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Effect of Different Packaging Materials and Calcium Chloride & Wax Coatings on Physical and Physiological Parameters of Mandarin

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Abstract

Postharvest losses pose a major challenge to the commercial viability of mandarins, making effective storage solutions essential. This study examines how calcium chloride and wax coatings, combined with different packaging materials, influence the physical and physiological quality of Nagpur mandarins during 25 days of storage. Fruits were treated with $CaCl_2$ (2% and 4%) and paraffin wax (10% and 12%) before being stored in various packaging materials, including LDPE, HDPE, CFB, gunny bags, newspaper, cling film, and liquid paraffin wax. Among the treatments, T10 ($CaCl_2$ 4% + Paraffin Wax 12% + CFB) significantly minimized physiological weight loss (3.47%, $p < 0.05$), maintained fruit length (4.85 cm, $p < 0.05$) and girth (6.47 cm, $p < 0.05$), and preserved fruit shape (index: 0.856, $p < 0.05$). T5 ($CaCl_2$ 2% + Paraffin Wax 10% + Cling Film) also demonstrated effective results, with a fruit length of 5.35 cm, girth of 6.7 cm, and a shape index of 0.850. Spoilage was lowest in T10 (42.09%), while the control group exhibited complete spoilage (100%). Specific gravity was best retained in T9 (0.94 g/cm^3), followed by T10 (0.85 g/cm^3). These results indicate that integrating $CaCl_2$ treatments with wax coatings and suitable packaging materials significantly reduces postharvest losses ($p < 0.05$) and extends fruit shelf life. This practical approach can help fruit producers, storage facilities, and retailers improve fruit quality, minimize wastage, and enhance market value, making it a viable solution for commercial mandarin storage.

Keywords: Mandarin; Packaging Materials; Calcium Chloride; Wax Coating; Physiological Loss; Postharvest Storage

Introduction

Citrus fruits, particularly mandarins, are highly valued for their economic and nutritional importance. They are rich in vitamins, antioxidants, and essential nutrients, making them a significant component of the human diet worldwide [1]. Mandarins are primarily grown in tropical and subtropical regions, with India being one of the leading producers [2]. However, due to their perishable nature, postharvest losses remain a major challenge, leading to economic losses and reduced consumer availability [3].

The postharvest quality of mandarins deteriorates due to physiological changes such as moisture loss, respiration, and microbial spoilage [4]. Various strategies, including waxing, calcium chloride application, and different packaging materials, have been adopted to improve storage potential [5]. Wax coatings help in reducing transpiration and respiration rates, while calcium chloride enhances cell wall integrity, thus delaying senescence [6]. Packaging materials provide a controlled environment, minimizing exposure to external deteriorating factors [7].

Several studies have reported that a combination of wax and calcium chloride, along with appropriate packaging materials, can significantly improve fruit quality and shelf life [8-10]. However, limited research has been conducted on their combined effect on the physical and physiological characteristics of Nagpur mandarin. Therefore, this study aims to systematically evaluate how different packaging materials, in combination with calcium chloride and wax coatings, influence the postharvest quality of Nagpur mandarins. By identifying the most effective treatment for reducing weight loss, spoilage, and quality deterioration, this research provides practical insights for enhancing commercial storage practices and minimizing postharvest losses.

Materials and Methods

This study was conducted at the Department of Fruit Science, IGKV, Raipur, during 2020-21, using a Completely Randomized Design (CRD) with three replications. Nagpur mandarin fruits were treated with two concentrations of $CaCl_2$ (2% and 4%) combined with wax coatings (10% and 12%) and stored in different packaging materials, including LDPE, HDPE, corrugated fiberboard (CFB), gunny bags, newspaper, cling film, and liquid paraffin wax. The untreated fruits served as the control. All fruits were stored at room temperature (25–30°C) with ambient relative humidity (50–70%) for 25 days. Observations were recorded at 5-day intervals up to 25 days to evaluate various physiological and biochemical parameters. Fruit length and girth were measured using a digital Vernier caliper with an accuracy of ±0.01 mm. The fruit shape index was calculated as the ratio of fruit length to fruit width, while fruit spoilage percentage was determined by counting the number of spoiled fruits and expressing it as a percentage of the total fruits. Specific gravity was measured using the water displacement method, whereas physiological loss in weight (PLW) was calculated by weighing the fruits at each interval and comparing them to the initial weight using the formula PLW (%) = ((Initial weight - Final weight) / Initial weight) × 100. Total Soluble Solids (TSS) were determined using a digital refractometer (ATAGO, 0-32% Brix), and titratable acidity was measured by titration with NaOH (0.1N) using phenolphthalein as an indicator. Ascorbic acid content was determined using the 2,6-dichlorophenol-indophenol visual titration method, and pH was measured using a calibrated digital pH meter. The TSS: Acid ratio was calculated by dividing TSS values by corresponding titratable acidity. Total, reducing, and non-reducing sugars were estimated using the Lane and Eynon volumetric method. All data were statistically analyzed using ANOVA, and significant differences among treatments were determined at a 5% significance level.

