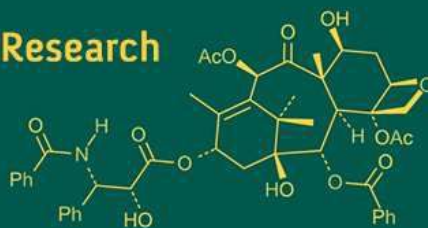
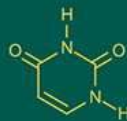


International Journal of Advanced Biochemistry Research



ISSN Print: 2617-4693
ISSN Online: 2617-4707
IJABR 2024; SP-8(10): 1402-1407
www.biochemjournal.com
Received: 15-07-2024
Accepted: 19-08-2024

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Optimization of packaging and storage conditions to enhance the chemical stability of osmotically dehydrated papaya (*Carica papaya* L.) cubes

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DOI: <https://doi.org/10.33545/26174693.2024.v8.i10Sq.2732>

Abstract

Papaya (*Carica papaya* L.) is a nutrient-rich fruit, rich in vitamins, minerals and antioxidants, contributing to health promotion and disease prevention. This study evaluates optimal packaging and storage conditions to maintain the color and quality of osmo-air dried papaya cubes. Various packaging materials, including low-density polyethylene (LDPE), high-density polyethylene (HDPE), brown paper bags and laminated aluminum pouches, were tested. Samples were stored at room temperature (20-25 °C) and refrigerated (0-5 °C) for three months, with monthly analyses conducted to assess changes in chemical composition and organoleptic qualities. Results indicated that samples in laminated aluminum pouches under refrigeration retained the highest ascorbic acid levels (17.35 mg/100 g). In contrast, samples stored at room temperature showed the highest acidity (0.12%). Additionally, significant increases in reducing sugars (from 47.15% to 51.40%) and total sugars (from 65.52% to 67.17%) were observed, while non-reducing sugars decreased (from 18.40% to 15.20%) over the storage period. The study conclude that refrigerated storage in laminated aluminum pouches effectively preserves the nutritional quality of osmo-air dried papaya cubes, particularly ascorbic acid levels. Optimal packaging and storage conditions significantly influence the chemical composition and overall quality of the fruit.

Keywords: Osmotic dehydration, packaging material, low temperature, refrigerated temperature, storage

1. Introduction

The melon tree, papaya (*Carica papaya* L.) is a prominent fruit in tropical and subtropical regions, valued for its rich nutritional and therapeutic properties, including high water content (88.33%), sugars, vitamins and minerals. However, fresh-cut papaya faces significant post-harvest handling and storage challenges, resulting in considerable waste. There is an urgent need to explore effective preservation techniques that sustain the fruit's health benefits and market appeal. Osmotic dehydration presents a viable solution for enhancing the shelf life and quality of papaya, involving immersion in concentrated solutions to facilitate water removal while preserving nutritional and sensory characteristics (Yadav & Singh, 2014) [33]. This study aims to optimize storage conditions and packaging materials to assess their impact on the physio-chemical composition of osmotically dehydrated papaya cubes. The research is justified by its potential to reduce post-harvest losses, extend shelf life and improve marketability, thereby supporting sustainable agricultural practices and food security.

2. Materials and Methods

The experiment was conducted at the Fruit Processing Unit, College of Agriculture, Dharashiv, Vasantrao Naik Marathwada Agricultural University, Parbhani, India. A Factorial Completely Randomized Design was employed, comprising eight treatment combinations. Treatments involved packaging osmo-air dried papaya cubes in four different materials: low-density polyethylene (LDPE), high-density polyethylene (HDPE), brown paper bags, and laminated aluminum pouches. The samples were stored at two temperature regimes: room temperature (20-25 °C) and refrigerated (0-5 °C). Each treatment was replicated three times for both temperature settings and packaging types.

The chemical properties of the osmotically dehydrated papaya cubes, including titratable acidity (%), ascorbic acid (mg/100 g pulp), moisture content (%) and sugar content

(%), were analyzed following the methods outlined by Ranganna. Following treatment combinations were employed.

