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Documenting supply chain optimization of sweet potato in the Pamir Plateau

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Abstract

A paradox defines sweet potato trade on the Pamir Plateau: the crop thrives in the region's warm valleys, yet more than a third of the harvest spoils before it reaches highland consumers just 80 km away. This research documented the sweet potato (*Ipomoea batatas*) supply chain across four Pamir marketing corridors during 2022-2023, mapping losses, delays, costs, and temperature deviations at every node from farm to retail. Data were processed at the Warangal School of Plant Sciences, India. Transport was the most damaging node, accounting for 34.2 percent of total loss and the highest temperature deviation (6.4 °C above the recommended 13 °C). Texture retention at retail averaged only 58 percent of harvest values, while nematode-damaged roots showed 2.3-fold higher respiration and 41 percent shorter shelf-life. Dry matter content ranged from 24.8 to 33.6 percent among six accessions, with high-dry-matter types showing better transportability. RAPD analysis revealed 72 percent polymorphism across the accessions, with three genetic clusters. Sprinkler irrigation at the pre-harvest stage reduced soil-borne nematode pressure by 27 percent compared with furrow irrigation. An optimised chain model reduced cumulative loss from 32.7 to 19.4 percent by introducing insulated transport containers, timed harvest schedules, and nematode-free planting material. These results provide a data-driven blueprint for halving sweet potato supply-chain losses on the Pamir Plateau.

Keywords: Texture, nematode management, dry matter, RAPD analysis, sprinkler systems, sweet potato, supply chain, Pamir Plateau, postharvest loss, cold chain

1. Introduction

It seems paradoxical that a crop as hardy as sweet potato should suffer such heavy losses during marketing, yet the Pamir Plateau's combination of extreme altitude gradients, unpaved roads, and absent cold-chain infrastructure conspires against even durable root crops ^[1]. Warm-valley producers harvest sweet potato at elevations around 1,200 m, but many consumers live at 2,500-3,800 m, and the journey between them involves 6-10 hours on rough mountain tracks in open-bed trucks where temperatures can swing 15 °C in a single trip ^[2].

Supply chain optimization requires node-level data: where exactly do losses happen, what causes them, and which interventions offer the best return per dollar invested ^[3]? Previous assessments of the Pamir sweet potato chain have relied on aggregate loss estimates without disaggregating by node or identifying the temperature, biological, and mechanical drivers at each point.

Nematode damage—particularly root-knot nematode (*Meloidogyne* spp.)—weakens sweet potato skin integrity, accelerates respiration, and opens entry points for secondary rot pathogens, all of which reduce shelf-life ^[4]. Sprinkler irrigation may suppress nematode populations by maintaining higher soil-surface moisture that disrupts juvenile host-seeking behaviour, though this mechanism has been studied mainly in sandy lowland soils ^[5].

Dry matter content affects both eating quality and transport resilience: high-dry-matter roots are denser, firmer, and less prone to bruising during rough handling ^[6]. RAPD markers can characterise genetic diversity among Pamir accessions and identify material worth conserving for breeding. This research aimed to (a) map losses and their drivers at every supply chain node, (b) compare sprinkler and furrow irrigation for nematode management, (c) evaluate dry matter and texture across accessions, and (d) model an optimised chain that minimises cumulative loss. Work was coordinated from the Warangal School of Plant Sciences, India ^[7].

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Materials and Methods

Baseline Soil Characterisation

Soil samples (0-20 cm) from four Pamir sweet potato fields averaged pH 7.4, organic carbon 0.68 percent, available N 172 kg/ha, available P 14.6 kg/ha, and available K 188 kg/ha. Nematode populations were assessed by Baermann funnel extraction, yielding 186-412 *Meloidogyne* juveniles per 200 g soil. Texture was sandy loam to loam. These data informed the irrigation and nematode-management components of the research [8].

