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Influence of different drying methods and packaging material on the quality of moringa leaf powder

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Abstract
The present experiment was conducted at Post Harvest Technology, College of Horticulture, Dr YSR Horticultural University, AP in a Completely Randomized Factorial Design with two factors at unequal levels and replicated thrice. Moringa leaves were dried by using different drying methods *viz.,* sun drying, solar drying, tray drying, vacuum drying and freeze drying. These dried powders were packed in three different packaging materials *viz.,* PET bottles, aluminium pouches, LDPE 200 gauge pouches to know their suitability in retention of nutrients. The physico-chemical parameters of the moringa leaf powder was evaluated at monthly intervals up to 90 days of storage period. The freeze dried moringa leaf powder recorded the lowest moisture content 7.66%, water activity 0.42, Highest protein content 24.31g 100 g^{-1}, antioxidants 88.59% and calcium content 2013.44 mg 100 g^{-1} at the end of storage period. PET bottles retained most of the nutrients during storage period. Maximum retention of nutrients was observed in freeze dried moringa leaf powder packed in PET bottles.

Keywords: Moringa, drying methods, freeze drying, packaging materials and storage

Introduction
Drumstick (*Moringa oleifera*) is an under exploited perennial vegetable species of Moringaceae family, native to the Sub-Himalayan tracts of India, Pakistan, Bangladesh and Afghanistan (Makkar and Becker, 1997) [6]. This fast growing tree is also known as the moringa, horseradish tree, benzolive tree, or ben oil tree. It is a perennial softwood tree and it has been suggested for medicinal and industrial uses. It is an important crop in India and is being grown in West, East and South Africa, tropical Asia, Latin America, and the Pacific islands as all parts of the moringa tree are edible and have been consumed by the humans since long time. India is the leading producer of moringa with an annual production of 2.20-2.40 million tons of tender fruits from an area of 38,000 ha. Andhra Pradesh stands first in both area and production (15,665 ha) followed by Karnataka (10,280 ha) and Tamil Nadu (7,408 ha) whereas other states occupy an area of 4,613 ha.

Moringa is one of the world's most nutritious crops. The leaves of moringa have more beta-carotene than carrots, more protein than peas, more vitamin C than oranges, more calcium than milk, more potassium than bananas, and more iron than spinach. Moringa leaves can be eaten fresh, cooked or stored as dried powder for many months without refrigeration and without loss of nutritional value. Its present commercial cultivation is limited to vegetable pod production. The potential uses of leaf either in fresh form or in dried form in the traditional food items of the rural population would certainly help in overcoming malnutrition in rural women and children. Moringa leaf products especially leaf powder becomes increasingly popular because of its outstanding indigenous nutritive value.

Materials and Methods
The present investigation entitled "Studies on the effect of different drying methods and packaging material on the quality of moringa leaf powder" was carried out during November 2020 to April 2021 at Post Harvest Laboratory, College of Horticulture, Dr. Y.S.R Horticultural University, Venkataramannagudem. The experiment was conducted in Completely Randomized Factorial Design with two factors at unequal levels and replicated thrice. Moringa variety PKM -1 was used for the experimental studies. The moringa leaves were harvested from the plants. The twigs were first separated from the stem, and then moringa leaves were stripped of the branches and taken for dehydration.

These moringa leaves were dried by using different drying methods *viz*., sun drying, solar drying, tray drying, vacuum drying, freeze drying and the leaf powder was packed in three different packaging materials *viz*., PET bottles, aluminium pouches, LDPE 200 gauge bags for storage up to 90 days. Objectives studied during this research work are a) drying behaviour of moringa leaves under different drying methods and identified optimum drying technique for best quality moringa leaf powder. b) studied the effect of packaging material on the quality of moringa leaf powder. c) studied the storability and quality attributes of dehydrated moringa leaf powder under different drying and packaging material.

Observations were recorded on physico-chemical parameters like moisture content (%), water activity (a_w), protein (g 100 g^{-1}), antioxidants (% DPPH) and calcium content (mg 100 g^{-1}) from initial day of storage to 90 days of storage.

Results and Discussion

Moisture content (%)

The data pertaining to the moisture content of the moringa leaf powder affected by different drying methods and packaging material after storage are presented in table 1.

