	20.51	29.60	20.321	2.587	9.248	23.587	8.852	39.658

Table 4.28 Quality Parameters of Pomegranate for II Sample set Treated with Varying Phosphine Dosages (10-Hour)

II Sample Set														
Dosage (ppm)	**TSS (°Brix)**	**Juice Yield (%)**	**pH**	**Total Phenolic Content (mg/100g)**	**Total Anthocyanin (mg/100g)**	**Titratable acidity (%)**	**Antioxidant capcity (micro mol TE/g)**	**Ascorbic Acid (mg/100 g)**	**Bioyield Point(N)**	**Skin Elasticity (mm)**	**Stiffness (N/sec)**	**Work to Penetrate Skin (N.sec)**	**Flesh Firmness (N)**	**Work to Penetrate Flesh (N.sec)**
0	15	75.71	3.8	119.20	12.31	0.384	19.002	17.76	21.604	3.168	9.939	20.74	7.744	40.027
0	15	67.14	4.2	126.35	10.50	0.397	19.737	22.2	22.395	3.193	8.127	23.493	9.039	44.302
0	14	77.14	4.2	118.68	11.12	0.410	18.908	22.2	20.287	3.658	9.857	22.179	8.147	42.127
500	14	77.14	3.43	121.40	11.83	0.461	19.223	23.68	20.404	2.984	10.584	21.6	8.082	41.777
500	15	70.00	3.21	112.88	10.49	0.487	20.140	29.6	20.9	3.509	8.116	22.616	8.357	43.193
500	13	71.43	3.8	116.73	11.05	0.410	18.888	26.64	21.369	3.276	9.258	22.104	8.597	42.518
1000	13	71.43	4.52	122.68	10.80	0.384	21.573	20.72	23.137	3.002	9.983	23.67	9.364	43.255
1000	15	77.14	3.62	120.15	11.80	0.359	20.142	23.68	20.474	3.176	9.652	20.837	8.399	43.41
1000	14	74.29	3.52	115.70	12.33	0.410	19.076	26.64	20.239	3.568	8.247	22.698	7.985	41.258
2000	15	70.00	3.5	120.80	12.21	0.410	16.824	26.64	18.182	3.263	8.612	22.19	8.615	44.192
2000	12	71.43	4.5	105.43	10.49	0.384	20.323	20.72	22.763	3.836	8.873	22.439	9.659	42.269
2000	14	74.29	3.6	121.98	11.55	0.435	18.509	28.12	20.587	3.024	9.876	22.412	7.054	41.879

b) Statistical Analysis

Table 4.29 Analysis of quality parameter data of the phosphine-treated Pomegranate using univariate ANOVA (α = 0.05)(10-Hour)

I Sample Set				
Quality Parameters	**Dosages**	**F Value**	**p-value**	**Significance**
TSS	0,500,1000,2000	0.900	0.482	Not Significant
Juice Yield	0,500,1000,2000	0.917	0.475	Not Significant
pH	0,500,1000,2000	0.577	0.646	Not Significant
Total Phenolic Content	0,500,1000,2000	0.955	0.459	Not Significant
Total Anthocyanins	0,500,1000,2000	1.282	0.345	Not Significant
Titratable acidity	0,500,1000,2000	0.771	0.542	Not Significant
Antioxidant	0,500,1000,2000	1.835	0.219	Not Significant
Ascorbic Acid	0,500,1000,2000	0.222	0.878	Not Significant
Bioyield Point	0,500,1000,2000	0.631	0.615	Not Significant
Skin Elasticity	0,500,1000,2000	0.160	0.920	Not Significant
Stiffness	0,500,1000,2000	0.379	0.771	Not Significant
Work to Penetrate Skin	0,500,1000,2000	0.199	0.894	Not Significant
Flesh Firmness	0,500,1000,2000	0.405	0.754	Not Significant
Work to Penetrate Flesh	0,500,1000,2000	1.517	0.283	Not Significant
II Sample Set				
TSS	0,500,1000,2000	0.452	0.723	Not Significant
Juice Yield	0,500,1000,2000	0.209	0.888	Not Significant
pH	0,500,1000,2000	0.977	0.450	Not Significant
Total Phenolic Content	0,500,1000,2000	0.525	0.677	Not Significant
Total Anthocyanins	0,500,1000,2000	0.214	0.884	Not Significant
Titratable acidity	0,500,1000,2000	3.522	0.069	Not Significant
Antioxidant	0,500,1000,2000	1.136	0.391	Not Significant
Ascorbic Acid	0,500,1000,2000	1.944	0.201	Not Significant

Bioyield Point	0,500,1000,2000	0.222	0.878	Not Significant
Skin Elasticity	0,500,1000,2000	0.114	0.949	Not Significant
Stiffness	0,500,1000,2000	0.027	0.993	Not Significant
Work to Penetrate Skin	0,500,1000,2000	0.062	0.979	Not Significant
Flesh Firmness	0,500,1000,2000	0.066	0.977	Not Significant
Work to Penetrate Flesh	0,500,1000,2000	0.108	0.953	Not Significant

4.4.2 24-Hour Exposure Period

a) Quality Parameters:

Table 4.30 Quality Parameters of Pomegranate for I Sample set Treated with Varying Phosphine Dosages (24-Hour)

I Sample Set														
Dosage	**TSS (°Brix)**	**Juice Yield (%)**	**pH**	**Total Phenolic Content (mg/100g)**	**Total Anthocyanin (mg/100g)**	**Titratable acidity (%)**	**Antioxidant capcity (micro mol TE/g)**	**Ascorbic Acid (mg/100 g)**	**Bioyield Point(N)**	**Skin Elasticity (mm)**	**Stiffness (N/sec)**	**Work to Penetrate Skin (N.sec)**	**Flesh Firmness (N)**	**Work to Penetrate Flesh (N.sec)**
0	13	71.43	3.4	103.85	14.62	0.384	14.55	20.72	20.628	3.419	8.838	23.043	9.605	44.089
0	16	71.43	3.6	105.13	15.78	0.371	15.82	19.24	20.106	3.362	9.952	21.662	9.262	42.243
0	14	74.29	3.5	105.43	15.94	0.410	15.78	22.2	21.89	3.117	9.985	20.369	8.958	44.257
500	14	72.86	3.2	100.73	16.87	0.359	15.86	23.68	21.45	3.037	10.006	21.44	9.038	41.543
500	13	74.29	3.2	115.05	15.39	0.359	17.32	22.2	19.94	3.079	9.85	20.949	9.184	43.712
500	15	74.29	3.4	103.93	14.75	0.397	15.79	20.72	21.36	3.65	9.25	22.398	9.574	44.528
1000	16	72.86	3.3	98.33	14.38	0.346	15.11	23.68	20.686	3.43	9.415	22.789	8.448	41.895
1000	14	72.86	3.4	107.00	15.66	0.448	15.10	20.72	22.494	2.933	10.777	21.241	9.216	46.416
1000	16	74.29	3.6	104.45	15.18	0.410	15.21	22.2	21.547	3.289	9.289	20.258	9.857	44.258

2000	14	71.43	3.5	102.35	16.33	0.384	17.96	19.24	22.003	3.397	9.978	23.721	9.138	44.847
2000	14	72.86	3.6	100.13	15.85	0.397	16.47	20.72	22.924	3.308	9.719	22.159	9.666	43.851
2000	15	74.29	3.4	106.45	16.14	0.371	16.25	23.68	20.169	3.021	9.658	20.147	9.025	44.369

Table 4.31 Quality Parameters of Pomegranate for II Sample set Treated with Varying Phosphine Dosages (24-Hour)

II Sample Set														
Dosage	**TSS (°Brix)**	**Juice Yield (%)**	**pH**	**Total Phenolic Content (mg/100g)**	**Total Anthocyanin (mg/100g)**	**Titratable acidity (%)**	**Antioxidant capcity (micro mol TE/g)**	**Ascorbic Acid (mg/100g)**	**Bioyield Point(N)**	**Skin Elasticity (mm)**	**Stiffness (N/sec)**	**Work to Penetrate Skin (N.sec)**	**Flesh Firmness (N)**	**Work to Penetrate Flesh (N.sec)**
0	15	67.14	3.65	112.30	9.43	0.474	18.86	22.2	21.504	3.106	11.534	21.522	9.703	39.523
0	13	72.86	3.5	114.48	9.65	0.512	21.93	29.6	21.439	2.857	11.511	22.125	8.931	37.487
0	14	71.43	3.9	109.95	9.42	0.461	18.32	26.64	22.587	2.987	11.847	21.847	9.854	38.369
500	13	68.57	3.5	109.30	9.56	0.461	17.61	26.64	22.888	2.972	11.146	23.445	8.827	39.671
500	15	71.43	3.55	104.93	9.26	0.384	19.40	26.64	22.154	2.668	12.992	21.862	9.785	36.439
500	13	72.86	3.6	114.68	9.12	0.461	18.18	23.68	22.142	2.966	11.258	21.587	9.125	38.527
1000	14	72.86	3.61	113.10	9.75	0.410	19.57	17.76	19.679	2.6	11.777	19.671	9.184	34.263
1000	15	68.57	3.36	113.83	9.13	0.448	18.18	20.72	23.838	3.332	11.563	22.157	9.55	42.418
1000	14	71.43	3.9	117.80	9.78	0.448	20.31	26.64	22.358	2.987	11.895	22.589	9.258	40.253
2000	15	68.57	3.9	105.98	9.00	0.423	17.62	20.72	19.773	2.623	11.364	21.779	8.546	39.856
2000	13	72.86	3.65	103.30	9.80	0.435	18.37	22.2	22.54	2.779	11.974	21.329	9.678	38.862
2000	14	71.43	3.5	112.95	9.46	0.448	20.51	28.12	21.528	3.12	11.954	21.854	9.858	38.147

b) Statistical Analysis

Table 4.32 Analysis of quality parameter data of the phosphine-treated Pomegranate using univariate ANOVA (α = 0.05)(24-Hour)

I Sample Set				
Quality Parameters	**Dosages**	**F Value**	**p-value**	**Significance**
TSS	0,500,1000,2000	0.800	0.528	Not Significant
Juice Yield	0,500,1000,2000	0.741	0.557	Not Significant
pH	0,500,1000,2000	2.569	0.127	Not Significant
Total Phenolic Content	0,500,1000,2000	0.375	0.774	Not Significant
Total Anthocyanins	0,500,1000,2000	1.029	0.430	Not Significant
Titratable acidity	0,500,1000,2000	0.486	0.702	Not Significant
Antioxidant	0,500,1000,2000	1.305	0.338	Not Significant
Ascorbic Acid	0,500,1000,2000	0.563	0.655	Not Significant
Bioyield Point	0,500,1000,2000	0.514	0.684	Not Significant
Skin Elasticity	0,500,1000,2000	0.057	0.981	Not Significant
Stiffness	0,500,1000,2000	0.100	0.958	Not Significant
Work to Penetrate Skin	0,500,1000,2000	0.099	0.958	Not Significant
Flesh Firmness	0,500,1000,2000	0.037	0.990	Not Significant
Work to Penetrate Flesh	0,500,1000,2000	0.365	0.781	Not Significant
II Sample Set				
TSS	0,500,1000,2000	0.242	0.864	Not Significant
Juice Yield	0,500,1000,2000	0.029	0.993	Not Significant
pH	0,500,1000,2000	0.306	0.820	Not Significant
Total Phenolic Content	0,500,1000,2000	2.098	0.179	Not Significant
Total Anthocyanins	0,500,1000,2000	0.358	0.785	Not Significant
Titratable acidity	0,500,1000,2000	1.998	0.193	Not Significant

Antioxidant	0,500,1000,2000	0.491	0.698	Not Significant
Ascorbic Acid	0,500,1000,2000	0.940	0.465	Not Significant
Bioyield Point	0,500,1000,2000	0.361	0.783	Not Significant
Skin Elasticity	0,500,1000,2000	0.257	0.854	Not Significant
Stiffness	0,500,1000,2000	0.051	0.984	Not Significant
Work to Penetrate Skin	0,500,1000,2000	0.412	0.749	Not Significant
Flesh Firmness	0,500,1000,2000	0.126	0.942	Not Significant
Work to Penetrate Flesh	0,500,1000,2000	0.077	0.971	Not Significant

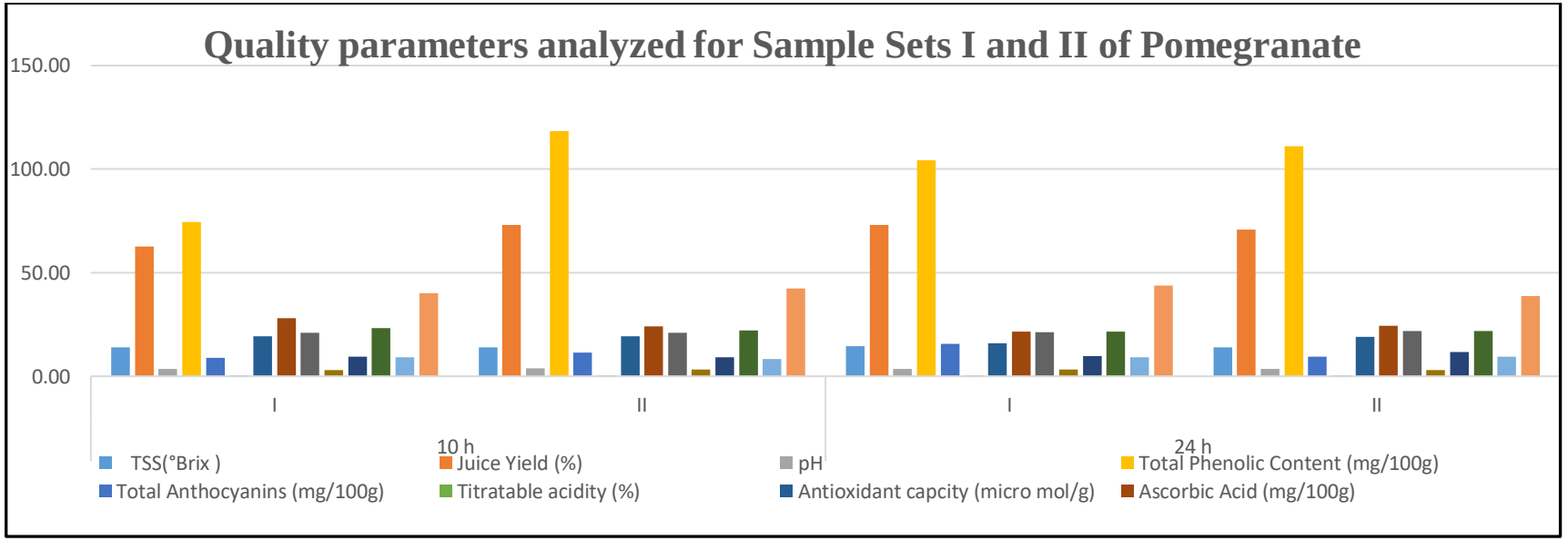


Figure 4.4 shows the Quality parameters analyzed for the Sample Sets I and II of Pomegranate.

4.5 Rose

Flower samples were subjected to varying concentrations of phosphine over exposure periods of 4, 6, 8, and 10 hours. The temperature during treatment was maintained between 18-20°C with relative humidity (RH) held at 65-70%. The study aimed to evaluate the impact of phosphine fumigation on the quality attributes of roses, specifically focusing on moisture Loss (%), anthocyanin content, and water uptake. These parameters were measured to assess how different phosphine dosages influenced both the aesthetic and physiological post-harvest quality of the roses.

4.1.2.1 04-Hour Exposure Period

a) Quality Parameters

Table 4.33 Quality Parameters of Rose Treated with Varying Phosphine Dosages over two Consecutive Years (04-Hour)

Year 2022			
Dosage	**Anthocyanin Content (mg/100g)**	**Water Uptake (%)**	**Moisture Loss (%)**
0	403.690	8	73.963
0	372.259	5	76.684
0	314.309	8	74.929
10	385.028	5	75.032
10	408.601	8	75.716
10	398.779	8	70.826
20	312.344	6	73.994
20	292.700	8	76.685
20	303.504	4	77.584
30	239.660	6	72.806
30	296.629	8	74.096

30	303.504	10	76.707
40	363.419	10	74.391
40	287.789	4	74.161
40	295.646	6	76.969
50	408.601	10	75.456
50	229.838	6	76.656
50	315.291	8	77.310
Year 2023			
0	540.612	3	80.2747
0	594.044	3	80.9470
0	569.685	4	80.7420
55	519.789	4	78.9049
55	507.216	3	81.0719
55	535.111	4	81.3634
65	563.006	3	79.3814
65	513.502	3	79.2777
65	551.612	4	80.2770

b) **Statistical Analysis**

Table 4.34: Analysis of quality parameter data of the phosphine-treated Rose using univariate ANOVA (α = 0.05)(04-Hour)

Year 2022				
Quality Parameters	**Dosages**	**F Value**	**p-value**	**Significance**
Moisture Loss (%)	0, 10, 20,30, 40, 50	0.851	0.540	Not Significant
Anthocyanin Content	0, 10, 20,30, 40, 50	2.518	0.088	Not Significant
Water Uptake (%)	0, 10, 20,30, 40, 50	0.400	0.840	Not Significant
Year 2023				
Moisture Loss (%)	0, 55, 65	1.149	0.378	Not Significant
Anthocyanin Content	0, 55, 65	3.200	0.113	Not Significant
Water Uptake (in mL)	0, 55, 65	0.333	0.729	Not Significant

4.5.1 06-Hour Exposure Period

a) **Quality Parameters**

Table 4.35 Quality Parameters of Rose Treated with Varying Phosphine Dosages over two Consecutive Years (06-Hour)

Year 2022			
Dosage	**Anthocyanin Content (mg/100g)**	**Water Uptake (%)**	**Moisture Loss (%)**
0	427.305	8	81.829
0	453.061	12	78.762
0	417.940	8	80.883
10	342.793	8	84.649

10	373.241	10	82.338
10	334.935	10	78.071
20	333.953	6	82.173
20	394.850	6	82.138
20	438.068	6	79.438
30	380.117	6	81.879
30	329.042	8	84.018
30	345.739	8	80.135
40	339.846	8	79.331
40	412.530	8	83.257
40	248.500	8	79.474
50	369.313	10	83.369
50	365.384	6	79.025
50	422.623	8	81.909
Year 2023			
0	462.820	4	83.208
0	458.891	4	81.359
0	450.248	3	82.718
45	467.142	3.5	79.428
45	488.358	3	80.779
45	476.964	4	81.910
55	425.103	4	82.272
55	443.962	3	82.144
55	471.071	3	82.022

b) Statistical Analysis

Table 4.36 Analysis of quality parameter data of the phosphine-treated Rose using univariate ANOVA (α = 0.05)(06-Hour)

Phase- I				
Quality Parameters	**Dosages**	**F Value**	**p-value**	**Significance**
Moisture Loss	0,10,20,30, 40, 50	0.205	0.954	Not Significant
Anthocyanin Content	0,10,20,30, 40, 50	1.963	0.157	Not Significant
Water Uptake	0,10,20,30, 40, 50	2.400	0.099	Not Significant
Phase – II				
Moisture Loss	0,45, 55	3.101	0.119	Not Significant
Anthocyanin Content	0,45, 55	3.197	0.113	Not Significant
Water Uptake	0,45, 55	0.273	0.770	Not Significant

4.5.2 08-Hour Exposure Period

a) Quality Parameters

Table 4.37 Quality Parameters of Rose Treated with Varying Phosphine Dosages over two Consecutive Years (08-Hour)

Year 2022			
Dosage	**Anthocyanin Content (mg/100g)**	**Water Uptake (%)**	**Moisture Loss (%)**
0	481.158	5	70.387
0	443.695	8	68.754
0	374.624	6	65.751
10	406.637	6	71.916

10	467.535	8	67.126
10	398.780	10	70.255
20	352.615	6	68.173
20	322.167	10	71.168
20	303.505	8	67.088
30	316.273	6	70.680
30	453.784	8	72.347
30	303.505	10	71.405
40	363.420	10	72.465
40	287.789	6	69.688
40	354.580	6	67.277
50	408.602	10	70.922
50	328.060	10	66.667
50	375.795	8	67.804
Year 2023			
0	591.883	2	80.024
0	557.388	3	80.973
0	588.111	3.5	81.151
40	597.973	2	81.586
40	593.180	2	81.846
40	592.983	3	82.374
50	597.462	3	81.380
50	587.247	3	81.116
50	583.711	2	79.474

b) **Statistical Analysis**

Table 4.38 Analysis of quality parameter data of the phosphine-treated Rose using univariate ANOVA (α = 0.05)(08-Hour)

Year 2022				
Quality Parameters	**Dosages**	**F Value**	**p-value**	**Significance**
Moisture Content	0,10,20,30, 40, 50	0.900	0.512	Not Significant
Anthocyanin Content	0,10,20,30, 40, 50	2.384	0.101	Not Significant
Water Uptake	0,10,20,30, 40, 50	0.829	0.553	Not Significant
Year 2023				
Moisture Content	0, 40, 50	2.940	0.129	Not Significant
Anthocyanin Content	0, 40, 50	1.357	0.326	Not Significant
Water Uptake (%)	0, 40, 50	0.467	0.648	Not Significant

4.5.3 10-Hour Exposure Period

a) Quality Parameters

Table 4.39 Quality Parameters of Rose Treated with Varying Phosphine Dosages over two Consecutive Years (10-Hour)

Phase- I			
Dosage	**Anthocyanin Content (mg/100g)**	**Water Uptake (%)**	**Moisture Loss (%)**
0	282.092	6	82.923
0	311.952	8	85.089
0	288.771	8	84.736
10	292.356	8	84.875
10	287.145	6	86.954

10	304.125	9	85.412
20	325.698	8	87.259
20	332.147	7	88.147
20	309.854	10	86.175
30	324.258	8	85.258
30	274.289	5	84.198
30	298.365	10	85.236
35	258.912	5	84.997
35	340.632	8	88.840
35	294.272	8	85.174
40	385.029	6	88.753
40	332.775	10	84.689
40	252.233	4	84.688
Phase- II			
0	282.092	3	83.733
0	311.952	4	85.089
0	288.771	4	84.736
35	298.201	3	84.997
35	340.632	4	82.434
35	294.272	4	85.174
40	329.239	3	83.248
40	332.775	4	84.689
40	328.846	2	84.688

b) **Statistical Analysis**

Table 4.40 Analysis of quality parameter data of the phosphine-treated Rose using univariate ANOVA (α = 0.05)(10-Hour)

Phase- I				
Quality Parameters	**Dosages**	**F Value**	**p-value**	**Significance**
Moisture Content	0,10,20,30,35, 40	1.406	0.290	Not Significant
Anthocyanin Content	0,10,20,30,35, 40	0.476	0.788	Not Significant
Water Uptake	0,10,20,30,35, 40	0.249	0.933	Not Significant
Phase – II				
Moisture Content	0,35, 40	0.084	0.921	Not Significant
Anthocyanin Content	0,35, 40	3.208	0.113	Not Significant
Water Uptake	0,35, 40	0.800	0.492	Not Significant

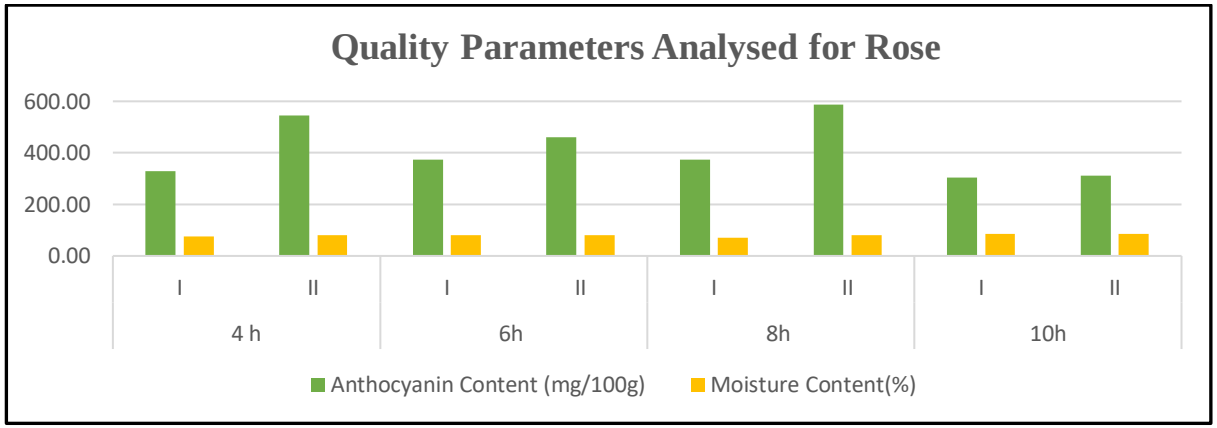


Figure 4.5 shows the quality parameters tested over the two years for Rose.

4.6 Chrysanthemum

Flower samples were exposed to various phosphine concentrations over 4, 6, 8, and 10-hour periods, with the temperature kept between 25.5-27°C and relative humidity (RH) ranging from 48-67%. The research aimed to investigate how phosphine fumigation affects the post-harvest quality of Chrysanthemum. Key quality indicators, including moisture Loss (%), anthocyanin content, and water uptake, were analyzed to understand the influence of different phosphine dosages on the flowers' physical condition and aesthetic value after treatment.