Table 1: Treatment combination

Treatments	Treatment combination	Treatment Details
T ₁	P ₁ S ₁	Low density polyethylene + Room Temperature
T ₂	P ₂ S ₁	High density polyethylene + Room Temperature
T ₃	P ₃ S ₁	Brown Paper Bag + Room Temperature
T ₄	P ₄ S ₁	Laminated Aluminium Pouch + Room Temperature
T ₅	P ₁ S ₂	Low density polyethylene + Refrigerated Temperature
T ₆	P ₂ S ₂	High density polyethylene + Refrigerated Temperature
T ₇	P ₃ S ₂	Brown Paper Bag + Refrigerated Temperature
T ₈	P ₄ S ₂	Laminated Aluminium Pouch + Refrigerated Temperature

3. Results and Discussion

3.1 Physico-chemical parameters of papaya fruit

The physico-chemical characteristics of fresh papaya fruits utilized for osmotically dehydrated papaya cubes are summarized in table 2. The average weight of the fruits was 2650 ± 250 grams, with the pulp comprising 71.6%, the peel 20.2% and the seeds 8.15% of the total weight. The soluble solids averaged $10.40 \pm 0.76\%$, while total sugars were approximately $7.90 \pm 0.57\%$, which included reducing sugars at $5.68 \pm 0.45\%$ and non-reducing sugars at $2.22 \pm 0.12\%$. The acidity level was measured at $0.17 \pm 0.06\%$ and the ascorbic acid content was found to be 41.6 ± 1.27 mg per 100 grams. These findings align with the results reported by Kumar *et al.* (2019) [14], Annegowda *et al.* (2013) [1], Binko *et al.* (2014) [3] and Ikram *et al.* (2015) [9], thereby enhancing the understanding of the physico-chemical profile of fresh papayas for processing applications.

Table 2: Physico-chemical parameters of fresh fruit of papaya variety EXP-15 used for osmotic dehydration

Sr. No.	Characteristics	Average value
1.	Average weight (g)	2650±250
2.	Pulp (%)	71.6±2.7
3.	Peel (%)	20.2±1.3
4.	Seed (%)	8.15±0.57
5.	Total soluble solids (%)	10.40±0.76
6.	Total sugar (%)	7.90±0.57
7.	Reducing sugar (%)	5.68±0.45
8.	Non reducing (%)	2.22±0.12
9.	Acidity (%)	0.17±0.06
10.	Ascorbic acid (mg/100 g)	41.6±1.27

3.2 Chemical Characteristics

3.2.1 Total Soluble Solid (TSS)

Total Soluble solid of prepared products shows increasing trend during storage (Table 3). Statistically significant differences were observed for total soluble solid content in osmotically dehydrated papaya cubes due to storage temperature, different packaging material and interaction between temperature and packaging material. Further, dried papaya cubes samples recorded higher content of total soluble solid (73.75%) at initial stage of storage.

In case of osmotically dehydrated papaya cubes it was found that with passing of storage period (1, 2 and 3 months) there was increase in the total soluble solid content of the samples. After 3 months storage of the osmotically dehydrated papaya cubes shreds significant differences were observed due to variations in temperature and interaction between temperature and packaging. Maximum total soluble sugar found in brown paper bag (77.25%) packaging

material over 90 days of storage. In case of temperature, significantly highest (76.27%) total soluble solid was observed in samples stored at room temperature. In general, there was gradual increase (73.75 to 77.25%) in total soluble solid content in all the samples during the 3 months of storage as compared to initial. The samples stored at refrigerated temperature (0-5 °C) had less increase (73.42 to 74.10%) in total soluble solid than those stored at room temperature (Table 3), might be due to limitation in conversion of polysaccharides into soluble sugar and also, oxygen free micro-environment might have prevented the oxidation reduction reaction.

The increase in total soluble solid might be due to conversion of polysaccharides to soluble sugar and increased sugar solubility. Analogous results were reported by Argaiz *et al.* (1994) [2], Islam *et al.* (2019) [10] in osmotically dehydrated papaya cubes, Mali (1997) [15], Palve (2002) [20] and Gawade (2002) [6] in dried figs.