The lowest mean moisture content was recorded in freeze dried moringa leaf powder (D_5) from initial day of storage (7.31%) to 90th day of storage (7.66%) The moisture content of freeze dried moringa leaf powder was found to be when compared to moringa leaf powder dried by other drying methods. Similar results were found by Jiapeng and Zhang (2016) [4] in okra and Umar *et al.* (2016) [16] in moringa. Freeze drying uses a process called lyophilization to lower the temperature of the product to below freezing temperature where in the moisture of the sample is converted into ice crystals and then a low pressure vacuum is applied to extract the water in the form of vapour. The highest moisture content was observed in sun dried moringa leaf powder (D_1) from initial day of storage (8.71%) to 90th day of storage (8.84%).

The minimum moisture content was recorded in moringa leaf powder packed in PET bottles (P_1) from initial day after storage (7.99%) to final day of storage (8.24%) and the maximum moisture content was recorded in moringa leaf powder packed in LDPE 200 gauge poly bags (P_3) from initial day after storage (8.23%) to final day of storage (8.39%). The maximum increase in moisture content was found in LDPE 200 gauge polybags (P_3) due to poor oxygen barrier properties followed by aluminium pouch. Similar results were found by Singh *et al.* (2003) [13] and Uadal *et al.* (2010) [15] whereas least increase in moisture content was observed in PET bottles (P_1). This was due to the differential permeability of packaging materials to water vapor. Similar trend in results were found by Mohammad *et al.* (2017) [7] in guava powder.

Table 1: Effect of different drying methods and packaging material on moisture (%) of moringa leaf powder

Drying methods (D)	Packaging materials (P)															
	Days of storage															
	Initial ('0' day)				30 days				60 days				90 days			
	P1	P2	P3	Mean	P1	P2	P3	Mean	P1	P2	P3	Mean	P1	P2	P3	Mean
D1	8.65	8.70	8.80	8.71	8.74	8.75	8.84	8.78	8.77	8.80	8.88	8.81	8.80	8.83	8.90	8.84
D2	8.16	8.30	8.52	8.32	8.49	8.50	8.51	8.50	8.52	8.53	8.55	8.53	8.57	8.60	8.57	8.58
D3	8.45	8.52	8.70	8.56	8.39	8.41	8.81	8.54	8.44	8.48	8.83	8.58	8.49	8.51	8.85	8.61
D4	7.47	7.52	7.62	7.54	7.68	7.70	7.71	7.70	7.71	7.72	7.77	7.73	7.78	7.83	7.83	7.81
D5	7.21	7.22	7.50	7.31	7.45	7.46	7.52	7.47	7.49	7.50	7.59	7.53	7.58	7.61	7.80	7.66
Mean	7.99	8.05	8.23	8.08	8.15	8.16	8.28	8.19	8.18	8.20	8.32	8.23	8.24	8.27	8.39	8.30
Comparing means	S.Em±		CD@5%		S.Em±		CD@5%		S.Em±		CD@5%		S.Em±		CD@5%	
(D)	0.021		0.060		0.026		0.074		0.021		0.062		0.020		0.059	
(P)	0.016		0.047		0.020		0.057		0.017		0.048		0.016		0.045	
Interaction (D×P)	0.036		NS		0.044		0.128		0.037		0.107		0.035		0.101	

Drying methods: D_1: Sun drying D_2: Solar drying D_3: Tray drying D_4: Vacuum drying D_5: Freeze drying
Packaging materials: P_1: PET bottle P_2: Aluminium pouch P_3: LDPE 200 gauge

Water activity (a_w): The data related to the water activity of the moringa leaf powder as affected by different drying methods and packaging material after packing and storage are presented in table 2.

Water activity was increased steadily with increase in storage period irrespective of the packaging materials and drying methods employed. The lowest mean water activity was recorded in freeze dried leaf powder (D_5) from initial day of storage (0.34) to 90th day of storage (0.42). The water activity of freeze dried moringa leaf powder was found to be lower compared to other drying methods because the free water is frozen and the water activity is decreased to almost zero under low pressure and low drying temperatures which prevented thermal and enzymatic degradation of the final product. These results were in accordance to the findings of Alicia *et al.* (2018) and Silva *et al.* (2019) [1, 12] in moringa seeds.

