International Scholars Journals

International Journal of Agricultural Sciences ISSN: 2167-0447 Vol. 15 (1), pp. 001-014, January, 2025. Available online at www.internationalscholarsjournals.org © International Scholars Journals

Full Length Research Paper

Assessment of shelf life of red chilli powder in bulk packaging for export

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Abstract

Accepted 17 December, 2024

Red chilli powder is a shelf-stable product with low respiration rates, yet biochemical, microbial, and other decomposition activities can still occur depending on storage conditions. Effective oxygen and gas barrier properties are essential for preserving the quality and aroma of spices. To this end, we have introduced innovative liner combinations to assess their effectiveness in extending the shelf life of red chilli powder. A study was conducted to develop effective bulk packaging solutions for red chilli powder to address these challenges. The study involved testing various packaging materials, analyzing shelf life, and establishing specifications for export packaging. Spice samples were packed in ten different types of packaging materials and subjected to accelerated climatic conditions (38±1°C and 90±2% RH) for six months. All physicochemical parameters were measured in triplicate. Over the exposure period, moisture content and water activity of the red chilli powder showed a gradual increase. Notable degradation in colour, aroma, and increased microbial growth were observed in samples packaged in PP and paper woven bags without liners, highlighting the importance of effective packaging. However, no damage to the packaging materials was observed during transport worthiness tests. The longest shelf life of 405 days was recorded for paper woven bag with liners. The experimental results indicate that various packaging materials can effectively prevent the ingress of moisture and oxygen, thereby extending the shelf life of red chilli powder. The implications of this research are particularly valuable for manufacturers and suppliers in the food industry, as it highlights the importance of choosing appropriate packaging to safeguard product integrity throughout storage and distribution.

Keywords: Red chilli powder, Packaging Innovation, Shelf Life Extension, Export, Bulk.

INTRODUCTION

India is the world's largest spice producer. It is also the largest consumer and exporter of spices. During 2023-24 (until February 2024), the country exported spices worth US$ 3.67 billion (IBEF, 2024). Chilli (*Capsicum annuum*), a member of the Solanaceae family is renowned for its high vitamin content, particularly vitamin C. Capsicum species vary by region and include five cultivated types: *C. frutescens, C. chinense, C. pubescens, C. baccatum*, and *C. annuum*. Among these, Capsicum annuum is the most widely cultivated across India due to its diverse flavour profiles, ranging from non-pungent to pungent. Chilli not only add pungency and vibrant red colour to dishes but are also rich in vitamins A, B, C, and E, including minerals such as calcium, phosphorus, iron, sodium, and trace amounts of copper (Alam et al., 2018). The pungency of chilli peppers is attributed to capsaicin, an alkaloid with significant medicinal properties. Capsaicin is a derivative of vanillylamine and 8-methyl-non-trans-6-enoic acid. The primary colouring pigments in chilli are carotenoids like capsanthin and capsorubin, along with cryptoxanthin and

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zeaxanthin, which are esterified fatty acids (Olatunji and Afolayan., 2018). Chilli powder is widely used for flavouring and colouring a variety of foods, including meats, snacks, and sauces. Its beneficial properties make it a valuable component in Ayurvedic medicine, where it is used to combat diseases, eliminate toxins, stimulate gastric juices for digestion, clear nasal congestion, alleviate throat infections, and act as a pain reliever for muscle spasms (Sricharoen et al., 2017; Aprilia et al. 2021).

India boasts ideal agro-climatic conditions for the cultivation of chillies, making it one of the world's leading producers of this valuable spice. The country's diverse climate, characterized by warm and humid weather, supports the growth of various chilli varieties, while its rich soil types enhance yield potential. Furthermore, India is home to one of the most technologically advanced spice industries globally, which underscores its capability to meet both domestic and international demand for high-quality spices. Despite these advantages, many spice manufacturers often overlook the importance of proper packaging, which poses significant challenges in preserving the quality of their products for export markets. Red chilli powder, in particular, is hygroscopic, meaning it readily absorbs moisture from the environment. This characteristic necessitates the use of packaging materials that possess high barrier properties to effectively prevent moisture and oxygen ingress. Currently, red chilli powder is frequently exported in bulk without adhering to specific technical packaging standards. This lack of standardized packaging complicates efforts for exporters to maintain consistent product quality throughout the supply chain. As a result, it becomes increasingly difficult to accurately assess the shelf life of red chilli powder, leading to potential losses in quality and marketability. Addressing these packaging challenges is essential for enhancing the competitiveness of Indian chilli exports and ensuring that consumers receive a product that meets their expectations for freshness and flavour.

