

Efficacy of Plant Extracts to Prolong Shelf Life: A Study on Neem and Turmeric in Preservation of Mango (*Mangifera indica* L.) Fruits

ABSTRACT

Natural products chemists, microbiologists, and ethnobotanists, are actively investigating plant-derived compounds and natural fungicide alternatives from around the world to improve post-harvest management of vegetables and fruits, reducing reliance on synthetic chemicals. Although 25 to 50% of modern medicines are originate from plants, not a single one currently utilized as anti-microbials. Conventional farmers have historically used plants to prevent and treat infections, and Western medicine is now aiming to replicate these effective practices. Plants comprise a diverse secondary metabolite such as flavonoids, alkaloids, tannins, and terpenoids, which demonstrated antimicrobial properties *in vitro*. This study aimed to assess the effectiveness of turmeric and neem plant extracts in extending the mango fruits shelf life (cv. Gulab Khas) under two different storage environments: cold storage and ambient temperature. The fruits were subjected to four different concentrations (5%, 10%, 15%, and 20%) of each plant extract and stored in perforated polyethylene bags. They were then stored under the specified conditions of cold and ambient storage. The combination of neem leaf extract treatment with cold storage yielded promising results. Our results showed that 20% neem leaf extract treatment in cold storage effectively inhibited pathogens, preventing any spoilage. This combination also demonstrated minimal physiological weight loss (6.2%), low spoilage rates, and maximum ascorbic acid content (28.5 mg per 100 g of pulp). Additionally, it exhibited minimal acidity (0.12%), maximum total soluble solids (20.1°B), and the highest levels of total sugars (12.50%), reducing sugars (3.5%), and non-reducing sugars (8.55%). The organoleptic score was also notably high at 7.3 out of 10. The repressive influence of neem leaf extract is attributed owing to the active compound azadirachtin. This study emphasizes the capability of neem leaf extract as an efficient and natural alternative for extending the shelf life of mango fruits during storage. Therefore, the successful application of neem extract provides a promising avenue for future research and practical implementation in post-harvest technology.

Keywords, Mango, plant extracts, cold storage, neem and turmeric

1. INTRODUCTION

Mango known as King of Fruits is cultivated in India across 1.23 million hectares, producing nearly 10.99 million tonnes annually [1]. This accounts for over 55% of the total mango production worldwide. Currently, **Gulab Khas** is the predominately cultivated early mango variety in Eastern and Southern India, prized for its sweet taste, short stature, pinkish hue, and early ripening [2]. As a perishable fruit, mango have a little shelf life and typically reach the peak of their respiration rate during the ripening process on the third or fourth day after harvest at ambient temperatures [3, 4]. The life span of mango differs among diverse cultivars and is influenced by storage environments. At room temperature, it ranges from 4 to 8 days, while in cold storage at 13°C, it can extend to 2 to 3 weeks [5, 6]. This limited shelf life poses significant challenges for the long distance transport of mango [7, 8]. Typically, mature green mangoes require 9 to 12 days to ripen after harvesting [9, 10]. The maturation of mango encompasses a complex sequence of biochemical reactions. This process is characterized by heightened respiration rates and ethylene production, leading to changes in structural polysaccharides that cause softening [11, 12]. Additionally, chlorophyll degradation occurs alongside the biosynthesis of pigments from carotenoids. Concurrently, carbohydrates undergo transformation, with starch converting into sugars, and the production of organic acids, lipids, phenolics, and volatile compounds. Collectively, these changes contribute to the ripening of the fruit, resulting in a softer texture that meets quality standards [10, 13]. The sensitivity of fruit to decay, combined with its low temperature tolerance and perishability caused by rapid ripening and softening, restricts its handling, storage, and transportation capabilities [14]. Conversely, the use of controlled atmosphere (CA) or modified atmosphere (MA) storage is not always suitable for mango. While CA storage demonstrated to prolong the mango shelf life, it can be prohibitively expensive. Although MA storage has been reported to delay mango ripening, it often leads to elevated carbon dioxide levels and undesirable off-flavors [15-17].

Fungal spoilage is primary reason of post-harvest rot in fresh vegetables and fruits during transportation and storage [18, 19]. This has led to significant losses during the commercialization phase. In recent years, growers have increasingly adopted the use of growth regulators, waxing materials, and different fungicides to extend the fruits shelf life. On the other hand, the rising resistance of certain fungal pathogens to approved fungicides has become a major concern [20, 21], their left over poisonousness, contribution to environmental pollution, and adverse effects on human health [22, 23]. There has been a growing effort to develop alternative control measures [16, 24, 25]. Plant extracts have recently attracted significant scientific interest and gained popularity for their antifungal and antibacterial properties [26, 27]. Several plants native to India have been effectively used for therapeutic purposes. The antimicrobial efficacy of various of these plant extract against post harvest pathogens has been confirmed in specifically in citrus [28], mango [8], papaya [8] and yam [29]. Grainge et al., [30] documented and classified various plants from different families known for their fungicidal and growth governing properties. For instance, neem (*Azadirachta indica*) has shown remarkable effectiveness, with several commercial products already available in the market. Likewise, turmeric (*Curcuma longa*) rhizome extracts and leaf extracts of casuarina (*Casuarina equisetifolia*) are well-known for their growth controlling, insecticidal, and germicidal properties. Previous studies have evaluated the capability of plant extracts from custard apple leaves, Karanj, neem, and marigold flowers for extending the apple fruits shelf life [31] and mango varieties (cv. 'Langra' and 'Dasher') [32]. Thus, the goals of this investigation was to assess the influence of these plant extracts on the shelf life and the physico chemical changes in mango fruits (cv. '**Gulab Khas**') during storage under ambient and cold conditions.