The minimum water activity was recorded in moringa leaf powder packed in PET bottles (P_1) from initial day after storage (0.34) to final day of storage (0.43) and the maximum water activity was recorded in moringa leaf powder packed in LDPE 200 gauge polybags (P_3) from initial day after storage (0.38) to final day of storage (0.44). There was a slight increase in water activity of moringa leaf powder packed in PET bottles owing to high moisture barrier material which caused minimal change in moisture content of samples, and hence minimal quality deterioration of dried products. It was found that PET bottles was least affected by the ambient storage atmosphere in food contact applications (Satish *et al*. 2012) [11]. As compared to PET bottles there was a slight increase in water activity was observed in aluminium foil pouches followed by LDPE which is due to the high rate of migration of water vapour from the storage environment into the packaging material. Similar trends were recorded by Swain *et al.* (2013) [14] in sweet pepper.

Protein (g 100 g^{-1}): The data pertaining to the protein content of moringa leaf powder as influenced by different drying methods and packaging material after packing and storage in ambient conditions are presented in the table 3.

The results revealed that there was a significant decrease in protein content with the increase in storage period irrespective of drying methods and packaging materials.

Table 2: Effect of different drying methods and packaging material on water activity (a_w) of moringa leaf powder

Drying methods (D)	Packaging materials (P)															
	Days of storage															
	Initial ('0' day)				30 days				60 days				90 days			
	P1	P2	P3	Mean	P1	P2	P3	Mean	P1	P2	P3	Mean	P1	P2	P3	Mean
D1	0.37	0.39	0.43	0.39	0.40	0.42	0.43	0.41	0.42	0.45	0.47	0.44	0.45	0.46	0.47	0.46
D2	0.36	0.37	0.38	0.37	0.38	0.38	0.42	0.39	0.41	0.44	0.45	0.43	0.42	0.44	0.46	0.44
D3	0.36	0.37	0.37	0.36	0.36	0.38	0.40	0.38	0.42	0.43	0.43	0.42	0.43	0.43	0.44	0.43
D4	0.33	0.35	0.37	0.35	0.36	0.38	0.38	0.37	0.41	0.42	0.42	0.42	0.42	0.43	0.44	0.43
D5	0.32	0.35	0.36	0.34	0.35	0.36	0.38	0.36	0.40	0.41	0.42	0.41	0.42	0.43	0.43	0.42
Mean	0.34	0.36	0.38	0.36	0.37	0.38	0.40	0.38	0.41	0.43	0.43	0.42	0.43	0.44	0.44	0.43
Comparing means	S.Em±		CD@5%		S.Em±		CD@5%		S.Em±		CD@5%		S.Em±		CD@5%	
(D)	0.005		0.013		0.003		0.010		0.004		0.011		0.003		0.009	
(P)	0.004		0.010		0.003		0.008		0.003		0.008		0.002		0.007	
Interaction D×P)	0.008		NS		0.006		NS		0.006		0.019		0.005		0.011	

Drying methods: D_1: Sun drying D_2: Solar drying D_3: Tray drying D_4: Vacuum drying D_5: Freeze drying
Packaging materials: P_1: PET bottle P_2: Aluminium pouch P_3: LDPE 200 gauge

Table 3: Effect of different drying methods and packaging material on protein content (g 100 g^{-1}) of moringa leaf powder

Drying methods (D)	Packaging materials (P)															
	Days of storage															
	Initial ('0' day)				30 days				60 days				90 days			
	P1	P2	P3	Mean	P1	P2	P3	Mean	P1	P2	P3	Mean	P1	P2	P3	Mean
D1	24.71	24.34	24.25	24.43	22.12	21.90	21.44	21.82	21.51	21.10	20.94	21.18	20.53	20.30	19.84	20.22
D2	25.26	25.13	24.93	25.11	23.15	22.99	22.41	22.85	22.59	22.31	22.04	22.31	21.49	21.16	20.78	21.14
D3	25.42	25.31	25.22	25.32	24.13	23.88	23.51	23.84	23.50	23.12	22.87	23.16	22.52	22.12	21.82	22.15
D4	26.73	26.67	26.51	26.64	25.05	24.59	24.33	24.66	24.85	24.32	23.83	24.33	23.68	23.18	22.98	23.28
D5	27.43	27.28	27.08	27.26	26.60	25.92	25.32	25.94	26.40	25.52	25.11	25.67	24.62	24.24	24.07	24.31
Mean	25.91	25.74	25.60	25.75	24.21	23.86	23.40	23.82	23.77	23.27	22.96	23.33	22.57	22.20	21.90	22.22
Comparing means	S.Em±		CD@5%		S.Em±		CD@5%		S.Em±		CD@5%		S.Em±		CD@5%	
(D)	0.031		0.090		0.052		0.150		0.062		0.180		0.026		0.075	
(P)	0.044		NS		0.040		0.116		0.048		0.139		0.020		0.058	
Interaction (D×P)	0.054		NS		0.089		0.259		0.107		0.312		0.045		0.130	