Results and Discussion

Fruit Length and Girth

The best preservation of fruit length and girth was recorded in T_5 ($CaCl_2$ 2% + Paraffin Wax 10% + Cling Film), with an average fruit length of 5.35 cm and a girth of 6.7 cm after 25 days. These measurements were significantly greater than those of the control, which had a length of 2.98 cm and a girth of 3.2 cm. The wax coating played a crucial role in minimizing moisture loss, which helped prevent shrinkage and maintained the integrity of the fruit's cell walls. Similar results were reported by [11], who found that wax coatings reduced transpiration, helping to retain fruit firmness and prevent shrinkage [12].

Fruit Shape Index

T_2 ($CaCl_2$ 4% + Paraffin Wax 12% + LDPE) retained the fruit shape index best, with a value of 0.925, followed by T_{10} ($CaCl_2$ 4% + Paraffin Wax 12% + CFB) at 0.856. In contrast, the control showed a much lower value of 2.77. This suggests that these treatments provided structural support, helping to reduce moisture loss and prevent mechanical damage to the fruit [13,14].

Table 1: Effect of different packaging materials on "Fruit length (cm)" in Nagpur mandarin

Notations	Treatments	Storage days					Mean	% increase over control
		5	10	15	20	25		
T_0	Control	5.70	5.10	4.10	*	*	2.98	0
T_1	$Cacl_2$ 2% + Paraffin wax emulsion 10% + LDPE	6.10	6.00	5.85	5.55	*	4.70	57.72
T_2	$Cacl_2$ 4% + Paraffin wax emulsion 12% + LDPE	5.90	5.70	5.45	5.15	4.30	5.30	77.85
T_3	$Cacl_2$ 2% + Paraffin wax emulsion 10% + HDPE	6.00	5.85	5.55	5.10	*	4.50	51.01
T_4	$Cacl_2$ 4% + Paraffin wax emulsion 12% + HDPE	6.10	5.90	5.60	5.10	*	4.54	52.35
T_5	$Cacl_2$ 2% + Paraffin wax emulsion 10% + Cling film	6.10	6.00	5.85	5.60	5.25	5.76	93.29
T_6	$Cacl_2$ 4% + Paraffin wax emulsion 12% + Cling film	5.90	5.80	5.70	5.40	4.70	5.50	84.56
T_7	$Cacl_2$ 2% + Paraffin wax emulsion 10% + Gunny bag	6.10	6.00	5.80	5.30	*	4.64	55.70
T_8	$Cacl_2$ 4% + Paraffin wax emulsion 12% + Gunny bag	6.10	6.00	5.70	5.25	*	4.61	54.70
T_9	$Cacl_2$ 2% + Paraffin wax emulsion 10% + CFB	5.90	5.75	5.60	5.30	4.80	5.47	83.56
T_{10}	$Cacl_2$ 4% + Paraffin wax emulsion 12% + CFB	6.10	6.00	5.75	5.40	4.95	5.64	89.26
T_{11}	$Cacl_2$ 2% + Paraffin wax emulsion 10% + News paper	5.85	5.75	5.50	5.25	*	4.47	50.00
T_{12}	$Cacl_2$ 4% + Paraffin wax emulsion 12% + News paper	5.80	5.65	5.40	5.20	*	4.41	47.99
	SEm±	0.07	0.10	0.09	0.06	0.04		
	CD at 5 %	0.20	0.30	O.26	0.19	0.13		

Note:- *fruits are completely spoiled

Table 2: Effect of different packaging materials on "Fruit girth (cm)" in Nagpur mandarin