2. MATERIALS AND METHODS

2.1 Preparation of Plant Extracts

Fresh leaves of *A. indica* and *C. equisetifolia*, as well as rhizomes of *C. longa*, were harvested. To prepare the plant materials for analysis, the dried samples were finely ground using a laboratory grinder to obtain a consistent powder, suitable for downstream processing and analysis. Subsequently, a 200 g portion of the finely ground plant powder was soaked in 1,000 ml of autoclaved distil water for 6 hours. After soaking, the mixture was filtered through muslin cloth to remove any solid residues, resulting in a clear extract. The resulting filtrate served as a stock solution (100%), which was further diluted to prepare coating solutions of varying strengths.

2.2 Treatment and Storage Conditions for Mature **Gulab Khas** Mango

Fully matured and uniformly sized fruits of the mango cultivars named **Gulab Khas** were selected for this investigation. The fruits used in the study were collected from the Fruit Research Station at OUAT, Odisha. In the laboratory, the fruits were sorted to ensure uniformity in shape, size, and maturity stage. After categorization, the fruits were thoroughly washed in running water to eliminate any dust and dirt, then air dried. The fruits were arbitrarily divided into ten lots, each receiving different plant extract treatments. The treatments included: distilled water (control, T1); neem leaf extracts at concentrations of 5% (T2), 10% (T3), 15% (T4), and 20% (T5); turmeric powder at 10% (T6) and 20% (T7); and casuarina leaf extracts at 10% (T8) and 20% (T9). Each treatment was supplemented with 2% guar gum as a sticking agent. The control fruits were preserved with purified water having 2% of guar gum. The fruits were immersed in their respective treatments for 30 minutes and then placed on newspaper sheets to dry in the shade for an additional 30 minutes. After treatment, the fruits from each group were carefully packed in polythene bags with a thickness of 200 gauge, featuring 5% perforated area to maintain the desired environmental conditions and prevent contamination during storage. Each treatment was replicated, and the fruits were stored under two conditions: in a refrigerator at 7 ± 1 °C and relative humidity was 85% in ambient conditions with an average temperature of 36 °C and 75.8% relative humidity

2.3 Assessment of Quality Attributes in **Gulab Khas** Mango During Storage

Observations on physiological loss in weight (PLW), acidity, organoleptic score, spoilage, total soluble solids (TSS), vitamin C, reducing sugars, and total sugars (TS) were measured at four-day intervals over a 12-day storage period. PLW was computed by weighing the fruits on a weight balance before and after the treatment. Spoilage was expressed in percentage of total weight loss, calculated by comparing the initial weight to the final weight of the fruits. TSS were estimated using a digital refractometer and reported in degrees Brix. The vitamin C and acidity of samples were measured using the titrimetric method outlined by [33]. The reducing and total sugar were analyzed using colorimetric methods as described by [34]. Organoleptic estimation was conducted by a panel of ten trained judges, who evaluated the samples based on factors such as taste, texture, aroma, and appearance. Each sample was scored on a scale of 1 to 10, with greater scores signifying better quality. The initial values recorded at the beginning of the experiment (day 0) were as follows: sensory score: 4.10; TSS: 17.1%; acidity: 0.38%; ascorbic acid: 47.45 mg per 100 g of pulp; total sugars: 10.03%; and reducing sugars: 2.8%.

2.4 Statistical analysis

The experiment was conducted using a factorial completely randomized design with 20 treatment combinations and three replicates. Each replicate consisted of five uniformly sized fruits of mango cv. Gulab Khas. The data were analyzed using analysis of variance (ANOVA), conducted with statistical software. To compare the means, the critical difference at $P \leq 0.05$ was employed [35]. To normalize the distribution of percentage data, percentages were transformed into arcsine square root values prior performing ANOVA. However, the results are presented as untransformed percentage data to maintain their original interpretation

3. RESULTS AND DISCUSSION

3.1 PLW

The fruits treated with 20% neem leaf extract exhibited a significantly lower PLW compared to both the control and the other treatments (Table 1).

Table 1. Influence of plant extracts and storage environments on the percentage of physiological loss in *Mangifera indica* cv. **Gulab Khas**.

