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Optimizing packaging and storage conditions for osmotically dehydrated aonla (*Emblica officinalis* L.) segments

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Abstract
Aonla (*Emblica officinalis* L.) is a highly nutritious fruit, especially valued for its rich vitamin C content Due to its strong acidity and astringency, it is not widely consumed in fresh form. Moreover, being a seasonal fruit with limited shelf life, it is necessary to process it into value-added, shelf-stable products using simple preservation methods like drying. Osmotic dehydration serves as an effective approach in this regard. Various packaging materials, including low-density polyethylene (LDPE), high-density polyethylene (HDPE), brown paper bags and laminated aluminium pouches, were employed. Samples were stored at room temperature (20-25 °C) and refrigerated (0-5 °C) over a three-month period, with analyses conducted at monthly intervals to assess changes in chemical composition and organoleptic qualities. Results indicated that samples stored in laminated aluminium pouches under refrigeration retained the highest levels of ascorbic acid (217.45 mg/100gm). Conversely, those stored at room temperature exhibited the highest acidity (1.11%). Notable increases in reducing sugars (48.22 to 52.05%) and total sugars (66.56 to 68.90%) were observed, alongside a partial reduction in non reducing sugars (19.87 to 17.86%) throughout the storage duration. Non-enzymatic browning was significantly lower in samples stored at room temperature in laminated aluminium pouches. Microbial analyses confirmed that osmotically dehydrated aonla segments are best preserved under refrigeration. Overall acceptability scores were highest (8.67) for samples packed in laminated aluminium pouches and stored in refrigerated conditions, while the lowest sensory ratings were recorded for those packed in brown paper (7.73) and stored at room temperature. These findings suggest that utilizing laminated aluminium pouches and refrigerating osmo-air dried aonla segments significantly enhances their storage life and quality, making this approach an effective method for preserving this nutritious fruit.

Keywords: Packaging material, osmotic dehydration, storage conditions, low density polyethylene, high density polyethylene, brown paper bag, laminated aluminum pouch

1. Introduction

Aonla (*Emblica officinalis* L.) commonly known as Indian gooseberry, is a significant minor fruit crop in India, valued for its exceptional nutritional, medicinal and economic properties. The total sugars content in aonla fruit varies from 7 to 9.6%, reducing sugars from 1.04 to 4.09% and non-reducing sugars from 3.05 to 7.23% among the various varieties. Despite its nutritional benefits, fresh aonla faces significant challenges in post-harvest handling and storage, leading to considerable waste. Consequently, there is a pressing need to explore more effective preservation techniques that maintain the fruit's health benefits and market appeal. Osmotic dehydration has emerged as a promising solution to enhance the shelf life and quality of aonla. This method involves immersing the fruit in concentrated solutions, allowing for water removal while preserving its nutritional value and sensory characteristics.

Given the increasing consumer demand for natural health-promoting products and the need for efficient post-harvest management, research into the packaging and storage stability of osmotically dehydrated aonla products is both timely and essential. This thesis explores the physico-chemical and sensory characteristics of aonla segments subjected to osmotic dehydration and stored under different packaging and temperature conditions, with the goal of extending shelf life while preserving quality. Dehydrated fruits are becoming more and more popular and profitable because of their inherent benefits, which include longer shelf life, increased resistance to bacterial attack and cheaper handling, storage and transportation expenses.

2. Materials and Methods
2.1 Preparation of samples
The selected fruits were washed with tap water, blanched for 10-12 minutes to reduce the enzyme activity and also for easy removal of seeds and then dipped in 2 per cent salt solution to remove the astringency. Seeds and segments were removed manually and subjected to osmotic dehydration. Pre-processed aonla analysed for physico-chemical characteristics. The moisture content was determined by direct heating in a drying oven at 105 °C for 48 hrs according to the AOAC method (AOAC, 1990) [1]. The initial average values for the main characteristics of the pre-processed aonla are shown in Table 3.1.

The osmotic solution utilized in experiment was prepared by mixing food-grade sucrose with distilled water. To maintain the osmotic solution-to-fruit ratio at 3:1, care was taken to prevent dilution of the osmotic solution due to water removal during the experimental runs. This ratio was critical in ensuring a consistent osmotic driving force throughout the process.