4.6.1 04-Hour Exposure Period

a) Quality Parameters

Table 4.41 Quality Parameters of Chrysanthemum flowers Treated with Varying Phosphine Dosages over two Consecutive Years (04-Hour)

Year 2021			
Dosage	**Anthocyanins**	**Water Uptake (%)**	**Moisture Loss (%)**
0	70.241	12	89.689
0	72.583	8	90.103
0	77.266	12	89.666
250	72.349	10	89.715
250	79.841	12	90.929
250	79.373	8	91.176
500	73.519	12	89.416
500	76.095	12	91.328
500	77.266	10	90.192

1000	79.607	10	89.722
1000	75.627	10	90.054
1000	81.714	8	89.948
2000	80.778	8	89.009
2000	79.139	10	90.066
2000	75.627	10	89.258
Year 2022			
0	70.242	10	86.592
0	72.583	8	88.829
0	65.559	12	87.195
800	70.242	12	86.488
800	65.559	10	87.167
800	65.559	12	89.617
1200	65.559	10	89.651
1200	74.925	12	89.225
1200	77.266	8	87.916
1600	70.242	12	86.370
1600	70.242	8	87.004
1600	74.925	10	89.915
2000	77.266	12	87.995
2000	67.901	12	86.626
2000	74.925	10	87.540
2400	63.218	12	87.639
2400	67.901	8	89.914
2400	77.266	10	89.568

b) **Statistical Analysis**

Table 4.42 Analysis of quality parameter data of the phosphine-treated Chrysanthemum flowers using univariate ANOVA (α = 0.05)(04-Hour)

Year 2021				
Quality Parameters	**Dosages**	**F Value**	**p-value**	**Significance**
Moisture Loss (%)	0,250,500, 1000, 2000	1.581	0.253	Not Significant
Anthocyanin Content	0,250,500, 1000, 2000	1.559	0.259	Not Significant
Water Uptake (in mL)	0,250,500, 1000, 2000	0.850	0.525	Not Significant
Year 2022				
Moisture Loss (%)	0,800,1200,1600,2000, 2400	0.906	0.509	Not Significant
Anthocyanin Content	0,800,1200,1600,2000, 2400	0.709	0.628	Not Significant
Water Uptake (%)	0,800,1200,1600,2000, 2400	0.457	0.801	Not Significant

4.6.2 06-Hour Exposure Period

a) Quality Parameters

Table 4.43 Quality Parameters of Chrysanthemum flowers Treated with Varying Phosphine Dosages over two Consecutive Years (06-Hour)

Year 2021			
Dosage	**Anthocyanin Content**	**Water Uptake (%)**	**Moisture Loss (%)**
0	90.846	8	89.715
0	91.314	8	91.523
0	88.973	6	89.766
250	81.246	8	89.465
250	90.143	10	89.332
250	84.992	10	90.465
500	91.548	8	91.113
500	87.100	10	90.298
500	86.631	10	90.135
1000	90.378	10	88.708
1000	92.016	10	89.614
1000	89.441	8	89.147
2000	87.100	8	90.010
2000	89.207	6	91.585

2000	88.270	10	89.926
Year 2022			
0	133.459	12	90.529
0	142.825	8	89.766
0	140.483	10	89.715
600	142.825	12	89.465
600	133.459	10	89.332
600	131.118	8	90.465
1000	142.825	10	89.440
1000	131.118	8	90.298
1000	138.142	12	90.135
1400	140.483	10	88.873
1400	128.776	10	89.411
1400	124.094	8	88.068
1800	138.142	10	88.708
1800	121.752	12	89.614
1800	133.459	12	90.378
2200	131.118	12	88.468
2200	138.142	8	89.072
2200	140.483	10	89.330

b) **Statistical Analysis**

Table 4.44 Analysis of quality parameter data of the phosphine-treated Chrysanthemum flowers using univariate ANOVA (α = 0.05)(06-Hour)

Year 2021				
Quality Parameters	**Dosages**	**F Value**	**p-value**	**Significance**
Moisture Loss (%)	0, 250,500,1000,2000	1.868	0.193	Not Significant
Anthocyanin Content	0, 250,500,1000,2000	2.044	0.164	Not Significant
Water Uptake (%)	0, 250,500,1000,2000	1.429	0.294	Not Significant
Year 2022				
Moisture Loss (%)	0,600,1000,1400,1800,2200	2.241	0.117	Not Significant
Anthocyanin Content	0,600,1000,1400,1800,2200	0.740	0.608	Not Significant
Water Uptake (%)	0,600,1000,1400,1800,2200	0.414	0.830	Not Significant

4.6.3 08-Hour Exposure Period

a) Quality Parameters

Table 4.45 Quality Parameters of Chrysanthemum flowers Treated with Varying Phosphine Dosages over two Consecutive Years (08-Hour)

Year 2021			
Dosage	**Anthocyanin Content**	**Water Uptake (%)**	**Moisture Loss (%)**
0	89.675	8	90.321
0	91.782	8	92.218
0	88.973	6	89.043
250	85.461	6	90.253
250	86.163	6	90.059
250	88.504	8	89.197
500	88.036	4	88.855
500	92.016	6	88.294
500	91.782	6	89.527
1000	91.548	8	89.048
1000	87.334	6	89.129
1000	89.675	8	89.212
Year 2022			
0	163.897	18	89.976
0	161.556	16	90.859

0	170.922	16	90.095
400	159.215	18	91.280
400	173.263	16	88.172
400	166.239	14	89.137
600	170.922	16	88.405
600	152.190	18	89.546
600	159.215	18	91.549
800	161.556	18	92.910
800	175.604	16	90.829
800	156.873	14	90.262
1000	168.580	16	91.548
1000	175.604	18	90.398
1000	161.556	18	89.392
1200	163.897	18	90.361
1200	154.532	16	89.398
1200	173.263	16	92.202

b) **Statistical Analysis**

Table 4.46 Analysis of quality parameter data of the phosphine-treated Chrysanthemum flowers using univariate ANOVA ($\alpha = 0.05$)(08-Hour)

Year 2021				
Quality Parameters	**Dosages**	**F Value**	**p-value**	**Significance**
Moisture Loss (%)	0,250,500,1000	2.013	0.191	Not Significant
Anthocyanin Content	0,250,500,1000	2.599	0.125	Not Significant
Water Uptake (%)	0,250,500,1000	2.000	0.193	Not Significant

Year 2022				
Moisture Loss (%)	0, 400,600,800,1000,1200	0.694	0.638	Not Significant
Anthocyanin Content	0, 400,600,800,1000,1200	0.307	0.899	Not Significant
Water Uptake (%)	0, 400,600,800,1000,1200	0.480	0.785	Not Significant

4.6.4 10-Hour Exposure Period

a) Quality Parameters

Table 4.47 Quality Parameters of Chrysanthemum flowers Treated with Varying Phosphine Dosages over two Consecutive Years (08-Hour)

Year 2021			
Dosage	**Anthocyanin Content**	**Water Uptake (%)**	**Moisture Loss (%)**
0	91.080	8	88.773
0	93.421	10	89.748
0	89.675	12	90.912
250	89.441	10	89.580
250	92.953	12	90.365
250	93.421	10	90.730
500	92.953	12	90.288
500	88.504	12	88.401
500	92.016	10	90.809
Year 2022			
0	81.948	16	90.665

0	74.924	14	90.693
0	74.924	18	88.825
600	77.266	14	90.860
600	70.241	18	91.216
600	74.924	16	90.522
800	81.948	16	89.783
800	74.924	14	91.118
800	77.266	18	89.316
1000	79.607	16	89.252
1000	74.924	14	89.315
1000	74.924	16	91.524
1200	79.607	16	92.078
1200	79.607	18	91.963
1200	77.266	14	92.508
1400	77.266	12	91.292
1400	79.607	16	90.855
1400	81.948	18	88.788

b) **Statistical Analysis**

Table 4.48 Analysis of quality parameter data of the phosphine-treated Chrysanthemum flowers using univariate ANOVA ($\alpha = 0.05$)(10-Hour)

Year 2021				
Quality Parameters	**Dosages**	**F Value**	**p-value**	**Significance**
Moisture Loss (%)	0,250,500	0.158	0.857	Not Significant
Anthocyanin Content	0,250,500	0.104	0.902	Not Significant

Water Uptake (%)	0,250,500	0.600	0.579	Not Significant
Year 2022				
Moisture Loss (%)	0,600,800,1000,1200,1400	2.249	0.116	Not Significant
Anthocyanin Content	0,600,800,1000,1200,1400	1.297	0.328	Not Significant
Water Uptake (%)	0,600,800,1000,1200,1400	0.080	0.994	Not Significant

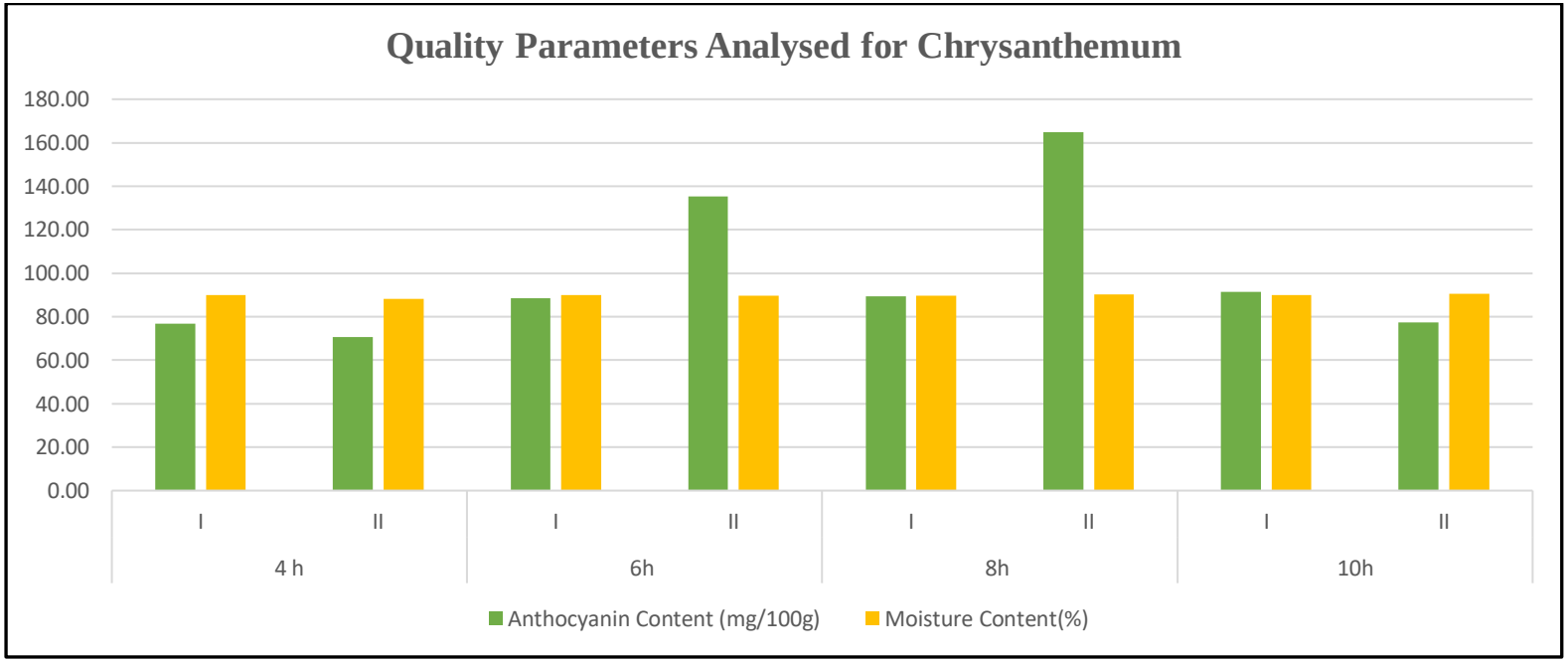


Figure 4.6 shows the quality parameters tested over the two years for Rose.

4.7 Sorption and Residue Analysis

4.7.1 Fruits and Vegetables

Due to the limited availability of Pomegranate samples, sorption and residue analyses were conducted only for Mango, Bitter Gourd, and Chilli**.** The samples were subjected to phosphine fumigation at varying concentrations and exposure durations under controlled conditions. Table 4.51 provides a detailed summary of the key parameters, including phosphine concentration, exposure period, sample weight, temperature, relative humidity, sorption percentage, and residue levels.

In **mango**, the sorption of phosphine remained relatively stable across all concentrations and exposure periods, with values ranging between 10% and 12%. The sorption pattern in **bitter gourd** showed a distinct trend: it began at 11% during a 4-hour exposure, gradually increased to a peak of 20% at 8 hours, and subsequently decreased to 5–7% after 15 hours of exposure. **chilli** exhibited the highest range of sorption percentages among the tested commodities. The sorption started at 22% after 4 hours of exposure, reached a maximum of 60% at 8 hours, and decreased to 30–34% after 10 hours.

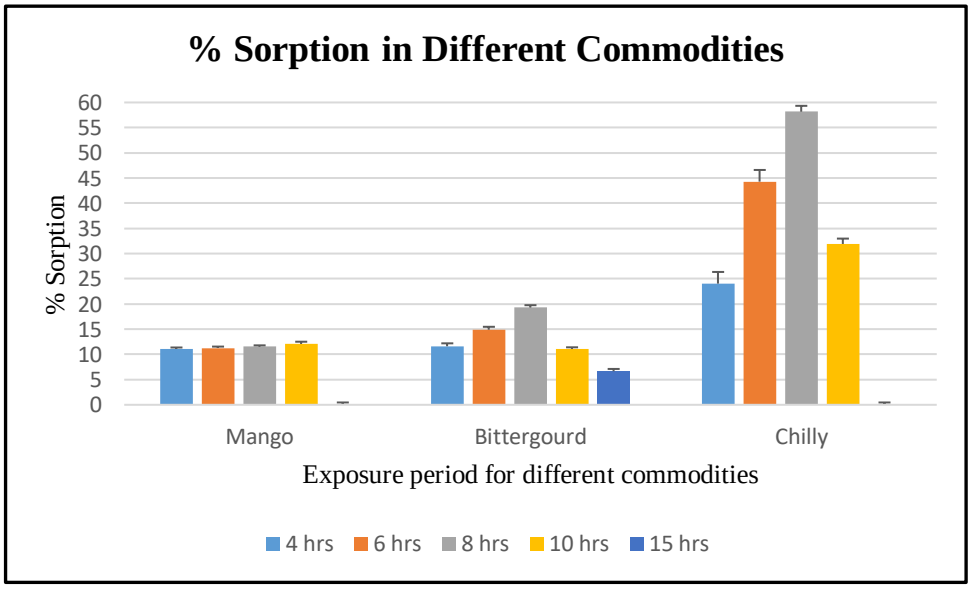


Figure 4.7 depicts the changes in sorption percentages observed in fruits and vegetables at different exposure periods, with error bars indicating the standard errors (SE).

4.7.1.1 Statistical Analysis

Descriptive statistics for the sorption percentage are presented in Table 4.48. The data indicated considerable variability in sorption, with values ranging from 6.66% to 63.26%. The mean sorption percentage was 20.98%, with a standard deviation of 17.01, highlighting the wide distribution in the dataset. A simple linear regression analysis was performed to evaluate the relationship between exposure period and sorption percentage (Table 4.49).

Table 4.49 Table showing the descriptive analysis of Sorption Percentage

Descriptive Statistics	**Value**
N	13
Minimum	6.66
Maximum	63.26
Mean	20.98
Standard Deviation	17.01

Table 4.50 Regression Analysis

Model	**Sum of Squares**	**Degree of freedom(df)**	**Mean Square**	**F Value**	**p-value**
Regression	249.460	1	249.460	0.851	0.376
Residual	3222.748	11	292.977		
Total	3472.208	12			

The regression model was not statistically significant, F(1,11)=0.851,p=0.376F(1, 11) = 0.851, p = 0.376F(1,11)=0.851,p=0.376, indicating that the exposure period did not significantly predict the sorption percentage at the 5% significance level. The model explained only 7.2% of the variance in sorption percentage ($R^2 = 0.072$).

Table 4.51 ANOVA Summary for Sorption Percentage by Exposure Period

	Sum of Squares	**Degree of freedom(df)**	**Mean Square**	**F Value**	**p-value**
Between Groups	636.255	4	159.064	0.449	0.771
Within Groups	2835.953	8	354.494		
Total	3472.208	12			

In addition, a one-way ANOVA was conducted to compare the sorption percentage across different exposure periods (Table 4.50). The analysis revealed no significant differences in sorption percentage between exposure periods, F (4,8) =0.449, p=0.771. These findings suggest that the exposure period is not a major determinant of the sorption percentage.

Residue Analysis

Residue analysis was conducted using gas-liquid chromatography at the UPL laboratory, Vapi, Gujarat, India. This analysis measured phosphine residues in food commodities post-fumigation after a 2-hour aeration period.

- **Mango:** residue levels were relatively low, ranging from 0.009 to 0.01 ppm
- **Chilli:** samples displayed negligible phosphine residues after aeration.
- **Bitter gourd:** required a longer aeration period of 4–6 hours, after which residue levels ranged from 0.003 to 0.01 ppm.

The observed residue levels for all commodities were within the maximum residue limit (MRL) specified by the EU Commission (EU, 2016).

Table 4.52 shows the % Sorption and Residues in different commodities (ND: Not Determined)

S. No	Effective Concentration (in ppm)	Weight of the sample (in g)	Exposure Period (in hrs)	Sorption Range (in %)	Phosphine Residues (in ppm)
	Bitter Gourd (28.5-31.5^{0}C, RH: 78-87%)				
1.	1400	1100	04	11-12	0.003±0.005
	1200	1100	06	14-16	0.01±0.009
	1000	1100	08	18-20	0.000
	800	1100	10	09-11	0.000
	600	1100	15	5-7	0.000
	Control	1100	04/06/08/10/15	ND	ND

2.	**Chilli (26-28^{0}C , RH: 62-75%)**				
	60	200	04	22-26	0.000
	50	200	06	40-48	0.000
	40	200	08	56-60	0.000
	30	200	10	30-34	0.000
	Control	200	04/06/08/10	ND	ND
3.	**Mango (27-28^{0}C; RH- 80-90%)**				
	1500	1250	04	10-11	0.01± 0.003
	1200	1250	06	11-11.9	0.01±0.002
	1100	1250	08	11.2-12	0.009±0.005
	800	1250	10	11.5-12	0.01±0.004
	Control	1250	04/06/08/10	ND	ND

4.7.2 Flowers

4.7.2.1 Sorption Analysis

The sorption analysis in rose and chrysanthemum showed an increase in sorption with longer exposure periods, although this increase did not follow a consistent pattern. The sorption percentage for chrysanthemum ranged from 0.5% to 15%, while for rose, it varied between 6% and 17% (Fig. 4.8). These results indicate that there are differences in sorption capacity between the two commodities when exposed to phosphine fumigation over varying periods.

In chrysanthemum, the sorption percentage varied from 0.5% at 2400 ppm for 4 hours to a maximum of 15% at 1200 ppm for 10 hours under controlled conditions (25.5–27.1°C, RH: 48–67%). Meanwhile, rose exhibited sorption percentages from 6% at 65 ppm for 4 hours to 17% at 40 ppm for 10 hours, under slightly different environmental conditions (28–32°C, RH: 55–77%).

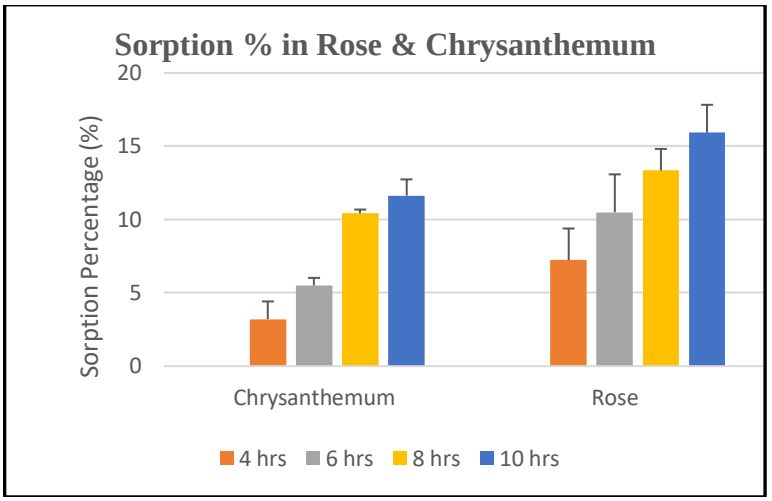


Figure 4.8 Variation in sorption percentage for chrysanthemum and rose across different exposure durations (bars indicate standard errors, SE).

4.7.2.2 Residue Analysis

The residue analysis was performed using gas-liquid chromatography at the UPL laboratory in Vapi, Gujarat, India. This method allowed for accurate quantification of phosphine residues in the treated food commodities. Chrysanthemum samples showed higher levels of phosphine residues, ranging from 0.07 to 1.89 ppm (Table 4.52), reflecting considerable variation in residue accumulation across the samples. In contrast, phosphine residues in rose samples were much lower, ranging from 0.003 to 0.01 ppm (Table 4.52), suggesting a lower and more consistent accumulation of residues. These findings indicate that the two flower varieties exhibit different rates of phosphine residue accumulation following fumigation.

Table 4.53 Sorption percentage & residue levels of phosphine in flower samples.

S. No	**Effective Concentration (in ppm)**	**Weight of the sample**	**Exposure Period (in hrs)**	**Sorption Range (in %)**	**Phosphine Residues (in ppm)**
	Chrysanthemum (25.5-27.1^{0}C, RH: 48-67%)				
4.	2400	7.5	04	0.5-7	1.89±0.192
	2000	7.5	06	3-10	0.16±0.059
	1400	7.5	08	8-13	0.07±0.017
	1200	7.5	10	08-15	0.08±0.040
	Control	7.5	04/06/08/10	ND	ND

5.	**Rose (28-32^{0}C, RH: 55-77%)**				
	65	60	04	6-8	0.01±0.001
	55	60	06	7-12	0.003±0.000
	50	60	08	8-15	0.004±0.001
	40	60	10	15-17	0.009±0.000
	Control	60	04/06/08/10	ND	ND

4.7.2.3 Statistical analysis

It was performed using IBM SPSS Statistics 20, and the descriptive statistics for sorption percentage and residue levels in both Chrysanthemum and Rose are presented in Table 4.53. The results show that Chrysanthemum had a higher mean sorption percentage (13.72 ± 3.91) and residue level (0.55 ± 0.89) compared to Rose (sorption percentage: 11.02 ± 0.40; residue level: 0.01 ± 0.00). Despite these differences, independent samples t-tests revealed that the differences in sorption percentage ($t(6) = -1.372$, $p = 0.219$) and residue level ($t(6) = -1.216$, $p = 0.270$) between the two commodities were not statistically significant.

Table 4.54 Descriptive Statistics for Sorption Percentage and Residue Levels

Commodity	**N**	**Sorption Percentage (Mean ± SD)**	**Residue (Mean ± SD)**
Chrysanthemum	4	13.72 ± 3.91	0.55 ± 0.89
Rose	4	11.02 ± 0.40	0.01 ± 0.00

Table 4.54 summarizes the results from correlation, regression, and ANOVA analyses. The correlation analysis showed no significant relationships between exposure period and sorption percentage ($r = -0.408$, $p = 0.315$) or residue level ($r = -0.504$, $p = 0.202$). Moreover, the correlation between sorption percentage and residue level was positive but non-significant ($r = 0.406$, $p = 0.319$). Regression analysis supported these findings, showing that exposure period was not a significant predictor of either sorption percentage ($R^2 = 0.167$, $p = 0.315$) or residue level ($R^2 = 0.254$, $p = 0.202$).

Table 4.55 Summary of Regression, Correlation, and ANOVA Analysis

Analysis Type	**Sorption Percentage**	**Residue**
Correlation with Exposure Period	r = -0.408, p = 0.315	r = -0.504, p = 0.202
Regression (Predictor: Exposure Period)	R^2 = 0.167, p = 0.315	R^2 = 0.254, p = 0.202
ANOVA (Exposure Period)	F(3, 4) = 0.780, p = 0.563	F(3, 4) = 0.901, p = 0.515
Coefficient from Regression model	B = -0.503, p = 0.315	B = -0.138, p = 0.202

The ANOVA results for sorption percentage (F (3, 4) = 0.780, p = 0.563) and residue level (F(3, 4) = 0.901, p = 0.515) further confirmed that exposure period had no significant effect on these variables. The regression model coefficients indicated non-significant effects of exposure period on sorption percentage (B = -0.503, p = 0.315) and residue level (B = -0.138, p = 0.202). Post-hoc analysis using Tukey's b test also showed no significant impact of exposure period on sorption percentage or residue levels in either Chrysanthemum or Rose.