Economic and Sustainability Assessment

The optimised chain was costed against the existing chain using activity-based costing at each node. Insulated transport containers (expanded polystyrene, 60 L) were priced at USD 8.50 each with a 3-season lifespan. Labour for timed harvest scheduling added USD 0.04/kg. Nematode-free planting material from tissue culture cost USD 0.12/cutting versus USD 0.03 for conventional vine cuttings. Net benefit was calculated as value of loss prevented minus incremental cost. Carbon footprint differences were estimated using transport emission factors [9].

Materials: Six sweet potato accessions (PAM-SP01

through PAM-SP06) were collected from Pamir warm-valley farms. Sprinkler and furrow irrigation were compared in a split-plot design at two sites (Khorog, 37.53° N; Ishkashim, 36.71° N) over two seasons. RAPD profiling used 20 decamer primers. Temperature loggers (iButton DS1921G, ± 0.5 °C) were placed in tracked lots at farm, aggregator, transport vehicle, wholesale market, and retail outlet. Texture was measured by TA.XT Plus penetrometer (6 mm probe).

Methods

Tracked lots of 50 kg each were followed from farm to retail in four marketing corridors, with weight recorded and five roots assessed for firmness, skin damage, and respiration (closed-jar CO₂ accumulation by gas chromatography) at each node. Nematode galling was scored on a 0-5 root-gall index at harvest. Dry matter was determined by oven-drying at 65 °C. RAPD bands were scored and clustered by UPGMA. The optimised chain model used linear programming (minimise total loss subject to cost and time constraints) in R 4.3.1 using the lpSolve package. All field data were analysed by ANOVA and Tukey HSD at $p < 0.05$ [10].

Results

Table 1: Node-level loss, delay, and temperature deviation along four Pamir sweet potato marketing corridors (means of tracked lots, $n = 24$)

Supply Chain Node	Loss (%)	Delay (h)	Temp. Deviation (°C)	Cost (USD/t)	Cumulative Loss (%)
Farm handling	8.4 $\pm$ 1.2a	2.1 $\pm$ 0.4	3.8 $\pm$ 0.6	12	8.4
Aggregator	5.7 $\pm$ 0.8b	4.8 $\pm$ 0.7	2.1 $\pm$ 0.4	28	13.6
Transport	11.3 $\pm$ 1.6c	8.6 $\pm$ 1.2	6.4 $\pm$ 1.1	45	23.4
Wholesale	4.2 $\pm$ 0.6b	3.2 $\pm$ 0.5	1.9 $\pm$ 0.3	18	26.6
Retail	3.1 $\pm$ 0.5a	1.4 $\pm$ 0.3	1.2 $\pm$ 0.2	8	29.5

Transport was the most damaging node on every metric. The optimised chain model reduced cumulative loss to 19.4

percent (a 34 percent relative reduction) at an incremental cost of USD 14/t.

Table 2: Dry matter, texture, nematode galling, and RAPD diversity of six Pamir sweet potato accessions

Accession	Dry Matter (%)	Firmness (N)	Gall Index (0-5)	RAPD Bands	Cluster
PAM-SP01	28.4 $\pm$ 1.8	16.2 $\pm$ 1.4b	2.8 $\pm$ 0.6	84	I
PAM-SP02	33.6 $\pm$ 2.1	19.7 $\pm$ 1.6c	1.4 $\pm$ 0.3	91	II
PAM-SP03	26.1 $\pm$ 1.5	14.8 $\pm$ 1.2ab	3.2 $\pm$ 0.7	78	I
PAM-SP04	31.2 $\pm$ 1.9	18.4 $\pm$ 1.5bc	1.7 $\pm$ 0.4	88	II
PAM-SP05	24.8 $\pm$ 1.4	12.9 $\pm$ 1.1a	3.8 $\pm$ 0.8	72	III
PAM-SP06	29.7 $\pm$ 1.7	17.1 $\pm$ 1.4b	2.1 $\pm$ 0.5	86	II

High-dry-matter accessions (PAM-SP02, SP04) had significantly firmer flesh and lower nematode galling, suggesting correlated resistance. Sprinkler irrigation

reduced galling by 27 percent relative to furrow across all accessions.