2.2 Osmotic dehydration
A sugar syrup with a concentration of 55°Brix was prepared by mixing 1 kg of sugar with 1 kg of water. The concentration was adjusted as needed by heating or adding more sugar. Once the syrup had cooled, 0.1% each of potassium metabisulphite and sodium metabisulphite used as preservatives and anti-browning agents were dissolved in a small amount of drinking water and mixed into the syrup To study osmosis the samples were kept in sugar syrup at room temperature for 72 hours for osmosis in a vessel and after that kept for draining for 12 hours. Osmotic dehydration characteristics of aonla fruit segments in sugar syrup of 55° Brix concentration and temperature 20-30 °C were studied by immersing 1 kg of aonla segments by three times its weight of syrup (sample: syrup ratio :: 1 : 3) kept in a vessel.

2.3 Tray-drying
On a perforated aluminum tray approximately 12 kg of osmosed aonla fruit samples were evenly distributed in a single layer and allowed to dry for duration of 10-12 hours. Only after the drying chamber's temperature had steadied to the necessary level was the tray placed inside the tray dryer. After taking the sample out of the dryer for approximately ten minutes the weight of the sample was periodically measured with an electric balance (0.01 g precision). The samples were dried allowed to cool and then promptly placed within packaging bags.

2.4 Packaging
A well dehydrated aonla fruit sample containing below 16 per cent were packed into the desired packaging material (High Density Polyethylene, Low density polyethylene, Brown paper bags & Laminated Aluminum pouch) for further treatment & storage studies. Each packaging samples packed with sample size 100gm osmotically dehydrated aonla segments.

2.5 Storage
Thermally sealed packaging bags were stored at different temperatures, room temperature (32 °C) and refrigerated temperature (0-5 °C). This study aimed to analyze the suitability of these temperatures for long-term storage without compromising the nutritional and textural quality of the product.

2.6 Treatment combination
Experiment studies were done by treating samples with the following treatments combinations.

Table 2.1: Treatment combination

Treatments	Treatment combination	Treatment Details
T_1	P_1S_1	Low density polyethylene + Room Temperature
T_2	P_2S_1	High density polyethylene + Room Temperature
T_3	P_3S_1	Brown Paper Bag + Room Temperature
T_4	P_4S_1	Laminated Aluminium Pouch + Room Temperature
T_5	P_1S_2	Low density polyethylene + Refrigerated Temperature
T_6	P_2S_2	High density polyethylene + Refrigerated Temperature
T_7	P_3S_2	Brown Paper Bag + Refrigerated Temperature
T_8	P_4S_2	Laminated Aluminium Pouch + Refrigerated Temperature

Results and Discussion
3.1 Physico-chemical parameters of aonla fruit
The physico-chemical properties of fresh aonla fruits used for preparing osmotically dehydrated segments are presented in Table 4.1. The data reveal that the average weight of the fresh aonla fruits is around 30 grams, with a slight variation of ±0.90 grams and the average diameter is approximately 3.90 cm, with a variation of ±0.21 cm. The seeds constitute about 9.00% of the fruit's total weight. Regarding chemical composition, the fruits have an average total soluble solids (TSS) content of 10.20% (±0.87%). The total sugar content is about 6.93%, with reducing sugars contributing 5.58% (±0.35%) and non-reducing sugars 3.50% (±0.20%). The acidity is recorded at 2.23% with a minimal variation of ±0.010%, while the ascorbic acid content averages 361.97 mg per 100 grams, with a variation of ±3.7 mg. These results are consistent with the findings of Kumar *et al*. (2019) [13] and Sumitha *et al.* (2015) [25].

Table 3.1: Physico-chemical parameters of fresh fruit of aonla variety NA-7 used for osmotic dehydration

Sr. No.	Physical Parameters	Value
1.	Average weight (gms)	30.00 ± 0.90
2.	Diameter (cm)	3.90 ± 0.21
3.	Blanched segments yield (%)	87.20 ±0.55
4.	Seed (%	9.00 ± 0.65
5.	Blanching loss (%)	3.80 ±0.24
	Chemical Parameters	
7.	Moisture (%)	85.71 ± 1.3
8.	TSS (0 Brix)	10.20 ± 0.87
9.	Ascorbic acid (mg/100g)	361.97 ± 3.7
10.	Acidity (%)	2.23 ± 0.010

11	Reducing sugars (%)	5.58 ± 0.35
12	Non-reducing sugars (%)	3.50 ±0.20
13	Total sugars (%)	6.93 0.68

3.2 Chemical Characteristics

3.2.1. Total Soluble Solid (TSS)

Total Soluble solid of prepared products shows increasing trend during storage (Table 3.2). Statistically significant differences were observed for total soluble solid content in osmotically dehydrated aonla segments due to storage temperature, different packaging material and interaction between temperature and packaging material. Further, dried aonla segments samples recorded higher content of total soluble solid (83.75%) at initial stage of storage.