Although red chilli powder is typically shelf-stable and exhibits minimal respiration, it remains susceptible to biochemical, microbial, and other forms of decomposition, particularly influenced by storage conditions. To maintain its quality, it is essential that the powder is packaged in materials that provide strong protection against oxidation. In India, the packaging industry is currently experiencing a significant transformation towards sustainability. This shift is being propelled by regulatory changes, evolving consumer preferences, and the adoption of innovative practices. By embracing sustainable packaging solutions, spice and packaging companies can not only reduce their environmental footprint but also enhance their attractiveness in a global market that is increasingly focused on eco-friendliness. This commitment to sustainability can lead to improved brand reputation and customer loyalty, aligning business practices with the values of environmentally conscious consumers.

In response to the existing challenges in the spice industry, the Indian Institute of Packaging (IIP) located in Mumbai has undertaken a comprehensive study focused on developing effective bulk packaging solutions for red chilli powder. This initiative is funded by the Spices Board of India under the Ministry of Commerce and Industry. The primary objective of this research is to identify and test various packaging materials, assess their impact on shelf life, and establish specific packaging standards tailored for the export market. By addressing these critical aspects, the study aims to enhance the preservation of red chilli powder's quality during storage and transportation, ultimately benefiting exporters and consumers. Thus, by addressing both packaging and environmental impact, it positions Indian spice manufacturers favourably in an evolving market landscape that values both product excellence and sustainability.

MATERIALS AND METHODS

Red chilli powder was procured from M/s Jabs International Private Limited, Navi Mumbai. The packaging materials specified by the Indian Institute of Packaging (IIP) were manufactured and supplied by M/s. Shree Ganesh FIBC Private Limited, Ankleshwar, Gujarat, and M/s. Vishakha Polyfab Private Limited, Gujarat. The packaging of samples was carried out at the R&D Department laboratory of Indian Institute of Packaging, Mumbai. For packaging of the red chilli powder, Polypropylene (PP) woven bag and Paper woven Bag were selected with different liners. The details of packaging materials used for packaging of the ground spice are mentioned below:

These packaging materials were tested for physical, mechanical and physico-chemical properties in order to evaluate their quality (Table 1 and 2). The shelf life of red chilli was evaluated by exposing 200 g sample in 10 packaging materials at the accelerated conditions of 38 ± 5°C and 90 ± 2% RH (Newtronic Walk-In Humidity Chamber). The accelerated conditions enable the evaluation of the resilience and adaptability of packaging materials under extreme environmental conditions. This approach provides valuable insights into potential vulnerabilities and allows for the observation of long-term effects within a shorter timeframe, thereby facilitating faster data collection and analysis. Samples were tested at 15-day intervals for the first 90 days, followed by 7-day intervals until 190 days or until spoilage occurred. The spice samples were stored at the accelerated condition for a period of six months. Each sample exposed was replicated thrice. The initial moisture content (IMC) of the red chilli powder was assessed upon its arrival at the laboratory, and compared with the critical moisture content (CMC) specified by FSSAI regulations (see Fig. 1). Moisture content was measured using the vacuum oven drying method, following AOAC (2003) standards. The water activity of the red chilli powder was determined using

Table 1: Specifications of PP Woven bag and Paper woven Bag.

Sr. no.	Parameter	Unit	PP Woven bag	Paper Woven bag
1	Breaking load	N		
	D1		739.40	716.95
	D2		396.60	544.24
2	Elongation	%		
	D1		14.32	11.50
	D2		16.48	13.40
3	Seam Strength	Kgf	21.23	26.80
4	Mass	gram	28.70	42.90
5	Length	cm	37.90	35.50
6	Width	cm	29.00	26.13
7	Ash	%	7.30	14.66
8	Thickness	µm	122.00	200.00
9	Grammage	g/m^2	Not Applicable	160.90

D1: Direction 1; D2: Direction 2

an Aqualab 4TEV Water Activity Meter. The sample was placed in a disposable cup, sealed with the chamber lid, and allowed to reach vapor equilibrium. An infrared beam directed at a small mirror measured the dewpoint temperature of the sample, which was then used to calculate the water activity. Visual observations of colour, aroma, appearance, and microbial growth were recorded for each sample throughout the exposure period. Besides assessing the product quality, the packaging materials were also observed for any changes like in the colour and aroma. Packaging

Table 2: Specification of Liners.

