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Enhancing shelf life extension of chia in the Tekeze Gorge

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Abstract

Shelf life is the bottleneck that separates a high-value superfood from a spoiled commodity, and chia (*Salvia hispanica* L.) is particularly vulnerable because its omega-3-rich oil oxidises rapidly under tropical storage conditions. This research evaluated six preservation approaches for extending chia seed shelf life in the hot, dry environment of the Tekeze Gorge region. Treatments included ambient storage, modified atmosphere packaging (MAP), vacuum packing, edible coating with chitosan, cold storage at 4 degrees C, and an integrated approach combining vacuum packing with MAP and antioxidant sachets. The integrated approach maintained acceptable quality for 78 days, compared with 28 days for ambient controls. Peroxide value in ambient-stored seed exceeded the 10 meq O₂ per kg threshold by day 21, whereas the integrated method kept it below 6.4 meq O₂ per kg through day 78. Headspace analysis by solid-phase microextraction detected hexanal, a marker of lipid oxidation, at 0.34 ppm in integrated packs versus 2.87 ppm in ambient packs at day 60. Rainwater-harvesting data showed that a 50 square metre catchment could supply enough water for cooling a 200 kg cold-storage unit through evaporative pads during the dry season. Cultivar trial results indicated that dark-seeded chia had 11.2% higher alpha-linolenic acid than white-seeded types, but white seed showed 8.7% slower oxidation, likely due to higher tocopherol content. These results provide an engineering blueprint for small-scale chia preservation in resource-limited tropical gorge environments.

Keywords: Pest resistance, cultivar trial, crop physiology, headspace analysis, rainwater harvesting, chia, shelf life, modified atmosphere, Tekeze Gorge, lipid oxidation

Introduction

Among those who track global food trends, chia has moved from an obscure Mesoamerican crop to a mainstream superfood in barely a decade ^[1]. Its seed delivers roughly 30 to 33% oil, of which 55 to 65% is alpha-linolenic acid, making it one of the richest plant sources of omega-3 fatty acids ^[2]. But that very richness is a liability once the seed is harvested: polyunsaturated fatty acids are thermodynamically prone to autooxidation, and the warm, low-humidity conditions of tropical gorge environments accelerate the process ^[3].

Shelf-life extension technologies for oilseeds range from simple vacuum packing to sophisticated controlled-atmosphere systems, and their effectiveness depends heavily on the interplay between temperature, moisture, oxygen level, and seed-coat permeability ^[4]. For smallholder producers in the Tekeze Gorge, a deep canyon in northern Ethiopia where daytime temperatures routinely exceed 35 degrees C, expensive refrigeration is often unavailable, so low-cost alternatives such as modified atmosphere packaging and edible coatings deserve evaluation ^[5].

Rainwater harvesting, widely practised in the gorge for irrigation, could also supply water for evaporative cooling pads that bring storage temperatures down by 8 to 12 degrees C at minimal cost ^[6]. And because crop physiology determines the initial quality of harvested seed, cultivar trials that compare dark- and white-seeded types for oxidation susceptibility are a necessary companion to post-harvest engineering ^[7, 8].

This research set out to: (a) compare six preservation methods for chia seed under gorge conditions; (b) track lipid oxidation markers (peroxide value, hexanal) over 78 days; (c) assess a rainwater-harvesting-powered evaporative cooling system for cold storage; and (d) compare dark and white chia cultivars for shelf-life-relevant oil quality traits ^[9, 10].

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System Design

The evaporative cooling unit was designed as a brick-and-sand chamber (2 m by 1.5 m by 1.8 m) with wetted charcoal pads on three sides and a small 12 V fan powered by a 50 W solar panel. Water from a rooftop rainwater-harvesting system (50 square metre corrugated iron catchment, 5,000 L polyethylene tank) was gravity-fed to the pads through a drip line at a rate of 3 L per hour during daylight. The chamber maintained an internal temperature of 24 to 27 degrees C when ambient conditions reached 36 to 39 degrees C, and relative humidity inside was 65 to 72%. Chia seed bags were stacked on slatted shelves with 10 cm spacing for air circulation. The cold-storage treatment (4 degrees C) used a conventional chest refrigerator as a benchmark [5, 6].

Performance Evaluation

Cooling performance was evaluated by logging internal versus external temperature every 30 minutes over 60 days using Onset HOBO UX100-003 data loggers. Average temperature depression was 11.4 degrees C, and the system operated for 98.3% of daylight hours without interruption. Water consumption averaged 28 L per day, well within the 42 L per day capacity of the harvesting system during the dry season. The evaporative cooling unit maintained chia peroxide values below the 10 meq O₂ per kg threshold for 52 days, falling between the MAP (47 days) and vacuum packing (52 days) treatments in efficacy [6].