CHAPTER 5
DISCUSSION

The present study aimed to evaluate the effects of phosphine fumigation on perishable commodities, focusing on nutrient quality, physical parameters, and residue levels. This chapter discusses the implications of the findings with the set objectives and existing literature while highlighting their relevance to practical applications in food safety and post-harvest management.

Phosphine fumigation has gained recognition as a viable alternative to traditional fumigants due to its low environmental impact and efficacy against pests. However, its effects on the nutrient quality, physical attributes, and chemical residues in perishable fruits and vegetables remain underexplored. The commodities selected for this research—Bitter Gourd, Chilli, Mango, Pomegranate, Rose, and Chrysanthemum—were chosen due to their significant role in India's export market, where maintaining quality and meeting international residue standards are critical for economic and trade sustainability. The study aimed to evaluate the impact of phosphine fumigation on these commodities, focusing on key quality parameters such as ascorbic acid, phenolic content, antioxidants, and physical attributes like weight loss, moisture content, and texture. Additionally, the study investigated phosphine's sorption and residue dynamics under controlled conditions to establish its safety and feasibility as a post-harvest treatment.

This chapter interprets the findings with the study's objectives and existing literature. The discussion is organized to provide a commodity-wise analysis, examining the specific effects of phosphine fumigation on nutrient retention, physical quality, and residue levels in each commodity.

5.1 Key Findings

Across all the selected commodities, phosphine fumigation showed no significant impact on the assessed nutritional and physical quality parameters, irrespective of dosage and exposure durations. This finding underscores the suitability of phosphine as a post-harvest fumigant for perishable commodities. Nutritional parameters such as ascorbic acid, total phenolic content, acidity, antioxidants, and physical attributes like weight loss, moisture content, and texture did not change when treated with phosphine.

The texture analysis encompassed various parameters, including Bioyield Point, Skin Elasticity, Stiffness, Work to Penetrate Skin, Flesh Firmness, and Work to Penetrate Flesh. The results indicated no significant differences between the untreated and phosphine-treated samples across all these texture attributes. Notably, no substantial variations were observed, regardless of the dosage or exposure duration of the fumigant. This consistency was observed irrespective of the phosphine dosage or exposure duration for all the tested commodities. Furthermore, these specific parameters have not been extensively documented in the existing literature, highlighting the novelty of their inclusion in this study and the need for further research to establish comparative data in similar contexts.

Residue analysis revealed that phosphine residues were either undetectable or remained within permissible limits under the tested conditions. Sorption dynamics exhibited slight variability among the commodities, reflecting their distinct physicochemical properties; however, these variations were independent of the phosphine dosage and exposure durations. These findings strongly support the dual objectives of ensuring consumer safety and maintaining the quality of perishable commodities during post-harvest management.

5.2 Commodity-wise Quality Analysis

5.2.1 Bitter gourd

The analysis of the physical characteristics of bitter gourd, including moisture content and texture attributes such as firmness, stiffness, elasticity, skin and flesh penetration, and bioyield point, revealed no significant differences between phosphine-treated and untreated fruits. These findings were consistent across both exposure phases, with no observable changes in the fruit's physical qualities, further supporting the idea that phosphine fumigation does not adversely affect these key attributes.

The total soluble solids (TSS) content of bitter gourd fruits ranged from 3 to 6 °Brix for all the dosages and exposure periods and both phases. Statistical analysis ($p > 0.05$) confirmed that there was no significant difference between the tested parameters in treated and untreated fruits, regardless of phosphine dosage (200-1400 ppm) and exposure times (4-15 hours). These results align with studies by Srinivasulu et al. (2024), which reported a similar TSS range of 4.97-5.64 °Brix, and Kumari et al. (2018), who found a range of 4.45-6.1 °Brix, thus confirming that phosphine fumigation did not alter TSS levels in the current study.

Chlorophyll content in the bitter gourd fruits ranged from 0.56 to 1.67 mg/g in both treated and untreated samples. The untreated control samples exhibited a chlorophyll content range of 0.58 to 1.66 mg/g, while the treated fruits displayed a

similar range of 0.56 to 1.63 mg/g across all the dosages and exposure periods for both treatment phases. No significant difference in chlorophyll content was observed between the treated and untreated fruits, indicating that phosphine fumigation did not affect chlorophyll levels. This result is in agreement with several studies, including those by Preetha and Varadharaju (2019), who reported chlorophyll content values of 0.17-0.19 mg/g at 8°C. Additionally, Behera et al. (2013) reported chlorophyll content in bitter gourd lines between 0.08 to 0.488 mg/g, and Prajapati et al. (2024) found it to be 0.32 mg/g. Numerous studies have documented varying chlorophyll content levels under diverse conditions, including shelf-life evaluations, storage experiments, and trials involving coating materials aimed at extending shelf life. The variation in chlorophyll content observed across different studies and conditions—such as storage, temperature, genetic factors, and treatments—highlights the influence of multiple factors on chlorophyll levels in bitter gourd fruits. This range of values underscores the complexity of processes governing chlorophyll synthesis, degradation, and stability under varying experimental conditions. In the current study, phosphine treatment did not significantly impact chlorophyll content, suggesting that the fumigation method employed does not affect chlorophyll levels in this context. Furthermore, no discernible effect of exposure duration on chlorophyll content was observed.

Ascorbic acid, commonly known as Vitamin C, in bitter gourd fruits, is influenced by various factors, including growing conditions, variety, and ripeness. Bitter gourd is generally regarded as a rich source of Vitamin C, with reported concentrations typically ranging between 30 and 80 mg per 100 grams of fresh fruit for both the phases and all the treatments. It ranged from 35 to 87 mg/100g in untreated samples, while phosphine-treated fruits exhibited values between 34 and 93 mg/100g. These values were within the general range of ascorbic acid content reported in the literature, such as the findings of Srinivasulu et al. (2024), who observed values ranging from 87-98 mg/100g in parent bitter gourd, and 76-100 mg/100g in hybrids. Moon et al. (2014) reported that bitter gourd pulp's total vitamin C content under plastic film greenhouse cultivation ranged from 50-112.4 mg/100g and was highest in the 'Nakanokoya' cultivar Moon et al, 2014). However, no significant effect of phosphine fumigation on ascorbic acid levels was observed in the present study, indicating that phosphine treatment did not affect the vitamin C content in bitter gourd fruits. These results suggest that phosphine fumigation does not influence the ascorbic acid levels, which is consistent with other studies where phosphine was found to have no significant impact on the vitamin C content of various fruits.

The moisture content of bitter gourd fruits ranged from 87% to 96%, with treated fruits showing a range of 87% to 96% and untreated control fruits ranging from 87% to 94%, indicating no significant difference between the two groups for both phases. These findings align with previous studies, such as Kusat et al. (2021) and

Kocchar et al. (2006), which reported moisture content values of 92.3% and 93.43%, respectively Kusat et al (2021) and Kochhar et al (2006). Similarly, Ozsan et al. (2023) observed that bitter gourd fruits contain approximately 90% moisture content, supporting the consistency of these results across different studies.

5.2.1.1 Statistical Interpretation of Results

Univariate Analysis of Variance (ANOVA) results for Bitter Gourd across various dosages and exposure periods revealed no significant impact of phosphine fumigation on the measured quality parameters.

a) 4-Hour Exposure

In the initial Phase, for dosages ranging from 600 to 1200 ppm, F-values ranged from 0.501 to 1.083, with p-values above 0.05 (ranging from 0.415 to 0.736), indicating no significant differences between treated and control samples. Even with higher phosphine dosages (1100–1400 ppm) in the confirmation phase, the F-values ranged from 0.661 to 3.521, with p-values greater than 0.05 (0.141 to 1.00), indicating no statistical significance. These results suggest even at higher dosages; phosphine does not alter the quality attributes of Bitter Gourd at this exposure duration.

b) 6-Hour Exposure

Similar to the 4-hour exposure, the 6-hour treatment did not show any significant changes. F-values for key parameters like Total Soluble Solids (TSS), Total Chlorophyll, Ascorbic Acid, and Moisture Content ranged from 0.648 to 3.189, with p-values greater than 0.05 (ranging from 0.062 to 0.641). Although "Work to Penetrate Skin" approached significance with an F-value of 3.189 and a p-value of 0.062, the difference was not statistically meaningful, reaffirming the overall lack of effect at this exposure duration. In the confirmation phase, even with phosphine dosages (1100–1300 ppm), the p-values were found to be greater than 0.05, indicating no statistical significance.

c) 8-Hour Exposure

The 8-hour exposure in the initial phase showed no significant effect on Bitter Gourd's quality attributes. The F-values for all parameters, such as TSS, Total Chlorophyll, and Ascorbic Acid, ranged from 0.184 to 2.314, with p-values above 0.05 (from 0.129 to 0.941). Similarly, in the confirmation phase, F-values ranged from 0.656 to 1.422, and p-values were consistently above 0.05 (ranging from 0.312 to 1.00).

d) 10-Hour Exposure

The F-values ranged from 0.153 to 2.537, and the p-values were all above 0.05, indicating no effect on all the tested parameters during the initial phase. In the confirmation phase with dosages up to 1000 ppm, F-values ranged from 0.014 to 4.004, and p-values remained above 0.05. confirming that increased exposure time did not impact the quality characteristics of Bitter Gourd.

e) 15-Hour Exposure

Similar to the shorter exposures, in the initial phase of the 15-hour treatment, F-values ranged from 0.258 to 1.867, with p-values consistently greater than 0.05. Also in the confirmation phase, p-values remained above 0.05. The data demonstrates that prolonged exposure does not affect the quality of Bitter Gourd.

Overall, these results indicate that phosphine fumigation did not significantly alter the nutritional or physical quality of Bitter Gourd across tested dosages (up to 1400 ppm) and exposure periods (4 to 15 h). This robustness underscores the suitability of Bitter Gourd for phosphine treatment without detrimental effects on its quality parameters, supporting its use as a safe post-harvest management strategy.

5.2.2 Chilli

It is a rich source of antioxidants and is known for its high vitamin C content Sharma et al (2017). The total soluble solids (TSS) content of chillies was found to range between 4 and 9 °Brix for both treated and untreated fruits for all the treatments. Statistical analysis indicated no significant difference in TSS between the treated and untreated fruits exposed to phosphine ($p>0.05$). Furthermore, different phosphine dosages for Phase I (250-1250 ppm) and Phase II (25-60ppm), along with exposure times varying from 4 to 10 hours, did not result in any significant changes in the TSS values of the treated fruits. These results are consistent with the findings of Maurya et al. (2017), who reported a TSS range of 5.5-10 °Brix, and Rahayu et al. (2021), who observed a TSS range of 6-8.7 °Brix when evaluating different genotypes of chillies for yield and quality traits Maurya et al (2017) and Rahayu et al (2021). Additionally, Molonaro et al. (2022) reported a maximum TSS value of 9.3 °Brix in their varietal evaluation of chillies AO et al (2022). The TSS values observed in the current study align closely with these previous reports, further confirming the consistency of the results.

The total chlorophyll content ranged from 0.27 to 0.93 mg/g Fresh Weight for all the samples. This range is consistent with the findings of Manolopoulou et al (2016) who reported total chlorophyll content at different temperatures varying from

0.4 to 0.8 mg/g FW. Similarly, Chitravathi et al (2016) found that shellac-based surface coating combined with modified atmosphere packaging for green chillies at low temperatures resulted in total chlorophyll content ranging from 0.16 to 0.43 mg/g FW over various storage periods. These variations in concentration can be attributed to differences in genetics and maturation Howard et al (2000).

The antioxidant activity in treated chillies (8.18–18.85 µmol TEAC/g) and untreated chillies (8.11–16.07 µmol TEAC/g) was found to be lower than the values reported by Paslı et al (2019), observed approximately 93.72 µmol TEAC/g in dried green pepper. In contrast, Castro-Concha et al (2014) documented a broader range of total CUPRAC antioxidant activity (3–40 µmol TEAC/g) in the pericarps and placentas of immature and ripe Habanero peppers. Similarly, Al-Sayyed et al (2019) reported antioxidant activities of 17.6 µmol TEAC/g for green bell pepper and 58 µmol TEAC/g for hot green pepper cultivated in Jordan. The differences in antioxidant activity observed in this study compared to the cited studies may be attributed to the diverse and complex antioxidant compounds present in chillies or variations in growing conditions, levels of maturity, and the specific cultivars used Alvarez-Parrilla et al (2010).

The ascorbic acid content in green chillies observed in this study for all the samples in both phases ranged from 21.33 to 114.58 mg/100g, with treated samples ranging from 21.33 to 110.42 mg/100g and untreated samples from 24.00 to 114.58 mg/100g. This range is comparatively lower than those reported in several previous studies. For instance, Igbokwe and Anagonye (2013) recorded 116.08 mg/100g, Sarker et al (2012) documented 110 mg/100g, and (Babu et al., 2020) reported 115.71 mg/100g for the Bogra Local variety. However, the findings of Adhikari and Pradhan (2014), who reported a range of 38.59 to 107.52 mg/100g, and Dahal et al (2006), with values ranging from 32.86 to 173.6 mg/100g, align more closely with the results of this study, reflecting a similarly high degree of variability. Such variability across studies can be attributed to differences in chilli varieties, cultivation practices, and environmental conditions.

5.2.2.1 Statistical Interpretation of Results

In the initial phase of experimentation, phosphine dosages ranging from 0 to 1500 ppm were employed to assess their comprehensive impact on pest control and the quality parameters of chillies. This broad dosage range ensured the inclusion of higher concentrations, crucial for evaluating potential adverse effects on quality metrics. Interestingly, even at the upper limit of 1500 ppm, no significant detrimental effects on the quality parameters, including TSS, total chlorophyll, ascorbic acid, antioxidant capacity, or physical characteristics, were observed. For instance, total

chlorophyll (F = 0.184, p = 0.942) and ascorbic acid content (F = 0.089, p = 0.984) remained unaffected, demonstrating the robustness of chillies under such treatments. Based on these findings and in conjunction with literature evidence, the confirmation phase refined the dosage range to 0–60 ppm. This narrower range was selected to achieve the desired pest control while minimizing exposure to high concentrations. The findings revealed consistent trends, with most parameters showing statistically non-significant differences across all conditions, reinforcing the compatibility of phosphine fumigation with preserving the quality of chillies.

a) 4-Hour Exposure

During the initial phase, chillies were subjected to phosphine dosages ranging from 0 to 1250 ppm. The analysis revealed that quality parameters such as TSS (F = 2.125, p = 0.152), total chlorophyll (F = 0.184, p = 0.942), and ascorbic acid (F = 0.089, p = 0.984) remained unaffected, as indicated by their non-significant p-values. Similarly, physical properties like skin elasticity (F = 1.707, p = 0.224) and bioyield point (F = 0.930, p = 0.484) also exhibited no adverse changes, indicating the resilience of chillies to phosphine treatment even at higher dosages. In the confirmation phase with a dosage range of 0, 50, and 60 ppm, a similar trend was observed. For instance, antioxidant capacity (F = 0.696, p = 0.535) and moisture content (F = 0.658, p = 0.552) showed minimal variation, reinforcing the conclusion that low concentrations of phosphine are sufficient to maintain the quality parameters while achieving effective pest control.

b) 6-Hour Exposure

Under 6-hour exposure in the initial phase, dosages up to 1000 ppm were tested. Quality attributes like TSS (F = 0.00, p = 1.00), total chlorophyll (F = 1.008, p = 0.448), and antioxidant capacity (F = 0.954, p = 0.473) showed no significant variations. Physical characteristics such as work to penetrate the skin (F = 0.065, p = 0.991) and stiffness (F = 0.690, p = 0.615) also remained consistent, indicating that this exposure duration was non-detrimental to the commodity's integrity. In the confirmation phase with dosages of 0, 40, and 50 ppm, a slight increase in the F value for antioxidant capacity (F = 3.949, p = 0.080) was observed. Although not statistically significant, this suggests a subtle response of biochemical attributes to treatment, which could warrant further exploration in future studies.

c) 8-Hour Exposure

During 8-hour exposure in the initial phase, higher dosages (0 to 1000 ppm) were employed, and the results continued to support the robustness of chillies under phosphine treatment. Total chlorophyll (F = 0.153, p = 0.957), ascorbic acid (F = 1.753, p = 0.215), and bioyield point (F = 0.129, p = 0.968) showed no significant

differences. Similarly, physical parameters such as work to penetrate the skin ($F = 0.308$, $p = 0.866$) and flesh firmness ($F = 0.189$, $p = 0.939$) were unaffected. In the confirmation phase with refined dosages (0, 30, and 40 ppm), TSS ($F = 4.00$, $p = 0.079$) showed the highest F value among all parameters, albeit still statistically non-significant. This suggests a consistent quality profile of chillies across varying phosphine concentrations and durations.

d) 10-Hour Exposure

At the longest exposure duration of 10 hours in the initial phase, chillies were tested under dosages of 0, 250, and 500 ppm. The results revealed no significant differences in any of the studied parameters. For instance, antioxidant capacity ($F = 0.282$, $p = 0.759$), moisture content ($F = 0.102$, $p = 0.904$), and stiffness ($F = 1.033$, $p = 0.385$) were unaffected by phosphine treatment. Similarly, flesh firmness ($F = 0.289$, $p = 0.754$) and work to penetrate flesh ($F = 1.198$, $p = 0.335$) showed minimal variation. The confirmation phase at even lower dosages (0, 25, and 30 ppm) yielded consistent results, with no parameter showing significant variation. For example, total chlorophyll ($F = 0.262$, $p = 0.778$) and ascorbic acid ($F = 1.914$, $p = 0.227$) were stable, confirming the reliability of these lower concentrations in preserving the quality of chillies.

5.2.3 Mango

India is the world's largest producer of mangoes, contributing approximately 40% to global production, followed by countries such as China, Kenya, Thailand, Indonesia, Pakistan, Mexico, Brazil, Bangladesh, and Nigeria Saxena and Gandhi (2014). Mango is a climacteric fruit, with its ripening process occurring rapidly post-harvest. This process is influenced by factors such as the cultivar, maturity stage at harvest, and postharvest conditions V´azquez-Caicedo, et al (2004). During ripening, several biochemical transformations take place, with carotenoid biosynthesis being one of the most significant V´azquez-Caicedo et al 2005). (Carotenoids are recognized as key micronutrients in cancer-preventative diets Cano and De Ancos (1994) . They play diverse roles in biological systems, including provitamin A activity, antioxidant properties, facilitation of cell communication, and protection against photo-oxidative damage Van de Berg et al (2000) and Mandal and Thokchom (2018) reported that sugar content in mango fruits initially increases rapidly due to the conversion of starch into sugars during ripening. However, after the ripening process is complete, sugar levels begin to decline as the fruit enters the senescence stage, during which sugars are consumed in respiration. Appearance and colour are among the primary factors influencing consumer preference for agricultural products, as they are closely linked to the chemical and sensory attributes Subedi et al (2007).

Total Soluble Solids (TSS) serve as a reliable indicator for assessing the eating quality of mangoes Subedi et al (2007) and Watanawan et al (2014) In this study, the TSS of the *Amrapali* variety, our chosen cultivar, varied across different exposure times and phases. In the initial phase, TSS ranged from 10–15 °Brix for treated samples and 13–15 °Brix for controls at 4 hours, increasing to 20–24 °Brix for treated and 21–24 °Brix for controls at 10 hours. In the consecutive-year experiment, TSS values were generally lower, ranging from 8–10 °Brix (treated) and 8–9 °Brix (control) at 6 hours, with the highest observed values being 12–20 °Brix (treated) and 12–15 °Brix (control) at 10 hours.

These findings align with reports for the *Amrapali* variety in the literature. Yaddanapudi, et al (2013) who reported TSS values ranging from 7.36–19.64 °Brix across 17 mango species, with the Amrapali variety reaching 19.64 °Brix. Bora et al. (2017) also observed TSS ranging from 16.90–22.41 °Brix for various varieties, including 20.12 °Brix for Amrapali under different agro-climatic conditions. Similarly, Islam et al (2013) documented TSS changes during post-harvest storage, ranging from 7.73–18.65 °Brix for one variety and 8.73–17.58 °Brix for another, with values increasing until the 12th day of storage.Further comparisons can be drawn with Shamili (2019), who reported TSS values ranging from 9.39–19.0 °Brix under different temperature conditions, and Pleguezuelo et al (2012), who documented TSS ranging from 15.7 ± 0.7 to 20.0 ± 1.9 °Brix at the maturity stage for different cultivars. The higher TSS values observed in treated samples at extended exposure times in the initial phase align with findings by Bora et al (2017) and Pleguezuelo et al (2012), suggesting that environmental factors, cultivar-specific traits, and treatment conditions significantly influence the accumulation of soluble solids. These results highlight the variability in TSS values due to cultivar differences and environmental conditions.

Titratable Acidity (TA) is a critical parameter that affects the flavor profile of mangoes, contributing to their balance of sweetness and tartness. In the current study, the TA of the Amrapali mango variety, measured across different exposure times and phases, exhibited variations. In the first year, TA ranged from 0.51–0.77% for both treated samples and controls at 4 hours, decreasing to 0.12–0.25% at 10 hours. However, in the second year, TA values were generally higher, with treated and control samples ranging from 1.2–1.6% at 6 hours and treated samples reaching up to 1.67% at 8 hours. The treated and control samples showed no significant variation in titratable acidity, consistently falling within a similar range for each specific treatment and exposure duration.

These findings align with the reported values in the literature. Yaddanapudi, et al (2013) observed TA ranging from 0.36–1.03% in unripe mangoes across 17 varieties, with values declining to 0.21–0.52% in ripe fruits. Specifically, for

Amrapali, the reported TA was 0.36%. Bora et al (2017) noted TA values ranging from 0.15–0.29% among 17 varieties, with Amrapali showing 0.25%. The observed values during our first year experiments are comparable to these reports, particularly at 6 and 10 hours, reflecting the typical range for ripe Amrapali mangoes.

Interestingly, Ayele et al (2012) documented significantly higher TA values, ranging from 0.99–1.37%, during postharvest ripening and shelf-life studies of mango. Similarly, Meena and Asrey (2018) reported TA values for Amrapali between 0.64–0.77%, influenced by tree age. The higher TA values observed in our second year experiment, particularly at 6 and 8 hours, align more closely with these studies, suggesting that environmental factors, ripening stage, or sample handling might contribute to these variations.

The subsequent decrease in acidity as the fruits ripened could be attributed to the varying activity of hydrolytic enzymes during the ripening process, which influences the hydrolysis of complex sugars into simpler ones. This enzymatic activity explains the observed reduction in TA during the first-year experiment, consistent with the natural ripening process of mangoes Liguori et al (2020). The comparison with the existing studies not only validates the observed TA values for Amrapali but also highlights the cultivar-specific and treatment-dependent influences on acidity levels.

Carotenoids, primarily synthesized during fruit ripening, result from the conversion of chlorophyll and are responsible for the yellow-orange colour of the mango mesocarp Fennema (1996) and V´azquez-Caicedo et al (2005). In the present study, the carotenoid content did not exhibit variations between treated and control samples for the same treatment, but the ranges across different treatments varied due to factors like harvesting time, fruit maturity, and seasonal differences. Initial phases were conducted during the same period, while confirmation phases were undertaken in a different year.

Carotenoid content in the 04 h first year ranged from 6.25–7.62 mg/100g in treated samples and 7.52–7.98 mg/100g in control. At 06 h, treated samples showed 14.28–16.48 mg/100g, with control values of 15.52–15.62 mg/100g. However, in the second year, treated samples decreased to 5.47–6.36 mg/100g, with control values ranging from 4.78–5.01 mg/100g. Similarly, in the 8 h during the experiment carried out in the year 2021, treated samples ranged from 11.01–13.97 mg/100g, and control from 12.13–13.82 mg/100g, while in the consecutive year the values were lower, at 3.64–5.77 mg/100g and 3.58–4.83 mg/100g for treated and control samples, respectively. For the 10 h phase, treated samples initially ranged from 10.37–13.97 mg/100g, with control values of 11.15–13.6 mg/100g, but the second year experiment exhibited reduced values of 4.66–7.95 mg/100g for treated and 5.86–6.62 mg/100g for

control samples.

These findings align with previous studies. Muralidhara et al (2018) reported an increase in carotenoid content from 2.23 to 11.47 mg/100g in mango cv. Amrapali during postharvest storage, spanning 12 days. In another study, Murlidhara et al (2019) found carotenoids ranging from 1.86 to 10.33 mg/100g in different mango varieties, with Amravalli recording the highest value of 10.33 mg/100g. Bora et al. (2017) reported a carotenoid range of 1.53–8.38 mg/100g, with Amrapali having the highest value. Kumari et al (2021) observed significantly higher carotenoid content in Amrapali, at 27 mg/100g, compared to other cultivars like Maldah (22.34 mg/100g), Jardalu (20.45 mg/100g), and Sinduri (21.67 mg/100g). The observed differences in the carotenoid content across studies highlight the influence of variety, maturity stage, and postharvest conditions on the synthesis and retention of carotenoids.

The percentage of Physiological Loss in Weight (PLW**)** for mangoes was observed during the second year, as limited samples were available during the first year phase. The PLW data showed varying trends across the different exposure durations (4, 6, 8, and 10 hours), with treated and control mango samples showing differences in weight loss over time.

