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Study of Bulk Packaging for Black Mustard [*Brassica nigra* (L.) W.D.J. Koch] and Assessment of Shelf Life for Export

Badal Dewangan* and Donal Bhattacharjee

R&D and Consultancy Department, Indian Institute of Packaging, Mumbai, Maharashtra, India

ABSTRACT

Mustard is a shelf-stable product with suspended respiration processes, though biochemical, microbial, and other decomposition activities can persist depending on storage conditions. To address these challenges, a study was undertaken to develop effective bulk packaging solutions for mustard. This involved testing various packaging materials, analyzing shelf life, and setting specifications for export packaging. The spice samples were packed in ten different packaging materials and subjected to accelerated climatic conditions (38±1°C and 90±2% RH) for six months. All physico-chemical parameters were measured in triplicate. During the exposure period, the moisture content and water activity of mustard exhibited a gradual increase. Notable changes in colour, aroma, and microbial growth were observed in samples packaged in PP and paper woven bags without liners. However, no damage to the packaging materials was detected during the transport worthiness test. The maximum recorded shelf life was for both the PP woven bag and the paper woven bag with Liners. Experimental results elaborate that the various packaging materials can efficiently obstruct the ingress of moisture and oxygen, consequently extending the shelf life of mustard.

***Corresponding author**

Badal Dewangan, R&D and Consultancy Department, Indian Institute of Packaging, Mumbai, Maharashtra, India.

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Introduction

Spices have played a crucial role in seasoning foods globally. They, along with herbs and essential oils, form the backbone of the flavours that characterize the diverse cuisines and culinary traditions around the world. 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. Mustards belong to the Cruciferae or Brassicaceae family, renowned for its condiments, therapeutic uses, and distinctive flavouring properties. This plant family is particularly noted for its organosulfur compounds. Among the various types of mustard seeds used in condiments, three are especially popular: Pale yellow or white mustard (Brassica alba), known as safed rai in Hindi; Brown or oriental mustard (Brassica juncea); and Black or dark brown mustard [Brassica nigra (L.) W.D.J. Koch], which are commonly referred to as true mustards Black mustard seeds are small, globular, and measure 1–1.6 mm in diameter. They are dark brown to nearly black, with a minute reticulate texture and a mucilaginous quality. The kernels are greenish-yellow and oily. Black mustard has a slight odour and delivers an acrid, pungent taste when crushed and moistened. Mustard plants, particularly their seeds, are utilized in a variety of food forms due to their unique functional properties. Whole black mustard seeds are commonly used in Indian cuisine, where they are typically sautéed to enhance the flavour of vegetable and legume dishes, as well as chutneys. The sharp flavour of these seeds softens when fried. Ground mustard is included in some curry powder blends and seafood recipes. In northern India, mustard oil is frequently used for culinary preparations and pickling vegetables. Mustard leaves are consumed as a vegetable, and processed foods frequently incorporate natural mustard seeds, particularly in pickled products. Mustard is also a common ingredient in many ready-to-eat items, including crackers, appetizers, various flours, and dehydrated soup mixes. Additionally, mustard is often found in spicy sauces and mayonnaises. Its distinct sharp and pungent flavour makes it a popular spice in various culinary applications [1,2].

India benefits from optimal agro-climatic conditions for mustard cultivation and boasts one of the most technologically advanced spice industries globally. Unfortunately, spice manufacturers frequently overlook proper packaging, creating substantial challenges for the industry in preserving quality in the export market. Mustard, being a hygroscopic product, necessitates packaging materials with high barrier properties. Currently, mustard is exported in bulk packages without technical specifications for packaging, resulting in difficulties for exporters in maintaining consistent quality and accurately assessing shelf life. Mustard is a shelf-stable product with suspended respiration processes, but biochemical, microbial, and other decomposition activities can continue based on storage conditions. To ensure product quality, it should be packaged in high-barrier materials that protect against oxidation and preserve its quality. It is noteworthy that the packaging industry in India is undergoing a significant transformation towards sustainability, fuelled by regulatory frameworks, consumer preferences, and innovative practices. By adopting sustainable designs, spice and packaging companies can reduce their environmental impact while also boosting their appeal in the increasingly eco-conscious global marketplace.

In response to current challenges, the Indian Institute of Packaging (IIP) in Mumbai has conducted a study aimed at developing effective bulk packaging solutions for mustard, funded by the Spices Board India under the Ministry of Commerce and Industry. The aim was to develop effective bulk packaging solutions for mustard by testing packaging materials, studying shelf life, and establishing specifications for export market packaging.