Treatments	Storage Duration in Days					
	3		6		9	
	Cold Storage	Ambient Temperature	Cold Storage	Ambient Temperature	Cold Storage	Ambient Temperature
Control	4.0	8.3	6.3	20.8	9.1	32.6
5% Neem Leaf Extract	3.2	5.4	5.9	18.3	8.2	29.2
10% Neem Leaf Extract	2.8	5.2	5.7	18.1	8.3	28.5
15% Neem	1.6	4.7	5.4	16.3	6.5	25.1

Leaf Extract						
20% Neem Leaf Extract	1.2	4.6	5.2	15.4	6.2	21.2
Turmeric 10%	3.8	6.7	6.3	19.9	8.8	29.5
Turmeric 20%	2.5	6.4	6.0	18.3	8.4	28.3
Casuarina 10%	2.2	5.8	5.8	18.0	7.2	27.7
Casuarina 20%	2.3	5.1	5.5	16.7	7.3	27.2
	S.E.(m)	C.D. at 5%	S.E.(m)	C.D. at 5%	S.E.(m)	C.D. at 5%
Treatments	0.021	0.053	0.012	0.042	0.031	0.891
Storage condition	0.003	0.022	0.002	0.032	0.021	0.062
Interaction	0.021	0.051	0.027	0.052	0.010	0.043

This effect may be attributed to the extracts capability to slow moisture loss and delay the senescence process, as noted by [36]. Additionally, the neem leaf extract antimicrobial properties may inhibit the growth of microorganisms accountable for decay and in elevation metabolic rates, further contributing to its effectiveness in reducing PLW [31, 32]. Among the different storage conditions, mango fruits stored under cool conditions exhibited the least PLW compared to those kept at ambient temperatures. The cold and elevated humidity associated with **cold storage** likely reduced PLW by minimizing moisture loss via decreased respiration transpiration and rates. These findings align with observations noted by Doreyappy and Huddar [37] for mature green Alphonso mango.

3.2 Spoilage

Spoilage was primarily caused by rotting due to pathogenic microorganisms. On the ninth day of storage, fruits treated with 15% and 20% neem leaf extract stored under cold conditions showed no signs of spoilage, whereas untreated fruits stored at ambient temperature exhibited spoilage rates of 38.6% and 35.1%, respectively (Table 2).

Table 2. Influence of plant extracts and storage environments on the spoilage percentage of *Mangifera indica* cv. **Gulab Khas**.

Treatments	Storage Duration in Days					
	3		6		9	
	Cold Storage	Ambient Temperature	Cold Storage	Ambient Temperature	Cold Storage	Ambient Temperature
Control	-	-	23.6	42.2	28.2	60.5
5% Neem Leaf Extract	-	-	5.1	28.1	9.1	48.1
10% Neem Leaf Extract	-	-	5.0	28.5	8.3	45.2
15% Neem Leaf Extract	-	-	0.0	20.0	0.0	38.6
20% Neem Leaf Extract	-	-	0.0	19.3	0.0	35.1
Turmeric 10%	-	-	12.2	37.7	17.1	50.2
Turmeric 20%	-	-	10.2	37.2	15.5	43.1
Casuarina 10%	-	-	8.7	31.4	13.2	38.6
Casuarina 20%	-	-	8.1	31.1	13.1	38.7
	S.E.(m)	C.D. at 5%	S.E.(m)	C.D. at 5%	S.E.(m)	C.D. at 5%
Treatments	-	-	2.570	6.765	2.123	6.210

Storage condition	-	-	1.118	3.021	1.061	3.280
Interaction	-	-	3.425	NS	3.125	9.122

The reduction in spoilage observed with neem leaf extract can be associated to active of the active compound azadirachtin, which effectively inhibits the growth of pathogens responsible for rotting [36, 38]. Additionally, the cold storage conditions resulted in less contamination and infection compared to ambient conditions [39]. It is evident that hindering effect of neem leaf extract was more pronounced in cold storage compared to ambient temperatures. Likewise findings have been observed by Baswa et al. [10].

3.3 Organoleptic score

Overall, the organoleptic score of the fruits initially greater before gradually declining, regardless of the treatment or storage condition. This pattern likely reflects the ripening process trailed by senescence. Though, within treatments, fruits treated with a 20% neem leaf extract exhibited slower alterations in organoleptic scores compared to the control group. These results are consistent with the outcomes of Bhardwaj et al. [15]. At the end of the storage period, fruits treated with 20% neem leaf extract recorded the highest organoleptic score, while the control group displayed the lowest mean score (Table 3).

Table 3. Influence of plant extracts and storage environments on the organoleptic score (Assessed out of 10) of *Mangifera indica* cv. *Gulab Khas*.

