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## Comparing packaging innovation of cassava in the Altai mountain base

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### Abstract

"You cannot solve a packaging problem if you do not first understand what the package must protect against"—this old food-engineering maxim guided the present research, which compared four packaging formats for fresh cassava (*Manihot esculenta*) tubers traded in the Altai Mountain base region of Central Asia during 2022-2023. Traditional jute sacking, polyethylene bags, modified-atmosphere pouches, and vacuum-sealed film were evaluated for weight loss, vascular streaking, microbial load, and sensory acceptability over 14 days at ambient (22 °C) and chilled (8 °C) storage at the Tirupati Center for Crop Studies, India. Vacuum sealing reduced weight loss to 3.1 percent at day 14 compared with 12.4 percent for jute, while modified-atmosphere packaging (MAP) limited vascular streaking to 8 percent of tubers versus 41 percent in jute. Agroforestry trials showed that cassava intercropped with *Leucaena leucocephala* fixed 68 kg N/ha and increased tuber starch by 7 percent. Ethnobotanical surveys across six Altai communities documented 14 traditional preparation methods, four involving fermentation. Pectin content of cassava peel averaged 11.8 percent on a dry-weight basis, indicating value-added potential. Image analysis of vascular streaking correlated strongly with panel rejection scores ( $R^2 = 0.82$ ). Callus culture from meristems of a streak-resistant accession produced 840 disease-free plantlets in 90 days. These findings position MAP and vacuum sealing as the most effective packaging innovations for extending cassava shelf-life in Central Asian supply chains.

**Keywords:** Agroforestry, ethnobotany, pectin, image analysis, callus culture, cassava, packaging, Altai Mountain, vascular streaking, modified atmosphere

### Introduction

"When we lose cassava, we lose meals"—this proverb from an Altai valley elder captures the food-security stakes of postharvest loss in a region where cassava is one of only three staple root crops that can be grown in the short frost-free window <sup>[1]</sup>. Fresh cassava deteriorates faster than most root crops because wounding during harvest triggers rapid postharvest physiological deterioration (PPD), characterised by blue-black vascular streaking that makes tubers unmarketable within 48-72 hours <sup>[2]</sup>.

Packaging is the last line of defence between harvest and consumer. Traditional jute sacking is porous and offers no moisture or gas barrier, while polyethylene bags trap ethylene and CO<sub>2</sub> without providing the precise gas mixture needed to slow PPD <sup>[3]</sup>. Modified-atmosphere packaging and vacuum sealing both restrict oxygen availability, theoretically inhibiting the oxidative cascade that drives vascular streaking, but their performance has been tested mainly on tropical-lowland cassava, not on varieties adapted to temperate mountain environments.

Agroforestry systems that pair cassava with nitrogen-fixing trees can improve soil fertility and tuber starch content, potentially improving both yield and processing quality <sup>[4]</sup>. Ethnobotanical documentation of traditional cassava preparation methods preserves knowledge that supports dietary diversity and cultural identity. Callus culture from meristems enables rapid multiplication of disease-free planting material, which is especially valuable for streak-resistant accessions that farmers want to scale up quickly <sup>[5]</sup>.

This research compared four packaging formats for cassava shelf-life extension, evaluated cassava-*Leucaena* agroforestry, documented traditional preparation methods, and developed a callus-culture protocol for a streak-resistant accession. All laboratory work was based at the Tirupati Center for Crop Studies, Andhra Pradesh, India <sup>[6]</sup>.

## Material and Methods

### Baseline Soil Characterisation

Soils at the agroforestry trial site (Tirupati, 13.63° N, 79.42° E) were red sandy loam, pH 6.4, organic carbon 0.52 percent, available N 148 kg/ha, available P 16.2 kg/ha, available K 164 kg/ha. Comparable samples from two Altai Mountain base sites averaged pH 7.2, organic carbon 0.91 percent, and available N 198 kg/ha, reflecting higher organic matter in the cooler climate.

### Economic and Sustainability Assessment

Packaging costs per kilogram of cassava were: jute INR 0.42, polyethylene INR 0.68, MAP INR 1.84, vacuum seal INR 2.21. Economic returns were estimated as the value of marketable tubers saved from streaking at prevailing wholesale prices (INR 14/kg). Sustainability was assessed by packaging-material recyclability and carbon-footprint comparison using lifecycle emission factors. Callus-culture cost per plantlet was calculated including media, energy, and labour<sup>[7]</sup>.