Notations	Treatments	Storage days					Mean	% increase over control
		5	10	15	20	25		
T_0	Control	6.10	5.50	4.40	*	*	3.2	0
T_1	$Cacl_2$ 2% + Paraffin wax emulsion 10% + LDPE	6.90	6.80	6.50	6.00	*	5.24	63.75

T_2	$Cacl_2$ 4% + Paraffin wax emulsion 12% + LDPE	6.70	6.50	6.25	5.85	5.50	6.16	92.5
T_3	$Cacl_2$ 2% + Paraffin wax emulsion 10% + HDPE	6.50	6.30	6.00	5.60	*	4.88	52.5
T_4	$Cacl_2$ 4% + Paraffin wax emulsion 12% + HDPE	6.80	6.60	6.30	6.00	*	5.14	60.63
T_5	$Cacl_2$ 2% + Paraffin wax emulsion 10% + Cling film	7.0	6.90	6.80	6.60	6.20	6.7	109.36
T_6	$Cacl_2$ 4% + Paraffin wax emulsion 12% + Cling film	6.75	6.65	6.45	6.10	5.80	6.35	98.44
T_7	$Cacl_2$ 2% + Paraffin wax emulsion 10% + Gunny bag	6.95	6.85	6.70	5.70	*	5.24	63.75
T_8	$Cacl_2$ 4% + Paraffin wax emulsion 12% + Gunny bag	6.85	6.70	6.40	5.80	*	5.15	60.94
T_9	$Cacl_2$ 2% + Paraffin wax emulsion 10% + CFB	6.70	6.60	6.40	6.00	5.90	6.32	97.50
T_{10}	$Cacl_2$ 4% + Paraffin wax emulsion 12% + CFB	6.80	6.70	6.55	6.30	6.00	6.47	102.19
T_{11}	$Cacl_2$ 2% + Paraffin wax emulsion 10% + News paper	6.80	6.75	6.50	6.35	*	5.28	65.00
T_{12}	$Cacl_2$ 4% + Paraffin wax emulsion 12% + News paper	6.85	6.60	6.45	6.30	*	5.24	63.75
	SEm±	0.10	0.10	0.07	0.09	0.06		
	CD at 5 %	0.29	0.30	0.22	0.25	0.19		

Note:- *fruits are completely spoiled

Table 3: Effect of different packaging materials on "Fruit shape index (cm)" in Nagpur mandarin

Notations	Treatments	Storage days						
		5	10	15	20	25	Mean	% increase over control
T_0	Control	0.91	0.92	0.94	*	*	2.77	0
T_1	$Cacl_2$ 2% + Paraffin wax emulsion 10% + LDPE	0.86	0.86	0.88	0.91	*	3.51	26.71
T_2	$Cacl_2$ 4% + Paraffin wax emulsion 12% + LDPE	0.83	0.88	0.91	0.92	0.93	4.46	61.01
T_3	$Cacl_2$ 2% + Paraffin wax emulsion 10% + HDPE	0.89	0.91	0.91	0.92	*	3.62	30.69
T_4	$Cacl_2$ 4% + Paraffin wax emulsion 12% + HDPE	0.82	0.87	0.86	0.88	*	3.44	24.19
T_5	$Cacl_2$ 2% + Paraffin wax emulsion 10% + Cling film	0.82	0.82	0.84	0.85	0.85	4.17	51.85
T_6	$Cacl_2$ 4% + Paraffin wax emulsion 12% + Cling film	0.85	0.85	0.86	0.86	0.86	4.28	54.51
T_7	$Cacl_2$ 2% + Paraffin wax emulsion 10% + Gunny bag	0.84	0.85	0.86	0.91	*	3.46	24.91
T_8	$Cacl_2$ 4% + Paraffin wax emulsion 12% + Gunny bag	0.87	0.87	0.86	0.88	*	3.49	25.99

T_9	$Cacl_2$ 2% + Paraffin wax emulsion 10% + CFB	0.85	0.85	0.86	0.86	0.86	4.28	54.51
T_{10}	$Cacl_2$ 4% + Paraffin wax emulsion 12% + CFB	0.82	0.84	0.84	0.85	0.86	4.2	51.62
T_{11}	$Cacl_2$ 2% + Paraffin wax emulsion 10% + News paper	0.85	0.86	0.86	0.87	*	3.43	23.83
T_{12}	$Cacl_2$ 4% + Paraffin wax emulsion 12% + News paper	0.85	0.86	0.86	0.87	*	3.43	23.83
	SEm±	0.01	0.01	0.01	0.04	0.03		
	CD at 5 %	0.03	0.04	0.04	0.02	0.01		