Treatments	Storage Duration in Days					
	3		6		9	
	Cold Storage	Ambient Temperature	Cold Storage	Ambient Temperature	Cold Storage	Ambient Temperature
Control	5.5	7.0	7.7	3.2	4.2	1.1
5% Neem Leaf Extract	5.5	7.8	7.2	3.8	6.9	1.3
10% Neem Leaf Extract	5.3	7.5	7.1	3.7	6.7	1.5
15% Neem Leaf Extract	5.2	7.1	7.2	3.5	6.5	0.7
20% Neem Leaf Extract	5.1	7.0	7.1	3.4	7.3	0.6
Turmeric 10%	5.8	7.9	7.3	3.7	7.1	3.1
Turmeric 20%	5.7	7.9	7.0	3.6	6.2	3.3
Casuarina 10%	5.6	7.6	6.9	3.5	5.6	2.6
Casuarina 20%	5.5	7.2	6.8	3.3	5.8	2.2
	S.E.(m)	C.D. at 5%	S.E.(m)	C.D. at 5%	S.E.(m)	C.D. at 5%
Treatments	0.011	0.021	0.011	0.012	0.010	0.031
Storage condition	0.002	0.011	0.002	0.25	0.001	0.012
Interaction	0.012	0.043	0.013	0.033	0.012	0.041

This decline in the control group can be attributed to rapid decomposition in carbohydrates, phenolic compounds, acids, and spoilage, leading to a loss of color and flavor [40]. Additionally, the variations in overall organoleptic scores were gradual in fruits stored in cold conditions compared to store at ambient temperature (Table 3). This difference may be owing to the reduced rate of metabolic linked with ripening and maturing in low temperature conditions of cold storage.

3.4 TSS

In the early stages, the TSS content in the fruits elevated, likely owing to hydrolysis of insoluble polysaccharides into simpler sugars. However, this content slowly declined, possibly due to a reduction in pectin and carbohydrates, incomplete hydrolysis of proteins, and the decay of glycosides into subunits throughout respiration. At the conclusion of the storage investigation, fruits treated with 20% neem leaf extract exhibited highest TSS content (Table 4).

Table 4. Influence of plant extracts and storage environments on TSS (°Brix) of *Mangifera indica* cv. Gulab Khas.

Treatments	Storage Duration in Days					
	3		6		9	
	Cold Storage	Ambient Temperature	Cold Storage	Ambient Temperature	Cold Storage	Ambient Temperature
Control	18.1	19.1	21.1	19.1	19.1	15.1
5% Neem Leaf Extract	18.3	19.1	20.2	19.3	19.2	15.2
10% Neem Leaf Extract	18.2	19.2	20.1	19.6	19.1	15.2
15% Neem Leaf Extract	18.7	19.6	20.7	19.8	19.2	16.2
20% Neem Leaf Extract	18.1	20.8	21.2	20.1	20.1	17.3
Turmeric 10%	18.2	18.1	19.1	18.7	18.1	15.1
Turmeric 20%	18.9	18.3	19.8	18.2	18.3	15.1
Casuarina 10%	18.2	18.3	20.2	18.2	19.2	16.5
Casuarina 20%	18.7	18.2	20.2	18.1	19.1	16.1
	S.E.(m)	C.D. at 5%	S.E.(m)	C.D. at 5%	S.E.(m)	C.D. at 5%
Treatments	0.011	0.032	0.011	0.021	0.011	0.031
Storage condition	0.001	0.011	0.020	0.010	0.001	0.011
Interaction	0.012	0.041	0.011	0.041	0.011	0.041

This increase may be attributed to a declined respiration rate and prolonged ripening associated with this treatment. In contrast, control fruits exhibited the lowest TSS content, likely due to greater respiratory losses since there was no barrier to impede gas exchange within the fruit [32]. The elevated in TSS was observed to be more rapid in fruits stored at ambient temperature compared to those stored in cold conditions. This occurrence can be explained to the high temperatures and low relative humidity at ambient temperature, which facilitate the conversion of other insoluble carbohydrates and starch into soluble sugars. Hence, the sugars and TSS were consumed during respiration, resulting in lesser concentrations within the tissues of fruit. In contrast, extended storage of mango fruits at low temperatures with higher humidity in cold storage may hinder the maturing process, leading to reduced TSS values. These findings align with previous studies by Joshi and Roy [41] regarding ambient temperature storage, as well as Kapse et al. [42] and Krishnamurthy and Joshi [43] regarding cold storage conditions for fruits of mango.

3.5 Total acids

The acidity of mango fruit was maximum at the start of the storage period and declined over time. This decrease might be attributed to the rapid consumption of acids in the pulp of mango fruit during respiration and the decay of citric acid, which likely contributes to the reduction in acidity as these acids are converted into sugars and subsequently utilized in the fruit's metabolic processes. Different treatments with plant extracts significantly affected the maturing processes, with fruits treated with neem leaf extract exhibiting a greater retaining of acidity in storage (Table 5).

Table 5. Influence of plant extracts and storage environments on acidity (%) of *Mangifera indica* cv. Gulab Khas.