For the 4-hour exposure, the PLW in both treated and control samples ranged from 1.34% to 8.56% between day 2 and day 10. **In the 6-hour exposure**, PLW values ranged from 2.026% to 17.452%, indicating a higher variability in weight loss compared to the 4-hour exposure. **The 8-hour exposure** showed a range from 1.117% to 12.938%, while **the 10-hour exposure** exhibited PLW values ranging from 1.593% to 10.970% over the same period. Notably, although the PLW values varied across different treatments, there were no significant differences in the PLW range within the same treatment group, suggesting that phosphine fumigation did not result in a notable change in weight loss between treated and control mangoes at each exposure time. However, the variation in PLW across different treatments could be attributed to factors such as the time of harvesting, maturity of the fruit, and moisture content, which influence the fruit's ability to retain water.

The findings from this study align with previous research on PLW in mangoes, although some key differences in storage conditions and fruit varieties may account for the observed variability. Yaddanapudi, et al (2013) found significant differences in PLW among 17 mango varieties on day 3, with PLW ranging from 5.34% to 17.73%. On day 6, PLW values ranged from 12.82% to 26.27%. This variation was partly attributed to the variety of mangoes, with some varieties such as Amini showing lower PLW (5.34%), and others like Sindhu showing higher PLW (17.73%) on day 3. The study highlighted that factors such as mango variety, harvest

time, and fruit maturity significantly influence the rate of weight loss. Similarly, the study by Dirpan et al (2018) reported that mangoes stored at ambient temperature experienced the highest PLW (20.3%) on day 8, followed by mangoes stored in a refrigerator and a Zero Energy Cool Chamber (ZECC) with PLW of 13.0% and 6.2%, respectively. This suggests that environmental factors such as temperature and humidity play a critical role in influencing the rate of water loss from mangoes.

These findings are in line with the work of Baldwin, et al (1999), which emphasized that water loss in fruits and vegetables is heavily dependent on temperature and relative humidity (RH) conditions. High RH and low-temperature storage conditions are typically considered the most effective for maintaining the quality of most fruits, as they reduce the respiration rate, transpiration, and production of ethylene—all of which contribute to ripening, senescence, and eventual fruit decay. This is also supported by Talcott et al (2006), who noted that storing fruits under high RH and low temperatures slows down the natural processes of ripening and aging, thus reducing the loss of moisture and extending the shelf life of fruits like mangoes.
In comparison with the studies quoted above, the results from this study highlight the role of various external factors in determining PLW in mangoes. While the phosphine fumigation treatments did not significantly alter the PLW, the harvest time, moisture content, and maturity of the mangoes could explain the observed variation in weight loss across different treatments. Additionally, the ambient conditions during storage, such as temperature and humidity, play a crucial role in the water retention capacity of mangoes, which could also be a contributing factor to the differences in PLW observed in this study compared to other studies. The study by Yaddanapudi, et al (2013) and Dirpan et al (2018). underscores the importance of controlling storage conditions to minimize weight loss and maintain the overall quality of mangoes.

5.2.3.1 Statistical Interpretation of Results

In this study, different dosages of phosphine were applied at various time exposures to assess their effects on the quality parameters of mangoes.

For the **4-hour (Year 2022)**, phosphine dosages of 0, 1200, and 1500 ppm were applied to the mango samples. These treatments were designed to test the effects of varying phosphine concentrations over a relatively short exposure time. Despite these varying dosages, no significant changes were observed in most of the quality parameters such as Total Soluble Solids (TSS), Titratable Acidity (TA), and Carotenoids. These findings were consistent with other mechanical properties, such as skin elasticity, flesh firmness, and work to penetrate both skin and flesh, which also showed no significant differences ($p > 0.05$). However, the Carotenoid levels did approach statistical significance with an F-value of 4.491 ($p = 0.064$), suggesting some

potential influence of the treatment, though not enough to be conclusive.

In the **6-hour (Year 2021)**, the dosages were increased to include a broader range of concentrations, specifically 0, 250, 400, 500, 750, and 900 ppm. These dosages aimed to provide a more detailed picture of how varying levels of phosphine impact mango quality over a longer exposure period. Again, no significant differences were observed for key quality parameters like TSS, TA, and Carotenoids ($F = 0.440$, $p = 0.812$ for TSS and $F = 1.844$, $p = 0.179$ for Carotenoids). The absence of significant effects on physical parameters like skin elasticity and flesh firmness reinforced the findings of minimal impact due to the phosphine treatment at these concentrations.

In the **6-hour (Year 2022)**, phosphine dosages of 0, 750, and 900 ppm were applied. While the confirmation phase showed similar non-significant results for TSS ($F = 0.375$, $p = 0.702$) and TA ($F = 1.067$, $p = 0.401$), Carotenoids ($F = 4.298$, $p = 0.069$) once again showed a near-significant trend. These results suggest that while phosphine exposure at these dosages does not significantly alter the fruit's biochemical composition or mechanical properties, there may be subtle variations that are not strong enough to reach statistical significance.

For the **8-hour (Year 2021)**, the dosages were set at 0, 50, 100, 200, and 300 ppm. Despite the broader dosage range, no significant differences were found for TSS, TA, or Carotenoids ($F = 0.244$, $p = 0.907$ for TSS, and $F = 1.182$, $p = 0.376$ for Carotenoids). This trend of non-significant differences continued for mechanical properties, with values for skin elasticity, flesh firmness, and work to penetrate the skin showing no statistical significance. The consistency of these results suggested that the longer exposure times did not further enhance the effects of the phosphine treatment on mango quality.

The **8-hour (Year 2022)**, followed a similar pattern with phosphine dosages of 0, 300, and 400 ppm. No significant differences were observed in Carotenoids ($F = 0.433$, $p = 0.667$) or any other quality parameters, such as TSS ($F = 1.50$, $p = 0.296$), confirming that phosphine treatment at these dosages did not result in notable alterations to the mango's postharvest characteristics.

Lastly, in the **10-hour (Year 2021)**, phosphine dosages of 0, 1500, 2000, and 3000 ppm were used to test the effects of even higher concentrations. However, no significant differences were found across the quality parameters, with TSS ($F = 0.244$, $p = 0.907$), TA ($F = 0.125$, $p = 0.970$), and Carotenoids ($F = 1.182$, $p = 0.376$) remaining stable across all dosages. This was consistent with the findings from earlier phases, where no significant differences were detected in the mechanical properties of the mangoes, such as flesh firmness and work to penetrate the flesh.

In the **10-hour (Year 2022)**, phosphine dosages of 0, 600, and 800 ppm were applied, again yielding no significant differences in TSS ($F = 0.176$, $p = 0.842$), TA ($F = 0.6$, $p = 0.579$), or Carotenoids ($F = 0.015$, $p = 0.985$). These findings reaffirmed that, despite varying concentrations of phosphine, the treatment did not significantly impact the quality of the mangoes at any phase or exposure duration tested.

In summary, the study demonstrated that while varying dosages of phosphine were applied across multiple phases and exposure times, no significant differences were observed in most quality parameters, including TSS, TA, and Carotenoids. These results suggest that phosphine fumigation, under the conditions and dosages used in this study, does not have a substantial effect on mango quality.

5.2.4 **Pomegranate**

Pomegranate is a highly valued fruit known for its nutritional, medicinal, and economic significance. The edible arils are rich in polyphenols, vitamins, proteins, sugars, polysaccharides, and essential minerals, contributing to their health-promoting properties (Ozgen et al., 2008). Pomegranate polyphenols encompass flavonoids (including flavonols, flavanols, and anthocyanins), condensed tannins (proanthocyanidins), and hydrolyzable tannins (such as ellagitannins and gallotannins) (Win and Nyo,2019) These are potent antioxidants capable of neutralising reactive oxygen intermediates and preventing oxidative damage (Negi and Jayapraksha 2003). This antioxidant activity is believed to play a critical role in mitigating chronic inflammation, which is linked to conditions such as cancer and other degenerative diseases (Lansky and Newman, 2007). Recent studies have highlighted pomegranate's growing relevance in nutrition and healthcare due to its diverse phytochemical profile. Beyond its medicinal benefits, the fruit is known for its ornamental and pharmaceutical applications, making it a versatile species with broad potential in both traditional and modern medicine (Viuda-Martos et al.,2010).

The samples were subjected to phosphine fumigation for 10 and 24 hours at maximum concentrations, as no infested samples were available for the study. Due to this limitation, only a single phase of treatment was conducted, focusing on high concentrations of phosphine to evaluate its effects. For each exposure time, two sets of samples were analyzed to monitor changes in quality parameters over time, considering the shelf life of the commodity.

In our study, the Total Soluble Solids (TSS) of pomegranate juice varied between 14.08 ± 0.9°Brix for Sample Set I and Sample Set II during the 10-hour exposure period. For the 24-hour exposure period, the TSS was observed to be 14.5 ± 1.087°Brix for Sample Set I and 14 ± 0.853°Brix for Sample Set II. These findings

align with the literature on TSS values in pomegranate juice. Maity et al (2019) reported a similar trend in TSS, where the values ranged from 15.50°Brix to 16.10°Brix, with the Ganesh variety having the highest TSS and Arakta the lowest. In a study by Kaur et al (2014) TSS across different pomegranate cultivars ranged from 15.72 ± 0.36°Brix to 18.18 ± 0.25°Brix, with the 'Mridula' variety showing a value of 18.06 ± 0.40°Brix, which is quite close to our results. Furthermore, Paul and Ghosh (2012) found the TSS of fresh pomegranate juice to be 14.5 ± 0.6°Brix, while heat-treated pomegranate juice showed a slightly lower TSS of 13.6 ± 0.5°Brix. Further comparisons include studies by Koppel et al (2015) where TSS ranged from 14.3 to 15°Brix, and Mphahlele et al (2016) who found slightly higher TSS values ranging from 16.03 to 16.34°Brix for pomegranate juice. Additionally, Catania et al (2020) reported TSS values around 14.0°Brix in most tests, except 2 tests, which recorded 15.2°Brix and 17.0°Brix, respectively. Our findings also align with these studies, demonstrating that the TSS in pomegranate juice remains relatively stable even after extended exposure to phosphine fumigation, with values comparable to those reported in other pomegranate varieties and treatments.

The juice yield for pomegranate arils in this study ranged from 60–67% for Sample Set I and 67–77% for Sample Set II under the 10-hour exposure period for both control and treated samples. For the 24-hour exposure period, the juice yield varied between 71–74% for Sample Set I and 67–72% for Sample Set II. These values are notably higher than those reported by Türkyılmaz et al (2013) were 39.2%, and by Catania et al (2020) who reported 33.5% ± 2.0. However, the obtained juice yields are in closer alignment with the findings of (Fischer et al., 2013) who reported a range of 42.9–61.4%. The differences in juice yield may be attributed to variations in pomegranate variety, fruit maturity, extraction methods, or environmental factors, highlighting the influence of cultivar-specific characteristics on juice recovery (Catania et al 2020).

The pH of pomegranate juice remained stable across all treatments, including untreated control samples. For the 10-hour exposure period, the pH ranged from 3.2–3.7 for Sample Set I and 3.2–4.5 for Sample Set II, while for the 24-hour exposure period, the pH varied between 3.2–3.6 for Sample Set I and 3.5–3.9 for Sample Set II. These values align closely with previous studies. Kaur et al (2014) documented the pH of various pomegranate varieties as ranging from 2.83–3.01, with the pH of the ‘Mridula’ variety specifically reported as 2.83, a variety that was also tested in this study. Koppel et al (2015) reported a pH range of 3.41–3.86 for the juice of the same cultivar, while Mphahlele et al (2016) recorded a range of 1.85–3.23. Additionally, Mousavi et al (2010) reported a pH of 3.09, which is consistent with our findings. The observed stability in pH values underscores the minimal impact of phosphine fumigation on this parameter.

The total phenolic content (TPC) in the pomegranate samples was determined using the Folin–Ciocalteu method, with gallic acid employed as a standard for calibration. The TPC varied significantly across the different sample sets, including the control. For the 10-hour exposure, Sample Set I exhibited TPC values ranging from 61–84 mg GAE/100 g, while Sample Set II ranged from 105–126 mg GAE/100 g. For the 24-hour exposure, Sample Set I showed values between 98–115 mg GAE/100 g, and Sample Set II ranged from 103–117 mg GAE/100 g. These results indicate notable variations, potentially influenced by exposure duration and sample handling. Comparatively, Mphahlele et al (2016) reported TPC values in pomegranate juice ranging from 138.36–289.94 mg GAE/100 g, which are considerably higher than our findings. Similarly, Maity et al (2019) documented a range of 106–177 mg GAE/100 g across various pomegranate varieties, with the 'Mridula' variety specifically reporting a value of 161.67 mg GAE/100 g. Kaur et al (2014) also recorded a TPC of 153.62 ± 2.67 mg GAE/100 g for the 'Mridula' variety, aligning closely with Maity et al.'s findings but higher than those observed in this study. Furthermore, Win and Nyo (2019) reported TPC values of 125.67 ± 7.64 mg GAE/100 g, which fall within the range observed for Sample Set II in our 24-hour exposure group. The differences in TPC values may be attributed to factors such as cultivar-specific characteristics, growing conditions, and extraction methods (Maity et al.,2019).

Anthocyanins are pigments responsible for the red, purple, and blue colours found in fruits, vegetables, and grains. The six common anthocyanidins—pelargonidin, cyanidin, peonidin, delphinidin, petunidin, and malvidin—differ in structure based on glycosidic substitutions at the 3 and 5 positions. Anthocyanin pigments exhibit reversible colour changes in response to pH variations. At pH 1.0, the pigments predominantly exist in their coloured oxonium form, while at pH 4.5, the colourless hemiketal form dominates. The difference in absorbance at 510 nm and 700 nm is directly proportional to the concentration of the pigments. Results are expressed in terms of cyanidin-3-glucoside equivalents (Lee J., 2005).

The anthocyanin content in the current study varied across different exposure times and sample sets. For the 10-hour exposure, Sample Set I recorded values between 8.01–9.5 mg/100g, while Sample Set II ranged from 10.48–12.33 mg/100g. For the 24-hour exposure, Sample Set I showed a higher range of 14.61–16.86 mg/100g, whereas Sample Set II exhibited lower values between 9.02–9.78 mg/100g. These results align with the findings of Mir et al (2007) who reported anthocyanin content ranging from 1.13 to 20.3 mg/100g across 10 pomegranate varieties, including 'Mridula,' which had a value of 15.35 mg/100g. Similarly, Samreen et al (2020) recorded a total anthocyanin content of 15.98 ± 0.02 mg/100g in pomegranate juice, which is comparable to the 24-hour Sample Set I values. However, Kaur et al (2014) reported significantly higher anthocyanin content for the 'Mridula'

variety at 42.13 mg/100g. In contrast, Gardeli et al., (2019) documented anthocyanin levels of 18.7 mg/100g for the 'Ermioni' variety, while Mphahlele et al (2016) reported a range of 10.96–13.91 mg/100g, closer to the results for the 10-hour Sample Set II in this study. These variations might be attributed to differences in extraction methods, pomegranate variety, maturity stage, or environmental conditions.

In the present study, the Titratable Acidity (TA) for the 10-hour and 24-hour exposure periods varied as follows: for 10-hour exposure, Sample Set I showed values ranging from 0.33% to 0.46%, while Sample Set II had a range of 0.36% to 0.49%. For the 24-hour exposure, Sample Set I showed values ranging from 0.35% to 0.45%, and Sample Set II ranged from 0.38% to 0.51%. These results were compared with values from previous studies. Maity et al (2019) reported TA values ranging from 0.42% to 0.50% for four pomegranate varieties, with the Mridula variety showing a value of 0.45%. In contrast, Kaur et al (2014) observed a lower range of 0.24% to 0.28% for six varieties, with Mridula specifically having a value of 0.28%. Mir et al (2007) reported a broader range of 0.41% to 0.81% across ten varieties, with Mridula reaching a value of 0.76%. Our findings for Mridula (in the range of 0.33%–0.51%) fall between these reported values, aligning more closely with those of Maity et al (2019) and slightly higher than those from Kaur et al (2014).

The **Cupric Ion Reducing Antioxidant Capacity (CUPRAC)** of pomegranate arils was evaluated following the method outlined by Apak et al (2004). This method involves measuring the ability of antioxidants present in the arils to reduce cupric (Cu^{2+}) ions to cuprous (Cu^{+}) ions in the presence of neocuproine. A standard curve was prepared using various concentrations of Trolox, a water-soluble vitamin E analog widely used as a reference antioxidant. The antioxidant capacity of the samples was quantified by comparing their absorbance values to those on the standard curve, and the results were expressed as micromoles of Trolox equivalents per gram (µmol TE/g) of arils. For this calculation, the molar absorptivity of Trolox, which is 1.67×10^4 l/mol/cm, was used. This approach provides a reliable measure of the antioxidant potential of the pomegranate arils, enabling comparisons with other antioxidant capacity studies.

The Cupric Ion Reducing Antioxidant Capacity (CUPRAC) values obtained in this study ranged between 17.65–20.70 µmol TE/g for 10-hour exposure (Sample Set I) and 16.82–21.573 µmol TE/g for Sample Set II. For 24-hour exposure, the antioxidant capacity ranged between 14.55–17.96 µmol TE/g for Sample Set I and 17.61–21.93 µmol TE/g for Sample Set II. These values reflect a broad range of antioxidant activity across samples and exposure periods.

Comparatively, Kaur et al. (2014) reported antioxidant capacity for six pomegranate varieties in the range of 7.87–16.24 µmol TE/g, with the 'Mridula' variety (tested in this study) documented at 16.24 µmol TE/g. While the CUPRAC values in our study are higher, they align closely with the values reported for Mridula, particularly in the 10-hour sample set. The slightly elevated results observed in our study could be attributed to differences in maturity, growing conditions, or other environmental factors.

However, comparisons with existing literature were limited, as most studies have employed other methods, such as DPPH, ABTS, or FRAP, to measure antioxidant capacity. Among the available literature, Kaur et al (2014) remain one of the few studies using a directly comparable method, highlighting the need for more standardization in antioxidant capacity evaluation methods. Despite these challenges, the results reinforce the robust antioxidant potential of the 'Mridula' variety when assessed using the CUPRAC assay.

In the current study, Ascorbic Acid content for the 10-hour exposure period ranged from 18.89–31.08 mg/100 g in Sample Set I and 17.76–21.57 mg/100 g in Sample Set II. For the 24-hour exposure, AA levels were observed to be 19.24–23.68 mg/100 g in Sample Set I and 17.76–29.6 mg/100 g in Sample Set II. These values were notably higher than those reported by Kaur et al (2014) who documented ascorbic acid levels ranging from 4.85–13.65 mg/100 g across six pomegranate varieties, with the ‘Mridula’ variety showing 13.13 mg/100 g. Similarly, (Maity et al., 2019) reported AA levels for four varieties between 17.50–20.42 mg/100 g, with 17.50 mg/100 g for the Mridula variety, aligning with the lower range of values obtained in this study.

Comparing these results to other studies, Paul and Ghosh (2012) reported an Ascorbic Acid content of 19.8 mg/100 g, closely matching the observed levels for 24-hour treated samples. Tehranifar et al (2010) recorded a range of 9.91–20.92 mg/100 g, while Dumbravă et al (2016) noted a higher value of 23.15 mg/100 g in pomegranate juice. The observed variation in ascorbic acid levels may be attributed to differences in cultivar, fruit maturity, environmental conditions, or extraction methods. Overall, the ascorbic acid content observed in this study is within or exceeds ranges reported in the literature, particularly for the Mridula variety, indicating good ascorbic acid retention across treatment conditions.

5.2.4.1 Statistical Interpretation of Results

a) 10-Hour Exposure

Pomegranate quality parameters for the **I sample set** were analyzed at different phosphine dosages (0, 500, 1000, and 2000 ppm) after a 10-hour exposure.

The results showed no statistically significant differences across all parameters, as indicated by p-values exceeding 0.05. Among the parameters, Total Soluble Solids (TSS) ($F = 0.900$, $p = 0.482$) and Juice Yield ($F = 0.917$, $p = 0.475$) demonstrated no variation with increasing dosage. Similarly, pH ($F = 0.577$, $p = 0.646$), Total Phenolic Content (TPC) ($F = 0.955$, $p = 0.459$), and Total Anthocyanins ($F = 1.282$, $p = 0.345$) remained unaffected. Texture parameters, such as Skin Elasticity, Bioyield Point, and Stiffness, also showed no significant changes, with p-values ranging from 0.615 to 0.920. These results indicate that phosphine treatment at the tested concentrations did not impact the measured quality parameters in the first sample set.

The **II sample set** exhibited trends consistent with the first, with no significant differences observed across all parameters. For instance, TSS ($F = 0.452$, $p = 0.723$) and Juice Yield ($F = 0.209$, $p = 0.888$) demonstrated stability regardless of the phosphine dosage. The pH levels and Total Phenolic Content ($F = 0.977$, $p = 0.450$ and $F = 0.525$, $p = 0.677$, respectively) also remained unaffected. Although Titratable Acidity showed a slightly higher F-value (3.522), the result was not statistically significant ($p = 0.069$). Flesh Firmness, Skin Elasticity, and Work to Penetrate Flesh, exhibited minimal variation, with p-values ranging from 0.949 to 0.993. These findings reinforce the observation that phosphine dosages up to 2000 ppm had no detrimental effect on Pomegranate quality attributes in the second sample set.

b) 24-Hour Exposure

In the **I sample set**, the quality attributes of Pomegranate were evaluated after a 24-hour exposure to phosphine dosages of 0, 500, 1000, and 2000 ppm. The results revealed no significant differences across all parameters, as indicated by p-values consistently greater than 0.05. For instance, Total Soluble Solids (TSS) and Juice Yield had F-values of 0.800 ($p = 0.528$) and 0.741 ($p = 0.557$), respectively, suggesting negligible variation due to phosphine application. Similarly, pH ($F = 2.569$, $p = 0.127$), Total Phenolic Content ($F = 0.375$, $p = 0.774$), and Total Anthocyanins ($F = 1.029$, $p = 0.430$) showed consistent values across treatments. Bioyield Point, Skin Elasticity, and Flesh Firmness also remained unaffected, as reflected by their low F-values and lack of statistical significance. These findings suggest that phosphine treatments had no discernible impact on the physicochemical or mechanical properties in this sample set.

The **II sample set** demonstrated similar patterns, with all p-values exceeding 0.05, indicating no significant differences in any measured parameters. For example, TSS ($F = 0.242$, $p = 0.864$) and Juice Yield ($F = 0.029$, $p = 0.993$) were unaffected by increasing phosphine levels. Slightly higher F-values were observed for Total Phenolic Content ($F = 2.098$, $p = 0.179$) and Titratable Acidity ($F = 1.998$, $p = 0.193$), although these results were still not significant. Mechanical characteristics such

as Stiffness, Work to Penetrate Flesh, and Skin Elasticity remained stable across treatments, with p-values ranging from 0.749 to 0.984. This consistency aligns with the findings of the first sample set, reinforcing the observation that phosphine exposure at the tested concentrations does not adversely affect Pomegranate quality attributes. Across both sample sets for the two exposures, no statistically significant effects were observed on the measured parameters. The stability of physicochemical and mechanical properties across different treatment levels suggests that phosphine can be applied safely at these concentrations without compromising Pomegranate quality. This highlights its potential as an effective treatment option for postharvest management.

5.2.5 Rose

The tested quality parameters included Moisture Content (%), Anthocyanin Content, and Water Uptake (%). The ability of the flower to take up water influences its overall quality and longevity. Flowers that take up more water tend to last longer, maintain their color, and stay fresher for a more extended period. Freshness and an adequate vase life are key factors that influence consumers' choice of flowers and influence export.

In our study, the anthocyanin content in the Pusa Virangana variety ranged from 252.23 mg/100g to 597.97 mg/100g across all samples. For the treated samples, the anthocyanin content varied from 229.83 mg/100g to 597.97 mg/100g, while the untreated control samples showed a range from 282.09 mg/100g to 594.04 mg/100g. This range of anthocyanin content is consistent with the findings reported in the literature. A study observed that anthocyanin content in various rose varieties ranged from 0.24 mg/100g to 578.10 mg/100g, reflecting a wide variation. Specifically, for the Pusa Virangana variety, they reported anthocyanin levels ranging from 125.78±1.71 mg/100g to 235.22±7.63 mg/100g depending on the season Kumari et al (2017). Our findings are also supported by Lee et al (2011), who reported an anthocyanin content of 375 mg/100g in red petals of Korean edible rose, and by Qin & Xiaojun (2013), who found an anthocyanin content of 353.56±2.50 mg/100g in the petals of Yunnan edible rose. It is important to note that anthocyanin content is known to vary in response to environmental factors such as growth temperature and light intensity, which can influence the synthesis and accumulation of anthocyanins in plants (Ginova et al.,2013).

In our lab study, the moisture loss (%) of the Rose flowers, determined from the fresh weight and dried weight, ranged from 65.75% to 88.84%. Specifically, for the treated samples, the moisture loss (%) varied between 66.67% and 88.84%, while for the untreated control, it ranged from 65.75% to 85.09%. These findings align with those reported by Boyer et al. (2013), where the moisture content in Isparta Rose

flowers was found to range from 76.3±1.20% to 81.7±4.10%, with drying times varying between 72 and 162 hours (3–7 days) depending on climatic conditions. The variations in moisture content may be due to the environmental factors that influence water retention in flowers (Boyar et al.,2013).