Note:- *fruits are completely spoiled

Table 4: Effect of different packaging materials on "Fruit spoilage (%)" in Nagpur mandarin

Notations	Treatments	Storage days						
		5	10	15	20	25	Mean	% decreaseover control
T_0	Control	17.6	36.1	69.3	100	100	64.6	0
T_1	$Cacl_2$ 2% + Paraffin wax emulsion 10% + LDPE	4.6	15.7	32.2	49.2	100	40.3	37.51
T_2	$Cacl_2$ 4% + Paraffin wax emulsion 12% + LDPE	4.5	14.6	28.3	48.1	68.2	32.8	49.26
T_3	$Cacl_2$ 2% + Paraffin wax emulsion 10% + HDPE	7.4	22.3	40.7	52.4	100	44.6	30.97
T_4	$Cacl_2$ 4% + Paraffin wax emulsion 12% + HDPE	7.62	21.2	38.7	49.2	58.94	35.13	45.59
T_5	$Cacl_2$ 2% + Paraffin wax emulsion 10% + Cling film	3.20	13.2	27.3	38.4	49.62	26.35	59.19
T_6	$Cacl_2$ 4% + Paraffin wax emulsion 12% + Cling film	3.12	12.7	26.3	36.7	48.55	25.48	60.53
T_7	$Cacl_2$ 2% + Paraffin wax emulsion 10% + Gunny bag	8.40	24.4	38.5	56.4	100	45.55	29.46
T_8	$Cacl_2$ 4% + Paraffin wax emulsion 12% + Gunny bag	8.12	23.1	39.6	58.9	100	45.94	28.85
T_9	$Cacl_2$ 2% + Paraffin wax emulsion 10% + CFB	2.41	10.1	19.2	30.1	43.26	21.02	67.45
T_{10}	$Cacl_2$ 4% + Paraffin wax emulsion 12% + CFB	2.12	9.62	17.4	29.9	42.09	20.24	68.65
T_{11}	$Cacl_2$ 2% + Paraffin wax emulsion 10% + News paper	3.45	16.1	22.6	43.4	100	37.13	42.50
T_{12}	$Cacl_2$ 4% + Paraffin wax emulsion 12% + News paper	4.65	14.3	21.0	42.2	100	36.44	43.57
23	**SEm±**	0.12	0.39	0.57	0.67	0.94		
	CD at 5 %	0.35	1.15	1.66	1.96	2.75		

Note:- *fruits are completely spoiled

Fruit Spoilage Percentage

The lowest spoilage rate was observed in T_{10} ($CaCl_2$ 4% + Paraffin Wax Emulsion 12% + CFB) at 42.09% after 25 days, followed by T_5 ($CaCl_2$ 2% + Paraffin Wax Emulsion 10% + Cling Film) at 49.62%. In contrast, the control group showed complete spoilage (100%). The antimicrobial

properties of calcium chloride, combined with the protective paraffin wax coating and the physical barrier of CFB, helped limit microbial growth and fruit decay. The higher spoilage in the control samples was likely due to a weaker defense against fungal infections and increased respiration, which led to shriveling [15,16].

Table 5: Effect of different packaging materials on "specific gravity" in Nagpur mandarin