Treatments	Storage Duration in Days					
	3		6		9	
	Cold Storage	Ambient Temperature	Cold Storage	Ambient Temperature	Cold Storage	Ambient Temperature
Control	0.21	0.21	0.21	0.14	0.18	0.03
5% Neem Leaf Extract	0.31	0.21	0.22	0.11	0.12	0.05
10% Neem Leaf Extract	0.31	0.21	0.21	0.13	0.12	0.03
15% Neem Leaf Extract	0.30	0.21	0.20	0.12	0.17	0.03
20% Neem Leaf Extract	0.30	0.23	0.20	0.11	0.12	0.03
Turmeric 10%	0.31	0.28	0.21	0.11	0.18	0.02
Turmeric 20%	0.31	0.28	0.21	0.12	0.19	0.03
Casuarina 10%	0.32	0.28	0.21	0.12	0.20	0.01
Casuarina 20%	0.35	0.21	0.20	0.1	0.19	0.01
	S.E.(m)	C.D. at 5%	S.E.(m)	C.D. at 5%	S.E.(m)	C.D. at 5%
Treatments	0.001	0.003	0.001	0.003	0.001	0.002
Storage condition	0.001	0.002	0.001	0.003	0.000	0.001
Interaction	0.001	0.003	0.001	0.005	0.001	0.003

This effect might be due to treatment ability to delay physiological aging and alter metabolic processes, resulting in higher acidity retention. Similar findings have been reported by [14, 44, 45]. The rate of acidity reduction was observed to be more rapid in fruits stored at ambient temperature compared to store in cold environments. This difference may be attributed to the high temperatures and little humidity typical of ambient storage, which likely accelerate the decomposition of organic acids into sugars and their consumption in respiration. In contrast, extended storage of fruits at lower temperatures and elevated humidity in **cold storage** appears to inhibit the deterioration of organic acids. Comparable findings have been noted by [41, 46] regarding ambient storage conditions, as well as by Krishnamurthy and Joshi [43] in **cold storage**. These outcomes are also consistent with the findings by Doreyapp and Huddar [37], Garcia et al. [47], and Srinivasa et al. [48].

3.6 Ascorbic acid

Typically, there was a slow decrease in vitamin C across all treatments during storage. The rate of vitamin C reduction was dramatically raised in the untreated fruits than in those that were treated. This difference may be attributed to a quick loss of vitamin C via oxidation, which is facilitated by the increased accessibility of oxygen. The reduction in vitamin C during storage could result from the swift change of L-ascorbic acid into dehydroascorbic acid in the existence of the enzyme ascorbinase [49]. The highest mean vitamin C retention was found in fruits treated with 20% neem leaf extract, recording 36.27 mg of vitamin C per 100 g of pulp (Table 6).

Table 6. Influence of plant extracts and storage environments on vitamin C (mg/100 g of pulp) of *Mangifera indica* cv. **Gulab Khas**.

Treatments	Storage Duration in Days					
	3		6		9	
	Cold Storage	Ambient Temperature	Cold Storage	Ambient Temperature	Cold Storage	Ambient Temperature
Control	41.3	40.2	36.6	25.1	26.2	15.2
5% Neem Leaf Extract	40.8	40.2	35.1	24.2	26.4	15.2
10% Neem Leaf Extract	41.4	41.4	36.1	25.2	27.6	16.2

15% Neem Leaf Extract	42.3	41.1	37.4	26.5	27.7	17.4
20% Neem Leaf Extract	43.5	41.7	38.7	27.6	28.5	17.6
Turmeric 10%	40.3	40.2	34.2	23.3	25.5	14.6
Turmeric 20%	40.1	40.1	34.6	23.4	26.7	14.7
Casuarina 10%	41.1	41.0	35.9	24.5	26.3	15.3
Casuarina 20%	42.1	41.1	36.1	25.4	27.1	16.1
	S.E.(m)	C.D. at 5%	S.E.(m)	C.D. at 5%	S.E.(m)	C.D. at 5%
Treatments	0.015	0.041	0.011	0.045	0.024	0.065
Storage condition	0.001	0.012	0.006	0.026	0.015	0.023
Interaction	0.021	0.051	0.023	0.075	0.034	0.092

This retention may be owing to the neem leaf extract influence in decreasing both respiration rates and oxidation processes in mango fruits. The superior retaining of vitamin C in **cold storage** compared to room temperature can be ascribed to the elevated relative humidity and cold conditions. This finding aligns with observations made by Keleny et al. [50] in the cold compartment of mango fruits.

3.7 Reducing and total sugars

Storage conditions had a significant impact on the efficacy of treatments in altering the reducing and content of total sugar in mango fruits (Table 7 and Table 8).

Table 7. Effect of plant extracts and storage environments on TS (%) of *Mangifera indica* cv. **Gulab Khas**.