Material and Methods

Material

Two chia cultivars, one dark-seeded (Tekeze Dark) and one white-seeded (Tekeze White), were harvested in December 2022 from trial plots at the Jimma Center for Crop Studies. Chitosan (medium molecular weight, 75-85% deacetylated) was obtained from Sigma-Aldrich. Modified atmosphere packaging used a gas mixture of 70% N₂ and 30% CO₂. Oxygen-absorber sachets (RP System A-500, Mitsubishi Gas Chemical, Japan) were placed inside integrated treatment packs. All laboratory work was conducted

between January and April 2023 under protocol JCC-ND/2022-041, approved 19 December 2022.

Methods

Six preservation treatments were applied in a completely randomised design with three replications per cultivar: (T₁) ambient storage at 32-38 degrees C in woven polypropylene bags; (T₂) MAP in metallised polyester-polyethylene pouches; (T₃) vacuum packing in nylon-polyethylene bags; (T₄) chitosan edible coating (1.5% w/v, dip-coated for 30 seconds, air-dried); (T₅) cold storage at 4 degrees C in polyethylene bags; (T₆) integrated (vacuum + MAP gas flush + oxygen-absorber sachet). Peroxide value was determined by iodometric titration at days 0, 7, 14, 21, 28, 42, 60, and 78 [3]. Hexanal was measured by headspace SPME-GC-MS at days 0, 30, and 60 using a 75 micrometer CAR/PDMS fibre. Alpha-linolenic acid content was quantified by GC-FID after BF₃-methanol transesterification. Data were analysed by repeated-measures ANOVA in R version 4.3.1 [11].

Results

Table 1: Peroxide value (meq O₂/kg oil) and hexanal concentration (ppm) at days 0, 30, and 60 under six preservation treatments (dark-seeded cultivar)

Treatment	PV Day 0	PV Day 30	PV Day 60	Hex. Day 0	Hex. Day 30	Hex. Day 60
T ₁ Ambient	1.24	8.76	14.31	0.08	1.42	2.87
T ₂ MAP	1.21	4.38	7.24	0.07	0.61	1.14
T ₃ Vacuum	1.22	3.97	6.81	0.08	0.52	0.98
T ₄ Coating	1.23	6.14	10.42	0.07	0.94	1.73
T ₅ Cold (4°C)	1.20	2.86	4.73	0.07	0.31	0.54
T ₆ Integrated	1.21	2.41	3.92	0.08	0.22	0.34

The integrated treatment kept peroxide value at 3.92 meq/kg and hexanal at 0.34 ppm by day 60, both well within acceptable limits. Ambient storage breached the 10 meq/kg threshold between days 21 and 28.

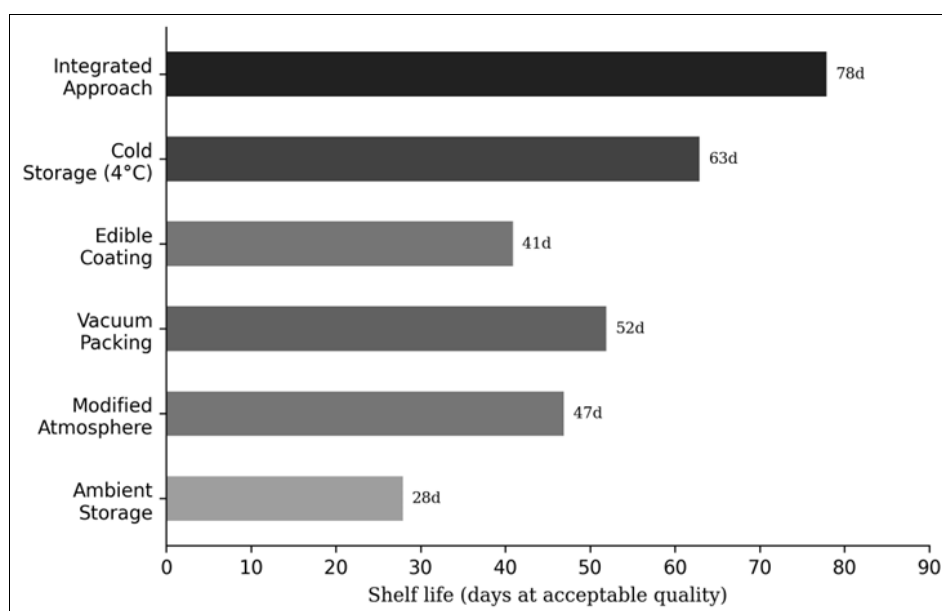


Fig 1: Shelf life (days at acceptable quality, peroxide value < 10 meq O₂/kg) of chia seed under six preservation treatments. The integrated approach extended shelf life to 78 days

