



International Journal of Research in Agronomy

E-ISSN: 2618-0618

P-ISSN: 2618-060X

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www.agronomyjournals.com

2024; 7(9): 774-776

Received: 15-07-2024

Accepted: 20-08-2024

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Assessment of packaging materials and their effects on the nutritional profile of grape pomace powder

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DOI: <https://doi.org/10.33545/2618060X.2024.v7.i9j.4717>

Abstract

The study investigated the influence of packaging materials and storage duration on the nutritional and microbial quality of grape pomace powder produced by solar dehydration. Dried grape pomace was powdered and stored under ambient conditions in low-density polyethylene (LDPE), metallised polyester (MP), and without packaging as a control. Samples were analyzed at monthly intervals over a 90-day storage period to evaluate changes in nutritional composition. A progressive decline in nutritional parameters was observed in all treatments during storage; however, the extent of deterioration varied with packaging type. Grape pomace powder packed in metallised polyester exhibited superior retention of nutritional quality and significantly lower microbial growth compared to LDPE and control samples. The findings demonstrate that metallised polyester is an effective packaging material for enhancing the shelf stability and biochemical quality of grape pomace powder under ambient storage conditions.

Keywords: Grape pomace, solar dehydration, packaging materials, nutritional quality, storage stability, metallised polyester

Introduction

Grape pomace, a major by-product of wine and juice processing, contains substantial amounts of dietary fibre and bioactive compounds, particularly polyphenols with antioxidant and antimicrobial properties (Almanza *et al.*, 2024) [7]. However, its adoption in food industry applications has been limited due to its short shelf life, susceptibility to spoilage, and instability of quality parameters during storage, which complicate bulk handling and commercialization at small-scale levels. In recent years, increasing consumer preference for natural antioxidants and functional food ingredients has intensified the demand for novel sources rich in polyphenols and dietary fibre. Grape pomace has been widely recognized as a sustainable and economical source of these bioactive compounds, with demonstrated potential for value-added applications in food, nutraceutical, and packaging industries. Several studies published in recent years have reported the high phenolic content, antioxidant activity, and functional properties of grape pomace, highlighting its suitability for incorporation into functional foods and as a natural preservative or active packaging component (Sousa *et al.*, 2022) [3]. However, knowledge regarding affordable and practical storage methods for grape pomace powder, particularly at the small-scale processing level, remains insufficient. In particular, systematic studies evaluating the influence of packaging materials and ambient storage conditions on the preservation of nutritional quality in grape pomace powder are scarce. Therefore, the present study was undertaken to assess the effectiveness of selected packaging materials in maintaining the nutritional composition of grape pomace powder during ambient storage.

Experimental Design and Methods

Pomace Powder Preparation

Fresh grape pomace was pretreated with either T₁: KMS 1% + CaCl₂ 1% or T₂: Citric acid (CA) 1% + KMS 0.5% for 5 minutes. The treated pomace was dried in a cabinet dryer at 40–65 °C for 15 hours and ground into fine powder.

Packaging and Storage

Powder from each treatment was packed in low-density polyethylene (LDPE, P₁) or metallised

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polyester (MP, P₂); unpacked samples served as control (P₀). Each 200-gauge packet contained 20 g of powder and was stored at ambient temperature for further analysis.

Protein and Fibre Analysis

Protein content was determined using the Lowry method (1951). Total dietary fibre (TDF) was measured enzymatically and gravimetrically following Indian Standard procedures.

Microbiological Analysis

Yeast and mold counts were determined by the dilution plate method.

Experimental Design and Statistics

A factorial Completely Randomized Design was used. Data were analyzed using ANOVA to assess treatment effects (Fisher, 1950).

Findings and Discussion

Protein (%)

Protein content declined in all samples over 90 days of storage, with the greatest loss observed in the unpackaged control. In T₁ (KMS 1% + CaCl₂ 1%), protein decreased from 14.06% to 12.83%, and in T₂ (CA 1% + KMS 0.5%), from 14.12% to 13.18%. LDPE-packaged samples showed moderate reductions (T₁: 14.06 → 13.16%; T₂: 14.12 → 13.26%), while metallised polyester (MP) maintained the highest protein retention (T₁: 14.06 → 13.71%; T₂: 14.12 → 13.85%) Table 1.

The improved retention in MP-packed powder is likely due to its enhanced barrier properties against moisture and oxygen, which slow protein degradation during storage. Similar effects of packaging on slowing protein oxidation and quality loss in stored food powders have been reported, where packaging with superior barrier characteristics reduced protein degradation and structural changes over time (Han *et al.*, 2023) [4].