The water relations of cut flowers are influenced by various physiological and anatomical characteristics that regulate both water uptake and water loss rates Van Doorn (2012). These traits are shaped during the preharvest period, resulting from the complex interaction between genotype and environmental conditions during cultivation. These factors ultimately determine the potential vase life, or maximum vase life, of the cut flower. For example, the relative air humidity (RH) level during cultivation does not significantly impact crop growth and visual quality (Torre and Fjeld , 2001). The water uptake (flow rate) is directly related to the driving force (water potential) and the conductance (which is the inverse of resistance) of the transport pathway (Doorn W.,2012). The water uptake percentage observed in the current study ranged from 2% to 12%, with treated samples showing a range of 2% to 10%, and untreated samples showing a range from 2% to 12%. No significant difference was observed between the treated and control samples across all treatments in both phases. While specific literature on water uptake percentages in similar conditions is limited, previous studies on water relations in cut flowers have shown a wide variation in uptake rates based on factors such as genotype, environmental conditions, and post-harvest treatment (Doorn W.,2012).

5.2.5.1 Statistical Interpretation of Results

a) 04-Hour Exposure:

For the 4-hour exposure period, for the first year experiment phase where the phosphine concentration ranged from 0 to 50 ppm and the moisture loss (%) showed no significant variation across the dosages ($F = 0.851$, $p = 0.540$). This suggests that the different concentrations of phosphine had little to no effect on the moisture retention of the flowers during this exposure period. Similarly, the anthocyanin content did not significantly change, with an F-value of 2.518 and a p-value of 0.088, indicating that phosphine fumigation did not substantially affect the anthocyanin levels within the flowers during this exposure time. Water uptake also remained unaffected by the treatment dosages, with an F-value of 0.400 and p-value of 0.840, further suggesting that varying concentrations of phosphine did not influence the ability of the flowers to absorb water at this exposure time.

Similarly, in the consecutive year, where three dosage levels (0, 55, 65) were tested, moisture loss (%) showed no significant difference between the dosages ($F = 1.149$, $p = 0.378$). This outcome reinforces the findings from the initial phase.

Likewise, anthocyanin content did not differ significantly (F = 3.200, p = 0.113), suggesting that the different phosphine treatments did not impact anthocyanin levels. Finally, water uptake showed no significant change across the dosages (F = 0.333, p = 0.729), further emphasizing that the varying concentrations of phosphine had no discernible impact on water uptake within the 4-hour exposure period.

b) 06-Hour Exposure

At the 6-hour exposure duration, in the first year experiment, moisture loss (%) was again tested across dosages of 0, 10, 20, 30, 40, and 50 ppm. With an F-value of 0.205 and a p-value of 0.954, there were no significant changes in moisture content, further supporting the earlier finding that phosphine fumigation does not affect moisture retention within flowers over this exposure period. Similarly, anthocyanin content remained stable, as indicated by an F-value of 1.963 and a p-value of 0.157. The water uptake percentage was also unaffected, with an F-value of 2.400 and a p-value of 0.099.

For the consecutive year experiement, the dosages tested were 0, 45, and 55 ppm. Moisture content was found to be statistically insignificant (F = 3.101, p = 0.119), similar to the results from the initial phase. Anthocyanin content also showed no significant variation across the dosages (F = 3.197, p = 0.113). Water uptake was again unaffected by the treatment levels, as shown by an F-value of 0.273 and a p-value of 0.770. These results from Phase II further confirm that neither moisture content, anthocyanin levels, nor water uptake are significantly impacted by phosphine exposure at this 6-hour duration.

c) 08-Hour Exposure

Moisture loss (%) across all dosages (0, 10, 20, 30, 40, 50 ppm) during the first year phase showed no significant changes, with an F-value of 0.900 and a p-value of 0.512. Similarly, anthocyanin content was not significantly affected by the phosphine treatment, with an F-value of 2.384 and a p-value of 0.101. Water uptake, too, remained unchanged across the dosages (F = 0.829, p = 0.553).

In the second year, when dosages of 0, 40, and 50 ppm were used, moisture loss (%) again showed no significant variation (F = 2.940, p = 0.129), confirming the consistency of the results from the previous exposure times. Anthocyanin content also remained unchanged (F = 1.357, p = 0.326), supporting the idea that phosphine treatment had no significant effect on the anthocyanin levels of the flowers during this extended exposure. Lastly, water uptake was again unaffected by the dosages (F = 0.467, p = 0.648), highlighting the consistency in water absorption across the different treatments.

d) 10-Hour Exposure:

In the longest exposure time, in the first year, moisture loss (%) showed no significant difference across the dosages (0, 10, 20, 30, 35, 40 ppm) with an F-value of 1.406 and a p-value of 0.290. Similarly, anthocyanin content did not show significant variation (F = 0.476, p = 0.788). Water uptake also showed no significant differences across the dosages (F = 0.249, p = 0.933), suggesting that even after 10 hours, phosphine fumigation did not impact water uptake in the flowers.

In the second year, when dosages of 0, 35, and 40 ppm were tested, moisture loss (%) remained statistically insignificant (F = 0.084, p = 0.921), and anthocyanin content also showed no significant difference (F = 3.208, p = 0.113). Water uptake was unaffected, with an F-value of 0.800 and a p-value of 0.492. This indicates that prolonged exposure to phosphine does not significantly alter the physiological parameters of moisture content, anthocyanin content, or water uptake in the flowers.

5.2.6 **Chrysanthemum**

Chrysanthemum is one of the most popular ornamental plants and ranks as the second most economically significant cut flower in the global market. Renowned for its vibrant colors, including shades of red, pink, orange, magenta, and scarlet, the hues of Chrysanthemum flowers are primarily attributed to anthocyanin, particularly cyaniding Mekapogu et al (2020). The evaluation of Chrysanthemum's quality heavily depends on its color, which is a key determinant of its commercial value. Additionally, Chrysanthemum is recognized as a rich source of anthocyanin due to the profusion of flowers produced by a single plant, offering a diverse spectrum of colors (Gantait and Pal , 2010).

The anthocyanin content of Chrysanthemum (Variety Jaya) in our study exhibited a wide range, from 63.218 to 175.604 mg/100g across all samples and Phases. The treated samples displayed an anthocyanin content range of 63.218 to 175.604 mg/100g, while the untreated control samples ranged from 65.559 to 170.922 mg/100g, indicating no significant differences between treatments. These results align with the findings of Ullas et al. (2018), who reported anthocyanin content in various Chrysanthemum varieties, including 'Jaya,' ranging from 50.17 to 65.38 mg/100g under different drying methods. Furthermore, our findings are supported by Magfiroh et al. (2023), who observed that the anthocyanin content in Red Chrysanthemum (*Chrysanthemum morifolium* Ramat.) varied with plant age, reaching its peak at 134 Days after planting (DAP) with 356 mg/100g, followed by 115 DAP at 240 mg/100g, and 125 DAP at 125 mg/100g declining further at 120 DAP to 169 mg/100g. These

variations emphasize that anthocyanin content can fluctuate due to factors like developmental stage and environmental conditions, which are consistent with the range observed in our study for Chrysanthemum 'Jaya' (Magfiroh et al.,2023).

The moisture loss (%) of Chrysanthemum flowers, calculated based on fresh and dry weights, ranged from 63.22% to 175.60%. Specifically, for treated samples, the moisture loss (%) varied between 63.22% and 175.60%, while for the untreated control, it ranged from 65.56% to 170.92%, showing no significant difference between the two. Among the total eight treatments conducted across two phases, only two treatments, namely the confirmation phases of 6 hours and 8 hours, exhibited higher moisture loss (%) ranges of 121.75–142.82% and 152.19–175.60%, respectively. The remaining treatments, including the untreated controls, were within a narrower range of 63.22–93.42%. This wide range of moisture loss (%) could be attributed to environmental factors such as temperature, relative humidity, and cultivation conditions, as well as intrinsic factors like the shape, size, and structural characteristics of the flowers.

Notably, the moisture content percentage (%) and the moisture loss percentage (%) are conceptually equivalent, though expressed differently. Moisture content measures the proportion of water relative to the fresh weight of the sample, while moisture loss represents the percentage reduction in weight due to water evaporation during drying. This relationship justifies the findings of studies that report moisture loss instead of content, as the values are directly comparable Krokida et al (2023).For instance, Dahiya et al (2003) reported the moisture loss (%) of Annual Chrysanthemum (*C. coronarium*) to range from 87.43% to 88.78%. Similarly, Wilson et al (2013) Wilson et al. (2003) examined the influence of drying techniques and found the moisture content to range from 71.39% to 79.31%.Gurjar et al (2023) investigated the effect of various pre-drying treatments and drying methods on Chrysanthemum flowers, reporting moisture loss percentages of 67.45% to 77.44% for pre-treatments and 72.02% to 82.44% for drying methods. Prabawa et al (2023) reported the moisture content of yellow Chrysanthemum to be approximately 83%, indicating variations that depend on the specific conditions and flower types. These results align with the current study, considering the equivalence between moisture content and moisture loss, further validating the observed ranges in Chrysanthemum flowers.

Water uptake plays a vital role in enhancing the vase life and quality of cut flowers. It is essential for maintaining the water balance in the stem and facilitating flower bud opening, both of which are critical for improving the longevity and overall quality of cut flowers Prabawati et al (2023). The water uptake percentage observed in the current study ranged from 6% to 18% for both treated and untreated control samples in both phases. The ability of flowers to take up water is influenced by various

factors, including the physiological state of the flower, stem anatomy, and environmental conditions during post-harvest storage Van Doorn (2012). The observed ranges of water uptake align with the general understanding that hydration dynamics play a pivotal role in maintaining flower freshness and vase life. No prior studies have reported water uptake percentages in Chrysanthemum flowers under similar experimental conditions.

5.2.6.1 Statistical Interpretation of Results

a) 04-Hour Exposure:

For the 4-hour exposure, the univariate analysis of variance (ANOVA) showed no statistically significant differences for any of the measured quality parameters in both years of experiments. In the first year, the moisture loss (%) varied across the dosages (0, 250, 500, 1000, 2000 ppm), yielding an F-value of 1.581 and a p-value of 0.253, indicating that the treatments had no significant effect. Similarly, the anthocyanin content demonstrated no notable variation, with an F-value of 1.559 and a p-value of 0.259. Water uptake also remained unaffected, with an F-value of 0.850 and a p-value of 0.525.

In the confirmation phase, moisture loss (%) across higher dosages (0, 800, 1200, 1600, 2000, 2400 ppm) remained consistent, with an F-value of 0.906 and a p-value of 0.509. Both anthocyanin content and water uptake exhibited no significant differences, with F-values of 0.709 and 0.457 and p-values of 0.628 and 0.801, respectively. This consistency across treatments and phases suggests that exposure up to 2000 ppm does not alter the measured parameters significantly at 4 hours.

b) **06-Hour Exposure:**

For the 6-hour exposure, all quality parameters remained statistically insignificant across dosages in both the years. During the year 2021, the moisture loss (%) displayed an F-value of 1.868 and a p-value of 0.193, indicating no significant impact. Similarly, the anthocyanin content ($F = 2.044$, $p = 0.164$) and water uptake ($F = 1.429$, $p = 0.294$) did not show significant variations. In the experiment during the year 2022, moisture loss (%) remained unaffected, with an F-value of 2.241 and a p-value of 0.117, while anthocyanin content ($F = 0.740$, $p = 0.608$) and water uptake ($F = 0.414$, $p = 0.830$) exhibited no significant differences. These consistent results highlight that even prolonged exposure at dosages up to 2200 ppm does not alter these parameters significantly.

c) 08-Hour Exposure:

The 8-hour treatments revealed no statistically significant differences in any of the quality parameters, consistent with the shorter exposure durations. The moisture loss (%) across dosages (0, 250, 500, 1000 ppm) showed an F-value of 2.013 and a p-value of 0.191. Similarly, anthocyanin content ($F = 2.599$, $p = 0.125$) and water uptake ($F = 2.000$, $p = 0.193$) displayed no significant differences during the first year phase. During the consecutive year, moisture content ($F = 0.694$, $p = 0.638$), anthocyanin content ($F = 0.307$, $p = 0.899$), and water uptake ($F = 0.480$, $p = 0.785$) remained unaffected across higher dosages (0, 400, 600, 800, 1000, 1200 ppm). These results suggest that Chrysanthemum flowers maintain their quality characteristics even at extended exposure durations.

d) 10-Hour Exposure:

Extended exposure for 10 hours also resulted in no significant differences in any of the measured parameters in both years. In the first year, moisture loss (%) showed no meaningful variation across the dosages (0, 250, 500 ppm), with an F-value of 0.158 and a p-value of 0.857. Similarly, anthocyanin content ($F = 0.104$, $p = 0.902$) and water uptake ($F = 0.600$, $p = 0.579$) remained statistically insignificant.

In the second year, the moisture loss (%) across higher dosages (0, 600, 800, 1000, 1200, 1400 ppm) displayed an F-value of 2.249 and a p-value of 0.116, indicating no significant differences. Anthocyanin content ($F = 1.297$, $p = 0.328$) and water uptake ($F = 0.080$, $p = 0.994$) also showed no notable variations.

5.3 Sorption and Residue Analysis

5.3.1 Fruits and Vegetables

5.3.1.1 Sorption in Fruits and Vegetables

Sorption, which is critical in determining the effectiveness and safety of fumigation treatments, involves two primary mechanisms: adsorption and absorption. Adsorption refers to the surface-level adhesion of molecules, while absorption involves the penetration of molecules into the material's internal structure (Darby, 2008). Both mechanisms play a vital role in understanding how fumigants interact with commodities during and after treatment.

The variability in phosphine sorption among different fruits and vegetables underscores the need for commodity-specific fumigation protocols. This variability highlights the importance of considering the physical and biochemical characteristics

of each commodity to optimize fumigation efficiency and safety. In this study, mangoes exhibited consistent phosphine sorption across all concentrations and exposure periods, suggesting that their relatively smooth, permeable skin plays a significant role in uniform phosphine uptake. This consistent sorption aligns with the findings of Friedemann et al. (2020), who reported that the adsorbed phosphine remained largely unaffected by fumigation parameters, emphasizing the inherent properties of the fruit's surface and skin that influence gas absorption.

In contrast, the sorption pattern in bitter gourd followed an initial increase that leveled off and subsequently decreased, indicating a dynamic process where equilibrium is first achieved, followed by desorption. This finding is consistent with the work of Sato and Suwanai (1974), who observed a similar sorption pattern in wheat, suggesting that a time-dependent equilibrium can occur in different crops. The fluctuating sorption observed in bitter gourd may also be attributed to its unique surface structure and porosity, which could facilitate a higher initial uptake of phosphine, followed by a gradual desorption process once equilibrium is reached. These findings emphasize the need to tailor fumigation treatments based on the specific characteristics of the commodity to ensure optimal phosphine retention during treatment (Ahmed et al.,2018).

Chillies, on the other hand, displayed a higher range of sorption compared to mangoes and bitter gourd, likely due to their soft, porous surface and higher moisture content, which enhance the uptake of phosphine. This observation aligns with the study by (Ahmed et al.,2018), who demonstrated that increased moisture content and larger surface area in celery bunches facilitated greater phosphine absorption. The porous structure of chillies may increase the surface area available for phosphine penetration, thus enhancing the overall sorption process. These results suggest that higher moisture content and surface area may play a critical role in determining the extent of phosphine sorption in fruits and vegetables, which must be factored into fumigation protocols.

5.3.1.2 Residue Analysis in fruits and vegetables

Phosphine residue analysis in mangoes revealed minimal residues, ranging from 0.009 to 0.01 ppm after just 2 hours of aeration. These low residue levels suggest that mangoes are highly effective in releasing phosphine after fumigation, making them suitable for export under stringent food safety regulations. Similar findings were reported by Wason and Selladurai (2023), where no detectable phosphine residues were found in java apples after short fumigation durations, reinforcing the efficacy of phosphine as a safe treatment method for maintaining the quality of fruits.

Chillies, which exhibited a higher sorption percentage, also demonstrated near-zero phosphine residues after aeration. These results suggest that chillies, despite their higher sorption capacity, also facilitate the efficient removal of phosphine residues, ensuring compliance with food safety standards and export regulations. The higher sorption observed in chillies may enhance their capacity to retain phosphine during treatment, but the subsequent aeration process appears equally effective in reducing residue levels to safe limits.

In contrast, bitter gourd, which exhibited lower sorption compared to chillies, required a longer aeration period (4-6 hours) to achieve residue levels within the maximum residue limits (MRL) set by regulatory bodies such as the EU Commission EU (2016). Despite this extended aeration time, phosphine residues in bitter gourd remained within acceptable limits, highlighting the effectiveness of the aeration process in mitigating residue accumulation. This underscores the importance of aeration duration in ensuring that fumigated produce complies with regulatory requirements, particularly when the sorption potential of the commodity is lower.

5.3.1.3 Statistical Interpretation of Results for Fruits and vegetables

The study evaluated the sorption characteristics of phosphine in different fruits and vegetables, which were fumigated at various concentrations and exposure periods under controlled conditions.

Descriptive statistics for sorption percentage provided an overview of the data distribution and central tendency. The analysis revealed a wide variability in sorption percentages, with a minimum of 6.66% and a maximum of 63.26%. The mean sorption percentage was 20.98%, with a standard deviation of 17.01%, indicating significant variation across the data points.

A simple linear regression analysis was performed to examine the relationship between exposure period and sorption percentage. The regression model showed no statistical significance ($F(1,11) = 0.851$, $p = 0.376$), suggesting that the exposure period does not significantly predict sorption percentage at the 5% significance level. The model explained only 7.2% of the variance in sorption percentage ($R^2 = 0.072$), indicating that exposure period alone is not a strong predictor of sorption variability.

Furthermore, a one-way Analysis of Variance (ANOVA) was conducted to compare the sorption percentages across different exposure periods. The ANOVA result also revealed no significant differences in sorption percentage between the different exposure durations ($F(4,8) = 0.449$, $p = 0.771$).

Taken together, the findings from both regression analysis and ANOVA indicate that exposure period does not significantly influence phosphine sorption in the tested fruits and vegetables. The descriptive statistics highlight the wide variability in sorption percentages, suggesting that other factors, beyond exposure period, may play a more prominent role in determining sorption levels.

5.3.2 Flowers

5.3.2.1 Sorption in Flowers

The study evaluated the sorption characteristics and residue levels of phosphine in roses and chrysanthemums, highlighting significant differences between the two floricultural commodities.

Roses exhibited higher sorption levels than chrysanthemums, which may be explained by differences in moisture content, petal surface area, and structural properties. Specifically, roses typically have higher relative moisture content and a larger surface area, which can enhance the adsorption of phosphine molecules. Additionally, genus-specific physiological and anatomical factors could also play a role, as suggested by Zhang et al. (2013), who reported a sorption order of Rose > Chinese rose > Chrysanthemum > Carnation in their study on cut flowers fumigated with phosphine. These findings underscore the importance of considering species-specific traits when developing fumigation protocols.

Previous studies support this trend, emphasizing that the physical and chemical properties of flowers, such as cuticle thickness, metabolic activity, and cellular water content, significantly influence sorption rates (Weller & Graver, 1996; Amorós et al., 2008). The effect of aeration post-fumigation was also evident, as aeration facilitated the desorption of phosphine, reducing residual levels in both roses and chrysanthemums. This aligns with findings by Reddy et al. (2007), who reported that aeration efficiency could mitigate sorption by expelling entrapped gases from treated commodities.

5.3.2.2 Residue Analysis in Flowers

Residue analysis revealed contrasting results for roses and chrysanthemums. While roses exhibited minimal phosphine residues, chrysanthemums showed greater variability, indicative of heterogeneous phosphine accumulation within the plant tissues. The observed residue levels in roses were well within the Maximum Residue Limits (MRL) of 0.01 mg/kg (ppm) established by Commission Regulation (EU) 2016/1785 (EU, 2016). This suggests that roses can safely undergo phosphine

fumigation under the tested conditions without posing risks to consumers.

However, no specific MRL values exist for chrysanthemums in the EU or Codex Alimentarius Commission (CAC) guidelines, presenting a regulatory gap. Despite this, the residue levels in chrysanthemums were substantially lower than the Threshold Limit Value - Time-Weighted Average (TLV-TWA) of 0.3 ppm for an 8-hour exposure and the Short-Term Exposure Limit (STEL) of 1 ppm set by CDC-NIOSH (2011). Given that chrysanthemums are non-edible ornamental crops; the detected residues pose no direct threat to human health but highlight the need for additional studies to establish standardized residue benchmarks for such commodities.

5.3.2.3 Statistical Interpretation of Results for Flowers

A) **Descriptive Statistics**

The study evaluated the sorption characteristics and residue levels of phosphine in two flower commodities, Chrysanthemum and Rose. Chrysanthemum exhibited a higher mean sorption percentage (13.72 ± 3.91%) compared to Rose (11.02 ± 0.40%). Similarly, the mean residue level was greater in Chrysanthemum (0.55 ± 0.89 mg/kg) than in Rose (0.01 ± 0.00 mg/kg). These findings suggest that Chrysanthemum retains more phosphine than Rose, potentially due to structural or physiological differences, such as variations in moisture content, surface area, or metabolic activity. The lower standard deviation in sorption and residue levels for Rose indicates less variability compared to Chrysanthemum.

B) **Correlation Analysis**

Correlation analysis revealed a negative relationship between exposure period and both sorption percentage ($r=-0.408$, $p=0.315$) and residue levels ($r=-0.504$, $p=0.202$). Although these results indicate a possible trend of decreasing sorption and residue levels with prolonged exposure, the correlations are weak and not statistically significant ($p>0.05$). This suggests that exposure period alone might not be a strong predictor of changes in sorption and residue levels.

C) Regression analysis

For sorption percentage, the predictor (exposure period) explained 16.7% of the variability ($R^2=0.167$, $p=0.315$), while for residue levels, it explained 25.4% ($R^2=0.254$, $p=0.202$). The regression coefficients for both sorption percentage ($B=-0.503$, $p=0.315$) and residue levels ($B=-0.138$, $p=0.202$) indicated a slight decline with increasing exposure time. However, these relationships were not statistically significant, emphasizing the limited predictive power of exposure period under the conditions of this study.

D) Analysis of Variance (ANOVA)

For exposure periods also revealed no significant differences in sorption percentage ($F(3,4) = 0.780$, $p = 0.563$) or residue levels ($F(3,4) = 0.901$, $p = 0.515$) across the tested periods. The lack of statistical significance could be attributed to the small sample size (N=4 for each commodity), which limits the ability to detect subtle trends or differences.

In summary, Chrysanthemum exhibited higher sorption and residue levels compared to Rose, consistent with its structural and compositional properties. While weak negative trends were observed between exposure period and both sorption and residue levels, these relationships were not statistically significant, highlighting the need for further studies with larger sample sizes or additional explanatory variables. This would help to better understand the factors influencing sorption and residue dynamics in these flower commodities.

CHAPTER 6

CONCLUSION, FUTURE SCOPE, AND SOCIAL IMPACT

Conclusion

This study aimed to evaluate the effectiveness of phosphine fumigation as a post-harvest treatment for export-oriented perishable commodities, specifically fruits, vegetables, and flowers, focusing on its impact on quality attributes, sorption characteristics, and residue accumulation. The study included Mango, Pomegranate, Bitter Gourd, Green Chilli, Rose, and Chrysanthemum as the perishable commodities under investigation.

The results of this study revealed that phosphine fumigation, at the tested concentrations and exposure durations, did not cause significant changes in the physical and nutritional quality of the commodities. Key quality parameters such as firmness, texture, juice yield, pH, moisture content, total soluble solids (TSS), ascorbic acid, antioxidant activity, and total phenolic content remained unaffected, with p-values greater than 0.05 indicating no discernible impact. These findings suggest that phosphine fumigation, when applied within the studied conditions, is effective in maintaining the quality and marketability of perishable commodities without any negative effects on their nutritional and physical attributes.

Sorption dynamics varied across the commodities, with Mango demonstrating relatively consistent phosphine sorption, Bitter Gourd exhibiting more variation, and Chilli showing the highest sorption percentages. However, statistical analysis revealed no significant relationship between sorption percentages and exposure time ($p > 0.05$), suggesting that sorption is influenced more by the intrinsic properties of the commodity rather than fumigation conditions. These findings are crucial in determining the required fumigation duration for effective pest control.
Residue analysis also supported the suitability of phosphine as a fumigant for export purposes. Phosphine residue levels remained within the Maximum Residue Limits 0.01mg/kg (ppm), with Mango and Chilli showing negligible residues, further assuring the safety of phosphine-treated produce for consumption and export. Bitter Gourd, although exhibiting higher residue levels after shorter aeration times, still remained within the regulatory MRL.