Sr. No.	Parameters	Unit	**Liner I** (PE/EVOH/PE – 5 Ply; 50-60 µ)	**Liner II** (PA/EVOH/PE – 5 Ply; 50-60 µ)	**Liner III** (PE/EVOH/PE – 9 Ply; 70- 80 µ)	**Liner IV** (PA/EVOH/PE – 9 Ply; 70- 80 µ)
1	Thickness	(µm)	61	63	72	73
	Elongation (%)					
2	D1	(%)	511.99	348.81	556.65	398.42
	D2		328.86	329.6	360.12	276.15
	Tensile Strength					
3	D1	(N/mm^2)	17.72	21.38	17.37	28.35
	D2		18.47	22.72	22.74	30.58
	Break stress					
4	D1	(N/mm^2)	15.54	16.14	15.85	25.95
	D2		16.10	21.41	17.94	25.54
	Break strain					
5	D1	(%)	511.12	562.32	517.60	407.59
	D2		499.32	376.79	335.65	305.02
6	Bottom seal	(N)	26.82	31.45	29.51	45.07
7	Oxygen Transmission Rate	cc/m^2 for 24 hours	1.47	1.20	1.19	1.16
8	Water Vapour Transmission Rate	g/m^2 for 24 hours	3.91	3.44	3.51	2.60
9	Migration	(mg/kg)	0.030	0.031	0.036	0.037

D1: Direction 1; D2: Direction 2.

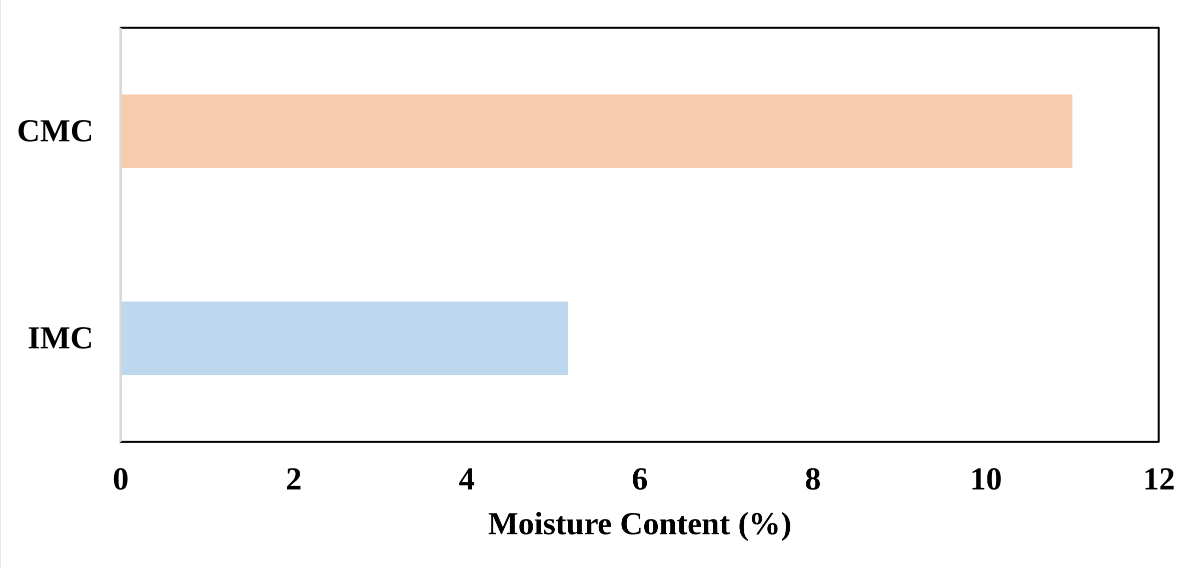
materials were also observed visually for any changes like cracks, discolouration, delamination etc. The samples which showed microbial deterioration earlier, were withdrawn and studies on that particular material were discontinued. The transport worthiness test was conducted to evaluate the performance of the bulk packages during transit, using drop and vibration tests. For drop test, total three sequential drops on each sack from a drop height of 1.2 m were carried out. The first drop was flat on one of the faces, second drop was flat on one of the edges and third drop was flat on the bottom (IS 7028-4 1987). For vibration test, the packed ground spice was kept on the vibration table and vibrated for one hour at a frequency of 120 cpm and 2.54 cm amplitude (IS 7028-2 2002). All the physico-chemical parameters were measured in triplicate. The statistical significance was determined at the 5% level ($p < 0.05$).

RESULTS AND DISCUSSION

Moisture Content

As shown in Table 3, moisture content was identified as the primary factor for determining shelf life. Although the samples were monitored even after surpassing the critical moisture content (CMC) limit, they were discarded upon the onset of microbial growth, and further testing was halted.

Fig.1: Initial Moisture Content (IMC) and Critical Moisture Content (CMC) of Red Chilli Powder.