Materials and Methods

Mustard (whole) was procured from M/s Jabs International Private Limited, Navi Mumbai. As per the packaging materials specified by 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 Mustard, Polypropylene (PP) woven bag and Paper woven Bag were selected with different liners. The details of packaging materials used for packaging of the seed spice are mentioned below:

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)

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 mustard 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). Samples were drawn and tested in the laboratory at an interval of 15 days initially for 90 days and then at an interval of 7 days till 190 days or till the sample is spoiled; or whichever is earlier. The spice samples were stored at the accelerated condition for a period of six months. Each sample exposed was replicated thrice.

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/m²	Not Applicable	160.90

D1: Direction 1; D2: Direction 2

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/mm²)	17.72	21.38	17.37	28.35
	D2		18.47	22.72	22.74	30.58
	Break stress					
4	D1	(N/mm²)	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

The mustard was checked for initial moisture content (IMC) when received in the laboratory for studies and it was compared against the critical moisture content (CMC) as per the FSSAI regulations (Figure 1). The moisture content was determined by vacuum oven drying method. Approximately, 5 g of sample was weighed in a dry dish and it was transferred to vacuum oven and the sample was dried at 103±2 °C, under 25 mm Hg pressure for 5 hours. The sample was cooled in a desiccator and weighed. The water activity of mustard was measured by Aqualab 4TEV Water Activity Meter. The sample was placed in the disposable cup, the chamber lid over the sample was sealed, and waited for vapour equilibrium. An infrared beam focused on a tiny mirror that determines the precise dewpoint temperature of the sample. That dewpoint temperature is then translated into water activity. Apart from that, visual observations on colour, aroma, visual appearance and microbial growth (visual observation) were recorded at every sample pull during the entire exposure period. Besides assessing the product quality, the packaging materials were also observed for any changes like in the colour and other changes. Packaging 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 [3].

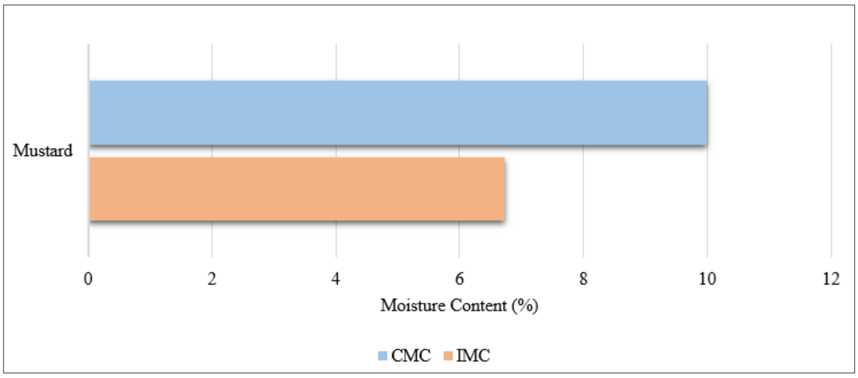

Figure 1: Initial Moisture Content (IMC) and Critical Moisture Content (CMC) of Mustard

The transport worthiness test was conducted to evaluate the transportation hazards and performance of the bulk packages during the transit. It was performed by drop test and vibration test of the packaged samples of mustard. 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. For vibration test, the packed seed and grounded spices were kept on the vibration table and vibrated for one hour at a frequency of 120 cpm and 2.54 cm amplitude. All the physico-chemical parameters were measured in triplicate. The significance was accepted at 5% levels of significance ($p<0.05$) [4,5]

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Results and Discussion

Moisture Content

It was observed from the results presented in Table 3 that the primary critical factor for determining shelf life was the moisture content. The samples were studied even after exceeding the CMC limit. However, when microbial growth was observed, the samples were discarded and further testing was not continued. It can be concluded that moisture content and the permeability of packaging materials were the main causes of product deterioration. Moisture content showed a steady increase during the exposure period, although the rate of increase varied depending on the packaging material. When the product exceeded the critical moisture level, a distinct change in texture was observed: the product became lumpy and, therefore, unsaleable. Being hygroscopic, mustard absorbs moisture based on atmospheric conditions. The moisture content of mustard has a linear relationship with storage conditions. As per the studies, the presence of moisture in low-moisture spices and seasonings can lead to issues such as stickiness, agglomeration, caking, clumping, crystallization of the spice material, and degradation of the components. These changes negatively impacted the storability of the mustard. Similar results were observed by Voelker et al., [6].