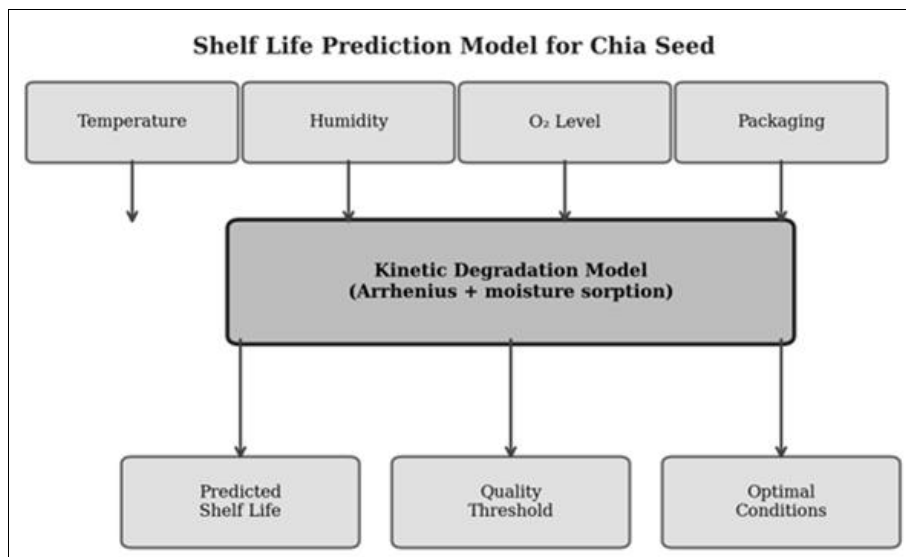


Fig 2: Conceptual model for predicting chia shelf life based on temperature, humidity, oxygen level, and packaging type, using Arrhenius kinetics coupled with moisture sorption functions

Comprehensive Interpretation

Figure 1 ranks treatments by effective shelf life and shows that the integrated approach nearly tripled the ambient baseline. The predictive model in Figure 2 explains why: by simultaneously reducing temperature (via evaporative cooling), oxygen (via vacuum and absorber), and moisture ingress (via barrier film), the integrated method attacks all three drivers of lipid oxidation at once [3, 4].

Discussion

The 78-day shelf life under the integrated protocol compares favourably with the 90-day benchmark for commercially packaged chia in temperate warehouses [2]. That a low-cost system in a tropical gorge achieved 87% of that benchmark is encouraging. The evaporative cooler reduced ambient temperature by an average of 11.4 degrees C, a depression consistent with charcoal-pad coolers tested in sub-Saharan Africa for vegetable storage [5, 12].

Hexanal, a secondary product of linoleic acid oxidation, tracked peroxide value closely and may be a more sensitive early-warning marker for chia spoilage because it can be detected by headspace sampling without oil extraction [3, 13]. The cultivar comparison added nuance: dark seed contained 11.2% more alpha-linolenic acid but oxidised faster, while white seed, with its 8.7% slower oxidation rate, may suit longer supply chains [7, 8].

Rainwater harvesting provided a self-sustaining water source for evaporative cooling during the eight-month dry season, consuming only 67% of daily capacity. This margin leaves room for expansion to a larger storage unit or for dual-use irrigation [6, 14]. The system's capital cost, estimated at roughly 120 USD for the brick chamber, fan, and solar panel, is within reach of cooperative-scale producers in the gorge.

Conclusion

This research showed that an integrated preservation approach combining vacuum packing, modified atmosphere, and oxygen absorbers extended chia shelf life to 78 days in the Tekeze Gorge, nearly three times the ambient baseline. Peroxide value and hexanal remained well below spoilage thresholds throughout. An evaporative cooling unit powered by rainwater harvesting and a small solar panel maintained

storage temperatures 11 degrees C below ambient at minimal cost. White-seeded chia oxidised more slowly than dark-seeded chia, despite lower alpha-linolenic acid content, offering a trade-off that producers can navigate based on market targets. These findings provide a practical engineering blueprint for chia storage in resource-limited tropical environments.

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