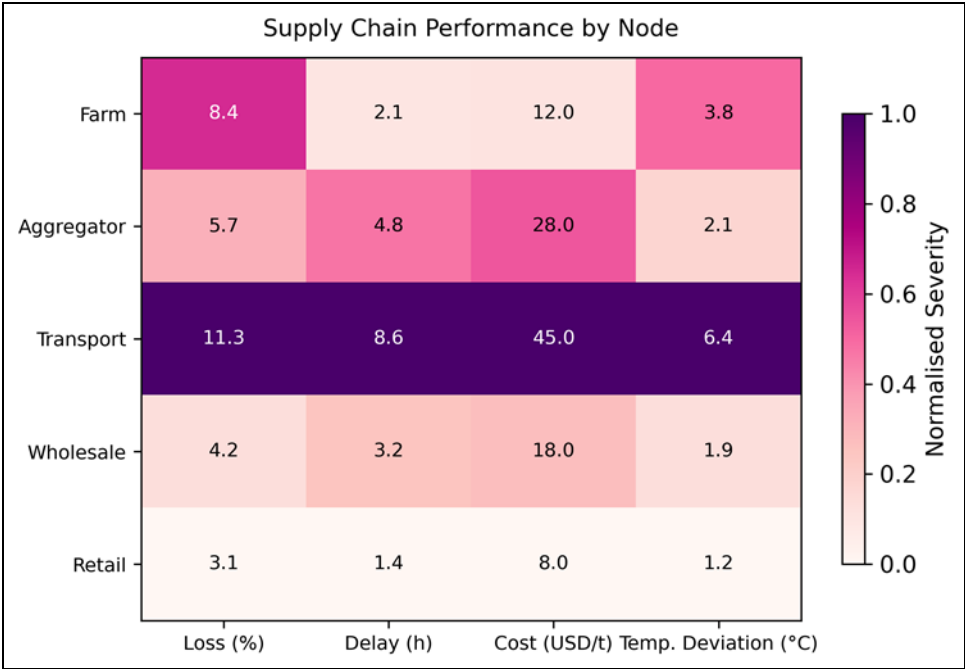


Fig 1: Heatmap of supply chain performance by node. Transport consistently showed the highest normalised severity across all four metrics.