Table 1: Protein (%) of pomace powder under different packaging and treatments during storage

Packaging	Treatment	0 days	30 days	60 days	90 days
P ₀ (Unpackaged)	T ₁ (KMS 1% + CaCl ₂ 1%)	14.06	13.60	13.20	12.83
P ₀ (Unpackaged)	T ₂ (CA 1% + KMS 0.5%)	14.12	13.70	13.40	13.18
P ₁ (LDPE)	T ₁ (KMS 1% + CaCl ₂ 1%)	14.06	13.70	13.40	13.16
P ₁ (LDPE)	T ₂ (CA 1% + KMS 0.5%)	14.12	13.78	13.50	13.26
P ₂ (Metallised Polyester)	T ₁ (KMS 1% + CaCl ₂ 1%)	14.06	13.95	13.82	13.71
P ₂ (Metallised Polyester)	T ₂ (CA 1% + KMS 0.5%)	14.12	14.00	13.92	13.85

Total Polyphenols (mg/100 g)

The interaction effect between packaging material and treatments was not significant at the initial stage (0 days); however, with storage up to 90 days, significant differences were observed among packages and treatments (Table 2). A gradual decline in total polyphenol content was recorded in all samples during storage. Pomace powder packed in LDPE (P₁) showed a comparatively higher reduction in polyphenol content, decreasing from 16.93 to 16.55 mg/100 g in T₁ (KMS 1% + CaCl₂ 1%) and from 17.02 to 16.68 mg/100 g in T₂ (citric acid 1% + KMS 0.5%) over 90 days Table 2.

In contrast, samples packed in metallised polyester (MP, P₂) exhibited the least reduction in total polyphenols, with values decreasing from 16.93 to 16.67 mg/100 g in T₁ and from 17.02

to 16.80 mg/100 g in T₂. The maximum loss of polyphenols was observed in the unpackaged control (P₀), where values declined from 16.93 to 16.48 mg/100 g in T₁ and from 17.02 to 16.58 mg/100 g in T₂ during the storage period.

The higher loss of polyphenols in LDPE-packed samples may be attributed to the greater permeability of LDPE films to oxygen and water vapour (Zhang *et al.*, 2023) [5] compared with metallised polyester, resulting in enhanced oxidative degradation of phenolic compounds. Similar trends have been reported in earlier studies on fruit and vegetable powders (Kurek *et al.*, 2020) [1], as well as in recent investigations demonstrating improved retention of phenolic compounds in high-barrier packaging materials during storage.

Table 2: Total Polyphenols (mg/100 g) of pomace powder under different packaging and treatments during storage

Packaging	Treatment	0 days	30 days	60 days	90 days
P ₀ (Unpackaged)	T ₁ (KMS 1% + CaCl ₂ 1%)	16.93	16.80	16.65	16.48
P ₀ (Unpackaged)	T ₂ (Citric acid 1% + KMS 0.5%)	17.02	16.88	16.72	16.58
P ₁ (LDPE)	T ₁ (KMS 1% + CaCl ₂ 1%)	16.93	16.83	16.68	16.55
P ₁ (LDPE)	T ₂ (Citric acid 1% + KMS 0.5%)	17.02	16.90	16.78	16.68
P ₂ (Metallised Polyester)	T ₁ (KMS 1% + CaCl ₂ 1%)	16.93	16.87	16.75	16.67
P ₂ (Metallised Polyester)	T ₂ (Citric acid 1% + KMS 0.5%)	17.02	16.92	16.85	16.80

Total Dietary Fibre (%)

The interaction between packaging and treatments was not significant at the initial stage of storage; however, significant differences were observed as the storage period progressed (Table 3). Over 90 days, pomace powder without packaging (P₀) showed the highest increase in dietary fibre, rising from 45.90% to 46.32% in T₁ (KMS 1% + CaCl₂ 1%) and from 46.04% to 46.29% in T₂ (citric acid 1% + KMS 0.5%).

Samples packed in LDPE (P₁) exhibited moderate increases, with dietary fibre rising from 45.90% to 46.17% in T₁ and from 46.04% to 46.25% in T₂. In contrast, metallised polyester (MP, P₂) packed samples showed minimal changes, with values increasing from 45.90% to 46.02% in T₁ and from 46.04% to 46.08% in T₂ over 90 days Table 3.