3.2.2 Ascorbic acid

Ascorbic acid content of papaya cubes shows gradual decrease during storage (Table 3). Statistically significant differences were observed for ascorbic acid content in osmotically dehydrated papaya cubes due to storage temperature, different packaging material and interaction between temperature and packaging material. Further, dried papaya cubes samples recorded higher content of ascorbic acid (17.88 mg/ 100 gms) at initial 30 days of storage in laminated aluminium pouch at refrigerated temperature. In case of osmotically dehydrated papaya cubes it was found that with passing of storage period (1, 2 and 3 months) there was decrease (17.88 to 13.30%) in the ascorbic acid content of the samples. After 3 months storage of the osmotically dehydrated papaya cubes shreds significant differences were observed due to variations in temperature and interaction between temperature and packaging. In case of temperature, significantly highest (15.06%) ascorbic acid was observed in samples stored at refrigerated temperature for 90 days of storage. In general, there was gradual decrease in ascorbic acid content in all the samples during the 3 months of storage as compared to initial. The samples stored at refrigerated temperature (0-5 °C) had less decrease (17.88 to 13.50%) in ascorbic acid than those stored at room temperature (17.02 to 13.30%) (Table 3), might be due to limitation in oxidation of papaya cube. The decrease in ascorbic acid might be due to oxidation of papaya cube. Analogous results were reported by Sumitha *et al.* (2015) [31] in osmotically dried aonla segments, Da *et al.* (2018) [5] in dried papaya, Chandra and Kumara (2015) [4] in osmotically

dehydrated papaya, Thonta and Patil, (1988) ^[32], Pawar *et al.* (1992) ^[23] in dried figs.

3.2.3 Acidity

Acidity of prepared products gradually declined during storage (Table 3). Statistically significant differences were observed for acidity content in osmotically dehydrated papaya cubes due to storage temperature, different packaging material and interaction between temperature and packaging material. Further, dried papaya cubes samples recorded higher content of acidity (0.13%) at initial 30 days stage of storage. In case of osmotically dehydrated papaya cubes it was found that with passing of storage period (1, 2 and 3 months) there was decrease (0.13 to 0.08%) in the acidity content of the samples. After 3 months storage of the osmotically dehydrated papaya cubes shreds significant differences were observed due to variations in temperature and interaction between temperature and packaging.

Minimum acidity (0.06%) found in low density polyethylene over 90 days of storage. In case of temperature, significantly highest (0.09%) acidity was observed in both samples stored at room temperature and refrigerated temperature. In general, there was gradual decrease in acidity content in all the samples during the 3 months of storage as compared to initial 30 days stored sample. The samples stored at refrigerated temperature (0-5 °C) had less decrease in acidity (0.11 to 0.06%) than those stored at room temperature (0.13 to 0.08%) (Table 3). The decrease in acidity might be due to cellular changes and breakdown of organic acids. Analogous results were reported by Chandra and Kumara (2015) ^[4] in osmotically dehydrated papaya, Rohani *et al.* (1997) ^[25] in stored papaya, Hazarika *et al.* (2017) ^[8] in stored papaya fruits, Othman (2009) ^[19] in stored papaya, Sumitha *et al.* (2015) ^[31] in osmotically dehydrated aonla segments.

Table 3: Effect of different temperatures and packaging on the total soluble solid, ascorbic acid (mg/100g) and acidity (%) in osmotically dehydrated papaya cubes at different stages of storage.