Treatments	Storage Duration in Days					
	3		6		9	
	Cold Storage	Ambient Temperature	Cold Storage	Ambient Temperature	Cold Storage	Ambient Temperature
Control	11.0	12.0	12.1	10.6	12.2	5.5
5% Neem Leaf Extract	11.2	12.1	12.2	10.1	12.2	5.6
10% Neem Leaf Extract	11.1	12.6	12.2	10.3	12.3	5.4
15% Neem Leaf Extract	11.1	12.7	13.3	10.2	12.3	5.4
20% Neem Leaf Extract	12.0	13.1	13.5	11.1	12.5	5.7
Turmeric 10%	11.2	12.3	12.0	10.1	12.1	5.4
Turmeric 20%	11.2	12.3	12.6	10.2	12.2	5.4
Casuarina 10%	11.4	12.5	12.4	10.2	12.4	5.5
Casuarina 20%	11.2	12.3	13.2	10.4	12.3	5.1
	S.E.(m)	C.D. at 5%	S.E.(m)	C.D. at 5%	S.E.(m)	C.D. at 5%
Treatments	0.005	0.022	0.008	0.001	0.010	0.020
Storage condition	0.001	0.012	0.001	0.010	0.004	0.011
Interaction	0.010	0.31	0.010	0.011	0.012	0.43

Table 8. Influence of plant extracts and storage environments on reducing sugar (%) of *Mangifera indica* cv. **Gulab Khas**.

Treatments	Storage Duration in Days					
	3		6		9	
	Cold Storage	Ambient Temperature	Cold Storage	Ambient Temperature	Cold Storage	Ambient Temperature
Control	3.2	3.1	3.3	2.8	3.2	2.6
5% Neem Leaf Extract	3.1	3.1	3.4	3.1	3.1	2.7
10% Neem Leaf Extract	3.1	3.2	3.4	3.1	3.1	2.8
15% Neem Leaf Extract	3.2	3.7	3.6	3.2	3.4	3.1
20% Neem Leaf Extract	3.4	4.0	3.8	3.4	3.5	3.1
Turmeric 10%	3.2	3.1	3.2	3.2	3.2	2.5
Turmeric 20%	3.1	3.1	3.4	3.3	3.2	2.7
Casuarina 10%	3.3	3.3	3.4	3.4	3.2	2.6
Casuarina 20%	3.2	3.2	3.6	3.1	3.0	2.7
	S.E.(m)	C.D. at 5%	S.E.(m)	C.D. at 5%	S.E.(m)	C.D. at 5%
Treatments	0.011	0.030	0.011	0.031	0.011	0.031
Storage condition	0.002	0.012	0.007	0.016	0.002	0.011
Interaction	0.013	0.300	0.018	0.043	0.013	0.042

On the third day, mango fruits stored at ambient temperature exhibited higher sugar levels compared to those stored in cold environments. This difference may be attributed to the lower relative humidity and high temperature at ambient temperature, which facilitate the alteration of starch and other insoluble carbohydrates into soluble sugars. These sugars are subsequently consumed during respiration, leading to reduced sugar content in the later stages of storage. In contrast, the low temperatures in **cold storage** reduce the metabolism of mango fruit, especially respiratory activity, which delays the maturing process and extends mango fruit shelf life by until two weeks [51]. These observations align with discoveries noted by Joshi and Roy (1985) for ambient temperature storage, as well as Kapse et al. [42] and Krishnamurthy and Joshi [43] in **cold** conditions for fruits of mango. In addition, fruits treated with neem leaf extract exhibited a slower rise in sugar content due to reduced rate of metabolic and slower rate of respiration compared to the control fruits.

4. CONCLUSION

This study underscores the effectiveness of neem and turmeric extracts as viable alternatives to synthetic fungicides for managing post-harvest mango fruit. The findings indicate that applying a 20% neem leaf extract during **cold storage** not only completely inhibits spoilage pathogens but also preserves fruit quality, as evidenced by minimal weight loss and elevated levels of ascorbic acid and sugars. These results highlight the significance of investigating plant-based solutions within agricultural practices, suggesting that integrating traditional knowledge with contemporary research can lead to sustainable and effective strategies for extending the shelf life of fruits and vegetables. The successful use of neem extract opens promising avenues for future research and practical applications in agro-processing technology.

INSTITUTIONAL REVIEW BOARD STATEMENT

Not applicable.

INFORMED CONSENT STATEMENT

Not applicable.

DATA AVAILABILITY STATEMENT

Data is available in the manuscript.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

The author(s) hereby declare that no generative AI technologies, including large language models (e.g., Copilot, ChatGPT) or text-to-image generators, were used in the writing or editing of this manuscript.