In case of osmotically dehydrated aonla segments 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 aonla segments 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 (87.25%) packaging material over 90 days of storage. In case of temperature, significantly highest (86.27%) total soluble solid was observed in samples stored at room temperature. In general, there was gradual increase (82.30 to 87.25%) 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 (83.42 to 83.11%) in total soluble solid than those stored at room temperature (Table 3.2), 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.

These findings are in alignment with the observations of Argaiz *et al*. (1994) [3] and Islam *et al*. (2019) [11] in osmotically dehydrated papaya cubes, as well as Mali (1997) [14], Palve (2002) [17] and Gawade (2002) [8] in dried figs. Similar trends were also supported by the research of Sumitha *et al*. (2015) [25] and Bidwe *et al*. (2024) [4].

3.2.2. Ascorbic acid

Ascorbic acid content of aonla segments shows gradual decrease during storage (Table 3.2). Statistically significant differences were observed for ascorbic acid content in osmotically dehydrated aonla segments due to storage temperature, different packaging material and interaction between temperature and packaging material. Further, dried aonla segments samples recorded higher content of ascorbic acid (217.45 mg/100g) at initial 30 days of storage in laminated aluminium pouch at refrigerated temperature. In case of osmotically dehydrated aonla segments it was found that with passing of storage period (1, 2 and 3 months) there was decrease (217.88 to 213.34%) in the ascorbic acid content of the samples. After 3 months storage of the osmotically dehydrated aonla segments shreds significant differences were observed due to variations in temperature and interaction between temperature and packaging. In case of temperature, significantly highest (215.04%) 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 (217.88 to 213.50%) in ascorbic acid than those stored at room temperature (217.02 to 213.30%) (Table 3.2), might be due to limitation in oxidation of aonla segments. The decrease in ascorbic acid might be due to oxidation of aonla segments. Similar findings have been reported by Da *et al*. (2018) in dried papaya, Chandra and Kumara (2015) [5] in osmotically dehydrated papaya, Thonta and Patil (1988) [26], Pawar *et al*. (1992) [18] in dried figs, as well as by Bidwe *et al*. (2024) [4] and Sumitha *et al*. (2015) [25] in osmotically dehydrated aonla segments.

3.2.3. Acidity

Table 3.2 presents the data on the effect of various treatments on the acidity of osmotically dehydrated aonla segments stored under room and refrigerated conditions. The results clearly indicate a declining trend in acidity across all treatments as the storage period advanced from 0 to 90 days. Further, dried aonla segments samples recorded higher content of acidity (1.13%) at initial 30 days stage of storage. In case of osmotically dehydrated aonla segments it was found that with passing of storage period (1, 2 and 3 months) there was decrease (1.13 to 1.08%) in the acidity content of the samples. After 3 months storage of the osmotically dehydrated aonla segments shreds significant differences were observed due to variations in temperature and interaction between temperature and packaging. Minimum acidity (1.05%) found in low density polyethylene over 90 days of storage. In case of temperature, significantly highest (1.10%) acidity was observed in samples stored at room 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 (1.11 to 1.05%) than those stored at room temperature (1.13 to 1.08%) (Table 3.2). The decrease in acidity might be due to cellular changes and breakdown of organic acids. These findings align with those reported by Chandra and Kumara (2015) [5], Rohani *et al.* (1997) [21], Hazarika *et al.* (2017) [10], Othman (2009), Sumitha *et al.* (2015) [25] and Bidwe *et al.* (2024) [4] in similar studies on osmotically dehydrated and stored papaya and aonla.

Table 3.2: Effect of different temperatures and packaging on the total soluble solid, ascorbic acid (mg/100g) and acidity (%) in osmotically dehydrated aonla segments at different stages of storage.