Treatments	Total soluble solid			Ascorbic acid(mg/100g)			Acidity (%)		
	30 Days	60 Days	90 Days	30 Days	60 Days	90 Days	30 Days	60 Days	90 Days
Factor A: Packaging material									
P ₁ - Low density polyethylene	73.51	74.50	75.61	16.77	16.24	13.95	0.08	0.08	0.08
P ₂ - High density polyethylene	73.43	74.40	75.60	16.91	16.36	14.13	0.10	0.10	0.09
P ₃ - Brown paper bag	73.46	75.13	76.48	16.60	14.92	13.08	0.11	0.09	0.09
P ₄ - Laminated aluminium pouch	72.54	73.23	73.92	17.45	16.83	16.62	0.12	0.12	0.11
S.E(m)+	0.11	0.21	0.11	0.04	0.05	0.05	0.01	0.01	0.00
C.D @ 5%	0.33	0.63	0.34	0.12	0.14	0.15	0.02	0.02	0.01
Factor B: Temperature									
S ₁ - Room temperature	73.37	74.96	76.27	16.74	16.04	13.83	0.11	0.11	0.09
S ₂ - Refrigerator temperature	73.10	73.67	74.53	17.12	16.14	15.06	0.09	0.09	0.09
S.E(m)+	0.08	0.15	0.08	0.03	0.03	0.03	0.01	0.00	0.00
C.D @ 5%	0.24	0.44	0.24	0.08	0.10	0.10	0.02	0.01	0.01
Interaction effect (A x B)									
P ₁ S ₁	73.75	75.34	76.53	16.70	16.60	13.30	0.10	0.10	0.10
P ₂ S ₁	73.43	75.03	76.57	16.85	16.67	13.57	0.09	0.09	0.08
P ₃ S ₁	73.50	75.63	77.25	16.40	14.60	13.65	0.12	0.09	0.08
P ₄ S ₁	72.78	73.83	74.73	17.02	16.28	15.80	0.13	0.12	0.12
P ₁ S ₂	73.27	73.65	74.68	16.83	15.88	14.60	0.06	0.06	0.06
P ₂ S ₂	73.42	73.77	74.63	16.97	16.05	14.70	0.11	0.10	0.09
P ₃ S ₂	73.42	74.63	74.70	16.80	15.23	13.50	0.09	0.09	0.09
P ₄ S ₂	72.30	72.63	73.10	17.88	17.38	17.35	0.11	0.11	0.11
S.E (m)+	0.16	0.29	0.16	0.06	0.06	0.07	0.01	0.01	0.01
C.D @ 5%	0.47	0.89	0.49	0.17	0.19	0.21	0.04	0.03	0.02

3.2.4 Moisture

Moisture of prepared products gradually declined during storage (Table 4). Statistically significant differences were observed for moisture content in osmotically dehydrated papaya cubes due to storage temperature, different packaging material and interaction between temperature and packaging material. Further, dried papaya cubes samples recorded higher content of moisture (15.62%) at initial 30 days stage of storage in laminated aluminium pouch. In case of osmotically dehydrated papaya cubes it was found that with passing of storage period (1, 2 and 3 months) there was decrease in the moisture content of the samples. After 3 months storage of the osmotically dehydrated papaya cubes shreds significant differences were observed due to variations in temperature and interaction between

temperature and packaging. In case of temperature, significantly highest (13.53%) moisture was observed in samples stored at refrigerated temperature at 90 days of storage. In general, there was gradual decrease (15.62 to 11.58%) in moisture content in all the samples during the 3 months of storage as compared to initial 30 days stored sample. The samples stored at refrigerated temperature (0-5 °C) had less decrease in moisture than those stored at room temperature (Table 4). The decrease in moisture might be due to water activity reduction and osmosis. Analogous results were reported by Sagar *et al.* (1999) ^[34] in mango slices, Thonda and Patil (1988) ^[32], Pawar *et al.* (1992) ^[23] in dried figs and Gharate (1984) ^[7] in Ber candy. The results obtained are within the range of reported values.

