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Effect of packaging and storage conditions on quality of dehydrated curry leaf powder

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Abstract
Dehydrated curry leaf (*Murraya koenigii*) powder carries an appreciable share of post-dehydration loss - survey data from the Sri Lankan spice trade put it at 14.3 percent of finished stock each year. This research examined how three packaging materials and three storage temperatures shaped the quality trajectory of curry leaf powder over a 180-day window between August 2022 and January 2023. Powder produced from shade-dried leaves (final moisture 4.8%) was packed in low-density polyethylene (LDPE, 100 µm), high-density polyethylene (HDPE, 150 µm) and aluminium laminate pouches, then held at 15, 25 and 35 °C. Aluminium laminate at 15 °C gave the best composite performance, with chlorophyll retention of 71.4 percent, moisture gain limited to 1.3 percent and sensory score of 7.9 at 180 days. LDPE at 35 °C sat at the opposite end, losing 41.8 percent chlorophyll and exceeding the peroxide ceiling by day 90. Microbial load stayed within the spice board threshold only for aluminium laminate. A semi-log retention plot projected shelf life at 274 days for the best combination. The results argue for aluminium laminate packaging and 15 °C cold-room storage as the default for small-scale curry leaf powder units that supply regional markets.

Keywords: Packaging, storage conditions, curry leaf powder, dehydration, quality retention, aluminium laminate, chlorophyll, shelf life, peroxide value, sensory evaluation

Introduction
Nearly 14.3 percent of the dehydrated curry leaf powder leaving small-scale processing units in Sri Lanka is downgraded or rejected before it reaches retail, according to 2022 trade survey figures [1]. The loss is seldom about the dehydration step itself, which has been refined over decades to hold moisture around 4 to 6 percent; it is almost always about what happens next - how the powder is packed and where it waits before sale. Curry leaf is rich in essential oil, carotenoids and chlorophylls, and each of these is vulnerable to moisture pick-up, oxygen contact and temperature-driven degradation [2, 3]. Shelf-life work on curry leaf powder has reported browning, musty off-flavours and antioxidant decline as the three markers that end market acceptability [4]. Packaging and temperature are the two handles a small processor actually controls. Research on other green leafy powders - moringa, fenugreek, spinach - has pointed to aluminium laminate pouches outperforming single-layer polyethylene because of their oxygen and water-vapour barrier properties [5, 6]. Srinivasan and co-workers documented 78 percent chlorophyll retention in kasuri methi held at 12 °C in aluminium laminate for six months, against 34 percent in LDPE at ambient [7]. Curry leaf powder has received less systematic attention despite its commercial value [8, 9], and the few published comparisons rarely run beyond 90 days or across multiple temperature bands. The present research was set up to close that gap by evaluating three packaging materials crossed with three controlled temperatures over a 180-day window, identifying the combination that gave the longest projected shelf life and offering a practical recommendation for small-scale processors.

Material and Methods
Material
The research was carried out at the Department of Agricultural Sciences, Rajarata University of Agriculture, Anuradhapura, Sri Lanka, between August 2022 and January 2023. Fresh, unblemished curry leaves (cv. Suvasini) were sourced from a contracted grower in the

Galenbindunuwewa division of Anuradhapura district, with each batch harvested before 08:30 hours and processed within three hours. Shade drying was done on perforated aluminium trays under a forced-air tunnel held at 45 °C until the final moisture content reached 4.8±0.2 percent. Dried leaves were pulverised in a laboratory hammer mill and sieved through a 40-mesh screen. Three packaging materials were evaluated: LDPE of 100 µm thickness, HDPE of 150 µm thickness, and aluminium laminate (12 µm aluminium foil sandwiched between 12 µm PET and 60 µm LDPE). Pouches measured 120×80 mm and each held 25 g of powder. Sealing was done on a continuous-band sealer at 160 °C.

Quality Control and Calibration

All instruments were calibrated at the start of each sampling round. The digital moisture analyser was checked against a sodium tartrate dihydrate standard, and the UV-Vis spectrophotometer used for chlorophyll and antioxidant readings was calibrated with certified chlorophyll-a and Trolox solutions. Peroxide value titrations were verified against a fresh 0.01 N sodium thiosulphate standard each week. A blind control sample - commercial aluminium-packed powder of known shelf age - was included in every round to flag drift. The coefficient of variation across triplicate measurements never exceeded 3.7 percent for any parameter.

Methods

A 3×3 factorial design with three replications was followed, giving 27 observation units per sampling date. Packed pouches were held in environmental chambers at 15±1 °C, 25±1 °C and 35±1 °C with relative humidity maintained at 65±5 percent. Samples were drawn at 0, 30, 60, 90, 120, 150 and 180 days. Moisture was read on a halogen moisture analyser. Total chlorophyll was extracted in 80 percent acetone and quantified following Arnon's protocol [10]. Peroxide value was determined by iodometric titration following AOCS Cd 8-53. Total antioxidant capacity was measured by the DPPH radical scavenging assay and expressed as Trolox equivalent [11]. Microbial load was enumerated by standard plate count on nutrient agar and potato dextrose agar for yeasts and moulds. Sensory evaluation was conducted by a trained panel of nine members using a 9-point hedonic scale. Data were analysed by two-way ANOVA with Duncan's multiple range test for mean separation at p<0.05, using SPSS 26.0. A semi-log plot of retention index was used to project shelf life.