Table 3: Moisture Content of Mustard 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	190
P1		6.93	8.25	10.62	10.82	11.47	11.61	12.05	12.21	12.31	12.47	12.74	12.95	15.80	D	D	D	D	D	D	D
P2		6.87	7.02	7.12	7.16	7.21	7.42	7.47	7.48	7.72	7.91	7.94	8.16	8.30	8.34	8.58	8.8	9.54	10.31	11.21	13.65
P3		6.75	6.77	6.82	7.09	7.24	7.39	7.54	7.56	7.60	7.61	7.62	7.65	7.69	7.89	8.13	8.16	8.38	10.04	10.83	13.33
P4		6.82	6.97	7.12	7.23	7.38	7.42	7.52	8.01	8.04	8.08	8.29	8.36	8.64	8.90	9.16	9.20	9.28	9.80	11.15	13.35
P5		6.80	6.95	7.10	7.25	7.40	7.55	7.67	7.83	8.02	8.10	8.17	8.19	8.27	8.33	8.48	8.64	8.93	9.18	10.67	12.47
P6	6.72	6.92	7.78	9.85	10.74	10.98	11.82	12.66	14.62	D	D	D	D	D	D	D	D	D	D	D	D
P7		6.86	6.98	7.02	7.17	7.32	7.47	7.62	7.77	8.09	8.21	8.53	8.59	8.86	9.06	9.09	9.14	9.25	10.08	12.13	13.59
P8		6.92	7.06	7.26	7.46	7.61	7.72	7.87	7.98	7.99	8.07	8.22	8.37	8.45	8.48	8.63	9.07	9.29	10.02	12.12	14.29
P9		6.98	6.99	7.09	7.19	7.25	7.35	7.38	7.50	7.65	7.95	8.01	8.01	8.02	8.14	8.14	8.44	8.86	9.23	10.39	12.99
P10		6.87	7.03	7.18	7.33	7.48	7.59	7.62	7.77	7.89	8.05	8.09	8.24	8.42	8.70	8.86	9.00	9.24	9.49	10.65	12.79

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

Water Activity

The water activity in mustard seeds during storage presented 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 0.4427, which was not suitable for microbial propagation. However, the water activity increased in all the packaging materials used for mustard. The highest value recorded was 0.6473 in the P1 sample which was followed by microbial spoilage. 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 Modi et al., [7].

Table 4: Water Activity of Mustard 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	190
P1		0.4449	0.4469	0.4481	0.4539	0.4571	0.4682	0.4797	0.4993	0.5481	0.5619	0.5973	0.6134	0.6473	D	D	D	D	D	D	D
P2		0.4449	0.4457	0.4479	0.4534	0.4644	0.4723	0.4896	0.5196	0.5289	0.5317	0.5345	0.5361	0.5393	0.5411	0.5425	0.5447	0.5469	10.31	11.21	13.65
P3		0.4448	0.4491	0.4517	0.4588	0.4624	0.4678	0.4716	0.4800	0.4971	0.5031	0.5065	0.5088	0.5107	0.5144	0.5173	0.5221	0.5257	10.04	10.83	13.33
P4		0.4445	0.4456	0.4465	0.4497	0.4513	0.4601	0.4693	0.4741	0.4801	0.4976	0.5011	0.5039	0.5055	0.5086	0.5118	0.5167	0.5193	9.80	11.15	13.35
P5		0.4431	0.4448	0.4489	0.4512	0.4523	0.4551	0.4566	0.4582	0.4599	0.4623	0.4647	0.4675	0.4692	0.4706	0.4731	0.4785	0.4961	9.18	10.67	12.47
P6	6.72	0.4439	0.4451	0.4517	0.4588	0.4811	0.5084	0.5897	0.6367	D	D	D	D	D	D	D	D	D	D	D	D
P7		0.4457	0.4526	0.4637	0.4755	0.4929	0.5006	0.5037	0.5081	0.5111	0.5143	0.5185	0.5220	0.5246	0.5287	0.5303	0.5324	0.5361	10.08	12.13	13.59
P8		0.4450	0.4552	0.4648	0.4711	0.4897	0.5056	0.5173	0.5188	0.5216	0.5138	0.5167	0.5195	0.5203	0.5251	0.5282	0.5308	0.5355	10.02	12.12	14.29
P9		0.4431	0.4452	0.4498	0.4512	0.4522	0.4586	0.4608	0.4631	0.4664	0.4689	0.4718	0.4771	0.4835	0.4887	0.4911	0.4976	0.5021	9.23	10.39	12.99
P10		0.4429	0.4433	0.4439	0.4446	0.4503	0.4514	0.4523	0.4531	0.4548	0.4559	0.4611	0.4624	0.4633	0.4647	0.4653	0.4693	0.4725	9.49	10.65	12.79