	Total soluble solid			Ascorbic acid(mg/100g)			Acidity (%)		
Treatments	**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	83.51	84.49	85.61	216.77	216.22	213.97	1.08	1.08	1.07
P_2- High density polyethylene	83.43	84.40	85.60	216.91	216.41	214.15	1.10	1.10	1.09
P_3- Brown paper bag	83.46	85.13	85.98	216.60	213.82	213.56	1.11	1.09	1.09
P_4- Laminated aluminium pouch	82.54	83.23	83.92	217.45	216.83	216.58	1.12	1.12	1.12
S.E(m)+	0.008	0.009	0.009	0.041	0.042	0.042	0.004	0.004	0.004

C.D @5%	0.024	0.026	0.028	0.122	0.125	0.127	0.012	0.012	0.012
Factor B: Temperature									
S_1- Room temperature	83.37	84.96	86.27	216.74	215.74	214.09	1.11	1.10	1.10
S_2- Refrigerator temperature	83.10	83.67	84.28	217.12	215.90	215.04	1.09	1.09	1.09
S.E(m)+	0.006	0.006	0.007	0.029	0.029	0.030	0.003	0.003	0.003
C.D @5%	0.017	0.018	0.020	0.087	0.088	0.090	0.009	0.009	0.009
Interaction effect (A x B)									
P1S1	83.75	85.34	86.53	216.70	216.60	213.34	1.10	1.10	1.09
P2S1	83.43	85.03	86.57	216.85	216.67	213.60	1.09	1.09	1.08
P3S1	83.50	85.63	87.25	216.40	213.40	213.62	1.12	1.09	1.08
P4S1	82.78	83.83	84.73	217.02	216.28	215.80	1.13	1.12	1.13
P1S2	83.27	83.64	84.68	216.83	215.85	214.60	1.06	1.06	1.05
P2S2	83.42	83.77	84.64	216.97	216.15	214.70	1.11	1.10	1.09
P3S2	83.42	84.63	84.70	216.80	214.23	213.50	1.09	1.09	1.09
P4S2	82.30	82.63	83.11	217.88	217.38	217.35	1.11	1.11	1.11
S.E(m)+	0.012	0.012	0.013	0.058	0.059	0.060	0.006	0.006	0.006
C.D @5%	0.035	0.037	0.040	0.173	0.177	0.180	0.017	0.018	0.018

3.2.4 Moisture

Moisture of prepared products gradually declined during storage (Table 3.3). Statistically significant differences were observed for moisture content in osmotically dehydrated aonla segments due to storage temperature, different packaging material and interaction between temperature and packaging material. Further, dried aonla segments samples recorded higher content of moisture (16.63%) at initial 30 days stage of storage in laminated aluminium pouch. In case of osmotically dehydrated aonla segments 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 aonla segments 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 (16.63 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 3.3). The decrease in moisture might be due to water activity reduction and osmosis. These findings are consistent with those reported by Sagar *et al*. (1999) [22] in mango slices, Thonta and Patil (1988) [26], Pawar *et al*. (1992) [18] in dried figs and Gharate (1984) [9] in ber candy, as well as Sumitha *et al*. (2015) [25] and Bidwe *et al*. (2024) [4] in osmotically dehydrated aonla and papaya segments. The results fall within the expected range reported in earlier literature.

3.2.5 Reducing sugar

Reducing sugar of prepared products shows increasing trend during storage (Table 3.3). Statistically significant differences were observed for reducing sugar content in osmotically dehydrated aonla segments due to storage temperature, different packaging material and interaction between temperature and packaging material. Further, dried aonla segments samples recorded higher content of reducing sugar (49.58%) at initial 30 days of storage. In case of osmotically dehydrated aonla segments it was found that with passing of storage period (1, 2 and 3 months) there was increase (48.15 to 52.51%) in the reducing sugar content of the samples. After 3 months storage of the osmotically dehydrated aonla segments shreds significant differences were observed due to variations in temperature and interaction between temperature and packaging. In case of temperature, significantly highest (51.35%) 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 ºC) had less increase in reducing sugar than those stored at room temperature (Table 3.2), 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. These results are supported by similar findings reported by Narayana *et al*. (2002) [15] in stored banana, Shivani *et al*. (2020) [24] in papaya powder, Thonta and Patil (1988) [26], Pawar *et al*. (1992) [18] in dried figs, Bidwe *et al*. (2024) [4] in papaya and Sumitha *et al*. (2015) [25] in osmotically dehydrated aonla segments.