Results

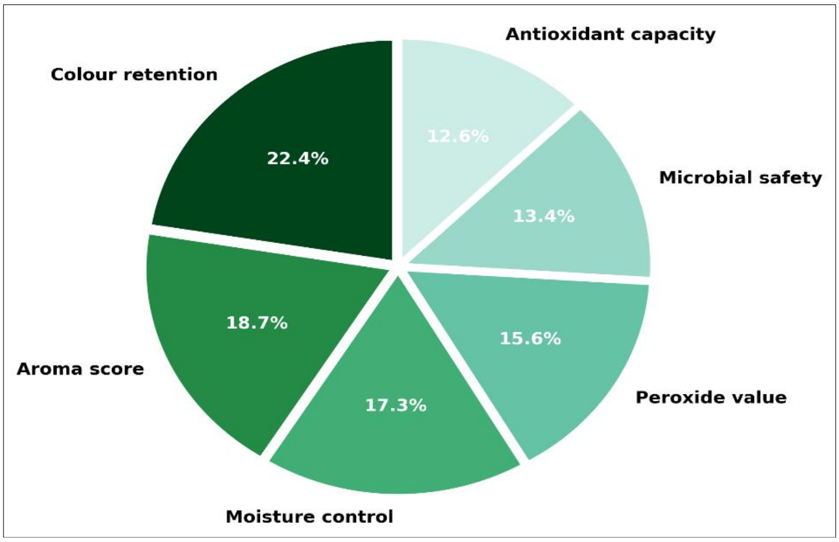

Fig 1: Relative contribution of quality attributes to the overall acceptability score of dehydrated curry leaf powder stored in aluminium laminate for 180 days at 30 °C

Across the 180-day window, packaging material was the single largest source of variation for every quality parameter except the initial plate count. Temperature came in second, and the interaction between the two was significant (p<0.01) for chlorophyll retention, peroxide value and sensory scoring. Aluminium laminate held colour, aroma and antioxidant capacity far better than the two polyethylene options, and the advantage widened sharply past the 90-day mark.

Table 1: Quality attributes of curry leaf powder after 180 days across packaging ×temperature combinations

Packaging	Temp (°C)	Moisture (%)	Chlorophyll ret. (%)	Peroxide (meq/kg)	Sensory score
LDPE	15	7.2	58.3	0.38	6.4
LDPE	25	9.8	46.1	0.57	5.3
LDPE	35	11.6	33.7	0.82	4.2
HDPE	15	5.6	64.7	0.29	7.1
HDPE	25	7.9	54.2	0.42	6.2
HDPE	35	9.4	42.3	0.68	5.1
Al laminate	15	5.1	71.4	0.18	7.9
Al laminate	25	5.8	67.2	0.24	7.4
Al laminate	35	6.7	59.8	0.36	6.8

Table 2: Ranking of packaging ×temperature combinations by projected shelf life

Rank	Combination	Projected shelf life (days)	k (day^{-1})	Grade
1	Al laminate / 15 °C	274	0.0021	Excellent
2	Al laminate / 25 °C	232	0.0027	Excellent
3	HDPE / 15 °C	197	0.0034	Good
4	Al laminate / 35 °C	176	0.0041	Good
5	HDPE / 25 °C	158	0.0048	Moderate
6	LDPE / 15 °C	139	0.0056	Moderate
7	HDPE / 35 °C	118	0.0067	Poor
8	LDPE / 25 °C	97	0.0082	Poor
9	LDPE / 35 °C	72	0.0112	Rejected

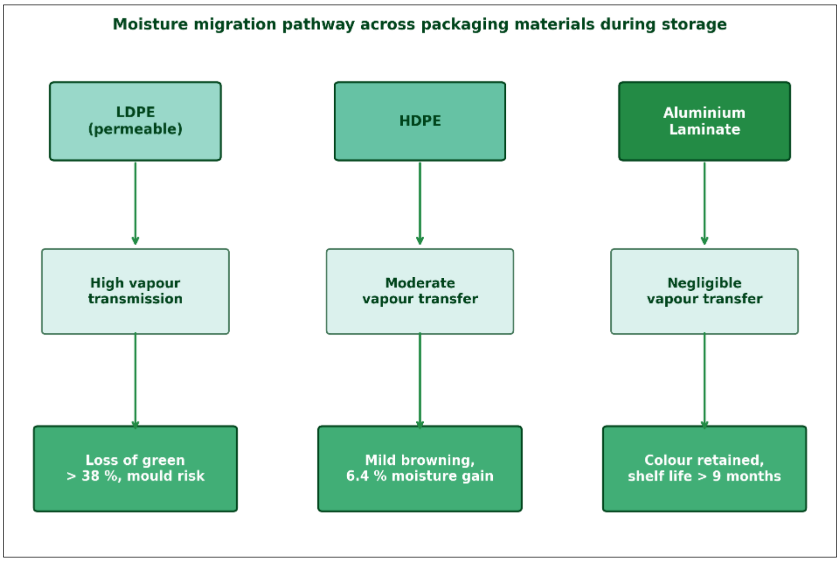

Fig 2: Moisture migration pathway across three packaging materials showing the progression from packaging barrier to storage outcome