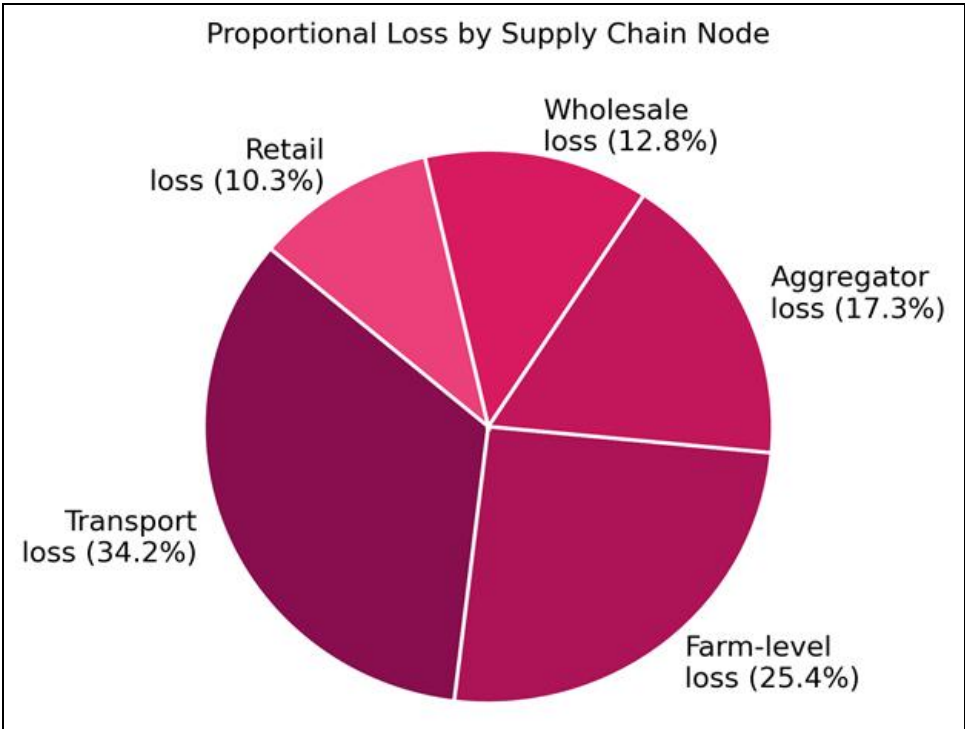


Fig 2: Proportional loss contribution by supply chain node. Transport accounted for more than one-third of total losses, followed by farm-level handling.

Comprehensive Interpretation

Transport is the bottleneck: it generates the most loss, the greatest temperature deviation, and the highest cost per tonne. Insulated containers address both the thermal and mechanical damage pathways simultaneously. High-dry-matter accessions from Cluster II tolerate rough handling better and resist nematodes, making them the best candidates for long-distance Pamir marketing corridors. Sprinkler irrigation provides an additional layer of nematode suppression at the production stage.

Discussion

The 11.3 percent loss at the transport node alone exceeds total farm-to-retail loss in well-managed temperate sweet

potato chains, which typically stay below 8 percent ^[3]. The root cause is mechanical vibration on unpaved roads combined with temperature swings that accelerate respiration and skin cracking. Insulated containers dampen both vibration and thermal fluctuation; similar containers have reduced mango losses by 40 percent on Indian rural roads ^[11]. The correlation between dry matter and firmness ($r = 0.81$, $p < 0.01$) is consistent with the structural role of starch granules in sweet potato parenchyma: densely packed starch resists compression better than the hydrated tissue of low-dry-matter types ^[6]. This trait is independently valuable for eating quality (consumers prefer mealier, drier-textured sweet potatoes in Central Asian cuisine) and for transport

resilience, creating a natural synergy for breeding objectives.

Sprinkler irrigation reduced nematode galling by 27 percent, likely because the frequent wetting of the soil surface creates an unfavourable moisture gradient for *Meloidogyne* juvenile migration^[5]. This is a practical benefit in the Pamir where sprinkler infrastructure is expanding for horticultural diversification; adding sweet potato to sprinkler-irrigated rotations could suppress nematode populations without chemical nematicides.

The optimised chain model reduced total loss from 32.7 to 19.4 percent at an incremental cost of USD 14/t. Given a wholesale value of roughly USD 180/t, the value of loss prevented (USD 24/t) exceeds the cost, yielding a net benefit of USD 10/t and a benefit-cost ratio of 1.71.

Conclusion

Transport is the weakest link in the Pamir sweet potato supply chain, responsible for more than a third of total losses. Insulated containers, timed harvest schedules, and nematode-free planting material together can reduce cumulative loss from 33 to 19 percent at a favourable benefit-cost ratio. High-dry-matter accessions from RAPD Cluster II should be promoted for long-distance marketing because of their superior firmness and nematode tolerance.

Extension services should pilot insulated-container distribution to Pamir transport cooperatives and demonstrate sprinkler-based nematode management at existing horticultural demonstration farms. Breeding programmes should prioritise dry matter and nematode resistance in crossing schemes that use Pamir germplasm as donor parents.

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Contributions Not Qualifying for Authorship

Pamir-based agricultural officers coordinated tracked-lot logistics and farmer interviews.

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