Drying methods: D_1: Sun drying D_2: Solar drying D_3: Tray drying D_4: Vacuum drying D_5: Freeze drying
Packaging materials: P_1: PET bottle P_2: Aluminium pouch P_3: LDPE 200 gauge

The highest protein content was recorded in freeze dried moringa leaf powder (D_5) from initial day of storage (27.26 g 100 g^{-1}) to 90 days after storage (24.31 g 100 g^{-1}) followed by vacuum dried moringa leaf powder (D_4) from initial day of storage (26.64 g 100 g^{-1}) to 90 days after storage (23.28 g 100 g^{-1}) and the lowest protein content was recorded in sun dried moringa leaf powder (D_1) from initial day of storage (24.43 g 100 g^{-1}) to 90 days after storage (20.22 g 100 g^{-1}).

The maximum protein content was better retained in freeze drying method. The least content of protein was found in sun dried moringa leaf powder compared to other drying methods which might be due to the thermal denaturation of proteins to free amino acids and nucleotides and might be the probable reason for the decrease in protein content with increase in drying temperatures. These findings agree with the reports of Njoroge *et al*. (2015) [9] in green leafy vegetables.

During storage, the highest protein content was recorded in the moringa leaf powder packed in PET bottles (P_1) from 30 days after storage (24.21 g 100 g^{-1}) to 90 days after storage (22.57 g 100 g^{-1}) followed by moringa leaf powder packed in aluminum pouches (P_2) from 30 days after storage (23.86 g 100 g^{-1}) to 90 days after storage (22.20 g 100 g^{-1}) and the lowest protein content was recorded in moringa leaf powder packed in LDPE 200 gauge polybags (P_3) from 30 days after storage (23.40 g 100 g^{-1}) to 90 days after storage (21.90 g 100 g^{-1}).

Among interactions between drying and packaging materials, no significant difference was observed on the initial day of storage. At 30, 60 and 90 days after storage the highest protein content was recorded in freeze dried leaf powder packed in PET bottles (D_5P_1) from 30 days after storage (26.60 g100 g^1) to 90 days after storage (24.62 g 100 g^{-1}).

Antioxidants (% DPPH activity)

The data related to the antioxidant content of moringa leaf powder influenced by different drying methods and packaging material after storage in ambient conditions are presented in the table 4.

Significant difference was recorded in antioxidant content among different drying methods till the end of storage period. The highest antioxidant content was recorded in freeze dried moringa leaf powder (D_5) from initial day of storage (93.78%) to 90 days after storage (88.59%) followed by vacuum dried moringa leaf powder (D_4) from initial day of storage (90.34%) to 90 days after storage (87.11%).

Table 4: Effect of different drying methods and packaging material on antioxidants (% activity) of moringa leaf powder

Drying methods (D)	Packaging materials (P)															
	Days of storage															
	Initial ('0' day)				30 days				60 days				90 days			
	P1	P2	P3	Mean	P1	P2	P3	Mean	P1	P2	P3	Mean	P1	P2	P3	Mean
D1	86.19	86.03	85.23	85.82	85.80	85.40	85.12	85.44	84.52	84.30	84.12	84.31	83.80	83.10	82.76	83.22
D2	89.46	89.22	88.99	89.22	87.81	87.41	86.87	87.36	87.11	86.70	86.22	86.67	86.48	86.07	85.50	86.02
D3	87.75	87.30	86.37	87.14	86.33	86.00	85.66	85.99	85.39	85.10	84.81	85.10	85.22	85.03	84.22	84.82
D4	91.25	90.56	89.23	90.34	89.80	89.43	89.06	89.43	89.10	88.91	88.52	88.84	87.78	86.87	86.69	87.11
D5	94.27	93.91	93.16	93.78	91.13	90.76	90.26	90.72	90.08	89.91	89.28	89.76	88.91	88.66	88.20	88.59
Mean	89.78	89.40	88.59	89.26	88.17	87.80	87.39	87.79	87.24	86.98	86.59	86.94	86.44	85.95	85.47	85.95
Comparing means	S.Em±		CD@5%		S.Em±		CD@5%		S.Em±		CD@5%		S.Em±		CD@5%	
(D)	0.137		0.397		0.031		0.089		0.014		0.040		0.024		0.070	
(P)	0.151		NS		0.024		0.069		0.011		0.031		0.019		0.054	
Interaction (D×P)	0.237		NS		0.053		0.154		0.024		0.068		0.042		0.121	