REFERENCES

1. Tharanathan R, Yashoda H, Prabha T. Mango (*Mangifera indica* L.), "The king of fruits"—An overview. *Food reviews international*. 2006;22(2):95-123.
2. Shrivastava M. *Amma's Daughters: A Memoir*. Athabasca University Press; 2018.
3. Singh Z, Singh RK, Sane VA, Nath P. Mango-postharvest biology and biotechnology. *Critical Reviews in Plant Sciences*. 2013;32(4):217-36.
4. Gelaye Y. A review of storage temperature and relative humidity effects on shelf life and quality of mango (*Mangifera indica* L.) fruit and implications for nutrition insecurity in Ethiopia. *Open Agriculture*. 2024;9(1):20220296.
5. Bhuiyan MSH, Hoque MA, Hossain MM, Zakaria M, Ahiduzzaman M. Influence of maturity stages on physicochemical properties and shelf-life of different varieties of mangoes under ambient storage conditions. *European Journal of Agriculture and Food Sciences*. 2023;5(1):119-25.
6. Baloch M, Bibi F. Effect of harvesting and storage conditions on the post harvest quality and shelf life of mango (*Mangifera indica* L.) fruit. *South African Journal of Botany*. 2012;83:109-16.
7. Laguerre O, Duret S, Chaomuang N, Denis A, Derens-Bertheau E, Mawilai P, et al. Influence of long-distance air transport conditions on horticultural product quality: Case study of fresh mango shipment from Thailand to France. *International Journal of Refrigeration*. 2023;152:16-25.
8. Baños SB, Necha LLB, Luna LB, Torres KB. Antifungal activity of leaf and stem extracts from various plant species on the incidence of *Colletotrichum gloeosporioides* of papaya and mango fruit after storage. *Revista Mexicana de Fitopatología*. 2002;20(1):8-12.
9. Farina V, D'Asaro A, Mazzaglia A, Gianguzzi G, Palazzolo E. Chemical-physical and nutritional characteristics of mature-green and mature-ripe Kensington Pride mango fruit cultivated in Mediterranean area during cold storage. *Fruits*. 2017;72(4):221-9.
10. Baswa M, Rath CC, Dash S, Mishra R. Antibacterial activity of Karanj (*Pongamia pinnata*) and Neem (*Azadirachta indica*) seed oil: a preliminary report. *Microbios*. 2001;105(412):183-9.
11. Liu B, Xin Q, Zhang M, Chen J, Lu Q, Zhou X, et al. Research progress on mango post-harvest ripening physiology and the regulatory technologies. *Foods*. 2022;12(1):173.
12. Pareek S. Ripening physiology: An overview. *Postharvest Ripening Physiology of Crops*. 2016:1-48.
13. Gundewadi G, Reddy VR, Bhimappa B. Physiological and biochemical basis of fruit development and ripening—a review. *Journal of Hill Agriculture*. 2018;9(1):7-21.
14. Bhardwaj R, Sen N. Zero energy cool-chamber storage of Mandarin (*Citrus reticulata* Blanco) cv. 'Nagpur Santra'. 2003.
15. Bhardwaj R, Dhashora L, Mukherjee S. Effect of Neem leaf extract and benzyladenine on post-harvest shelf life of orange (*Citrus reticulata* Blanco). *J Adv Dev Res*. 2010;1(1):32-7.
16. Casals C, Teixidó N, Viñas I, Silvera E, Lamarca N, Usall J. Combination of hot water, *Bacillus subtilis* CPA-8 and sodium bicarbonate treatments to control postharvest brown rot on peaches and nectarines. *European Journal of Plant Pathology*. 2010;128:51-63.
17. Yahia EM. Modified and controlled atmospheres for tropical fruits. *Stewart Postharvest Review*. 2006;5(6):1-10.
18. Alegbeleye O, Odeyemi OA, Strateva M, Stratev D. Microbial spoilage of vegetables, fruits and cereals. *Applied Food Research*. 2022;2(1):100122.
19. Moss MO. Mycotoxin review-1. aspergillus and penicillium. *Mycologist*. 2002;16(3):116-9.
20. Reimann S, Deising H. Fungicides: risks of resistance development and search for new targets. 2000.
21. Diane F, Santos M, Blanco R, Tello J. Fungicide resistance in *Botrytis cinerea* isolates from strawberry crops in Huelva (southwestern Spain). *Phytoparasitica*. 2002;30:529-34.
22. Ling W. Health risk evaluation of pesticide contaminations in drinking water. 1991.
23. Unnikrishnan V, Nath B. Hazardous chemicals in foods. 2000.