The slight differences in dietary fibre between the treatments may be attributed to variations in the chemical composition of the pomace powder. The minimal change observed in MP-packed samples suggests that high-barrier packaging effectively limits compositional changes under ambient storage. The gradual increase in dietary fibre during storage is consistent with maturation-related changes, possibly due to the accumulation of structural components such as uronic acids in the insoluble fibre fraction (Zhou *et al.*, 2021) [2]. Moreover, recent research highlights how processing and storage conditions influence the structural and functional properties of dietary fibres in fruit and vegetable matrices, affecting their physicochemical behaviours over time.

Table 3: Total Dietary Fibre (%) of pomace powder under different packaging and treatments during storage

Packaging	Treatment	0 days	30 days	60 days	90 days
P ₀ (Unpackaged)	T ₁ (KMS 1% + CaCl ₂ 1%)	45.9	46.05	46.2	46.32
P ₀ (Unpackaged)	T ₂ (Citric acid 1% + KMS 0.5%)	46.04	46.12	46.21	46.29
P ₁ (LDPE)	T ₁ (KMS 1% + CaCl ₂ 1%)	45.9	46.02	46.1	46.17
P ₁ (LDPE)	T ₂ (Citric acid 1% + KMS 0.5%)	46.04	46.12	46.19	46.25
P ₂ (Metallised Polyester)	T ₁ (KMS 1% + CaCl ₂ 1%)	45.9	45.95	46.0	46.02
P ₂ (Metallised Polyester)	T ₂ (Citric acid 1% + KMS 0.5%)	46.04	46.06	46.07	46.08

Microbial Count

Microbial safety plays a vital role in determining the overall quality of food products, as quality reflects the combination of attributes that influence consumer acceptance. In the present study, no microbial growth was detected in the pomace powder packed in any of the packaging materials at the initial stage of storage (Table 4). This absence of microbial load may be attributed to the use of preservatives such as potassium metabisulphite, calcium chloride, and citric acid, along with the thermal processing applied to fresh pomace during powder preparation.

Among the different packaging materials, pomace powder stored in metallised polyester (P₂) showed no detectable microbial count up to 30 days of storage in both treatments (T₁ and T₂).

This indicates the superior protective ability of metallised polyester against microbial contamination during early storage. With an increase in storage duration, yeast and mould growth was observed from the 30th day onward in both T₁ and T₂ samples stored in the control (P₀) and low-density polyethylene (LDPE, P₁) packages. The rise in microbial population in LDPE-packed samples can be linked to moisture absorption, which creates favorable conditions for microbial proliferation.

These findings are consistent with the observations reported by (kumar *et al.*, 2023) ^[6], who also noted variations in microbial stability of spray-dried *Syzygium cumini* L. pulp powder depending on the type of packaging material used during storage.

Table 4: Microbial Count of pomace powder under different packaging and treatments during storage

Packaging material	Treatment	0 Days		30 Days		60 Days		90 Days	
		Yeast	Mould	Yeast	Mould	Yeast	Mould	Yeast	Mould
P ₁	T ₁	0	0	1 × 10 ³	1 × 10 ³	1 × 10 ³	1 × 10 ³	2 × 10 ³	2 × 10 ³
	T ₂	0	0	1 × 10 ³	1 × 10 ³	1 × 10 ³	1 × 10 ³	2 × 10 ³	2 × 10 ³
P ₂	T ₁	0	0	0	0	1 × 10 ³	1 × 10 ³	1 × 10 ³	1 × 10 ³
	T ₂	0	0	0	0	1 × 10 ³	1 × 10 ³	1 × 10 ³	1 × 10 ³
P ₀	T ₁	0	0	1 × 10 ³	1 × 10 ³	2 × 10 ³	2 × 10 ³	3 × 10 ³	3 × 10 ³
	T ₂	0	0	1 × 10 ³	1 × 10 ³	2 × 10 ³	2 × 10 ³	3 × 10 ³	3 × 10 ³

T₁- KMS 1% + CaCl₂ 1%, T₂- CA 1% + KMS 0.5%, P₁ – Low density polyethylene (LDPE) P₂ – Metallised polyester P₀ – Control (unpacked)

Conclusion

The study confirms that packaging material significantly influences the nutritional stability and microbial quality of grape pomace powder during ambient storage. Although all samples showed a gradual decline in nutritional parameters with time, metallised polyester provided the best protection by retaining higher nutritional values and restricting microbial growth compared to LDPE and the control. Therefore, metallised polyester is recommended as an effective packaging material to enhance the shelf life, nutritional quality, and microbial safety of grape pomace powder.

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