Drying methods: D_1: Sun drying D_2: Solar drying D_3: Tray drying D_4: Vacuum drying D_5: Freeze drying
Packaging materials: P_1: PET bottle P_2: Aluminium pouch P_3: LDPE 200 gauge

Freeze-dried samples showed the highest antioxidant activities. The same finding was reported by Chan *et al.* (2010) [3] in tea which might be due to a considerably low temperature (-50°C) employed during moisture removal. Such low temperature during the drying process results in the constrained enzymatic degradation of antioxidant compounds. However, the antioxidant activity of vacuum-oven dried sample was significantly lower than that of freeze-dried samples, but the value was still in a high range. Similar observations were reported by Mahirah *et al.* (2018) [5] in dehydrated ocimum leaves.

The low retention of antioxidant activity was recorded in sundried leaf powder, that might have been caused by enzymatic processes leading to the significant changes in the composition of phytochemicals. This is in line with the findings of Mueller and Harvey (2001) [8] in fruits and Capecka *et al*. (2005) [2] while working in antioxidant activity of lamiaceae species.

The lowest retention of antioxidant activity of moringa leaf powder was recorded in LDPE 200 gauges and highest retention in PET bottles. Similar trend in results were found by Potisate *et al.* (2015) [10] in moringa leaves. This may be due to the higher permeability of LDPE to oxygen and moisture and lower permeability of the PET bottles.

Interaction effect in antioxidant content was found to be non significant on the initial day of storage. The highest antioxidant content was recorded in freeze dried moringa leaf powder packed in PET bottles (D_5P_1) from 30 days after storage (91.13%) to 90 days after storage (88.91%) and the lowest antioxidant content was recorded in sun dried moringa leaf powder packed in LDPE 200 gauge polybags (D_1P_3) from 30 days after storage (85.12%) to 90 days after storage (82.76%).

Calcium content (mg 100 g^{-1})

The data pertaining to the calcium content of moringa leaf powder influenced by different drying methods and packaging material after storage in ambient conditions are presented in the table 5.

Steady decline in calcium content was recorded with the extended storage period and the similar results were recorded by Singh *et al.* (2003) [13]. The highest calcium content was recorded in freeze dried moringa leaf powder (D_5) from initial day of storage (2121.66 mg 100 g^{-1}) to 90 days after storage (2013.44. mg 100 g^{-1}) followed by vacuum dried moringa leaf powder (D_4) from initial day of storage (2084.55 mg 100 g^{-1}) to 90 days after storage (1982.55 mg 100 g^{-1}) and the lowest calcium content was recorded in sun dried moringa leaf

Table 5: Effect of different drying methods and packaging material on calcium content (mg 100 g^{-1}) of moringa leaf powder