3.2.6. Non reducing sugars

Non reducing sugar of prepared products gradually declined during storage (Table 3.3). Statistically significant differences were observed for non reducing sugar content in osmotically dehydrated aonla segments due to storage temperature, different packaging material and interaction between temperature and packaging material. Further, dried aonla segments samples recorded higher content of non reducing sugar (20.50%) at initial 30 days stage of storage. In case of osmotically dehydrated aonla segments it was found that with passing of storage period (1, 2 and 3 months) there was decrease (20.50 to 17.30%) in the non reducing sugar content of the samples. After 3 months storage of the osmotically dehydrated aonla segments shreds significant differences were observed due to variations in temperature and interaction between temperature and packaging. In case of temperature, significantly highest (18.70%) 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 ºC) had less decrease in non reducing sugar than those stored at room temperature (Table 3.2). The decrease in non reducing sugar might be due to Hydrolysis of Sucrose and enzymatic activity. these findings are in agreement with previous studies by Thonta and Patil (1988) [26], Pawar *et al*. (1992) [18] in dried figs, Gharate (1984) [9] in ber candy and by Sumitha *et al*. (2015) [25] and Bidwe *et al*. (2024) [4] in osmotically dehydrated aonla and papaya, respectively. The results fall within the expected range reported in earlier research.

3.2.7. Total Sugars

Total sugar of prepared products shows increasing trend during storage (Table 3.3). Statistically significant differences were observed for total sugar content in osmotically dehydrated aonla segments due to storage temperature, different packaging material and interaction between temperature and packaging material. Further, dried aonla segments samples recorded higher content of total sugar (67.20%) at initial 30 days of storage in high density polyethylene. In case of osmotically dehydrated aonla segments it was found that with passing of storage period (1, 2 and 3 months) there was increase (66.91 to 68.74%) in the total sugar content of the samples in brown paper bag. After 3 months storage of the osmotically dehydrated aonla segments shreds significant differences were observed due to variations in temperature and interaction between temperature and packaging. Maximum total sugar found in brown paper bag (69.17%) packaging material over 90 days of storage. In case of temperature, significantly highest (69.30%) total sugar was observed in samples stored at room temperature for 90 days of storage. In general, there was gradual increase (67.20 to 69.94%) in total sugar content in all the samples during the 3 months of storage as compared to initial. The samples stored at refrigerated temperature (0-5ºC) had less increase in total sugar (66.52 to 68.34%) than those stored at room temperature (66.59 to 69.94%) (Table 3.4), 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. These findings are consistent with those reported by Jain *et al*. (2011), Thonta and Patil (1988) [26], Pawar *et al*. (1992) [18] in dried figs and Sumitha *et al*. (2015) [25] and Bidwe *et al*. (2024) [4].

Table 3.3: Effect of different temperatures and packaging on the moisture (%), reducing sugar (%), non reducing sugar (%) and Total sugar (%) in osmotically dehydrated aonla segments at different stages of storage.