It is evident that both moisture content and the permeability of packaging materials were significant contributors to product deterioration. The highest moisture content recorded was 22.48% in P9: Paper Woven Bag with Liner III (PE/EVOH/PE – 9 Ply; 70-80 µ). Once the moisture content exceeded the critical level, the product's texture notably changed, becoming lumpy and unsaleable. From the results obtained, it can be opined that that packaging plays an important role in determining the stability of foods by influencing those factors which cause or contribute to food deterioration during storage. The nature of a package determines the composition of air inside the package, which in turn is known to affect the rate and extent of nutrient loss and microbial activity among other things. The changes in moisture content were primarily due to the barrier properties of the packaging materials (Nath et al., 2019). These findings align with those of Al-sebaeai et al. (2017) and Anjaneyulu and Sharangi (2022) who explained the increase in moisture content during storage mostly due to the permeability of the packaging materials and the hygroscopic nature of the chilli powder.

Water Activity

The water activity changes in red chilli powder during storage were shown in Table 4. It was found that the water activity values showed a continuous increase during the entire duration of storage. The initial water activity value was 0.5169, which was not suitable for microbial propagation. However, the water activity later increased exponentially in all the packaging materials used for red chilli powder. The highest value recorded was 0.7249 in **P1:** PP woven Bag without Liner which was followed by microbial spoilage. The increase in water activity during storage could be due to concomitant increase in moisture content from the initial value of 6.72 to 15.80 %. Similar results were reported by Khobragade and Borkar (2018).

Colour, Aroma changes and Microbial Growth

Changes in color, aroma, and microbial growth were monitored for all packaging materials throughout the sample exposure period, with findings summarized in Tables 5, 6, and 7, respectively. For most packaging materials, there were no noticeable changes in color or aroma by the end of the storage period. However, samples in P1: PP Woven Bag without Liner and P6: Paper Woven Bag without Liner exhibited whitish discoloration, followed by greenish discoloration and fungal growth (Fig. 2). The aroma of these samples also deteriorated, shifting to a mushy odor and eventually to a bad odor. Take et al. (2012) studied that color of chilli spice powder is due to the presence of red pigmented carotenoids. The main pigments are capsanthin, capsorubin, zeaxanthin and cryptoxanthin Carotenoids are stable in intact plant tissue, but processing can lead to auto-oxidation, resulting in a less intense coloration. The colour of ground spice deteriorated faster than the whole during storage and exposure to air and sunlight accelerated the loss of colour, considered to be due to autocalysed degradation of carotenoids Khobragade and Borkar (2018). The infected with mold and simultaneous occurrence unusual smell is primarily attributed to the moisture content in red chilli powder (Anjaneyulu and Sharangi, 2022).

Shelf Life of Red Chilli powder

Based on the results of moisture content, it was reported that the maximum shelf life of up to 405 days was recorded in Paper woven Bag with Liner IV (PA/EVOH/PE – 9 Ply;

Table 3: Moisture content of Red Chilli powder during storage in different packaging materials.

P.M	Moisture Content (%)																			
	Days in Storage																			
	0	**15**	**30**	**45**	**60**	**75**	**90**	**97**	**104**	**111**	**118**	**125**	**132**	**139**	**146**	**153**	**160**	**167**	**174**	**181**
P1	5.17	9.32	11.52	13.92	13.28	14.14	15.31	16.03	16.07	D	D	D	D	D	D	D	D	D	D	D
P2	5.17	5.49	6.33	7.11	7.23	7.37	9.59	10.65	11.85	12.77	12.80	12.96	12.98	13.72	14.32	15.64	16.43	17.43	18.51	20.34
P3	5.17	6.56	7.72	7.76	8.17	8.85	9.56	10.42	11.44	11.48	11.72	11.51	12.02	13.19	15.62	15.83	16.54	18.15	20.83	22.21
P4	5.17	5.93	6.32	6.73	6.86	7.36	8.23	8.66	11.30	11.60	11.95	12.02	12.50	13.58	15.37	16.22	17.15	18.40	19.42	19.81
P5	5.17	5.23	6.09	6.46	6.59	6.78	7.87	8.45	10.32	11.44	11.52	11.67	11.99	12.94	14.10	15.61	16.33	17.08	18.77	20.17
P6	5.17	6.80	10.68	11.60	14.04	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D
P7	5.17	6.49	7.01	7.04	7.90	8.27	9.13	9.87	10.38	11.12	11.17	11.24	11.96	13.25	14.03	15.43	16.26	17.48	18.43	19.40
P8	5.17	6.82	7.61	8.13	8.20	8.69	10.01	10.25	10.57	10.78	10.86	11.18	11.41	13.00	14.09	15.77	16.91	17.49	18.67	20.10
P9	5.17	6.97	7.21	7.76	8.67	8.77	9.19	9.70	9.77	10.62	10.79	11.09	11.81	12.68	13.46	14.95	15.42	16.71	17.30	18.77
P10	5.17	6.15	6.47	6.89	6.92	6.99	7.75	8.60	9.23	9.64	9.66	10.62	10.63	11.52	13.49	14.73	16.29	17.00	17.89	19.08