Drying methods (D)	Packaging materials (P)															
	Days of storage															
	Initial ('0' day)				30 days				60 days				90 days			
	P1	P2	P3	Mean	P1	P2	P3	Mean	P1	P2	P3	Mean	P1	P2	P3	Mean
D1	1971.00	1961.66	1952.66	1961.77	1952.33	1941.66	1931.33	1941.77	1932.66	1918.66	1910.66	1920.66	1885.00	1876.00	1867.33	1876.11
D2	2014.33	2008.33	1982.00	2001.55	2007.00	1993.33	1973.33	1991.22	1971.00	1965.33	1945.00	1960.44	1920.00	1910.00	1896.00	1908.66
D3	2053.33	2032.33	2021.66	2035.77	2031.33	2022.00	2013.00	2022.11	2007.00	1992.66	1983.66	1994.44	1960.33	1947.00	1937.33	1948.22
D4	2106.33	2084.00	2063.33	2084.55	2073.33	2064.33	2052.33	2063.33	2032.33	2022.33	2012.66	2022.44	1992.00	1983.00	1972.66	1982.55
D5	2131.33	2121.66	2112.00	2121.66	2106.00	2092.33	2081.00	2093.11	2063.00	2052.00	2042.33	2052.44	2021.33	2012.33	2006.66	2013.44
Mean	2055.26	2041.60	2026.33	2041.06	2034.00	2022.73	2010.20	2022.30	2001.20	1990.20	1978.86	1990.08	1955.73	1945.66	1936.00	1945.79
Comparing means	S.Em±		CD@5%		S.Em±		CD@5%		S.Em±		CD@5%		S.Em±		CD@5%	
(D)	0.588		1.706		0.762		2.211		0.818		2.374		0.795		2.307	
(P)	0.455		NS		0.590		1.712		0.634		1.839		0.616		1.787	
Interaction (D×P)	1.018		NS		1.319		NS		1.417		4.112		1.377		3.996	

Drying methods: D_1: Sun drying D_2: Solar drying D_3: Tray drying D_4: Vacuum drying D_5: Freeze drying
Packaging materials: P_1: PET bottle P_2: Aluminium pouch P_3: LDPE 200 gauge

powder (D_1) from initial day of storage (1961.77 mg 100 g^{-1}) to 90 days after storage (1876.11 mg 100 g^{-1}).

Steady decline in calcium content was recorded with the extended storage period and the similar results were recorded by Singh *et al.* (2003) [13]. The highest calcium content was recorded in freeze dried moringa leaf powder (D_5) from initial day of storage (2121.66 mg 100 g^{-1}) to 90 days after storage (2013.44. mg 100 g^{-1}) and the lowest calcium content was recorded in sun dried moringa leaf powder (D_1) from initial day of storage (1961.77 mg 100 g^{-1}) to 90 days after storage (1876.11 mg 100 g^{-1}).

The highest calcium content in freeze dried moringa leaf powder which might be due to low temperatures and low vacuum pressure employed during freeze drying resulting in reduction in moisture content leading to better retention of minerals.

The highest calcium content was recorded in leaf powder packed in PET bottles (P_1) from 30^{th} day of storage (2034.00 mg 100 g^{-1}) to 90 days after storage (1955.73 mg 100 g^{-1}) and the lowest calcium content was recorded in moringa leaf powder packed in LDPE 200 gauge polybags (P_3) from 30^{th} day of storage (2010.20 mg 100 g^{-1}) to 90 days after storage (1936 mg 100 g^{-1}).

Interaction effect in calcium content was found to be non significant on initial and 30^{th} day of storage. The highest calcium content was recorded in freeze dried moringa leaf powder packed in PET bottles (D_5P_1) from 60^{th} day of storage (2063 mg 100 g^{-1}) to 90 days after storage (2021.33 mg 100 g^{-1}) and the least content of calcium was recorded in sun dried leaf powder packed in LDPE200 gauge polybags (D_1P_3) from 60^{th} day of storage (1910.66 mg 100 g^{-1}) to 90 days after storage (1867.33 mg 100 g^{-1}).

Conclusion

Results revealed that moisture content, water activity followed a increasing trend from the day of storage to 90 days after storage, whereas protein, antioxidants and calcium content exhibited a decreasing trend throughout the storage. Among the different drying methods, the freeze dried moringa leaf powder retained most of the quality parameters *viz.,* lowest moisture content, water activity, highest protein content, antioxidants and calcium content followed by vacuum dried moringa leaf powder during the storage period. Freeze drying relies on the principle of sublimation whereby ice held under conditions of partial vacuum (less than 10 pa)

low temperature (-50°C) will evaporate on heating without going through a liquid phase. The absence of liquid water during the dehydration process means that undesirable chemical reactions will not occur and due to low temp nutrient losses will not occur. With respect to packaging material, moringa leaf powder packed in PET bottles was found to be superior in terms of retention of most of the quality parameters *viz.,* lowest moisture content, water activity, highest protein, antioxidants and calcium. Among the interactions, the freeze dried moringa leaf powder packed in PET bottles was found to be superior in retaining nutrients.

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