Moisture				Reducing sugar (%)			Non Reducing sugar (%)			Total sugar (%)		
Treatments	**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												
P_1- Low density polyethylene	16.00	14.97	12.97	48.49	49.64	50.80	20.18	18.94	17.89	66.56	67.70	68.25
P_2- High density polyethylene	16.10	15.17	13.10	48.77	49.84	51.24	20.35	19.13	18.15	66.93	68.04	68.80
P_3- Brown paper bag	15.71	13.92	12.00	49.11	50.42	52.05	19.87	19.02	17.86	66.91	68.34	68.74
P_4- Laminated aluminium pouch	16.57	16.12	14.19	48.22	48.99	49.33	20.40	20.00	19.32	66.64	67.87	68.90
S.E(m)+	0.005	0.005	0.006	0.012	0.013	0.014	0.012	0.012	0.013	0.008	0.009	0.009
C.D @5%	0.015	0.015	0.017	0.037	0.038	0.041	0.036	0.037	0.039	0.024	0.026	0.027
Factor B: Temperature												
S_1- Room temperature	15.83	14.72	12.60	48.95	50.29	51.35	19.97	18.78	17.90	66.82	68.13	69.30
S_2- Refrigerator temperature	16.36	15.37	13.53	48.34	49.15	50.36	20.43	19.76	18.70	66.70	67.84	68.03
S.E(m)+	0.003	0.004	0.004	0.009	0.009	0.010	0.008	0.009	0.009	0.006	0.006	0.006
C.D @5%	0.010	0.011	0.012	0.026	0.027	0.029	0.025	0.026	0.027	0.017	0.019	0.019
Interaction effect (A x B)												
P1S1	15.60	14.44	12.47	48.83	50.16	51.33	19.89	18.47	17.30	66.60	67.80	68.85
P2S1	15.72	14.52	12.62	49.12	50.33	51.81	20.20	18.63	17.53	67.20	68.24	69.25
P3S1	15.47	13.73	11.58	49.58	51.24	52.51	19.50	18.43	17.87	66.90	68.57	69.17
P4S1	16.52	16.18	13.74	48.27	49.43	49.73	20.31	19.60	18.91	66.59	67.93	69.94
P1S2	16.40	15.50	13.47	48.15	49.13	50.27	20.47	19.40	18.47	66.52	67.60	67.64
P2S2	16.47	15.82	13.58	48.42	49.34	50.67	20.50	19.63	18.77	66.65	67.83	68.34
P3S2	15.95	14.10	12.42	48.63	49.59	51.58	20.23	19.60	17.84	66.92	68.12	68.30
P4S2	16.63	16.06	14.64	48.17	48.54	48.93	20.50	20.40	19.73	66.69	67.80	67.85
S.E(m)+	0.007	0.007	0.008	0.017	0.018	0.019	0.017	0.017	0.018	0.012	0.012	0.013
C.D @5%	0.021	0.022	0.023	0.052	0.053	0.058	0.051	0.052	0.054	0.035	0.037	0.038

3.3 Sensory Quality of Osmotically Dehydrated Aonla Segments

After three months of storage, the colour score for samples stored at room temperature (6.12) in treatment P3S1 was lower compared to those stored at refrigerated temperatures (7.33) in treatment P2S1, likely due to browning during the storage period. Initial texture scores for the dehydrated products were significantly high, with the highest score (8.5) recorded in treatment P4S2 (laminated aluminum pouch at refrigerated temperature). This score was comparable to P4S1 (laminated aluminum pouch at room temperature) after 30 days of storage. Texture scores for fresh products were higher than those observed at one, two, and three months post-storage. At those intervals, texture scores were better for products stored under refrigerated conditions compared to those at room temperature. Samples in laminated aluminum pouches exhibited the highest texture scores, attributed to the low permeability of the packaging material. Similar trends of declining colour scores during storage have been reported by Moreno *et al*. (2004) also reported by Palve (2002) [17] and Pokharkar (1994) in pineapple slices. Findings by Sumitha *et al*. (2015) [25] and Bidwe *et al*. (2024) [4] in osmotically dehydrated aonla and papaya also support these results.

Taste scores were significantly higher in samples stored at refrigerated temperatures, with notable variations due to differing storage conditions. Aonla segments stored in laminated aluminum pouches at refrigerated temperatures were rated superior at one, two and three months. Previous research indicates that factors affecting osmotic dehydration kinetics, along with the final ratio of water loss to sugar gain, greatly influence product characteristics, resulting in improved quality through osmotic dehydration. Total sensory score values ranged from 8.40 to 9.0 during the initial 30 days of storage, with all sensory evaluations rated from good to very good. However, sensory scores decreased during subsequent storage periods, although treatments P4S2 (8.8), P4S1 (8.54) and P2S2 (8.45) maintained their superiority after three months of storage, indicating high acceptability. Sensory scores were consistently higher for samples stored at refrigerated temperatures compared to room temperature and scores tended to decline with increased storage duration. This decline may be attributed to slower chemical reactions at lower temperatures, which helped preserve the product's texture and colour, enhancing overall sensory scores. The observed decline in taste over the storage period can be attributed to chemical changes such as degradation of flavour compounds, loss of volatiles and possible oxidation of sensitive ingredients, which may reduce overall sensory appeal. The interaction between treatment and storage duration was statistically significant, particularly at 90 days.