P.M- Packaging Materials
[**P1:** PP woven Bag without Liner**; P2:** PP woven Bag with Liner I (PE/EVOH/PE – 5 Ply; 50-60 µ); **P3:** PP woven Bag with Liner II (PA/EVOH/PE – 5 Ply; 50-60 µ); **P4:** PP woven Bag with Liner III (PE/EVOH/PE – 9 Ply; 70- 80 µ); **P5:** PP woven Bag with Liner IV (PA/EVOH/PE – 9 Ply; 70- 80 µ)**; P6:** Paper woven Bag without Liner**; P7:** Paper woven Bag with Liner I (PE/EVOH/PE – 5 Ply; 50-60 µ)**; P8:** Paper woven Bag with Liner II (PA/EVOH/PE – 5 Ply; 50-60 µ); **P9:** Paper woven Bag with Liner III (PE/EVOH/PE – 9 Ply; 70- 80 µ); **P10:** Paper woven Bag with Liner IV (PA/EVOH/PE – 9 Ply; 70- 80 µ)]
D: Discontinued due to microbial growth.

70- 80 µ) when stored at accelerated conditions. This was followed by 375 and 360 days in Paper woven Bag with Liner III (PE/EVOH/PE – 9 Ply; 70-80 µ) and Paper woven Bag with Liner II (PA/EVOH/PE – 5 Ply; 50-60 µ) respectively. The shelf life of 330 and 306 days were observed in both Paper woven Bag with Liner I (PE/EVOH/PE – 5 Ply; 50-60 µ) and Paper woven Bag with Liner II (PA/EVOH/PE – 5 Ply; 50-60 µ) respectively. The

Table 4: Water Activity of Red Chilli powder during storage in different packaging materials.

P.M	Water Activity																			
	Days in Storage																			
	0	**15**	**30**	**45**	**60**	**75**	**90**	**97**	**104**	**111**	**118**	**125**	**132**	**139**	**146**	**153**	**160**	**167**	**174**	**181**
P1	0.5169	0.5978	0.6046	0.6271	0.6411	0.6597	0.6771	0.6933	0.7249	D	D	D	D	D	D	D	D	D	D	D
P2	0.5169	0.5351	0.5408	0.5475	0.5583	0.5619	0.5635	0.5688	0.5725	0.5741	0.5773	0.5795	0.5827	0.5846	0.5883	0.5918	0.5946	0.5960	0.5993	0.6014
P3	0.5169	0.5336	0.5357	0.5389	0.5400	0.5435	0.5473	0.5495	0.5523	0.5550	0.5682	0.5717	0.5753	0.5785	0.5811	0.5847	0.5870	0.5924	0.5951	0.5995
P4	0.5169	0.5328	0.5370	0.5435	0.5497	0.5527	0.5568	0.5605	0.5639	0.5674	0.5708	0.5743	0.5765	0.5790	0.5819	0.5847	0.5881	0.5910	0.5935	0.5971
P5	0.5169	0.5313	0.5392	0.5438	0.5501	0.5560	0.5589	0.5614	0.5640	0.5669	0.5695	0.5720	0.5751	0.5784	0.5809	0.5844	0.5861	0.5893	0.5912	0.5945
P6	0.5169	0.5965	0.6027	0.6540	0.7231	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D
P7	0.5169	0.5305	0.5351	0.5418	0.5480	0.5530	0.5579	0.5613	0.5645	0.5677	0.5706	0.5723	0.5765	0.5791	0.5830	0.5861	0.5889	0.5903	0.5925	0.5957
P8	0.5169	0.5277	0.5328	0.5387	0.5401	0.5439	0.5495	0.5540	0.5581	0.5617	0.5661	0.5694	0.5729	0.5753	0.5789	0.5810	0.5837	0.5860	0.5879	0.5922
P9	0.5169	0.5229	0.5283	0.5341	0.5375	0.5436	0.5469	0.5521	0.5553	0.5580	0.5619	0.5635	0.5672	0.5711	0.5763	0.5789	0.5822	0.5851	0.5890	0.5903
P10	0.5169	0.5194	0.5218	0.5268	0.5307	0.5349	0.5388	0.5410	0.5441	0.5493	0.5520	0.5559	0.5588	0.5625	0.5671	0.5733	0.5760	0.5784	0.5817	0.5861