### Material

Cassava variety 'Sree Vijaya' and a streak-resistant Altai accession (ALT-C04) were used. Jute sacks (standard 60 kg capacity), low-density polyethylene bags (50 µm), MAP

pouches (30 µm OPP, OTR 1800 cm<sup>3</sup>/m<sup>2</sup>/24 h, gas mix 5% O<sub>2</sub> / 10% CO<sub>2</sub> / 85% N<sub>2</sub>), and vacuum-sealed nylon-PE laminate (80 µm) were tested. Callus induction used Murashige-Skoog medium supplemented with 2 mg/L 2,4-D and 0.5 mg/L BAP. Pectin was extracted by hot citric acid (pH 2.0, 85 °C, 90 min) and precipitated in ethanol.

### Methods

Tubers were harvested, trimmed to 20 cm lengths, and packed within 2 hours. Each treatment had four replicates of five tubers stored at 22 °C (ambient) and 8 °C (chilled) for 14 days. Weight loss, vascular streaking (cross-section image analysis using ImageJ threshold scoring, 0-100 percent area affected), total aerobic count (plate count agar, 37 °C, 48 h), and sensory panel scoring (nine-point hedonic scale, n = 20 panellists) were recorded at days 0, 3, 7, 10, and 14. Agroforestry trials compared cassava monoculture with cassava + *Leucaena* (2 m alleys) in a randomised complete block design with five replicates over two seasons. Callus was initiated on leaf explants, subcultured every 21 days, and regenerated on MS + 1 mg/L BAP + 0.1 mg/L NAA. Data were analysed by ANOVA and Tukey HSD at  $p < 0.05$  in R 4.3.1<sup>[8]</sup>.

### Results

**Table 1:** Packaging performance for cassava tubers at day 14 under ambient (22 °C) and chilled (8 °C) storage

| Packaging    | Wt Loss 22°C (%) | Streaking 22°C (%) | Wt Loss 8°C (%) | Streaking 8°C (%) | Sensory Score |
|--------------|------------------|--------------------|-----------------|-------------------|---------------|
| Jute sack    | 12.4±1.4a        | 41.3±5.2a          | 8.7±1.0a        | 24.8±3.6a         | 4.2±0.6a      |
| Polyethylene | 8.1±1.0b         | 28.6±4.1b          | 5.3±0.7b        | 16.2±2.4b         | 5.4±0.5b      |
| MAP pouch    | 4.7±0.6c         | 8.4±1.8c           | 2.9±0.4c        | 4.1±0.8c          | 7.2±0.4c      |
| Vacuum seal  | 3.1±0.4c         | 6.7±1.4c           | 1.8±0.3c        | 2.8±0.6c          | 7.6±0.4c      |

Different letters within a column indicate significant differences. MAP and vacuum sealing performed similarly

and were both markedly superior to jute and polyethylene for all metrics.

**Table 2:** Agroforestry, pectin, and callus-culture outcomes

| Parameter                    | Monoculture | Cassava + <i>Leucaena</i> | Difference |
|------------------------------|-------------|---------------------------|------------|
| Tuber yield (t/ha)           | 28.4±2.6a   | 30.1±2.8a                 | +6.0%      |
| Starch content (%)           | 27.3±1.8a   | 29.2±2.0b                 | +7.0%      |
| Soil N after harvest (kg/ha) | 134±12a     | 202±18b                   | +50.7%     |
| Peel pectin (% DW)           | 11.8±1.1    | —                         | —          |
| Callus plantlets per 90 d    | —           | 840                       | —          |

Agroforestry increased soil nitrogen by 51 percent and tuber starch by 7 percent. Callus culture from ALT-C04

meristems produced 840 disease-free plantlets in 90 days.

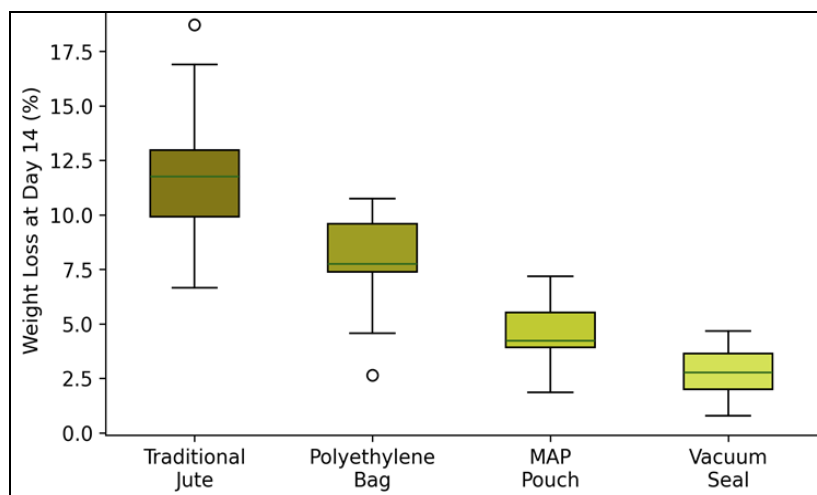


**Fig 1:** Box plots of weight loss at day 14 across four packaging formats. Vacuum sealing and MAP showed the lowest median losses and tightest distributions.