This study underscores the potential of phosphine fumigation as a viable alternative to other fumigants, such as methyl bromide, particularly for use in the quarantine treatment of export-oriented commodities. Its minimal impact on both the

quality of produce and residue levels makes it an attractive solution for the preservation of perishable commodities. Additionally, the variability in sorption rates among the different commodities suggests that future research should explore the optimization of fumigation conditions, such as exposure time and fumigant concentration, to enhance efficacy for specific commodity types.

Overall, this research contributes valuable insights into the use of phosphine fumigation in post-harvest management of perishable commodities. The findings suggest that phosphine fumigation, when properly optimized, can effectively reduce post-harvest losses due to pest infestations, while preserving both the nutritional and physical quality of the treated products. This has important implications for the export industry, as it supports the continued growth of India's horticulture and floriculture sectors by reducing post-harvest losses and ensuring compliance with international safety standards.

The observed differences in sorption and residue patterns between roses and chrysanthemums underscore the importance of tailoring fumigation practices to commodity-specific characteristics. Genus-specific variations in physical and chemical properties, such as moisture content, petal structure, and metabolic activity, must be considered when developing fumigation protocols to optimise treatment efficiency and minimise residues. Furthermore, the regulatory void concerning chrysanthemum MRLs highlights the need for international bodies, such as the Codex Alimentarius Commission, to establish guidelines for ornamental crops.

Despite the promising results, certain limitations and concerns associated with the use of phosphine fumigation warrant further investigation. One major drawback is the potential for developing phosphine resistance in pests, which could reduce the long-term efficacy of phosphine treatments. Monitoring pest resistance levels across different regions and commodity types will be crucial to ensure the continued effectiveness of phosphine fumigation.

Additionally, while phosphine showed minimal impact on the quality and nutritional attributes of the treated commodities, its long-term effects on the shelf-life of perishable goods and on consumers' health, particularly for ornamental crops like Chrysanthemum, remain uncertain.

6.1 Future Scope

Although this study has provided valuable insights into the use of phosphine fumigation for maintaining the quality and safety of export-oriented perishable commodities, several areas offer significant potential for future research and improvement. One such area is the optimization of fumigation parameters. While this study did not find significant effects on quality parameters, there is still scope to fine-tune the fumigation process by adjusting concentrations, exposure durations, and environmental conditions such as temperature and humidity. Future research should explore these factors in greater detail, with a particular focus on balancing pest control efficacy with minimal sorption and residue accumulation, ensuring compliance with international food safety standards.

Another key area for further research is the extension of this study to a wider range of commodities. While this research focused on mango, pomegranate, bitter gourd, green chilli, rose, and chrysanthemum, there is a need to assess how phosphine fumigation impacts other perishable commodities such as berries, citrus fruits, and leafy vegetables. Different commodities may exhibit unique sorption behaviors or require modified fumigation protocols. Expanding the scope of the study to include a broader range of fruits, vegetables, and flowers would enhance the understanding of phosphine's overall effectiveness and safety across various produce types.

Future studies could also delve deeper into long-term residue analysis and the potential accumulation of phosphine residues during extended storage or transportation. While this study found that residues remained within permissible limits, further research should investigate the behavior of phosphine residues under real-world storage conditions. Understanding how these residues behave over longer periods would provide a clearer picture of the safety of phosphine fumigation for both consumers and international markets.

Improving post-harvest treatment infrastructure is another area with great potential. The lack of adequate treatment facilities, such as fumigation chambers and cold storage, remains a significant constraint in India's horticultural sector. There is a need for the establishment of more efficient treatment facilities, particularly in export centers, to reduce post-harvest losses. These improvements would ensure that both fresh produce and flowers are preserved to meet international quality standards, thus enhancing India's competitiveness in the global export market. Future research could explore consumer and market acceptance of phosphine-treated produce. Understanding how phosphine fumigation affects consumer preferences, taste, and overall product acceptability is critical for determining the marketability of fumigated commodities. Studies focusing on the sensory qualities of treated produce, as well as

consumer awareness and concerns about food safety, would provide valuable insights into the economic feasibility of phosphine as a post-harvest treatment.

By addressing these future research directions, the post-harvest fumigation process can be refined, ensuring that phosphine fumigation remains a viable and effective method for preserving the quality and safety of export-oriented perishable commodities. This will contribute not only to reducing post-harvest losses but also to meeting the increasing demand for high-quality, safe food in international markets.

6.2 Social Impact

The social impact of this research on phosphine fumigation and its effect on post-harvest preservation is multifaceted, particularly in agriculture and food security. One of the key findings of this study is that the nutritional parameters of perishable commodities, such as fruits, vegetables, and flowers, remained largely intact after phosphine fumigation. This is crucial as it ensures that the nutritional value of the produce is preserved during storage and transportation, leading to high-quality perishable goods reaching consumers without any loss of nutritional content.

The use of phosphine fumigation for preserving the quality of export-oriented crops like fruits, vegetables, and flowers can reduce post-harvest losses, which are a major concern in agriculture. By extending the shelf life and maintaining the quality of produce, farmers and exporters can ensure better marketability and profitability. This, in turn, supports the livelihoods of agricultural workers, including farmers, packers, and distributors, by improving the economic stability of the agricultural sector.

The adoption of safe and effective fumigation techniques like phosphine can enhance the global competitiveness of Indian agricultural exports. By complying with international food safety standards, India can strengthen its position in the global marketplace, thereby boosting national economic growth and fostering international trade relations.

Reduction in post-harvest losses contributes to food security by making more produce available for consumption and export, which can help address hunger and malnutrition, particularly in regions where food supply chains are inefficient. This is especially important in a country like India, where significant quantities of fruits, vegetables, and flowers are lost due to inadequate post-harvest management. By improving the post-harvest treatment processes, such as fumigation, the quality of the produce can be preserved, reducing waste and ensuring that more food reaches consumers in optimal condition.

On a broader scale, the ability to preserve perishable commodities through effective fumigation methods also promotes sustainability. It encourages more efficient use of agricultural resources; as fewer crops need to be discarded. This has a positive impact on environmental sustainability by reducing the energy, water, and other resources required to grow and transport new crops to replace those that are lost.

Lastly, by addressing the challenges related to the export of agricultural goods, the research and application of post-harvest treatments contribute to rural development. The increased demand for high-quality produce can lead to the development of rural infrastructure, such as improved storage facilities, transportation networks, and export processing units. These developments can help uplift communities, creating job opportunities and improving the standard of living for people in rural areas.

Thus, the social impact of research focused on improving post-harvest treatments is wide-ranging, encompassing economic, social, environmental, and health benefits for both local communities and the global market.

REFERENCES

1. Abbott, J. (2004). Textural Quality Assessment for Fresh Fruits and Vegetables. Quality ofFresh and Processed Foods, 542, 265-279.
2. Abhishek, R. U., S., T., Kiragandur, M., & Mohana, D. C. (2014). Pest Infestations and Contaminants in Foodstuffs: A Major Cause for the Decline of India's Contribution to the Global Food Market. Proceedings of the Indian National Science Academy, 80, pp. 931-935.
3. Adhikari, B. M., & Pradhan, N. (2014). Study on functional properties of selected chilli varieties grown in Kathmandu, Nepal. Journal of microbiology, biotechnology and food sciences, 3(6), 488-490.
4. Agarwal, M., Ren, Y., Newman, J., & Learmonth, S. (2015). Ethyl Formate: A Potential Disinfestation Treatment for Eucalyptus Weevil (Gonipterus platensis) (Coleoptera: Curculionidae) in Apples. Journal of Economic Entomology, 108(6), 1-6.
5. Ahmed, Q., Ren, Y., Emery, R., Newman, J., & Agarwal, M. (2018). Evaluation of Ethyl Formate, Phosphine, and Their Combination to Disinfest Harvested Celery against Purple Scum Springtails. HortTechnology, 28(4), 492–501.
6. Al-Dairi, M., Pathare, P. B., & Al-Yahyai, R. (2021). Chemical and nutritional quality changes of tomato during postharvest transportation and storage. Journal of the Saudi Society of Agricultural Sciences, 20(6), 401-408.
7. Al-Sayyed, H. F., Al-Kurd, R., Mwalla, M., Arafat, T., & AbdelQader, S. (2019). Spectrophotometric Evaluation of Antioxidant Content and Capacity of Three Aqueous Extracts of Four Types of Capsicum Annuum (Pepper) Grown in Jordan. Jordan Journal of Chemistry, 14(4), 139-146.
8. Alvarez-Parrilla, E., Rosa, L. d., Amarowicz, R., & Shahidi, F. (2010). Antioxidant Activity of Fresh and Processed Jalapeño and Serrano Peppers. Journal of Agricultural and Food Chemistry, 59(1), 163-173.
9. Amorós, A., Pretel, M. T., Zapata, P. J., et al. (2008). "Postharvest responses of ornamental flowers to ethylene treatments." Postharvest Biology and Technology, 48(1), 56-62
10. Ananda, N., Kotikal, Y. K., & Balikai, R. A. (2009). Sucking insect and mite pests of pomegranate and their natural enemies. Karnataka J. Agric. Sci., 22 (4), 781-783.
11. Ansari, M. S., Basri, R., & Shekhawat, S. S. (2019). Insect Pests Infestation During Field and Storage of Fruits and Vegetables. In A. Malik, Z. Erginkaya, & H. Erten, Health and Safety Aspects of Food Processing Technologies (pp. 121-207). Springer.
12. AO, M., Topno, S. E., & Kerketta, A. (2022). Varietal evaluation of Chilli (Capsicum annuum) under Prayagraj agro-climatic conditions. The Pharma Innovation Journal, 11(2), 2454-2556.
13. AOAC. (1990). Official Methods of Analysis,15th edition. 1028-39. (K. Helrich, Ed.) Arlington, VA: Association of Official Analytical Chemists Inc.
14. AOAC. (2000). Official Methods of Analysis, 17th edition. Washinton DC: Association of Official Analytical Chemists.

15. Apak, R., Güçlü, K., Ozyürek, M., & Karademir, S. E. (2004). Novel total antioxidant capacity index for dietary polyphenols and vitamins C and E, using their cupric ion reducing capability in the presence of neocuproine: CUPRAC method. J Agric Food Chem, 52(26), 7970-81.
16. Apeda.(2012).http://apeda.in/agriexchange/Market%20Profile/MOA/Product/Pomegranate.Retrieved from apeda.in: http://apeda.in/agriexchange/Market%20Profile/MOA/Product/Pomegranate.pdf
17. APEDA. (2024). Retrieved from Apeda: https://apeda.gov.in/apedawebsite/six_head_product/FFV.htm
18. Arah, I. K., Ahorbo, G. K., Anku, E. K., Kumah, E. K., & Amaglo, H. (2016). Postharvest Handling Practices and Treatment Methods for Tomato Handlers in Developing Countries: A Mini Review. Advances in Agriculture. doi:https://doi.org/10.1155/2016/6436945
19. Arif, M. J., Gogi, M. D., Sufyan, M., Nawaz, A., & Sarfraz, R. M. (2017). Principles of Insect Pests Management. In Sustainable Insect Pest Management (pp. 17-47).
20. Armstrong, J. W. (1992). Fruit fly disinfestation strategies beyond methyl bromide. New Zealand Journal of Crop and Horticultural Science, 20, 181-193.
21. Armstrong, J. W. (1992). Fruit fly disinfestation strategies beyond methyl bromide. New Zealand Journal of Crop and Horticultural Science, 20, 181-193.
22. Ayele, L., Tsadik, K., Abegaz, K., & Yetneberk, S. (2012). Postharvest Ripening and Shelf Life of Mango (Mangifera indica L.) Fruit as Influenced by 1-Methylcyclopropene and Polyethylene Packaging. Ethiop. J. Agric. Sci., 22, 26-44.
23. Babu, M., Mahmud, A., Basunia, A. K., & Iqbal, T. (2020). Preparation and Storage Quality of Green Chilli (Capsicum Annuum L.) Powder and Paste. Acta Scientific Agriculture, 4(2), 1-9.
24. Bala, S., Gautam, K. K., & Sahu, M. (2020). A review of Post-Harvest Management and value addition of horticultural crops: A source of income generation for the farmers of Easter Uttar Pradesh. International Journal of Creative Research Thoughts (IJCRT), 8(7), 3772-77.
25. Baldwin, , E., Burns, J., Kazokas, W., Brecht, J., Hagenmaier, R., Bender, R., & Pesis, , E. (1999). Effect of two edible coatings with different permeability Effect of two edible coatings with different permeability. Postharvest Biology and Technology, 17(3), 215-226.
26. Bana, J., Sharma, H., Chavan, S., Sharma, D., & Patil, S. (2023). Assessment of losses caused by major insect-pests and diseases of mango (Mangifera indica L) under humid tropics. Pest Management in Horticultural Ecosystems, 29(2), 213-220.
27. Banks, H. (1992). Uptake and release of fumigants by grain: sorption/desorption phenomena. In S. Navarro, & E. Donahaye (Ed.), Proceedings of an International Conference on Controlled Atmosphere and Fumigation in Grain Storages, (pp. 241-260). Winnipeg, Canada.
28. Bodbodak, S., & Moshfeghifar, M. (2016). Advances in controlled atmosphere storage of fruits and vegetables. In Eco-Friendly Technology for Postharvest Produce Quality (pp. 39-76).

29. Bora, L., Singh, A., & Singh, C. (2017). Characterization of mango (Mangifera indica L.) genotypes based on physio-chemical quality attributes. Journal of Applied and Natural Science, 9(4), 2199-2204.
30. Boyar, S., Bayhan, A., & Dikmen, E. (2013). Investigation on drying behavior of isparta rose flowers (Rosa Damascena mill.) Under natural shade conditions. Bulgarian Journal of Agricultural Science, 19(2), 361-374.
31. Britton, G. (1995). Structure and properties of carotenoids in relation to function. The FASEB Journal, 9(15), 1551-1558.
32. Cano, M., & De Ancos, B. (1994). Carotenoid and carotenoid ester composition in mango fruit as influenced by processing method. J. Agric. Food Chem, 42, 2737-2742.
33. Cantin, C. M., Minas, I., Goulas, V., Jiménez, M., Manganaris, G., Michailides, T. J., & Crisosto, C. (2012). Sulfur dioxide fumigation alone or in combination with CO2-enriched atmosphere extends the market life of highbush blueberry fruit. Postharvest Biology and Technology, 67, 84-91.
34. Castro-Concha, L., Tuyub-Che , J., Moo-Mukul , A., Vazquez-Flota , F., & Miranda-Ham , M. (2014). Antioxidant Capacity and Total Phenolic Content in Fruit Tissues from Accessions of Capsicum chinense Jacq. (Habanero Pepper) at Different Stages of Ripening. The Scientific World Journal.
35. Catania, P., Comparetti, A., Pasquale, C. D., Morello, G., & Vallone, M. (2020). Effects of the Extraction Technology on Pomegranate Juice Quality. Agronomy, 10(1483), 1-14.
36. CDC-NIOSH. (2011). 1988 OSHA PEL Project Documentation. Retrieved from https://www.cdc.gov/niosh/pel88
37. Cha, G. H., Prathibhani, H. M., Kumariham, C., Kim, H. L., Kwack, Y. B., & Kim, J. G. (2019). Storage Temperature Influences Fruit Ripening and Changes in Organic Acids of Kiwifruit Treated with Exogenous Ethylene. HORTICULTURAL SCIENCE and TECHNOLOGY, 37(5), 618-629.
38. Chen, Y., Hu, X., Shi, Q., Lu, Y., Yan, J., Wu, D.-T., & Qin, W. (2023). Changes in the Fruit Quality, Phenolic Compounds,and Antioxidant Potential of Red-Fleshed Kiwifruit during Postharvest Ripening. Foods, 12(1509).
39. Chitravathi, K., Chauhan, O., & Raju, P. (2016). Shelf life extension of green chillies (Capsicum annuum L.) using shellac-based surface coating in combination with modified atmosphere packaging. Journal of Food Science and Technology, 53, 3320-3328.
40. DA&FW. (2023). ANNUAL REPORT 2022-23.
41. Dahal, K., Sharma, M., Dhakal, D., & Shakya, S. (2006). Evaluation of heat tolerant chilli (Capsicum annuum l.) Genotypes in western terai of Nepal. Journal of the Institute of Agriculture and Animal Science., 27(1), 59-64.
42. Dahiya, D., Unnikrishnan, D., Gupta, A., Sehrawat, S., & Siddiqui, S. (2003). Dehydration of annual chrysanthemum (C. coronarium). Acta Hortic., 624, 385-388.
43. Darby, J. A. (2008). A kinetic model of fumigant sorption by grain using batch experimental data. Pest Manag Sci, 64, 519-526.
44. Dirpan, A., Sapsa, M. T., Syarifuddin, A., Tahir, M., Ali, K., & Muhammad, A. K. (2018). Quality and Storability of Mango During Zero Energy Cool Chamber (ZECC). International Journal of Agriculture System, 6(2), 119-129.

45. Dubey, A., & Anchal, L. S. (2020). Post-Harvest Quality. In Advnaces in Agriculture Sciences (pp. 51-71).
46. Dumbravă, D.-G., Moldovan, C., Raba, D.-N., Popa, M.-V., & Drugă, M. (2016). Evaluation of antioxidant activity, polyphenols and vitamin C content of some exotic fruits. Journal of Agroalimentary Processes and Technologies, 22(1), 13-16.
47. Erturk, S., & Alkan, M. (2022). Efficacy of Phosphine Fumigation under Cold Temperature against Frankliniella occidentalis (Pergande, 1895) (Thysanoptera: Thripidae) on Carnation. European Journal of Science and Technology, 41, 144-149.
48. Erturk, S., Sen, F., Alkan, M., & Olculu, M. (2018). Effect of different phosphine gas concentrations against Frankliniella occidentalis (Pergande, 1895) (Thysanoptera: Thripidae) on tomato and green pepper fruit, and determination of fruit quality after application under low-temperature storage conditions. Türk. entomol. derg., 42(2), 85-92.
49. Eseberri, I., Trepiana, J., Léniz, A., Gómez-García, I., Carr-Ugarte, H., González, M., & Portillo, M. P. (2022). Variability in the Beneficial Effects of Phenolic Compounds: A Review. Nutrients, 14(9), 1929.
50. EU. (2016). COMMISSION REGULATION (EU) 2016/1785. Official Journal of the European Union.
51. Fallik, E. (2004). Prestorage hot water treatments (immersion, rinsing and brushing). Postharvest Biology and Technology, 32, 125-134.
52. FAO. (1975). Recommended methods for the detection and measurement of resistance of agricultural pests to pesticides. Tentative method for adults of some major pest species of stored cereals, with methyl bromide and phosphine - FAO Method no. 16. Plant Protection Bulletin.
53. FAO. (2019). The State of Food and Agriculture 2019. Moving forward on food loss and waste reduction. Food and Agriculture Organization of the United Nations.
54. FAO. (2023). FAO in India, India at a glance.
55. Fennema, O. (1996). Food Chemistry. New York (3rd eds.): Marcel Dekker Inc.
56. Fischer, U., Jaksch, , A., Carle, R., & Kammerer, D. (2013). Influence of origin source, different fruit tissue and juice extraction methods on anthocyanin, phenolic acid, hydrolysable tannin and isolariciresinol contents of pomegranate (Punica granatum L.) fruits and juices. Eur. Food Res. Technol., 237, 209-221.
57. Friedemann, A., Andernach, L., Jungnickel, H., Borchmann, D. W., Baltaci, D., Laux, P., Schulz, H., Luch, A. (2020). Phosphine fumigation – Time-dependent changes in the volatile profile of table grapes. Journal of Hazardous Materials.
58. Gaffney, J., Hallman, G., & Sharp, J. (1990). Vapor Heat Research Unit for Insect Quarantine Treatments. Journal of Economic Entomology, 83(5), 1965-1971.
59. Gajanana, T., Murthy, D. S., & Sudha, M. (2011). POST HARVEST LOSSES IN FRUITS AND VEGETABLES IN SOUTH INDIA – A REVIEW OF CONCEPTS AND QUANTIFICATION OF LOSSES. Indian Food Packer, 65(6), 178-187.
60. Gantait, S., & Pal, P. (2010). Anthocyanin content of spray Chrysanthemum cultivars under polyhouse and open field conditions. Indian Journal of Natural Products and Resources, 1(2), 236-242.

61. Gardeli, C., Varela, K., Krokida, E., & Mallouchos, A. (2019). Investigation of Anthocyanins Stability from Pomegranate Juice (Punica Granatum L. Cv Ermioni) under a Simulated Digestion Process. Medicines, 6(90).
62. Ginova, A., Mihalev, K., & Kondakova , V. (2013). Antioxidant capacity of petals and leaves from different rose (Rosa damascena mill.) plantations in Bulgaria. International Journal of Pure and Applied Bioscience, 1(2), 38-43.
63. Gupta, J., & Dubey, R. (2018). Factors Affecting Post-Harvest Life of Flower Crops. International Journal of Current Microbiology and Applied Sciences, 7(1), 548-557.
64. Gupta, K., & Khetarpal, R. K. (2005). Facilitating trade in fresh fruits and vegetables by developing disinfestation protocols: a case study. OEPP/EPPO.
65. Gurjar, A., Laishram, N., Singh, A., Pandey, R., & Sinha, B. (2023). Morphological and Quality Parameters of Chrysanthemum Flowers as Infuenced by Different Pre-drying Treatments and Drying Methods. Agriculture Association of Textile Chemical and Critical Reviews Journal, 11(4), 168-175.
66. Hansen, J. D., & Hara, A. H. (1994). A review of postharvest disinfestation of cut flowers and foliage with special reference to tropicals. Postharvest Biology and Technology, 4, 193-212.
67. Hansen, J. D., & Johnson, J. A. (2007). Introduction. In E. M. Juming Tang, HEAT TREATMENTS FOR POSTHARVEST PEST CONTROL (pp. 1-26). CABI.
68. Hegazy, R. (2016). Post-harvest Situation and Losses in India. doi: 10.6084/M9.FIGSHARE.3206851
69. Hegde, J. N., Ashrith, K. N., Suma, G., Chakravarthy, A., & Gopalkrishna, H. (2020). Insect Pests of Roses and Their Management. In Advances in Pest Mnagement in Commercial Flowers (pp. 85-101). doi:10.4324/9780429284120-6
70. Hodges, R., Buzby, J., & Bennett, B. (2011). Postharvest Losses and Waste in Developed and Less Developed Countries: Opportunities to Improve Resource Use. Journal of Agricultural Science, 149, 37-45.
71. Horn, F. F., Horn, F. P., Horn, P. P., Horn, J. P., & Diaz, R. M. (2010). The USA Patent No. US 7,740,890 B2.
72. Horn, P., Horn, F., Tumambing, J., & Rogers, M. (2010). Studies and Commercial Application of VAPORPH3OS Phosphine Fumigant for Disinfestation of Exported Fruits and Vegetables in South America. Acta Horticulturae, 880, 407-414.
73. Howard, L., Talcott, S., Brenes, C., & Villalon, B. (2000). Changes in phytochemical and antioxidant activity of selected pepper cultivars (Capsicum Species) as influenced by maturity. Journal of Agricultural and Food Chemistry, 48(5), 1713-1720.
74. Igbokwe, G., & Anagonye, C. (2013). Determination of β–Carotene & Vitamin C content of Fresh Green Pepper (Capsicum annnum), Fresh Red Pepper (Capsicum annum) and Fresh Tomatoes (Solanumly copersicum) Fruits. The Bioscientist Journal, 1(1), 89-93.
75. Islam, M., Khan, M., Sarkar, M., Absar, N., & Sarkar, S. (2013). Changes in Acidity, TSS, and Sugar Content at Different Storage Periods of the Postharvest Mango (Mangifera indica L.) Influenced by Bavistin DF. International Journal of Food Science.
76. Jacobi, K. K., MacRae, E. A., & Hetherington, S. E. (2001). Postharvest heat disinfestation treatments of mango fruit. Scientia Horticulturae, 89(3), 171-193.