P.M- Packaging Materials
[**P1:** PP woven Bag without Liner**; P2:** PP woven Bag with Liner I (PE/EVOH/PE – 5 Ply; 50-60 µ); **P3:** PP woven Bag with Liner II (PA/EVOH/PE – 5 Ply; 50-60 µ); **P4:** PP woven Bag with Liner III (PE/EVOH/PE – 9 Ply; 70- 80 µ); **P5:** PP woven Bag with Liner IV (PA/EVOH/PE – 9 Ply; 70- 80 µ)**; P6:** Paper woven Bag without Liner**; P7:** Paper woven Bag with Liner I (PE/EVOH/PE – 5 Ply; 50-60 µ)**; P8:** Paper woven Bag with Liner II (PA/EVOH/PE – 5 Ply; 50-60 µ); **P9:** Paper woven Bag with Liner III (PE/EVOH/PE – 9 Ply; 70- 80 µ); **P10:** Paper woven Bag with Liner IV (PA/EVOH/PE – 9 Ply; 70- 80 µ)]
D: Discontinued due to microbial growth.

extended shelf life is attributed to the structural properties of the packaging materials. Polyethylene (PE) is a dominant material in the packaging industry due to its unique properties. The combination of high moisture resistance, excellent heat sealability at low temperature, and strong tear resistance makes polyethylene a preferred choice and its adaptability along with cost-effectiveness further solidify its position as a leading material for diverse packaging needs. Ethylene-vinyl alcohol copolymer (EVOH) is renowned for its superior oxygen barrier properties. The ethylene component provides hydrophobic and olefinic characteristics, while the hydroxyl groups impart hydrophilic properties. However, EVOH's performance can be compromised by humidity if exposed to the environment, due to its hydrophilic nature (Gavara et al., 2016). To improve its moisture resistance, EVOH is often incorporated as a sandwich layer with other polymers, such as polypropylene (PP) and polyethylene (PE), through coextrusion. Packaging materials that include EVOH offer excellent mechanical resistance to stretching and puncturing,

Table 5: Colour changes in Red Chilli powder during storage in different packaging materials.

P.M	Colour changes																			
	Days in Storage																			
	15	30	45	60	75	90	97	104	111	118	125	132	139	146	153	160	167	174	181	190
P1	NC	NC	NC	NC	WD	WD	GD	GD	GD	GD	GD	GD	GD	GD	GD	GD	GD	YD	YD	YD
P2	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
P3	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
P4	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
P5	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
P6	NC	NC	NC	NC	NC	NC	NC	NC	WD	WD	WD	WD	GD	GD	GD	YD	YD	YD	YD	YD
P7	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
P8	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
P9	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
P10	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC

P.M- Packaging Materials
[**P1:** PP woven Bag without Liner**; P2:** PP woven Bag with Liner I (PE/EVOH/PE – 5 Ply; 50-60 µ); **P3:** PP woven Bag with Liner II (PA/EVOH/PE – 5 Ply; 50-60 µ); **P4:** PP woven Bag with Liner III (PE/EVOH/PE – 9 Ply; 70- 80 µ); **P5:** PP woven Bag with Liner IV (PA/EVOH/PE – 9 Ply; 70- 80 µ)**; P6:** Paper woven Bag without Liner**; P7:** Paper woven Bag with Liner I (PE/EVOH/PE – 5 Ply; 50-60 µ)**; P8:** Paper woven Bag with Liner II (PA/EVOH/PE – 5 Ply; 50-60 µ); **P9:** Paper woven Bag with Liner III (PE/EVOH/PE – 9 Ply; 70- 80 µ); **P10:** Paper woven Bag with Liner IV (PA/EVOH/PE – 9 Ply; 70- 80 µ)]

NC- No change
WD- Whitish discoloration
GD- Greenish discoloration
YD- Yellowish discoloration

as well as reduced gas permeability compared to other films.
Polyamide (PA) is an engineering polymer well-known for its outstanding chemical resistance, gas barrier properties, aroma retention, puncture strength, and burst strength. As a result, PA is being used in the outermost layer of packaging to enhance mechanical properties, replacing PE to take advantage of the higher performance capabilities of PA. The study observed that the maximum shelf life was achieved with the paper woven bag compared to PP woven bags. This is likely because the paper woven bag combines a paper outer layer with a PP woven inner layer, eliminating gaps or spaces between the two and providing an effective barrier against environmental conditions. In contrast, PP woven bags lack additional lamination and, due to their

Table 6: Aroma changes in Red Chilli powder during storage in different packaging materials.