3.2.5 Reducing sugar

Reducing sugar of prepared products shows increasing trend during storage (Table 4). Statistically significant differences were observed for reducing sugar content in osmotically dehydrated papaya cubes due to storage temperature, different packaging material and interaction between temperature and packaging material. Further, dried papaya cubes samples recorded higher content of reducing sugar (48.50%) at initial 30 days of storage. In case of osmotically dehydrated papaya cubes it was found that with passing of storage period (1, 2 and 3 months) there was increase (48.50 to 50.80%) in the reducing sugar content of the samples. After 3 months storage of the osmotically dehydrated papaya cubes shreds significant differences were observed due to variations in temperature and interaction between temperature and packaging. In case of temperature, significantly highest (50.32%) reducing sugar was observed in samples stored at room temperature at 90 days of storage. In general, there was gradual increase in reducing sugar content in all the samples during the 3 months of storage as compared to initial. The samples stored at refrigerated temperature (0-5 °C) had less increase in reducing sugar than those stored at room temperature (Table 4), might be due to limitation in Inversion of Sucrose and also, Cellular Breakdown of polysaccharides into simple sugar. The increase in reducing sugar might be due to Inversion of Sucrose and also, Cellular Breakdown of polysaccharides into simple sugar. Analogous results were reported by Sumitha *et al.* (2015) ^[31] in osmotically dehydrated aonla segments, Narayana *et al.* (2002) ^[18] in stored banana at different storage conditions, Atri *et al.* (2014) ^[35] in stored papaya fruit, Shivani *et al.* (2020) ^[28] in papaya powder, Thonta and Patil (1988) ^[32], Pawar *et al.* (1992) ^[23] in dried figs and Kakade *et al.* (2021) ^[12] in Sweet orange.

3.2.6 Non reducing sugars

Non reducing sugar of prepared products gradually declined during storage (Table 4). Statistically significant differences were observed for non reducing sugar content in osmotically dehydrated papaya cubes due to storage temperature, different packaging material and interaction between temperature and packaging material. Further, dried papaya cubes samples recorded higher content of non reducing sugar (18.40%) at initial 30 days stage of storage. In case of osmotically dehydrated papaya cubes it was found that with passing of storage period (1, 2 and 3 months) there was decrease (18.40 to 15.20%) in the non reducing sugar content of the samples. After 3 months storage of the osmotically dehydrated papaya cubes shreds significant differences were observed due to variations in temperature

and interaction between temperature and packaging. In case of temperature, significantly highest (16.62%) non reducing sugar was observed in samples stored at refrigerated temperature. In general, there was gradual decrease in non reducing sugar content in all the samples during the 3 months of storage as compared to initial 30 days stored sample. The samples stored at refrigerated temperature (0-5 °C) had less decrease in non reducing sugar than those stored at room temperature (Table 4). The decrease in non reducing sugar might be due to Hydrolysis of Sucrose and enzymatic activity. Analogous results were reported by Thonda and Patil (1988) ^[32], Pawar *et al.* (1992) ^[23] in dried figs and Gharate (1984) ^[7] in Ber candy. The results obtained are within the range of reported values.

3.2.7 Total Sugars

Total sugar of prepared products shows increasing trend during storage (Table 4). Statistically significant differences were observed for total sugar content in osmotically dehydrated papaya cubes due to storage temperature, different packaging material and interaction between temperature and packaging material. Further, dried papaya cubes samples recorded higher content of total sugar (66.20%) at initial 30 days of storage in high density polyethylene. In case of osmotically dehydrated papaya cubes it was found that with passing of storage period (1, 2 and 3 months) there was increase (65.90 to 67.17%) in the total sugar content of the samples in brown paper bag. After 3 months storage of the osmotically dehydrated papaya cubes shreds significant differences were observed due to variations in temperature and interaction between temperature and packaging. Maximum total sugar found in brown paper bag (67.17%) packaging material over 90 days of storage. In case of temperature, significantly highest (66.20%) total sugar was observed in samples stored at room temperature for 90 days of storage. In general, there was gradual increase (66.20 to 67.17%) in total sugar content in all the samples during the 3 months of storage as compared to initial. The samples stored at refrigerated temperature (0-5 °C) had less increase in total sugar (65.52 to 66.34%) than those stored at room temperature (65.59 to 67.17%) (Table 4), might be due to limitation in degradation of polysaccharides and also, hydrolysis of Sucrose. The increase in total sugar might be due to degradation of polysaccharides and hydrolysis of sucrose. Analogous results were reported by Sumitha *et al.* (2015) ^[31] in osmotically dehydrated aonla segments, Jain *et al.* (2011) ^[11] and Moreno *et al.* (2004) ^[16-17] in osmotically dehydrated papaya cubes, Thonta and Patil (1988) ^[32], Pawar *et al.* (1992) ^[23] in dried figs.