24. Smilanick JL, Mansour MF, Gabler FM, Sorenson D. Control of citrus postharvest green mold and sour rot by potassium sorbate combined with heat and fungicides. *Postharvest Biology and Technology*. 2008;47(2):226-38.
25. Droby S, Wisniewski M, Macarasin D, Wilson C. Twenty years of postharvest biocontrol research: is it time for a new paradigm? *Postharvest biology and technology*. 2009;52(2):137-45.
26. Lee S-H, Chang K-S, Su M-S, Huang Y-S, Jang H-D. Effects of some Chinese medicinal plant extracts on five different fungi. *Food control*. 2007;18(12):1547-54.
27. Santas J, Almajano MP, Carbó R. Antimicrobial and antioxidant activity of crude onion (*Allium cepa*, L.) extracts. *International journal of food science & technology*. 2010;45(2):403-9.
28. Singh H, Fairs G, Syarhabil M. Anti-fungal activity of *Capsicum frutescence* and *Zingiber officinale* against key post-harvest pathogens in citrus. *International Conference on Biomedical Engineering and Technology, IPCBEE2011*. p. 1-6.
29. Okigbo R, Ogbonmaya U. Antifungal effects of two tropical plant leaf extracts (*Ocimum gratissimum* and *Aframomum melegueta*) on postharvest yam (*Dioscorea* spp.) rot. *African Journal of biotechnology*. 2006;5(9).
30. Grainge M, Ahmed S, Mitchell W, Hysin J. Plant species reportedly possessing pest-control properties. An EWC/UH database. 1986.
31. Chauhan SK, Thakur K, Dwivedi S, Amandeep Bhanot AB. Storage behaviour of apple as affected by pre-and post-harvest treatments of neem based formulations, plant extracts and leaves. 2008.
32. Singh J, Pinaki Acharyya PA, Singh B. Effect of GA3 and plant extracts on storage behavior of mango (*Mangifera indica* L.) cv. Langra. 2000.
33. Ranganna S. Handbook of analysis and quality control for fruit and vegetable products. Tata McGraw-Hill Education; 1986.
34. Blakeney AB, Mutton LL. A simple colorimetric method for the determination of sugars in fruit and vegetables. *Journal of the Science of Food and Agriculture*. 1980;31(9):889-97.
35. Gomez K. Statistical procedures for agricultural research. John NewYork: Wiley and Sons. 1984.
36. Gakhukar R. Commercial and industrial aspects of neem based pesticide. *Pestology*. 1996;22(10):15-32.
37. Doreyappa Gowda I, Huddar A. Studies on ripening changes in mango (*Mangifera indica* L.) fruits. *Journal of food science and technology (Mysore)*. 2001;38(2):135-7.
38. CHAI YL, OTT DB, CASH JN. Shelf-life extension of Michigan apples using sucrose polyester. *Journal of food processing and preservation*. 1991;15(3):197-214.
39. Narayana C, Pal R, Roy S. Effect of pre-storage treatments and temperature regimes on shelf-life and respiratory behaviour of ripe Baneshan mango. 1996.
40. Malundo TM, Baldwin EA, Moshonas MG, Baker RA, Shewfelt RL. Method for the rapid headspace analysis of mango (*Mangifera indica* L.) homogenate volatile constituents and factors affecting quantitative results. *Journal of Agricultural and Food Chemistry*. 1997;45(6):2187-94.
41. Joshi G, Roy SK. Effect of integrated post-harvest handling on biochemical changes in Alphonso mango fruits. 1985.
42. Kapse B, Rane D, Salunkhe D, Khedkar D. Sensory evaluation of different varieties of mango during storage. *Indian Food Packer*. 1985;39(2):43-8.
43. Krishnamurthy S, Joshi S. Studies on low temperature storage of Alphonso mango. *Journal of food science and technology (Mysore)*. 1989;26(4):177-80.
44. Mitra S, Harangi A, Kar N. Effect of polyethylene at low temperature and different growth regulators at ambient temperature on changes in total soluble solids, total sugar, titratable acidity and ascorbic acid content of litchi (cv. Bombai) during storage. 1996.
45. Gautam S, Chundawat B. Postharvest Changes in Sapota Cv.'Kalipatti': I-Effect of Various Postharvest Treatments on Biochemical Changes. *Indian Journal of Horticulture*. 1989;46(3):310-5.
46. Sahni C, Khurdia D. Physico-chemical changes during ripening in Dashehari, Chausa, Neelum and Amrapali mango. *Indian Food Packer*. 1989;13(1):36-41.
47. García MA, Martino MN, Zaritzky NE. Plasticized starch-based coatings to improve strawberry (*Fragaria x ananassa*) quality and stability. *Journal of Agricultural and Food Chemistry*. 1998;46(9):3758-67.
48. Srinivasa P, Baskaran R, Ramesh M, Harish Prashanth K, Tharanathan R. Storage studies of mango packed using biodegradable chitosan film. *European Food Research and Technology*. 2002;215:504-8.
49. Mapson L. Vitamin in fruits. *The biochemistry of fruits and their products*. 1970;1:369-86.
50. Keleny A, Sahar M, Abdel-Wahab AA, Usman M. Using modified atmosphere and different storage temperature for storing 'Kent' mango fruits. *J Hort Sci Ornament plants*. 2010;2(1):46-56.

51. İlhami Köksal A. Research on the storage of pomegranate (cv. Gök Bahçe) under different conditions. International Symposium on Postharvest Handling of Fruit and Vegetables 2581988. p. 295-302.

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