P.M	Aroma changes																			
	Days in Storage																			
	15	30	45	60	75	90	97	104	111	118	125	132	139	146	153	160	167	174	181	190
P1	NC	NC	NC	NC	MO	MO	MO	MO	MO	MO	MO	MO	MO	MO	MO	MO	MO	BO	BO	BO
P2	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
P3	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
P4	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
P5	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
P6	NC	NC	NC	NC	NC	NC	NC	NC	MO	MO	MO	MO	MO	MO	MO	BO	BO	BO	BO	BO
P7	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
P8	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
P9	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
P10	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC

P.M- Packaging Materials
[**P1:** PP woven Bag without Liner**; P2:** PP woven Bag with Liner I (PE/EVOH/PE – 5 Ply; 50-60 µ); **P3:** PP woven Bag with Liner II (PA/EVOH/PE – 5 Ply; 50-60 µ); **P4:** PP woven Bag with Liner III (PE/EVOH/PE – 9 Ply; 70- 80 µ); **P5:** PP woven Bag with Liner IV (PA/EVOH/PE – 9 Ply; 70- 80 µ)**; P6:** Paper woven Bag without Liner**; P7:** Paper woven Bag with Liner I (PE/EVOH/PE – 5 Ply; 50-60 µ)**; P8:** Paper woven Bag with Liner II (PA/EVOH/PE – 5 Ply; 50-60 µ); **P9:** Paper woven Bag with Liner III (PE/EVOH/PE – 9 Ply; 70- 80 µ); **P10:** Paper woven Bag with Liner IV (PA/EVOH/PE – 9 Ply; 70- 80 µ)]

NC- No change
MO- Mushy odour
BO- Bad odour

mesh-like structure, are more permeable to moisture and gases. Therefore, paper woven bags are generally superior to PP woven bags in maintaining shelf life. However, under highly humid conditions, both the PP woven and paper woven bags would exhibit similar shelf life properties, as the paper would not withstand high humidity effectively. The combination of PA, EVOH, and PE in liner structures offers a promising approach to sustainable packaging, providing both superior performance and improved recyclability.

Evaluation of Bulk Pack of Red Chilli powder for Transport Worthiness Trials

To evaluate the transport suitability of 10 selected packaging materials, both drop tests and vibration tests were conducted. No ruptures or leakage of red chilli powder was observed in any of the packages. Effective packaging is essential for protecting products from transportation challenges.

Table 7: Microbial growth in Red Chilli powder during storage in different packaging materials.

P.M	Microbial Growth																			
	Days in Storage																			
	15	30	45	60	75	90	97	104	111	118	125	132	139	146	153	160	167	174	181	190
P1	NG	NG	NG	NG	NG	NG	NG	NG	FG	FG	FG	FG	FG	FG	FG	FG	FG	FG	FG	FG
P2	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG
P3	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG
P4	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG
P5	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG
P6	NG	NG	NG	NG	FG	FG	FG	FG	FG	FG	FG	FG	FG	FG	FG	FG	FG	FG	FG	FG
P7	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG
P8	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG
P9	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG
P10	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG

P.M- Packaging Materials
[**P1:** PP woven Bag without Liner**; P2:** PP woven Bag with Liner I (PE/EVOH/PE – 5 Ply; 50-60 µ); **P3:** PP woven Bag with Liner II (PA/EVOH/PE – 5 Ply; 50-60 µ); **P4:** PP woven Bag with Liner III (PE/EVOH/PE – 9 Ply; 70- 80 µ); **P5:** PP woven Bag with Liner IV (PA/EVOH/PE – 9 Ply; 70- 80 µ)**; P6:** Paper woven Bag without Liner**; P7:** Paper woven Bag with Liner I (PE/EVOH/PE – 5 Ply; 50-60 µ)**; P8:** Paper woven Bag with Liner II (PA/EVOH/PE – 5 Ply; 50-60 µ); **P9:** Paper woven Bag with Liner III (PE/EVOH/PE – 9 Ply; 70- 80 µ); **P10:** Paper woven Bag with Liner IV (PA/EVOH/PE – 9 Ply; 70- 80 µ)]

NG- No growth
FG- Fungus growth

Fig.2: Sample of best results and sample with microbial growth

Best results were observed in Paper woven Bag with Liner IV (PA/EVOH/PE – 9 Ply; 70- 80 µ)

Microbial growth was observed on PP woven Bag without Liner

Table- 8: Shelf Life of Red Chilli powder

Packaging Materials	Shelf Life in Days at 38 ± 1ºC & 90 ± 2 % R. H.	Expected Shelf Life in Days at 27 ± 2ºC & 65 ± 2 % R. H
P1	15 days	45 days
P2	97 days	291 days
P3	100 days	300 days
P4	102 days	306 days
P5	108 days	324 days
P6	30 days	90 days
P7	110 days	330 days
P8	120 days	360 days
P9	125 days	375 days
P10	135 days	405 days