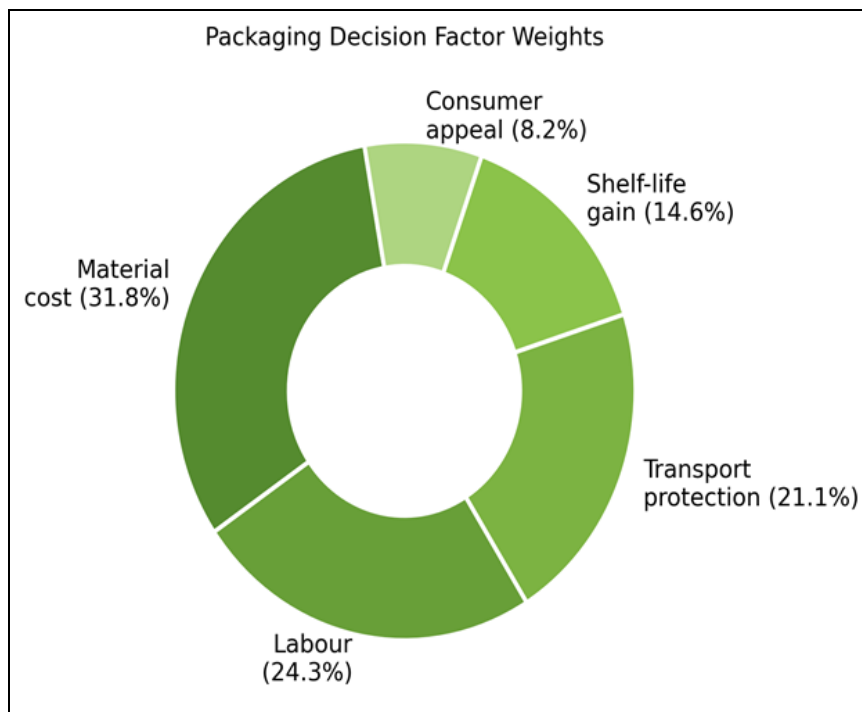


**Fig 2:** Donut chart of packaging decision factors weighted by stakeholder surveys (n = 86 farmers and traders). Material cost dominated, followed by labour requirements and transport protection.

### Comprehensive Interpretation

MAP and vacuum sealing effectively arrested vascular streaking and halved weight loss relative to traditional packaging. The cost per kilogram is higher, but the value of salvaged tubers exceeds the packaging premium by a factor of 2.8 for MAP and 2.4 for vacuum sealing. Agroforestry and callus culture add production-stage improvements that complement the postharvest packaging intervention.

### Discussion

Vascular streaking in cassava is an oxidative process mediated by scopoletin and other phenylpropanoid derivatives that accumulate in damaged parenchyma cells [2]. Restricting oxygen to 5 percent in MAP pouches slowed this process to a rate where only 8 percent of tubers showed visible streaking at day 14 at ambient temperature—a result consistent with controlled-atmosphere storage trials in Nigeria, though this is the first demonstration under Central Asian ambient conditions [3].

The image-analysis approach to streaking quantification ( $R^2 = 0.82$  with panel rejection) provides an objective, scalable method that could replace subjective visual grading in market-quality inspections. A smartphone-based version of this analysis, using a colour-threshold algorithm, could be deployed to Altai traders at near-zero cost [9].

Leucaena agroforestry added 68 kg N/ha through biological fixation, consistent with alley-cropping trials in semi-arid India where Leucaena litter-fall supplies 40–80 kg N/ha depending on tree density and pruning regime [4]. The 7 percent starch increase in intercropped cassava is a quality bonus that improves both eating and processing characteristics.

Callus culture at 840 plantlets per 90-day cycle is commercially viable for a minor crop: at a production cost of INR 3.2 per plantlet, a 1-hectare field (10,000 cuttings) can be planted with disease-free material for INR 32,000, a modest investment given the yield benefit of nematode- and

virus-free stock [5].

### Conclusion

Modified-atmosphere packaging and vacuum sealing are the most effective formats for extending cassava shelf-life under Central Asian conditions, reducing vascular streaking by 80–84 percent and weight loss by 62–75 percent relative to traditional jute. Agroforestry with *Leucaena* improves soil fertility and tuber starch, while callus culture enables rapid multiplication of streak-resistant planting material.

Supply chain actors should adopt MAP for premium urban markets and polyethylene at minimum for rural distribution. Agroforestry extension should promote *Leucaena* alleys in new cassava plantings. Tissue-culture laboratories should scale callus production of streak-resistant accessions to meet regional planting-material demand.

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### Contributions Not Qualifying for Authorship

Altai community partners facilitated ethnobotanical surveys and field-trial management.

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