Specific gravity								
Notations	**Treatments**	**Storage days**						
		5	**10**	**15**	**20**	**25**	**Mean**	**% change over control**
T_0	Control	0.85	0.85	0.83	*	*	2.53	0
T_1	$Cacl_2$ 2% + Paraffin wax emulsion 10% + LDPE	0.93	0.92	0.91	0.88	*	3.64	43.87
T_2	$Cacl_2$ 4% + Paraffin wax emulsion 12% + LDPE	0.90	0.88	0.86	0.85	0.83	4.33	71.15
T_3	$Cacl_2$ 2% + Paraffin wax emulsion 10% + HDPE	0.91	0.90	0.88	0.86	*	3.55	40.32
T_4	$Cacl_2$ 4% + Paraffin wax emulsion 12% + HDPE	0.93	0.91	0.88	0.88	0.86	4.46	76.28
T_5	$Cacl_2$ 2% + Paraffin wax emulsion 10% + Cling film	0.92	0.91	0.89	0.87	0.86	4.44	75.49
T_6	$Cacl_2$ 4% + Paraffin wax emulsion 12% + Cling film	0.93	0.92	0.89	0.87	*	3.61	42.69
T_7	$Cacl_2$ 2% + Paraffin wax emulsion 10% + Gunny bag	0.92	0.90	0.88	0.82	*	3.52	39.13
T_8	$Cacl_2$ 4% + Paraffin wax emulsion 12% + Gunny bag	0.91	0.90	0.89	0.86	*	3.56	40.71
T_9	$Cacl_2$ 2% + Paraffin wax emulsion 10% + CFB	0.95	0.94	0.94	0.93	0.90	4.66	84.19
T_{10}	$Cacl_2$ 4% + Paraffin wax emulsion 12% + CFB	0.94	0.91	0.90	0.87	0.85	4.48	77.08
T_{11}	$Cacl_2$ 2% + Paraffin wax emulsion 10% + News paper	0.88	0.87	0.87	0.85	*	3.47	37.15
T_{12}	$Cacl_2$ 4% + Paraffin wax emulsion 12% + News paper	0.89	0.88	0.87	0.86	*	3.50	38.34
	SEm±	0.01	0.01	0.01	0.01	0.01		
	CD at 5 %	0.04	0.04	0.03	0.03	0.02		

Note:- *fruits are completely spoiled

Table 6: Effect of different packaging materials on "Physiological loss in weight (%)"in Nagpur mandarin

Notations	**Treatments**	**Storage days**						
		5	**10**	**15**	**20**	**25**	**Mean**	**% decrease over control**
T_0	Control	8.28	15.24	23.80	*	*	9.46	0

T_1	$Cacl_2$ 2% + Paraffin wax emulsion 10% + LDPE	0.78	1.34	2.32	3.84	*	1.66	82.45
T_2	$Cacl_2$ 4% + Paraffin wax emulsion 12% + LDPE	0.96	1.89	2.64	3.48	4.45	2.68	71.67
T_3	$Cacl_2$ 2% + Paraffin wax emulsion 10% + HDPE	1.18	2.08	3.36	4.91	*	2.31	75.58
T_4	$Cacl_2$ 4% + Paraffin wax emulsion 12% + HDPE	0.97	1.28	2.64	3.96	4.86	2.74	71.03
T_5	$Cacl_2$ 2% + Paraffin wax emulsion 10% + Cling film	1.08	1.39	2.69	4.09	4.98	2.85	69.87
T_6	$Cacl_2$ 4% + Paraffin wax emulsion 12% + Cling film	0.92	1.32	2.54	3.98	4.13	2.58	72.73
T_7	$Cacl_2$ 2% + Paraffin wax emulsion 10% + Gunny bag	0.82	1.12	2.45	3.86	*	1.65	82.56
T_8	$Cacl_2$ 4% + Paraffin wax emulsion 12% + Gunny bag	0.87	1.65	2.36	3.44	*	1.66	82.45
T_9	$Cacl_2$ 2% + Paraffin wax emulsion 10% + CFB	0.54	1.23	2.28	3.09	4.02	2.23	76.43
T_{10}	$Cacl_2$ 4% + Paraffin wax emulsion 12% + CFB	0.32	0.98	2.01	2.93	3.47	1.94	79.49
T_{11}	$Cacl_2$ 2% + Paraffin wax emulsion 10% + News paper	3.45	5.23	7.31	9.18	*	5.03	46.83
T_{12}	$Cacl_2$ 4% + Paraffin wax emulsion 12% + News paper	4.65	5.36	6.68	8.78	*	5.09	46.19
	SEm±	0.06	0.11	0.17	0.08	0.07		
	CD at 5 %	0.17	0.32	0.51	0.24	0.22		