[**P1:** PP woven Bag without Liner**; P2:** PP woven Bag with Liner I (PE/EVOH/PE – 5 Ply; 50-60 µ); **P3:** PP woven Bag with Liner II (PA/EVOH/PE – 5 Ply; 50-60 µ); **P4:** PP woven Bag with Liner III (PE/EVOH/PE – 9 Ply; 70- 80 µ); **P5:** PP woven Bag with Liner IV (PA/EVOH/PE – 9 Ply; 70- 80 µ)**; P6:** Paper woven Bag without Liner**; P7:** Paper woven Bag with Liner I (PE/EVOH/PE – 5 Ply; 50-60 µ)**; P8:** Paper woven Bag with Liner II (PA/EVOH/PE – 5 Ply; 50-60 µ); **P9:** Paper woven Bag with Liner III (PE/EVOH/PE – 9 Ply; 70- 80 µ); **P10:** Paper woven Bag with Liner IV (PA/EVOH/PE – 9 Ply; 70-80 µ)]

The results of the vibration and drop tests for the 10 selected packaging options are summarized in Table 9. These tests replicate real-world conditions to ensure that packaging can endure physical-mechanical hazards such as shocks, drops, and compression forces that are typically encountered in distribution cycles. Packaging effectiveness extends beyond aesthetics, providing essential protection against potential transportation hazards. The successful performance of these ten packaging materials under rigorous testing conditions

Table 9: Evaluation of Bulk Pack of Red Chilli powder for Transport Worthiness Trials

Packaging Materials	Vibration test		Drop test	
	External	**Internal**	**External**	**Internal**
P1	No damage	No damage	No damage	No damage
P2	No damage	No damage	No damage	No damage
P3	No damage	No damage	No damage	No damage
P4	No damage	No damage	No damage	No damage
P5	No damage	No damage	No damage	No damage
P6	No damage	No damage	No damage	No damage
P7	No damage	No damage	No damage	No damage
P8	No damage	No damage	No damage	No damage
P9	No damage	No damage	No damage	No damage
P10	No damage	No damage	No damage	No damage

P.M- Packaging Materials
[**P1:** PP woven Bag without Liner**; P2:** PP woven Bag with Liner I (PE/EVOH/PE – 5 Ply; 50-60 µ); **P3:** PP woven Bag with Liner II (PA/EVOH/PE – 5 Ply; 50-60 µ); **P4:** PP woven Bag with Liner III (PE/EVOH/PE – 9 Ply; 70- 80 µ); **P5:** PP woven Bag with Liner IV (PA/EVOH/PE – 9 Ply; 70- 80 µ)**; P6:** Paper woven Bag without Liner**; P7:** Paper woven Bag with Liner I (PE/EVOH/PE – 5 Ply; 50-60 µ)**; P8:** Paper woven Bag with Liner II (PA/EVOH/PE – 5 Ply; 50-60 µ); **P9:** Paper woven Bag with Liner III (PE/EVOH/PE – 9 Ply; 70- 80 µ); **P10:** Paper woven Bag with Liner IV (PA/EVOH/PE – 9 Ply; 70-80 µ)]

underscores their reliability and effectiveness in maintaining product integrity throughout the shipping process.

CONCLUSION

The comparison of packaging materials that achieved the longest shelf life with control samples revealed significant differences in storage life. It is evident that spice quality is heavily influenced by moisture content increased significantly throughout the storage period. Based on the analysis of moisture content, water activity, visual observations, microbial deterioration, transport worthiness tests, and the shelf life performance of ten packaging options, the recommended packaging materials are:

- PP Woven Bag with Liner IV (PA/EVOH/PE – 9 Ply; 70-80 µ);
- PP Woven Bag with Liner III (PE/EVOH/PE – 9 Ply; 70-80 µ);
- Paper Woven Bag with Liner IV (PA/EVOH/PE – 9 Ply; 70-80 µ) and
- Paper Woven Bag with Liner III (PE/EVOH/PE – 9 Ply; 70-80 µ).

Consequently, employing sustainable packaging combinations like PE/EVOH/PE and PA/EVOH/PE can substantially enhance barrier properties compared to conventional LDPE or LLDPE options, leading to an extended shelf life. Thus, these findings underscore the critical role of selecting appropriate packaging materials in extending the shelf life and maintaining the quality of red chilli powder, ultimately benefiting both producers and consumers.

ACKNOWLEDGEMENT

The authors acknowledge the Spices Board India for the financial assistance.

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