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

Colour, Aroma changes and Microbial Growth

The changes in colour, aroma, and microbial growth were monitored for all packaging materials throughout the sample exposure period and are summarized in Tables 5, 6, and 7, respectively. For all types of packaging, no changes in colour or aroma were observed 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 yellowish discoloration during storage. The aroma shifted to a mushy odor and then a bad odor. Fungal growth was detected in P1 from day 146 onwards and in P6 from day 111 onwards (Figure 2). No changes in softening, cracking, or delamination were observed in any of the packaging materials. The contamination of mustard may arise from poor hygienic conditions during harvesting, processing, transportation, poor barrier properties of packaging materials and storage. Fungal contamination is further intensified by warm humid tropical conditions and partial drying which provide optimal conditions for fungal growth and consequently production of mycotoxins. Additionally, the complete drying, proper packaging and storage can minimize growth of microorganisms such as fungi, bacteria, and yeasts. Other factors such as presence of antimicrobial activity properties such as essential oils such as allyl-iso-thiocyanate in case of mustard can also limit their growth [8,9].

Table 5: Colour Changes in Mustard 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	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	WD	WD	WD	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	WD	WD	WD	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
YD- Yellowish discoloration

Table 6: Aroma Changes in Mustard 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	NC	NC	NC	NC	NC	NC	NC	NC	NC	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

Table 7: Microbial Growth in Mustard 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	NG	NG	NG	NG	NG	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	NG	NG	NG	NG	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

Figure 2: Sample of Best Results and Sample with Microbial Growth

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

Microbial growth was observed on Paper woven Bag without Liner

Shelf Life of Mustard

Based on the moisture content results as tabulated in Table 8, the maximum shelf life recorded was up to 535 days for both the PP Woven Bag with Liner IV (PA/EVOH/PE – 9 Ply; 70-80 µ) and the Paper Woven Bag with Liner IV (PA/EVOH/PE – 9 Ply; 70-80 µ) under accelerated conditions. This was followed by a shelf life of 534 days for the Paper Woven Bag with Liner III (PE/EVOH/PE – 9 Ply; 70-80 µ), and 525 days for the PP Woven Bag with Liner III (PE/EVOH/PE – 9 Ply; 70-80 µ). The extended shelf life can be attributed to the structure of the packaging materials. In this case, EVOH is used in the form of multilayer structures, where the EVOH layer is sandwiched between films that protect it from water, particularly polyolefins. This material's effectiveness stems from its high barrier, its suitability for coextrusion into both flexible and rigid structures, its cost-efficiency, and its lower environmental impact compared to other polymers. Additionally, it has been observed during study that the maximum shelf life was achieved in the paper woven bag compared to the PP woven bags. It could be attributed to the structure of the paper woven bag which is paper on the outer side and PP woven structure on the inner. Hence, there is no gap or space between the paper and the woven structure, making it a good barrier for the environmental conditions. However, on the other hand, the PP woven bags have no extra layer of lamination and owing to its mesh like structure, it is permeable to the moisture and gases. Thus, the paper woven bags are superior than the PP woven bag. In highly humid conditions, the shelf life properties exhibited by the PP woven bag and paper woven bag would be equal since, paper would not be able to sustain high humid conditions [10].

Table 8: Shelf Life of Mustard

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	40 days	120 days
P2	170 days	Up to 510 days
P3	173 days	Up to 520 days
P4	175 days	Up to 525 days
P5	178 days	Up to 535 days
P6	50 days	150 days
P7	172 days	Up to 515 days
P8	173 days	Up to 520 days
P9	178 days	Up to 534 days
P10	178 days	Up to 535 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)]

Evaluation of Bulk Pack of Mustard for Transport Worthiness Trials

To assess the transport worthiness of 10 selected packaging materials, drop test and vibration test were performed. Neither rupture of the bag nor seepage of the mustard seeds were observed from any of the packs. Packaging plays a major role to protect the products from various transportation hurdles. Hence, the transport worthiness test predicts the stability of the transport pack. The results of the vibration test and drop tests performed on 10 selected packaging options are tabulated in Table 9.

Table 9: Evaluation of Bulk Pack of Mustard 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)]

Conclusion

The comparison between the packaging materials which has achieved the highest shelf life and the control samples clearly revealed the variation in the storage life and importance of proper packaging materials for storing mustard. It can be concluded that the quality of spices primarily depends on the moisture content and the moisture content increased exponentially over the period of storage. The water activity helped to predict the microbial deterioration of the spices in storage. The water activity of spices is a function of moisture content and temperature which is essential to monitor during processing, handling, packaging and storage to prevent the deleterious phenomena of caking, clumping, collapse and stickiness. Thus, controlling water activity in spices would maintain proper product structure, texture, stability, and density. Based on the results obtained from the analysis of moisture content, water activity, visual observations, microbial deterioration, insect infestation, transport worthiness tests and the shelf life achieved in ten packaging options, the possible packaging options recommended 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).

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