Note:- *fruits are completely spoiled

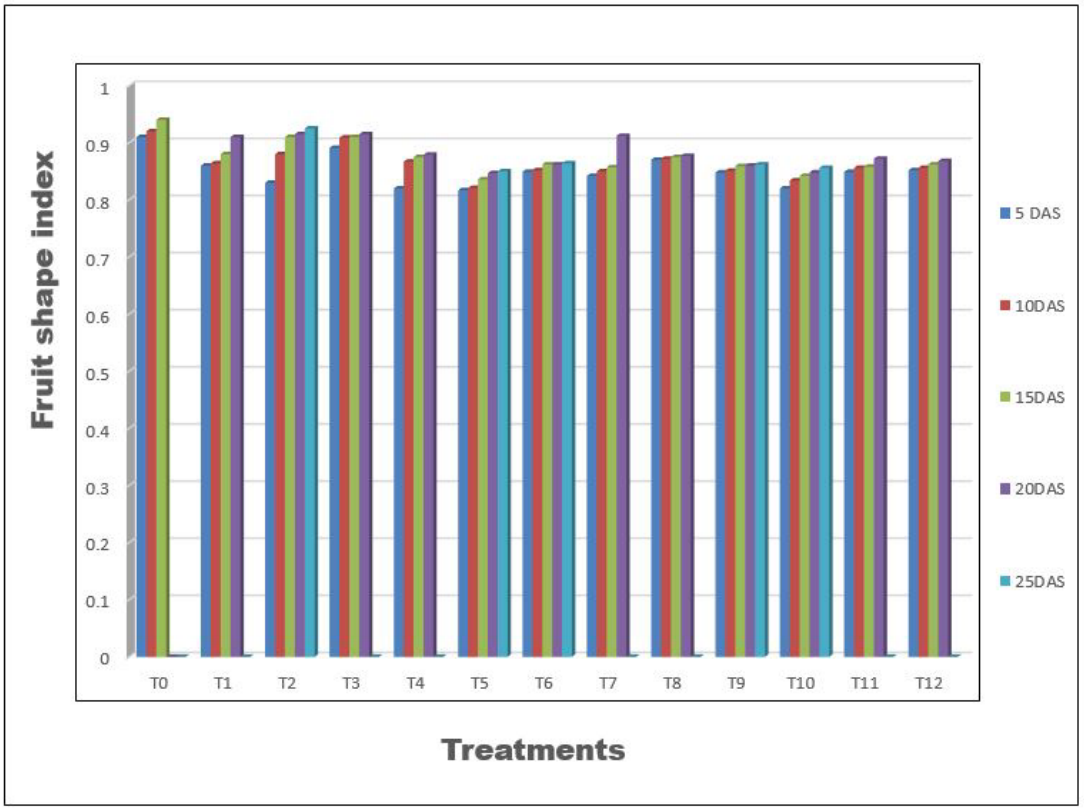

Figure 1: Effect of different packaging materials on "Fruit shape index (cm)" in Nagpur mandarin

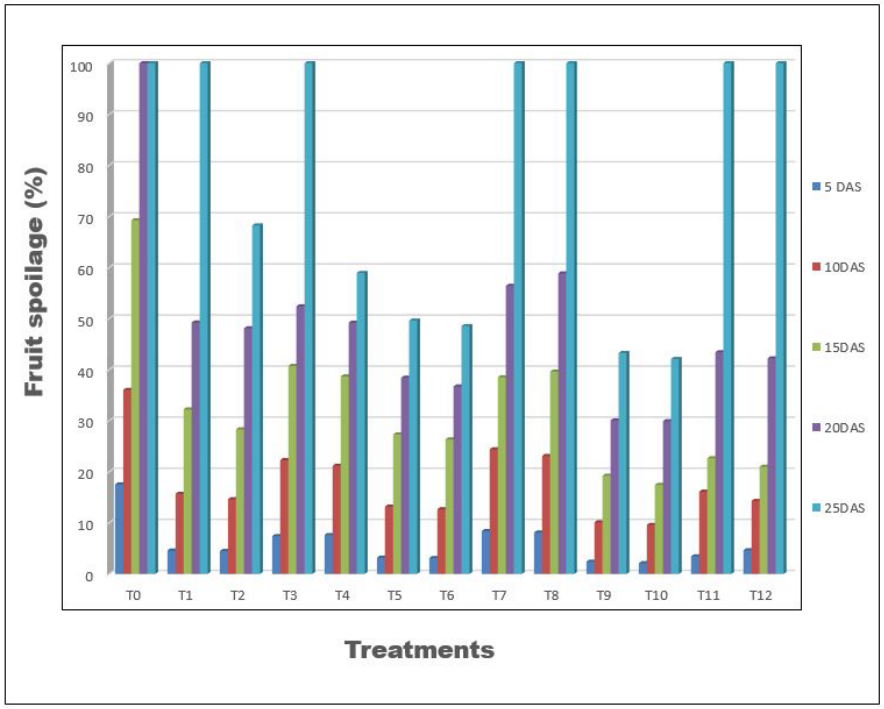

Figure 2: Effect of different packaging materials on "Fruit spoilage (%)" in Nagpur mandarin