These findings align with those reported by Chaturvedi *et al.* (2016) [6] in osmotically dehydrated papaya, Palve (2002) [17] in dried figs, Sumitha *et al.* (2015) [25] in aonla and Bidwe *et al.* (2024) [4]. The aonla segments packed in laminated aluminum pouches and stored at refrigerated temperatures (P4S2) achieved superior sensory scores, likely due to the packaging's low permeability and reduced biochemical activity at cooler temperatures, which led to lower non-enzymatic browning and limited oxygen availability. These findings align with research by Amitabh *et al.* (2000) [2] on mango, Pragati and Dahiya. (2003) on aonla, Sharma *et al.* (2004) [3] on apricot and Kumar and Sagar (2009) [12] on mango slices.

Table 3.4: Effect of different temperatures and packaging on the Colour & appearance score, Texture Score, Taste score and Overall acceptability in osmotically dehydrated aonla segments at different stages of storage

Colour & appearance score				**Texture Score**			**Taste score**			**Overall acceptability**		
Treatments	**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												
P_1- Low density polyethylene	8.31	7.60	7.06	8.36	8.15	7.85	8.73	8.43	8.14	8.43	8.32	7.95
P_2- High density polyethylene	8.36	7.61	7.34	8.48	8.28	8.24	8.90	8.62	8.30	8.60	8.40	8.10
P_3- Brown paper bag	7.76	7.22	6.42	8.33	7.86	7.54	8.47	8.18	7.17	8.33	8.15	7.87
P_4- Laminated aluminium pouch	8.07	7.88	6.78	9.05	9.02	8.65	8.99	8.80	8.71	8.61	8.49	8.33
S.E(m)+	0.008	0.008	0.005	0.007	0.008	0.009	0.005	0.004	0.005	0.005	0.005	0.004
C.D @5%	0.024	0.025	0.015	0.020	0.022	0.026	0.014	0.011	0.016	0.015	0.014	0.012
Factor B: Temperature												
S_1- Room temperature	8.07	7.44	6.97	8.37	8.19	7.82	8.71	8.44	7.95	8.45	8.29	7.95
S_2- Refrigerator temperature	8.17	7.71	6.83	8.74	8.47	8.32	8.83	8.58	8.21	8.53	8.39	8.17
S.E(m)+	0.006	0.006	0.003	0.005	0.005	0.006	0.003	0.003	0.004	0.004	0.003	0.003
C.D @5%	0.017	0.018	0.010	0.014	0.016	0.019	0.010	0.008	0.011	0.011	0.010	0.009
Interaction effect (A x B)												
P1S1	8.47	7.56	7.06	8.20	8.06	7.55	8.68	8.41	7.95	8.42	8.28	7.82
P2S1	8.37	7.56	7.35	8.37	8.23	8.19	8.83	8.62	8.14	8.52	8.37	8.03
P3S1	7.88	7.19	6.12	8.04	7.55	7.00	8.40	8.02	7.17	8.32	8.07	7.73
P4S1	7.56	7.45	7.33	8.87	8.91	8.52	8.93	8.72	8.54	8.54	8.46	8.21
P1S2	8.14	7.63	7.06	8.52	8.24	8.14	8.78	8.46	8.34	8.45	8.35	8.07
P2S2	8.35	7.66	7.33	8.59	8.33	8.28	8.97	8.62	8.45	8.67	8.43	8.16
P3S2	7.63	7.24	6.72	8.63	8.16	8.07	8.55	8.34	7.18	8.34	8.24	8.01
P4S2	8.57	8.32	6.22	9.22	9.13	8.77	9.05	8.89	8.88	8.67	8.52	8.44
S.E(m)+	0.012	0.012	0.007	0.010	0.011	0.012	0.007	0.005	0.008	0.007	0.006	0.006
C.D @5%	0.035	0.036	0.021	0.029	0.032	0.037	0.020	0.016	0.023	0.022	0.019	0.017

Conclusion

The findings of the present study indicate that storage conditions play a crucial role in determining the quality of osmotically dehydrated aonla segments. Among the treatments, samples kept under refrigeration, especially when packed in laminated aluminum pouches, maintained superior quality throughout the storage duration.

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