Table 4: Effect of different temperatures and packaging on the moisture (%), reducing sugar (%), non reducing sugar (%) and Total sugar (%) in osmotically dehydrated papaya cubes at different stages of storage.

Treatments	Moisture (%)			Reducing sugar (%)			Non Reducing sugar (%)			Total sugar (%)		
	30 Days	60 Days	90 Days	30 Days	60 Days	90 Days	30 Days	60 Days	90 Days	30 Days	60 Days	90 Days
Factor A: Packaging material												
P1- Low density polyethylene	15.0	13.97	12.97	47.48	48.60	49.80	18.08	16.83	15.78	65.56	65.60	65.75
P2- High density polyethylene	15.09	14.17	13.10	47.75	48.82	50.23	18.25	17.03	16.05	65.93	66.04	66.30
P3- Brown paper bag	14.72	12.92	12.00	48.07	49.37	50.95	17.77	16.92	15.78	65.91	66.30	66.74
P4- Laminated aluminium pouch	15.52	15.07	14.13	47.32	47.97	48.33	18.30	17.90	17.27	65.64	65.87	65.90
S.E(m)+	0.06	0.11	0.09	0.06	0.06	0.08	0.06	0.06	0.06	0.06	0.14	0.05
C.D @ 5%	0.19	0.32	0.27	0.17	0.18	0.25	0.19	0.17	0.17	0.17	0.42	0.14
Factor B: Temperature												
S1- Room temperature	14.80	13.69	12.58	47.94	49.28	50.32	17.88	16.68	15.83	65.82	66.13	66.30
S2- Refrigerator temperature	15.36	14.37	13.53	47.36	48.10	49.34	18.33	17.66	16.62	65.70	65.77	66.03
S.E(m)+	0.04	0.08	0.06	0.04	0.04	0.06	0.04	0.04	0.04	0.04	0.10	0.03
C.D @ 5%	0.13	0.23	0.19	0.12	0.12	0.18	0.13	0.12	0.12	0.12	0.29	0.10
Interaction effect (A x B)												
P1S1	14.60	13.44	12.47	47.80	49.10	50.33	17.80	16.37	15.20	65.60	65.80	65.85
P2S1	14.72	13.52	12.62	48.10	49.33	50.80	18.10	16.53	15.43	66.20	66.24	66.25
P3S1	14.48	12.73	11.58	48.50	50.23	51.40	17.40	16.33	15.77	65.90	66.56	67.17
P4S1	15.42	15.08	13.63	47.37	48.43	48.73	18.20	17.50	16.90	65.59	65.93	65.94
P1S2	15.40	14.50	13.47	47.15	48.10	49.27	18.37	17.30	16.37	65.52	65.60	65.64
P2S2	15.47	14.82	13.58	47.40	48.30	49.67	18.40	17.53	16.67	65.65	65.83	66.34
P3S2	14.95	13.10	12.42	47.63	48.50	50.50	18.13	17.50	15.80	65.92	66.00	66.30
P4S2	15.62	15.05	14.63	47.27	47.50	47.93	18.40	18.30	17.63	65.69	65.80	65.85
S.E(m)+	0.09	0.15	0.12	0.08	0.08	0.12	0.09	0.08	0.08	0.08	0.19	0.07
C.D @ 5%	0.26	0.46	0.37	0.24	0.25	0.35	0.27	0.24	0.24	0.24	0.59	0.20

4. Conclusion

It can be concluded from the present investigation that different storage conditions have profound effect on chemical quality of osmotically dehydrated papaya cubes. Samples stored under refrigerated temperature conditions were able to maintain the chemical quality, especially when packed in laminated aluminum pouch till the end of storage period.

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