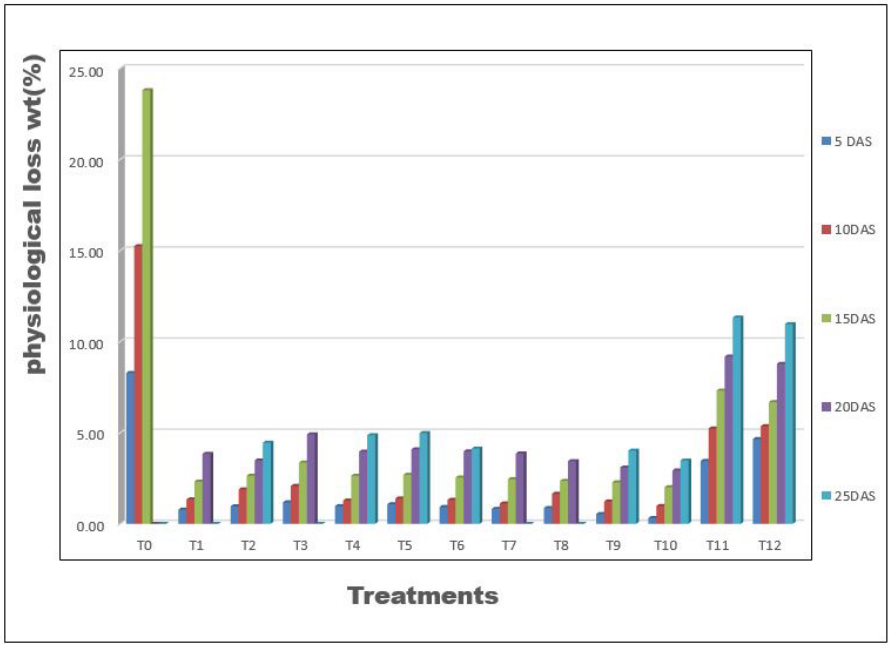

Figure 3: Effect of different packaging materials on "Physiological loss in weight (%)"in Nagpur mandarin

Specific Gravity

Specific gravity was best maintained in T_9 ($CaCl_2$ 2% + Paraffin Wax Emulsion 10% + CFB) at 0.94 g/cm³, followed by T_{10} ($CaCl_2$ 4% + Paraffin Wax Emulsion 12% + CFB) at 0.85 g/cm³. In contrast, the control showed a much higher value of 2.53. The improved retention in treated samples was likely due to the coating's ability to seal lenticels, reducing water loss and preventing dehydration [13,17]. Over time, the breakdown of structural polysaccharides led to a decrease in pulp concentration, which contributed to the decline in specific gravity [18].

Physiological Loss in Weight (PLW)

The lowest physiological loss in weight (PLW) was observed in T_{10} ($CaCl_2$ 4% + Paraffin Wax Emulsion 12% + CFB) at 3.47%, followed by T_9 ($CaCl_2$ 2% + Paraffin Wax Emulsion 10% + CFB) at 4.02%. In contrast, the control experienced the highest weight loss at 9.46%. The combination of $CaCl_2$ and wax helped reduce transpiration and respiration rates, effectively minimizing weight loss [19]. PLW primarily resulted from water evaporation, respiration, and degradation, but these processes were significantly restricted by the applied coatings [20,21].

Conclusion

This study demonstrates the effectiveness of postharvest treatments combining calcium chloride and wax coatings with suitable packaging in reducing weight loss and preserving the quality of Nagpur mandarins. Among the tested treatments, T_{10} ($CaCl_2$ 4% + Paraffin Wax 12% + CFB) showed the most promising results, showing the minimum weight loss (3.47%), maintaining fruit dimensions (length: 4.85 cm, girth: 6.47 cm), and preserving fruit shape (index: 0.856). T_5 ($CaCl_2$ 2% + Paraffin Wax 10% + Cling Film) also performed well, highlighting the role of coating formulations in prolonging fruit freshness. In contrast, the control exhibited complete spoilage and significant weight loss (9.46%), underscoring the importance of postharvest interventions. These findings reinforce the potential of coatings and optimized packaging in extending shelf life and enhancing the commercial viability of mandarins. Future research should focus on optimizing storage conditions over longer durations and exploring alternative coating materials to further improve postharvest fruit preservation techniques.

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