77. Jamieson, L., Page-Weir, N., Chhagan, A., Brash, D., Klementz, D., Bycroft, B., . . . Woolf, A. (2012). Phosphine fumigation to disinfest kiwifruit. New Zealand Plant Protection, 65, 35-43.
78. Jayalaxmi, Narayan & Hegde, & Ashrith, K & Suma, G & Chakravarthy, Akshay & R., Gopalkrishna. (2020). Insect Pests of Roses and Their Management. 10.4324/9780429284120-6.
79. Jha, S. N., Vishwakarma, R. K., Ahmad, T., Rai, A., & Dixit, A. K. (2016). Assessment of Quantitative Harvest and Post-Harvest Losses of Major Crops/Commodities in India. ICAR-All India Coordinated Research Project on Post-Harvest Technology, ICAR-CIPHET, PO-PAU, Ludhiana-141004 (India).
80. Jiang, X., Yang, M., & Wang, C. (2006). Researches of the resistant mechanism and preventive measures about rose on methyl bromide. Plant Quarantine China, 20(3), 141-142.
81. Jiao, Y., Tang, J., Wang, Y., & Koral, T. L. (2018). Radio-Frequency Applications for Food Processing and Safety. Annual Review of Food Science and Technology, 9, 105-127.
82. Kader, A. (2002). Postharvest Technology of Horticultural Crops. University of California Agriculture and Natural Resources.
83. Kalpana, E. N., Parayil, C., Divya, K. M., & Vijayaraghavan, R. (2023). Do Post-harvest Losses Affect the - Post-Harvest Loss Estimation for Major Vegetables in South India. Asian Journal of Agricultural Extension, Economics & Sociology, 41(08), 277-294.
84. Kalt, W. (2005). Effects of Production and Processing Factors on Major Fruit and Vegetable Antioxidants. JOURNAL OF FOOD SCIENCE, 70(1), R11-R19.
85. Karunaratne, C., Moore, G. A., Jones, R. B., & Ryan, R. F. (1997). Vase Life of Some Cut Flowers Following Fumigation with Phosphine. HortScience, 32(5), 900-902.
86. Kaur, C., Pal, R., Kar, A., Sen, S., Kumar, P., Chandra, R., . . . Khan, I. (2014). Characterization of antioxidants and hypoglycemic potential of pomegranate grown in india: a preliminary investigation. Journal of Food Biochemistry.
87. Kawakami, F., Soma, Y., Tsutsumi, T., Sato, T., Yuge, T., Yamamoto, M., . . . Inque, T. (1996). Disinfestation of Pests on Cut Flowers with Gas Mixtures of Methyl Bromide, Phosphine and Carbon Dioxide. RES. BULL. PL. PROT. JAPAN, 32, 39-46.
88. Kim, B.-S., Hong, K.-J., Kwon, T.-H., Lee, K.-Y., Lee, B.-H., & Lee, S.-E. (2022). Phosphine Fumigation Followed by Cold Treatment to Control Peach Fruit Moth, Carposina sasakii, Larvae on “Fuji” Apples Intended for Export. Appl. Sci., 12(7514).
89. Klementz, D., Heckemüller, H., Reichmuth, C., Huyskens-Keil, S., Büttner, C., Horn, F., & Horn, P. (2005). Disinfestation of table grapes with pure phosphine – residues and quality aspects.
90. Kochhar, A., Nagi, M., & Sachdeva, R. (2006). Proximate Composition, Available Carbohydrates, Dietary Fibre and Anti Nutritional Factors of Selected Traditional Medicinal Plants. Journal of Human Ecology, 19(3), 195-199.
91. Kong, J.-M., Chia, L.-S., Goh, N.-K., Chia, T.-F., & Brouillard, R. (2003). Analysis and biological activities of anthocyanins. Phytochemistry, 64, 923-933.

92. Koppel, K., Anderson, E., & Chambers, E. (2015). Influence of processing on pomegranate (Punica granatum L.) juice flavor and aroma. J. Sci. Food Agric., 95, 1066-1071.
93. Krokida, M., Karathanos, V., Maroulis, Z., & Marinos-Kouris, D. (2023). Drying kinetics of some vegetables. Journal of Food Engineering, 59(4), 391-403.
94. Kumar, P. N. (2012). Post-Harvest Handling of Cut Flowers. Directorate of Floricultural Research. Krishisewa.
95. Kumar, V., Kakkar, G., McKenzie, C. L., Seal, D. R., & Osborne, L. S. (2013). An overview of chilli thrips. Scirtothrips dorsalis (Thysanoptera: Thripidae) biology, distribution and management. In S. S. (eds.), Weed and Pest Control - Conventional and New Challenges (pp. 53-77). Rijeka-Croatia: IntechOpen.
96. Kumari, P., Raju, D., Prasad, K., Singh, K. P., Saha, S., Arora, A., & Hossain, F. (2017). Quantification and correlation of anthocyanin pigments and their antioxidant activities in rose (Rosa hybrida) varieties. Indian Journal of Agricultural Sciences, 87(10), 1340-1346.
97. Kumari, V., Kumar, B., Sinha, N., & Sharma, S. (2021). Comparative Study of Phytochemical Contents of Various Mango (Mangifera indica L.) Cultivars of Bihar. International Journal of Research in Engineering Science and Management., 4(2), 22-26.
98. Kusat, A., Sahoo, A., Lokhande, S., Mote, G., & Udachan, I. (2021). Optimisation of drying process parameters for bitter guard drying. Journal of Postharvest Technology, 9(2), 81-88.
99. Ladaniya, M. S. (2008). FRUIT QUALITY CONTROL, EVALUATION, AND ANALYSIS. In Citrus Fruit (pp. 475-499). Academic Press.
100. Lansky, E., & Newman, R. (2007). Punica granatum (pomegranate) and its potential for prevention and treatment of inflammation and cancer. J. Ethnopharmacol., 109, 177-206.
101. Lee, J., Durst, R. W., & Wrolstad, R. E. (2005). Determination of Total Monomeric Anthocyanin Pigment Content of Fruit Juices, Beverages, Natural Colorants, and Wines by the pH Differential Method: Collaborative Study. JOURNAL OF AOAC INTERNATIONAL, 88(5), 1269-1278.
102. Lee, J., Lee, H., & Choung, M. (2011). Anthocyanin compositions and biological activities from the red petals of Korean edible rose (Rosa hybrida cv. Noblered). Food Chemistry, 129, 272-78.
103. Lee, S. K., & Kader, A. A. (2000). Preharvest and postharvest factors influencing vitamin C content of horticultural crops. Postharvest Biology and Technology, 20(3), 207-220.
104. Liguori, G., Gentile, C., Sortino, G., Inglese, P., & Farina, V. (2020). Food Quality, Sensory Attributes and Nutraceutical Value of Fresh “Osteen” Mango Fruit Grown under Mediterranean Subtropical Climate Compared to Imported Fruit. Agriculture, 10(4).
105. Liu, S. S., Liu, Y.-B., & Simmons, G. S. (2015). Oxygenated Phosphine Fumigation for Control of Light Brown Apple Moth (Lepidoptera: Tortricidae) Eggs on Cut-Flowers. J. Econ. Entomol., 108(4), 1630-1636.

106. Liu, Y.-B. (2018). Low-Temperature Fumigation of Harvested Lettuce Using a Phosphine Generator. Journal of Economic Entomology, 111(3), 1171-1176.
107. Liu, Y.-B. (2018). Low-Temperature Fumigation of Harvested Lettuce Using a Phosphine Generator. Journal of Economic Entomology, 111(3), 1171-1176.
108. Magfiroh, A., Hastuti, E. D., Nurchayat, Y., & Setiari, N. (2023). Anthocyanin Content and Antioxidant Activity of Red Chrysanthemum (Chrysanthemum morifolium Ramat.) at Different Flower Ages. Borneo Journal of Resource Science and Technology, 13(1), 72-80.
109. Mahajan, P., Caleb, O., Singh, Z., Watkins, C. B., & Geyer, M. (2014). Postharvest treatments of fresh produce. Philosophical Transactions of the Royal Society, 372.
110. Maity, A., Gaikwad, N., Babu, K., More, A., & Sarkar, A. (2019). Physico-chemical and nutritional characteristics of main pomegranate (Punica granatum L.) cultivars grown in Deccan Plateau. Agrochimica, LXIII, 105-121.
111. Mandal, G., & Thokchom, R. (2018). Evaluation of different mango (Mangifera indica L.) varieties for high density orchard in lateritic zone of eastern India. Indian Journal of Agricultural Sciences, 88(12), 28-30.
112. Manolopoulou, E., Varzakas, T. H., & Petsalaki, A. (2016). Chlorophyll Determination in Green Pepper Using two Different Extraction Methods. Current Research in Nutrition and Food Science Journal, 4(1), 52-60.
113. Maurya, A. K., Kushwaha, M., Maurya, S., & Panchbhaiya , A. (2017). Estimation of Per se performace of chilli (Capsicum annuum L.) genotypes for yield and quality traits. Journal of Pharmacognosy and Phytochemistry, 6(1), 333-335.
114. Meena, N. K., & Asrey, R. (2018). Tree Age Affects Postharvest Attributes and Mineral Content in Amrapali Mango (Mangifera indica) Fruits. Horticultural Plant Journal, 4(2), 55-61.
115. Meenatchi, R., Vanmath, K., & Brimapureeswaran, R. (2016). Studies on the Sorption of Phosphine in Paddy and Rice. Advances in Life Sciences, 5(16), 5968-5973.
116. Mei-zi, Z., Guang-bin, W., & Fa-he, C. (2014). Effect of Nitric Oxide Fumigation on Lignification of Loquat Fruits during Cold Storage. FOOD SCIENCE, 35(16), 232-237.
117. Mekapogu, M., Vasamsetti, B., Kwon, O.-K., Ahn, M.-S., Lim, S.-H., & Jung, J.-A. (2020). Anthocyanins in Floral Colors: Biosynthesis and Regulation in Chrysanthemum Flowers. Int J Mol Sci., 21(18).
118. Miguel, G., Dandlen, S., Antunes, D., Neves, A., & Martins, D. (2004). The Effect of Two Methods of Pomegranate (Punica granatum L) Juice Extraction on Quality During Storage at 4°C. Journal of Biomedicine and Biotechnology, 2004(5), 332-337.
119. Ministry of Agriculture & Farmers Welfare. (2023, March 24). POST HARVEST LOSS OF FRUITS AND VEGETABLES. Delhi.
120. Mir, M., Jhon, A., Khan, F., & Nelofar. (2007). Studies on physical and chemical characteristics of pomegranate cultivars in Kashmir valley. J. Hort. Sci, 2(2), 139-142.
121. Mitra, S., Banik, A. K., Mani, A., & Kuchi, V. S. (2019). TRENDS AND PROSPECTS IN POST-HARVEST MANAGEMENT OF HORTICULTURAL CROPS. Today and Tomorrow's Printers and Publishers.

122. Moon, D.-G., Cho, K.-M., Kim, C.-H., Seong, K.-C., Son, D., Cho, M.-W., . . . Cho, I.-H. (2014). Content of vitamin C and physiological properties of bitter gourd cultivars in plastic greenhouse. Acta Horticulturae, 1037, 407-412.
123. Mousavi, Z., Mousavi, S., Razavi, S., Emam-Djomeh, Z., & Kiani, H. (2010). Fermentation of pomegranate juice by probiotic lactic acid. World J Microbiol Biotechnol, 27, 123-128.
124. Mphahlele, R., Fawole, O., Mokwena, L., & Opara, U. (2016). Effect of extraction method on chemical, volatile composition and antioxidant properties of pomegranate juice. South African Journal of Botany, 103, 135-144.
125. Muralidhara, B., Veena, G., Rajan, S., Bhattacharjee, A., & Hudedamani, U. (2018). Effect of post-harvest ripening on bioactive secondary metabolites and antioxidant activity in mango cv. Amrapali. J. Hortl. Sci, 13(2), 152-158.
126. Murlidhara, B., Veena, G., Bhattacherjee, A., & Rajan, S. (2019). Antioxidants in ripe peel and pulp of twelve mango (Mangifera indica) cultivars. Indian Journal of Agricultural Sciences, 89(10), 1580-4.
127. Nath, P., & Jha, S. (2020). Potential and Challenges of Indian Floriculture Industry. International Journal of Applied Agricultural Sciences, 6(4), 61-65.
128. Navarro, S. (2019). Controlled atmosphere storage in fruits and vegetables. Postharvest Management of Horticultural Crops, 49-72.
129. Navarro, S., Navarro, J. L., & Rojas-Argudo, C. (2015). Advances in controlled atmosphere storage of fruits and vegetables. Critical Reviews in Food Science and Nutrition, 55(11), 1462-1483.
130. Negi, P., & Jayapraksha, G. (2003). Antioxidant and antimutagenic activities of pomegranate peel extracts. Food Chem., 80, 393-397.
131. Nolpradubphan, A., & Lichanporn, I. (2016). Effect of nitric oxide on postharvest quality of lime fruit (Citrus aurantifolia Swingle). Asia-Pacific Journal of Science and Technology, 21(1), 86-96.
132. Nowicki, T. W. (1978). Gas-liquid chromatography and flame photometric detection of phosphine in wheat. J Assoc Off Anal Chem., 61(4), 829-836.
133. Obenland, D., Cranney, J. R., Tebbets, S., Walse, S., & Arpaia, M. L. (2021). Fumigating Citrus with Phosphine Does Not Impact Marketability or Eating Quality. Plant Health Progress, 22, 516-523.
134. Obi, O. F., Ezeoha, S., & Egwu, C. (2016). Evaluation of air oven moisture content determination procedures for pearl millet (Pennisetum glaucum L.). International Journal of Food Properties, 454-466.
135. Ozgen, M., Durgac, C., Serce, S., & Kaya, C. (2008). Chemical and antioxidant properties of pomegranate cultivars grown in the Mediterranean region of Turkey. Food Chem., 111, 703-706.
136. Palanisingh, V., & Vijayalakshmi, R. (2022). FLORICULTURE EXPORTS IN INDIA-DIRECTION AND TRENDS. RABINDRA BHARATI JOURNAL OF PHILOSOPHY, 30-36.
137. Palanisingh, V., Vijayalakshmi, R., Palanichamy, V., Samundeswari, R., & Jeyapandiyan, N. (2022). Floriculture Exports In India-Direction And Trends. RABINDRA BHARATI JOURNAL OF PHILOSOPHY, 23(01), 30-36.

138. Park, M.-G., Sung, B.-K., & Tumambing, J. (2010). Effect of PH3 and CO2 mixture as a quarantine fumigant in cut flowers. Annual International Research Conference on Methyl Bromide Alternatives and Emissions Reductions. Florida.
139. Paslı, a., Yavuz-Düzgün, M., Altuntaş, Ü., & Altin-Yavuzarslan, G. (2019). In vitro bioaccessibility of phenolics and flavonoids in various dried vegetables, and the determination of their antioxidant capacity via different spectrophotometric assays. International Food Research Journal, 26(3), 793-800.
140. Patel, D. K., Chawla, S., & Vithu, G. N. (2018). Effect of Botanicals on vase life of cut flowers: A Review. Bulletin of Environment, Pharmacology and Life Sciences, 8(1), 1-8.
141. Patel, K., Saxena, S., & Patel, K. (2013). Fluctuation of fruit fly oriented damage in mango in relation to major abiotic factors. HortFlora Research Spectrum, 2(3), 197-201.
142. Paul, R., & Ghosh, U. (2012). Effect of thermal treatment on ascorbic acid content of pomegranate juice. Indian Journal of Biotechnology, 11(3), 309-313.
143. Pidakala, P., Esfandi, K., Afsar, S., Baldassarre, C., Ortiz, G., Page-Weir, N., . . . Woolf, A. B. (2022). Effects of phosphine (ECO2FUME®) on 'Hass' avocado fruit quality and target pest mortality. New Zealand Journal of Crop and Horticultural Science.
144. Pleguezuelo, C., Zuazo, V. D., Fernández, J., & Tarifa, D. (2012). Physico-chemical Quality Parameters of Mango (Mangifera indica L.) Fruits Grown in a Mediterranean Subtropical Climate (SE Spain). J. Agr. Sci. Tech., 14, 365-374.
145. Poonam, Jakhar, R. K., Kumawat, P., Prajapat, A., & Kumawat, S. (2022). Post-Harvest Management of Fruits and Vegetables. 148-160.
146. Porat, R., & Ben-Yehoshua, S. (2005). Heat Treatments to Reduce Decay. Environmentally Friendly Technologies for Agricultural Produce Quality, 11-42.
147. Prabawa, S., Raida, A., Hartanto, R., & Yudhistira, B. (2023). The physicochemical quality of yellow chrysanthemum flower (Chrysanthemum indicum) brewed drink. Food Research, 7(3), 12-21.
148. Prabawati S., Sjafrina N., Sulistyaningrum A., Rahayu E., Widayanti S.M., Waryat, Ahmadi N.R., Rachmawati F., Arif A.B. (2023). Increasing the Vase Life of Chrysanthemum Cut Flowers by Using Silver and Zinc Nanoparticles. Scientific World Journal, 8871491.
149. Qin, G., & Xiaojun M. (2013). Composition and antioxidant activity of anthocyanins isolated from Yunnan edible rose. Food Science and Human Wellness, 2, 68-74.
150. Raghuteja, P.; Rao, Chalapathi; Rao, A.V.D. (2023). Pests of Chrysanthemum in Winter Season. *Just Agriculture Newsletter*. 3(5).
151. Rahayu, S., Kirana, R., & Levianny, P. (2021). Quality evaluation for chilli hybrid variety candidate cultivated on highland. Annual Conference on Science and Technology (ANCOSET 2020). 1869. IOP Publishing.
152. Rai, R. K., & Singh, P. (2022). Postharvest deterioration of tomato and it's management strategies: a review. Journal of Postharvest Technology, 10(3), 78-93.
153. Ramasamy, S., Mohanty, S. P., & Goud, V. V. (2020). Integrated pest management in sustainable agriculture: Innovations and policy challenges. In Handbook of Research on Organic Farming for Sustainable Agriculture. (pp. 159-176). IGI Global.

154. Ranjbari, F., Moradinezhad, F., & Khayyat, M. (2016). Effect of nitric oxide on biochemical and antioxidant properties of pomegranate fruit cv. Shishe-kab during cold storage. International Journal of Horticultural Science and Technology, 3(2), 211-219.
155. Ranjbari, F., Moradinezhad, F., & Khayyat, M. (2018). Effect of Nitric Oxide and Film Wrapping on Quality Maintenance and Alleviation of Chilling Injury on Pomegranate Fruit. J. Agr. Sci. Tech., 20, 1025-1036.
156. Reddy, P., Rajashekar, Y., Begum, K., Leelaja, B., & Rajendran, S. (2007). The relation between phosphine sorption and terminal gas concentrations in successful fumigation of food commodities. Pest Manag Sci, 63(1), 96-103.
157. Reddy, K. G., Reddy, A. S., & Reddy, M. S. (2011). Adoption of Integrated Pest Management (IPM) in chilli (Capsicum annuum L.): A case study from Guntur District, Andhra Pradesh. J. Hortl. Sci., 159-162.
158. Reddy, P. V., Baradevanal, U., & Chakravarthy, A. (2018). Pests of Mango. In Pests and Their Management (pp. 415-440). Springer Nature Singapore Pte Ltd.
159. Reed, C., & Pan, H. (2000). Loss of phosphine from unsealed bins of wheat at six combinations of grain temperature and grain moisture content. Journal of Stored Products Research, 36, 263-279.
160. Rodriguez-Amaya, D. B. (2001). A GUIDE TO CAROTENOID ANALYSIS IN FOODS. ILSI PRESS.
161. Rogers, D., Bycroft, B., Somerield, K., Brash, D., Klementz, D., Cole, L., . . . Waddell, B. (2013). Efficacy of phosphine fumigation of apples for codling moth (Cydia pomonella) disinfestation. New Zealand Plant Protection, 66, 75-81.
162. Roy, S. K. (1973). Simple rapid method for estimation of total carotenoid pigments in mango. Journal of Food Science and Technology, 10(45).
163. Samreen, Chilukuri, S. v., Lingathoti, E., & Beera, V. (2020). Physicochemical Characteristics of Pomegranate and Pineapple Juice. Indian Journal of Ecology, 47(11), 60-63.
164. Sandarani, M., DCMCK, D., & CVL, J. (2018). Strategies Used to Prolong the Shelf Life of Fresh Commodities. Journal of Agricultural Science and Food Research, 9(1).
165. Sardana, H., Bhat, M., Ahuja, D., & Sehgal, M. (2017). Validated Integrated Pest Management Strategies for Major Vegetable Crops. Technical bulletin, National Research Center for Integrated Pest Management, ICAR.
166. Sarker, M., Hasan, S., Aziz, M., Islam, M., Azam, S., Roy, S., & Ibrahim, M. (2012). The Effect of Processing Treatments on the Shelf Life and Nutritional Quality of Green Chilli (Capsicum annuum L.) Powder. Pertanika J. Trop. Agric., 35(4), 855-864.
167. Satin, M., & Loaharanu, P. (1997). Irradiation as an Alternative Post Harvest Treatment. NAPPO Proceedings, (pp. 19-28). Mexico.
168. Sato, K., & Suwanai, M. (1974). Adsorption of hydrogen phosphide to cereal products. Appl Entomol Zool, 9, 127-132.
169. Saxena, M., & Gandhi, C. (2014). Major mango and guava producing countries in the world. Indian Horticulture Database.
170. Shamili, M. (2019). The estimation of mango fruit total soluble solids using image processing technique. Scientia Horticulturae, 249, 383-389.

171. Sharma, G., & Singh, S. P. (2011). Economic Analysis of postharvest Losses in Marketing of Vegetables in Uttarakhand. Agricultural Economics Research Review, 24(2).
172. Sharma, J., Sharma, P., Sharma, B., & Chaudhary, P. (2017). In-Vitro Estimation of Antioxidant Activity in Green Chilli (Capsicum Annuum) and Yellow Lantern Chilli (Capsicum Chinense). International Journal of Research and Review, 4(6), 54-61.
173. Singh, P., Kakade, D., Majumder, N., Sridhar, V., Girish, K., Prabha, K., . . . Holajjer, P. (2015). Disease and Pest Management in Flower Crops under Polyhouse. Director, DFR, Pune.
174. Singleton, V. L., Orthofer, R., & Lamuela-Raventós, R. M. (1999). Analysis of total phenols and other oxidation substrates and antioxidants by means of folin-ciocalteu reagent. In Methods in Enzymology (Vol. 299, pp. 152-178).
175. Sisquella, M., Picouet, P., Viñas, I., Teixidó, N., Segarra, J., & Usall, J. (2014). Improvement of microwave treatment with immersion of fruit in water to control brown rot in stone fruit. Innovative Food Science and Emerging Technologies, 26, 168-175.
176. Stable Micro Systems. (2024). Retrieved July 24, 2024, from https://www.stablemicrosystems.com/.
177. Subedi, P., Walsh, K., & Owens, G. (2007). Prediction of mango eating quality at harvest using short-wave near infrared spectrometry. Postharvest Biol. Technol., 43, 326-334.
178. Talcott, S. T., Moore, J. P., Lounds-Singleton, A., & Percival, S. (2006). Ripening associated phytochemical changes in mangos (Mangifera indica) following. Journal of Food Science, 70(5).
179. Tang, J., Ikediala, J. N., Wang, S., Hansen, J. D., & Cavalieri, R. P. (2000). High-temperature-short-time thermal quarantine methods. Postharvest Biology and Technology, 21, 129-145.
180. Tarantino, A., Difonzo, G., Disciglio, G., Frabboni, L., Paradiso, V. M., Gambacorta, G., & Caponio, F. (2022). Fresh pomegranate juices from cultivars and local ecotypes grown in southeastern Italy: comparison of physicochemical properties, antioxidant activity and bioactive compounds. Journal of the science of food and agriculture, 102(3), 1185–1192.
181. Tehranifar, A., Zarei, M., Nemati, Z., Esfandiyari, B., & Vazifeshenas, M. (2010). Investigation of physico-chemical properties and antioxidant activity of twenty Iranian pomegranate (Punica granatum L.) cultivars. Scientia Horticulturae, 126, 180-185.
182. TIWARI, A., AFROZ, S. B., & KUMAR, V. (2021). Market vulnerabilities and potential of horticulture crops in India: with special reference to top crops. Indian Journal of Agricultural Marketing, 35(3).
183. Torre, S., & Fjeld, T. (2001). Water loss and postharvest characteristics of cut roses grown at high or moderate relative air humidity. Scientia Horticulturae, 89(3), 217-226.
184. Tumambing, J., & Dikin, A. (2013). ECO2FUME phosphine fumigant as a primary alternative to Methyl Bromide for QPS application in Indonesia. In Obenauf G. L. (Ed.), Proceedings of the Annual International Research Conference on Methyl Bromide Alternatives and Emissions Reductions, 30-1. San Diego.