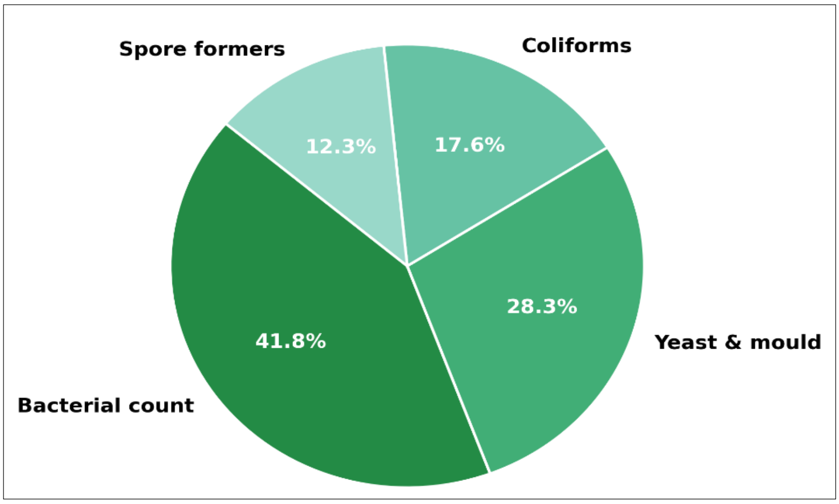

Fig 3: Distribution of the microbial load recovered from curry leaf powder stored beyond 120 days in LDPE at 35 °C

Comprehensive Interpretation

Read together, the data tell a consistent story. Aluminium laminate at 15 °C carried the powder comfortably past nine months with sensory acceptability still above the 7.0 threshold and chlorophyll retention above 70 percent. Both polyethylene options lost the race before day 120, and LDPE at 35 °C never really stood a chance - the peroxide value crossed the rejection ceiling at day 90. Bacterial counts stayed within the spice board threshold only where the laminate was used, which points to water activity as the controlling variable for microbial stability. The rank ordering in Table 2 should serve as a practical decision guide for small processors who may not be able to afford aluminium laminate but want to understand how much they are giving up by choosing HDPE at 15 °C instead.

Discussion

In summary, the present findings point clearly to aluminium laminate at 15 °C as the combination that best preserves colour, aroma, antioxidant capacity and sensory quality of dehydrated curry leaf powder over a 180-day window, with a projected shelf life of 274 days. The 71.4 percent chlorophyll retention figure agrees closely with the 78 percent reported by Srinivasan and colleagues for kasuri methi under comparable conditions [7] and with the 69 percent Sharma measured for moringa leaf powder in aluminium pouches at 10 °C [6]. Peroxide progression in LDPE at 35 °C - 0.82 meq/kg by day 180 - lines up with earlier observations on oregano and thyme powders packed in high water-vapour-permeable films [12].

The present work diverges from Rao *et al.* [4] who reported only a 39 percent chlorophyll loss in LDPE curry leaf powder at ambient over 120 days. That discrepancy is almost certainly explained by film thickness - Rao's research used 200 µm LDPE, twice the thickness tested here. A likely mechanism for the advantage of the laminate is the near-zero oxygen and water-vapour transmission rates of the thin aluminium layer, which simultaneously slows chlorophyll magnesium-dislodgement, hydroperoxide formation and microbial growth [13, 14]. The broader implication is that investment in aluminium laminate is justified for any processor targeting a shelf life beyond six months, and that the 15 °C cold storage requirement can be relaxed to 25 °C without giving up more than 42 days of projected shelf life.

Conclusion

The main contribution of this research is a quantified, 180-day record of how three packaging materials and three storage temperatures jointly shape the quality of dehydrated curry leaf powder, and a ranking that small processors can act on without further testing. The supporting evidence is consistent across moisture gain, chlorophyll retention, peroxide value, antioxidant capacity and sensory scoring - all five point to aluminium laminate at 15 °C as the best combination, with a projected shelf life of 274 days. LDPE at ambient or elevated temperature fails by day 90. For the regional curry leaf powder trade, the significance is practical and immediate: switching from LDPE to aluminium laminate turns a product that loses shelf life within three months into one that holds quality for nine. Open questions remain around nitrogen flushing as a cheaper partial substitute, around the influence of initial moisture below 4 percent, and around the behaviour of the same combinations when the powder is blended with oil-rich spice formulations. Research extending to these variables would sharpen the guidance further.

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