185. Tumambing, J., Christenson, C., Taner, A., & Amoroso, D. (2018). Recent Developments in the Global Application of ECO2FUME® and VAPORPH3OS® Phosphine Fumigants. 12th International Working Conference on Stored Product Protection (IWCSPP), (pp. 952-959). Berlin. doi:10.5073/jka.2018.463.205.
186. Türkyılmaz, M., Tagi, S., Dereli, U., & Özkan, M. (2013). Effects of various pressing programs and yields on the antioxidant activity, antimicrobial activity, phenolic content and colour of pomegranate juices. Food Chem., 138, 1810-1818.
187. Ullas, S., Namita, Singh, K., Panwar, S., Kundu, A., Krishnan S., G., & Kumar, G. (2018). Influence of drying techniques on retention of anthocyanin and their antioxidant activities in chrysanthemum (Chrysanthemum × morifolium) flowers. Indian Journal of Agricultural Sciences, 88(2), 228-233.
188. Usall, J., Ippolito, A., Sisquella, M., & Neri, F. (2016). Physical treatments to control postharvest diseases of fresh fruits and vegetables. Postharvest Biology and Technology, 122, 30-40.
189. V´azquez-Caicedo, A., Neidhart, S., & Carle, R. (2004). Postharvest ripening behavior of nine Thai mango cultivars and their suitability for industrial applications. ActaHortic, 645, 617-625.
190. V´azquez-Caicedo, A., Sruamsiri, P., Carle, R., & Neidhart, S. (2005). Accumulation of all-trans carotene and its 9-cis and 13-cis stereoisomers during postharvest ripening of nine Thai mango cultivars. J. Agric. Food Chem, 53, 4827-4835.
191. Van de Berg, H., Faulks, R., Granado, H., Hirschberg, J., Olmedilla, B., Sandmann, G., Southan S., Stahl, W. (2000). The potential for the improvement of carotenoid levels in foods and the likely systemic effects. J. Sci. Food. Agric, 80, 880-912.
192. Van Doorn, W. (2012). Water Relations of Cut Flowers: An Update. In Horticultural Reviews (pp. 55-106).
193. Viuda-Martos, M., Fernández-López, J., & Pérez-Álvarez, J. (2010). Pomegranate and its many functional components as related to human health: a review. Compr. Rev. Food Sci. Food Saf., 9(6), 635-654.
194. Wang, C., & Lin, R. T. (1984). Study on the quarantine treatments of insect pests on chrysanthemum cut flowers--fumigation and smoking methods. Journal of agricultural research of China, 33, 88-93.
195. Wang, Y., Luo, Z., & Du, R. (2015). Nitric oxide delays chlorophyll degradation and enhances antioxidant activity in banana fruits after cold storage. Acta Physiol Plant, 37(74).
196. Wason, S., & Selladurai, M. (2023). Is phosphine an ideal candidate for fruit fly disinfestation in Java apple, *Syzygium samarangense*? *Food and Humanity*, 2023, 662–669.
197. Watada, A. (1995). Methods for determining quality of fruits and vegetables. Acta Horticulturae, 379, 559-568.
198. Watanawan, C., Thananya, W., Srilaong, V., & Wongs-Aree, C. (2014). Near infrared spectroscopic evaluation of fruit maturity and quality of export Thai mango (Mangifera indica L. var. Namdokmai). International Food Research Journal, 21(3), 1073-1078.

199. Weller, G., & Graver, V. S. (1998). Cut flower disinfestation: Assessment of replacement fumigants for methyl bromide. Postharvest Biology and Technology, 14(3), 352-333.
200. Williams, P., & Muhunthan, M. (1998). Fumigants for postharvest control of insect pests of cut flowers. Acta Horticulturae, 96, 291-296.
201. Williams, P., Hepworth, G., Goubran, F., Muhunthan, M., & Dunn, K. (2000). Phosphine as a replacement for methyl bromide for postharvest disinfestation of citrus. Postharvest Biology and Technology, 19, 193-199.
202. Wilson, D., Attri, B., & Sharma, S. K. (2013). Evaluation of different methods for drying of chrysanthemum flowers. THE ASIAN JOURNAL OF HORTICULTURE, 8(2), 743-745.
203. Win, A., & Nyo, A. (2019). Evaluation of Total Phenolic and Flavonoid Content of Pomegranate Juice. Journal of Emerging Technologies and Innovative Research (JETIR), 6(3).
204. Winefield, C., Davies, K., & Gould, K. (2009). Anthocyanins Biosynthesis, Functions, and Applications. Springer.
205. Yaddanapudi, P., Kumar, A. K., Kumar, M. R., Aparna, K., Sathish, G., & Kumar, B. N. (2013). Evaluation of mango (Mangifera indica L.) varieties under ultra-high density planting system in Telangana state. The Pharma Innovation Journal, 12(5), 2483-2489.
206. Yahia, E. M., Jones, R. W., & Thomas, D. B. (2011). Quarantine pests of tropical and subtropical fruits and their control. In E. M. Yahia, Postharvest biology and technology of tropical and subtropical fruits. (Vol. 1, pp. 224-287). Woodhead Publishing.
207. Yang, J., Park, Y., Hyun, I.-H., Kim, G.-H., Kim, B.-S., Lee, B.-H., & Ren, Y. (2016). A Combination Treatment Using Ethyl Formate and Phosphine to Control Planococcus citri (Hemiptera: Pseudococcidae) on Pineapples. Journal of Economic Entomology, 109(6), 2355-2363.
208. Zambrano, M. V., Dutta, B., Mercer, D. G., MacLean, H. L., & Touchie, M. F. (2019). Assessment of moisture content measurement methods of dried food products in small-scale operations in developing countries: A review. Trends in Food Science & Technology, 88, 484-496.
209. Zhang, F., Wang, Y., Li, L., & Liu, T. (2013). Effects of phosphine fumigation on postharvest quality of four Chinese cut flower species. Postharvest Biology and Technology, 86, 66-72.
210. Zhang, F., Wang, Y., Liu, T., Li, L., & Li, T. (2012). Effects of low temperature phosphine fumigation on postharvest quality of white chrysanthemum ‘Dabaiju’. Scientia Horticulturae, 142, 92-97.

LIST OF PUBLICATIONS WITH PROOF

Journal Publications

1. **Research Paper:** Anisha Kathpalia, Sumitra Arora & Jaigopal Sharma. (2024). Sorption and residue analysis of phosphine in fruits and vegetables. *New Zealand Journal of Crop and Horticultural Science.* 1–11. https://doi.org/10.1080/01140671.2024.2394137. Published: 30 Sep 2024.

2. **Review Paper:** Anisha Kathpalia, Sumitra Arora & Jaigopal Sharma. (2024). Impact of different fumigants on the quality of perishables. *Journal of Food Safety and Food Quality*.75(4).96-105. Published: August 2024.

3. **Review Paper:** Anisha Kathpalia, Sumitra Arora & Jaigopal Sharma. (2022). Post-Harvest Pest Management of Perishables: A Review *Journal of Community Mobilization and Sustainable Development.*17(4).1065-1081.

NEW ZEALAND JOURNAL OF CROP AND HORTICULTURAL SCIENCE
https://doi.org/10.1080/01140671.2024.2394137

Taylor & Francis
Taylor & Francis Group

RESEARCH ARTICLE

Sorption and residue analysis of phosphine in fruits and vegetables

Anisha Kathpalia [a,b], Sumitra Arora [b] and Jai Gopal Sharma [a]

[a]Department of Biotechnology, Delhi Technological University, Delhi, India; [b]ICAR–National Research Centre for Integrated Pest Management, Delhi, India

ABSTRACT

This study investigated the sorption and residues of phosphine in fruits and vegetables relevant for export. Sorption patterns varied among the commodities: mango exhibited a constant sorption range of 10–12%, bitter gourd displayed a distinct pattern with peak sorption of 20% at 8 hours, and chilli demonstrated a higher range of sorption percentage, peaking at 60% at 8 hours. ANOVA ($F(4,8) = 0.449$, $p = 0.771$) and regression ($F(1,11) = 0.851$, $p = 0.376$) analysis revealed a non-significant relationship between the sorption percentage and exposure period. Residue analysis using Gas Chromatography with FPD detector revealed relatively low levels of phosphine residues in mango (0.009–0.01 µL/L), negligible traces in chilli samples, residues within the maximum residue limit (MRL) range for bitter gourd after 4–6 hours of aeration. Detecting phosphine residues within acceptable limits underscores the significance of post-fumigation protocols to meet stringent food safety standards, thereby safeguarding product integrity for global trade. Therefore, phosphine fumigation could serve as a viable alternative to methyl bromide fumigation for quarantine treatment of perishables as it doesn't leave detectable toxic residues in produce following aeration and has no role in ozone depletion thus making it a more sustainable solution for international trade in fresh produce.

ARTICLE HISTORY
Received 18 June 2024
Accepted 14 August 2024

KEYWORDS
Fumigation; perishables; export; food safety; international trade

Introduction

To meet the escalating demand for food quality, safety, and security in domestic and international markets, horticultural producers must adopt the safest and most cost-effective methods to manage insect pests. Compared to treatments applied during production, postharvest interventions often offer greater flexibility in aligning treatment schedules with logistical, infrastructural, and regulatory constraints associated with marketing. Despite ongoing advancements in various postharvest strategies such as cold treatments, heat treatments, irradiation, and controlled atmosphere, fumigation retains its significance as an indispensable option for controlling insect pests (Johnson et al. 2012).

For the past many decades, methyl bromide has reigned supreme as a fumigant in the postharvest treatment of horticultural crops. It has been the preferred choice for

CONTACT Anisha Kathpalia anisha.kathpalia@gmail.com
Supplemental data for this article can be accessed online at https://doi.org/10.1080/01140671.2024.2394137.

Journal of Food Safety and Food Quality 75, Heft 4 (2024), Seiten 93–120

Arch Lebensmittelhyg 75,
96–105 (2024)
DOI 10.53194/0003-925X-75-96

ISSN 0003-925X

Korrespondenzadresse:
anisha.kathpalia@gmail.com

[1]) Department of Biotechnology, Delhi Technological University, Delhi, Bawana Rd, Shahbad Daulatpur Village, Rohini, New Delhi, Delhi, 110042, India; [2]) ICAR – National Research Centre for Integrated Pest Management, Delhi, Near Rajpur Khurd Extension, Maidan Garhi, New Delhi, Delhi 110030, India

Impact of different fumigants on the quality of perishables

Auswirkungen verschiedener Begasungsmittel auf die Qualität verderblicher Waren

Anisha Kathpalia[1]), Sumitra Arora[2]), Jai Gopal Sharma[1])

Summary

This paper examines the concerns surrounding the adverse effects of fumigants on the quality of treated perishables. Fumigation is a widely used strategy in the food industry, particularly for exporters, to control insect pests in food commodities under storage. As global trade in perishables continues to expand, the balance between effective fumigation for pest control and preserving product quality becomes increasingly crucial. The selection of an appropriate fumigant is important for a successful export, as the chemical components present in the commodity can interact with the fumigant, leading to changes in flavour, taste, odour, nutritional value, and processing capabilities. Understanding these effects is crucial for optimizing fumigation strategies while maintaining the quality and safety of food commodities. This review provides an overview of the various fumigants used worldwide for fruits and vegetables and evaluates their impact on the quality of treated perishable commodities.

Keywords: Perishables, fumigants, postharvest quality, food quality

Journal of Community Mobilization and Sustainable Development
Vol. 17(4), October-December 2022, 1065-1081

Review Article

Post-Harvest Pest Management of Perishables: A Review

Anisha Kathpalia[1,2], Sumitra Arora[2]* and Jai Gopal Sharma[1]
[1]Department of Biotechnology, Delhi Technological University, Delhi
[2]ICAR-National Research Centre for Integrated Pest Management, Delhi-110012

ABSTRACT

Fruits and Vegetables constitute 90 per cent of the total horticulture production in India. The post-harvest losses in fruits and vegetables account for almost 30-40 per cent which is adversely affecting the country's economy in terms of foreign exchange. In addition to poor harvesting practices, pest infestations as a result of improper storage and transportation contribute to significant losses. Several changes in taste, color, flavor, texture and appearance take place in the harvested fruits and vegetables making them unacceptable for the export market. Therefore, post-harvest losses and preservation of quality have become major issues which need to be addressed to meet the growing domestic and international market demands. This article reviews the common insect pests attacking the perishables and the various Physical/Chemical/ Non-chemical and combination treatments available to prevent pest infestation, thereby improving the post-harvest shelf-life and quality of the perishables. These treatments if assessed and deployed properly, will help India to build a momentum in rapidly emerging export markets.

Keywords: Perishables, Storage, Pests, Management, Postharvest

INTRODUCTION

Fruits and vegetables are not only a vital source of nutrients for a country but also complement it as a high-income source for it (Neeraj *et al.,* 2017). India has been accorded with a climate which is conducive for the growth of fruits and vegetables. Hence, India stands second in production of fruits and vegetables after China. Despite large production, India is not able to achieve significant export of the produce. The country's share is very low at 1 per cent of the total production in the export trade.

These fruits and vegetables are highly perishable entities and prone to deterioration due to biotic and abiotic factors so their storage becomes all the more critical. They have high moisture content as they are biologically active and continue to undergo several biological transitions like transpiration, respiration, ripening and other biochemical activities in transit and storage. India faces enormous post-harvest loss of 30 to 40 per cent of fruits and vegetable due to poor infrastructure in terms of storage and transportation facilities and inadequate pre- and post-harvest management (Hegazy, 2013).

A major threat to the fresh produce is infestation by insects and pests during storage. Pest infestations and presence of unacceptable levels of pesticide residues, heavy metals and microbes have been reported as serious problems for the export of fruits and vegetables (Abhishek *et al.,* 2014). The most critical challenge is the post-harvest pest management during storage of perishables. So, the identification and management of pests becomes vital to feed our ever-increasing population and also make money by exporting these highly nutritious fruits and vegetables across the globe. The core destinations for Indian fruits and vegetables are Bangladesh, UAE, Netherland, Nepal, Malaysia, UK, Europe, Singapore, Sri Lanka, Oman and Qatar. Table 1 depicts the values and

*Corresponding author email id: sumitraarora@hotmail.com

CONFERENCES ATTENDED

1. International Conference on Strategies for Global Food and Nutritional Security, Sustainability, and Wellness (NUTRI 2023). **(Dec 2023)** CCS Haryana Agricultural University, Hisar, Haryana. (II Prize in Poster Presentation).
2. Participated in International Conference- Environment and Social Development Association (ESDA) Conference 2020, P. M. Auditorium, V. P. Chest Institute, University of Delhi, (Jan 2020).
3. Participated in International Seminar on Using Phosphine as QPS under WTO-SPS Agreement and minimizing the use of Methyl Bromide under the Montreal Protocol at Le Meridien, Windsor Place, New Delhi-110001. (2019) (Best Poster).

Reg. No. : 1963

INTERNATIONAL CONFERENCE
ON
STRATEGIES FOR GLOBAL FOOD AND
NUTRITIONAL SECURITY, SUSTAINABILITY AND WELLNESS
(NUTRI-2023)

DECEMBER 04-06, 2023

Certificate of Participation

This certificate is awarded to Ms. ANISHA KATHPALIA, Delhi Technological University, Delhi for Participation and Poster presentation on "Post-Harvest Pest Management Treatments for Fruits and Vegetables" in the International Conference on Strategies for Global Food and Nutritional Security, Sustainability and Wellness (NUTRI-2023) held at CCS Haryana Agricultural University, Hisar (Haryana) India.

Dr. Rajesh Gera
Co-Organizing Secretary-cum-
Additional Director of Research

NAHEP

Dr. Jeet Ram Sharma
Organizing Secretary-cum-
Director Research

ESDACON 2020
Annual International Conference of ESDA
18 to 19 January, 2020 | Delhi (India)

WORLD ENVIRONMENT SUMMIT 2020

18-19 January, 2020

P.M. AUDITORIUM, V. P. CHEST INSTITUTE, UNIVERSITY OF DELHI, DELHI (INDIA)

Organized by

Environment and Social Development Association (ESDA) Delhi

in Association with

CSIR-NEERI | Dr. Bhim Rao Ambedkar College, University of Delhi, Delhi | ANA G. Mendez University, PR, USA
Delhi Technological University, Delhi | G.D. Goenka University, Gurugram | ECPFO Delhi | Save The Environment | Global Foundation

Certificate of Participation

This is to certify that ANISHA KATHPALIA
of DELHI TECHNOLOGICAL UNIVERSITY, DELHI.
has participated in the World Environment Summit 2020 as Volunteer / Delegate and presented a Paper
(Oral/Poster) entitled ALTERNATIVES TO METHYL BROMIDE (AN OZONE DEPLETING
SUBSTANCE) FOR STORAGE FUMIGATION. during the technical session.

Dr. R. K. Rana	Dr. S. K. Goyal	Dr. G. K. Arora	Prof. Jaigopal Sharma	Dr. Jitendra K. Nagar
President	Head	Principal	Convener, WES 2020	Organising Secretary, WES 2020
ESDA, Delhi	CSIR-NEERI-Delhi Zonal	Dr. Bhim Rao Ambedkar College, DU	DTU, Delhi	General Secretary, ESDA, Delhi

BEST POSTER AWARD

On Paper Entitled

Ideal Fumigation practices for controlling storage insect pests

Conferred to

Anisha Kathpalia, Dheerender Pandey and Sumitra Arora

ICAR-NCIPM, Pusa Campus, New Delhi
On the occasion of One-Day Seminar

Using Phosphine as QPS fumigant under WTO-SPS Agreement & minimizing the use of methyl bromide under the Montreal Protocol

Organized by

Indian Chemical Council

6th June, 2019

held at **Le Meridien**, Windsor Place, New Delhi-110001

K. Ganesh
Organizing Secretary

Nirmala Pathrawal
Convener

PLAGIARISM VERIFICATION

DELHI TECHNOLOGICAL UNIVERSITY
(Formerly Delhi College of Engineering)
Shahbad Daulatpur, Main Bawana Road, Delhi-42

PLAGIARISM VERIFICATION

Title of the Thesis: **Impact of Phosphine on Quality Parameters of Stored Perishable Commodities**

Total Pages 142 pages (excluding references)

Name of the Scholar: **Anisha Kathpalia**

Supervisor (s)

(1) Prof. Jai Gopal Sharma, Department of Biotechnology, Delhi Technological University, Delhi

(2) Dr. Sumitra Arora, Principal Scientist, ICAR-NCIPM, Delhi

Department of Biotechnology

This is to report that the above thesis was scanned for similarity detection. Process and outcome is given below:

Software used: TURNITIN

Similarity Index: 3%

Total Word Count: 42386

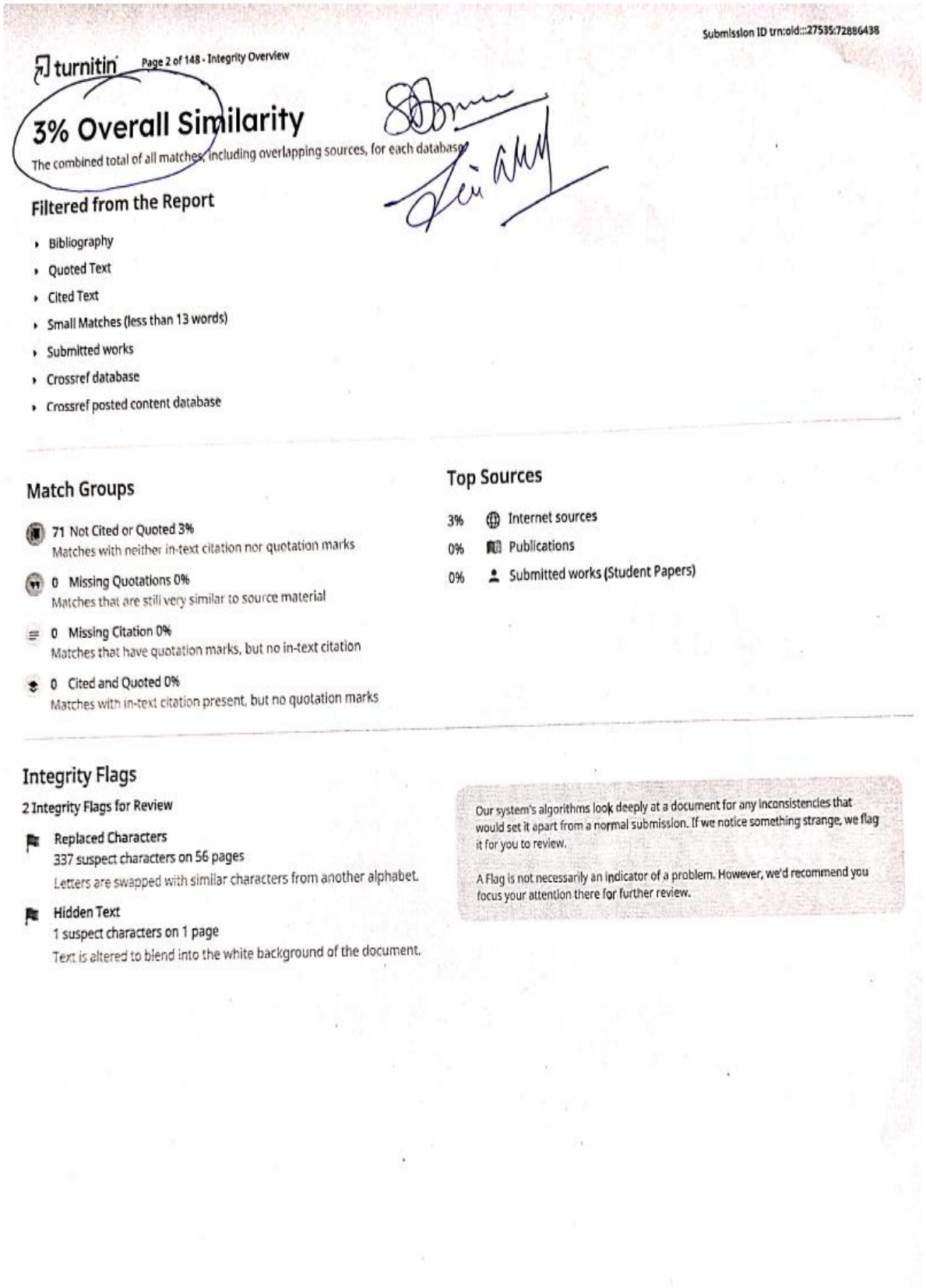
Date: 2/12/24

Candidate's Signature

Anisha Kathpalia

2K18/PHD/BT/16

Signature of Supervisor(s)



Submission ID trn:oid:::27535:72886438

turnitin Page 2 of 148 - Integrity Overview

3% Overall Similarity

The combined total of all matches, including overlapping sources, for each database

Filtered from the Report

- Bibliography
- Quoted Text
- Cited Text
- Small Matches (less than 13 words)
- Submitted works
- Crossref database
- Crossref posted content database

Match Groups

71 Not Cited or Quoted 3%
Matches with neither in-text citation nor quotation marks

0 Missing Quotations 0%
Matches that are still very similar to source material

0 Missing Citation 0%
Matches that have quotation marks, but no in-text citation

0 Cited and Quoted 0%
Matches with in-text citation present, but no quotation marks

Top Sources

3% Internet sources
0% Publications
0% Submitted works (Student Papers)

Integrity Flags

2 Integrity Flags for Review

Replaced Characters
337 suspect characters on 56 pages
Letters are swapped with similar characters from another alphabet.

Hidden Text
1 suspect characters on 1 page
Text is altered to blend into the white background of the document.

Our system's algorithms look deeply at a document for any inconsistencies that would set it apart from a normal submission. If we notice something strange, we flag it for you to review.

A Flag is not necessarily an indicator of a problem. However, we'd recommend you focus your attention there for further review.

CURRICULUM VITAE

ANISHA KATHPALIA
Qualification: PHD. Biotechnology *(Pursuing)*
Area of specialization: Food Science & Post Harvest Technology
Supervisor: Prof. Jai Gopal Sharma
Co. Supervisor: Dr. Sumitra Arora

Work Experience

Presently serving as a Technical Assistant (Quality Control) at the Food Corporation of India (FCI, A Government of India Undertaking) since August 2014.

Educational Qualifications

Education Details	Institute/University	Year of Passing	Percentage /SGPA
Pursuing PHD (Biotechnology)	Delhi Technological University (formerly Delhi College Of Engineering)	NA	NA
M.Tech (Bioinformatics)	Delhi Technological University (formerly Delhi College Of Engineering)	2012	8.6
B.Tech (Biotechnology)	D.C.R University Of Science & Technology, Murthal, Haryana	2010	80.6
Senior Secondary	D.P.S, R.K PURAM, New Delhi	2006	88
Matriculation	Bal Bharti School, Bahadurgarh	2004	92.4

Publications

1. Kathpalia, Anisha & Arora, Sumitra & Sharma, Jaigopal. (2024). Sorption and residue analysis of phosphine in fruits and vegetables. New Zealand Journal of Crop and Horticultural Science. 1-11. 10.1080/01140671.2024.2394137.
2. Kathpalia, Anisha & Arora, Sumitra & Sharma, Jaigopal. (2024). Impact of different fumigants on the quality of perishables. Journal of Food Safety and Food Quality.75(4).96-105.
3. Kathpalia, Anisha & Arora, Sumitra & Sharma, Jaigopal. (2022). Post-Harvest Pest Management of Perishables: A Review. Journal of Community Mobilization and Sustainable Development .17(4). 1065-1081
4. Published 3 articles in BIOTECH ARTICLES - An Online Pharma and Biotechnology industry magazineArticles on:
   - Personalized Medicine: Customized Medicines for Your Specific Genes
   - Impact of Whole Genome Sequencing
   - Antibiotics Vs Probiotics

Conferences

1. Participated in International Conference on Strategies for Global Food and Nutritional Security, Sustainability, and Wellness (NUTRI 2023). CCS Haryana Agricultural University, Hisar, Haryana. (II Prize in Poster Presentation).
2. Participated in International Conference- Environment and Social Development Association (ESDA) Conference 2020, P. M. Auditorium, V. P. Chest Institute, University of Delhi, Delhi.
3. Participated in International Seminar on Using Phosphine as QPS under WTO-SPS Agreement and minimizing the use of Methyl Bromide under the Montreal Protocol.Le Meridien, Windsor Place, New Delhi-110001. (Best Poster).

Personal Information

Father's Name	Dr. Virender Kathpalia
Mother's Name	Mrs. Sunita Kathpalia
Date of Birth	7 December, 1988
Email	anisha.kathpalia@gmail.com
Contact No	+91- 9953862057