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Mukesh Malhotra
Department of Spice and
Aromatic Crops, Kochi
Graduate School of
Bioagricultural Studies, Kochi,
Kerala, India

Nandini Srinivasan
Department of Spice and
Aromatic Crops, Kochi
Graduate School of
Bioagricultural Studies, Kochi,
Kerala, India

Girish Kamat
Department of Spice and
Aromatic Crops, Kochi
Graduate School of
Bioagricultural Studies, Kochi,
Kerala, India

Corresponding Author:
Mukesh Malhotra
Department of Spice and
Aromatic Crops, Kochi
Graduate School of
Bioagricultural Studies, Kochi,
Kerala, India

Evaluating postharvest loss reduction of amaranth in the Irrawaddy Delta

Mukesh Malhotra, Nandini Srinivasan and Girish Kamat

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Abstract

A surprising fact about amaranth (*Amaranthus* spp.) production is that nearly 37% of harvested leaf and grain yield never reaches consumers, lost to wilting, microbial decay, and handling damage along the supply chain. This research evaluated postharvest loss reduction strategies for amaranth in the Irrawaddy Delta, comparing traditional and improved supply chain models at the Kochi Graduate School of Bioagricultural Studies between May 2022 and April 2023. Tagged-lot tracking across five supply chain stages showed total losses of 36.9% in the traditional model versus 18.8% in the improved model that incorporated shade drying, insulated transport, and cold pre-cooling. Biofortification through foliar iron sprays increased leaf iron by 28.4% without affecting ethylene production or shelf life. Hydroponics-grown amaranth maintained 22.7% longer shelf life than soil-grown, attributed to lower microbial load at harvest. Supply chain cost analysis showed that the improved model added USD 0.14/kg in handling costs but recovered USD 0.52/kg through reduced waste. Ethylene production was highest in conventionally harvested leaf amaranth (4.8 $\mu\text{L/kg/h}$ at 25°C) and lowest in pre-cooled bunches (2.1 $\mu\text{L/kg/h}$). Precision farming tools (NDVI-based harvest timing) reduced over-maturity losses by 31.2%. Solar drying retained 91.4% of protein and 88.3% of iron compared to 82.3% and 78.6% for open sun-drying. These findings provide an evidence base for reducing amaranth postharvest losses through integrated supply chain interventions.

Keywords: Biofortification, hydroponics, supply chain, ethylene production, precision farming, amaranth, postharvest loss, drying methods, cold chain, Irrawaddy Delta

Introduction

Here is a surprising number: for every tonne of amaranth that reaches a consumer's kitchen in tropical developing countries, roughly 600 kg was lost somewhere between the field and the market stall ^[1]. Amaranth (*Amaranthus* spp.) is both a leafy vegetable and a pseudocereal, valued for its high protein content (14-18% in grain, 24-30% in leaves DW), iron, calcium, and lysine an amino acid deficient in most cereal grains ^[2]. Yet this nutritional bounty is squandered by postharvest systems that were designed for hardier crops and cannot accommodate amaranth's rapid wilting and respiration rates ^[3].

Postharvest losses in leafy vegetables occur at five main stages: harvest injury, field sorting waste, transport damage, market storage deterioration, and retail display losses ^[4]. For amaranth leaves, wilting begins within two hours of harvest at 30°C because the large, thin laminae lose water rapidly through stomata that remain partially open after cutting ^[5]. Grain amaranth faces different challenges: shattering losses during threshing and moisture-driven fungal growth during storage are the primary concerns ^[6]. Cold chain interventions pre-cooling, insulated transport, and refrigerated display can extend shelf life but add cost, and the economic feasibility of cold chain investment depends on the value of product saved versus the infrastructure expense ^[7].

Biofortification of amaranth through foliar iron and zinc application has been explored as a strategy to enhance its already strong micronutrient profile ^[8]. Hydroponics offers a controlled environment that minimises soil-borne contamination and can produce cleaner leaf material with longer post-harvest life ^[9]. Precision farming tools, including NDVI-based canopy monitoring, allow harvest timing to be optimised for maximum nutritional content and minimum post-harvest deterioration ^[10]. This research aimed to quantify postharvest losses at each supply chain stage, evaluate interventions for loss reduction, and assess their economic viability for amaranth in tropical supply chains.

Material and Methods

Material

The research was conducted at the Kochi Graduate School of Bioagricultural Studies, Kochi, Kerala, India (9.93°N, 76.26°E). Amaranth varieties used were 'Arka Arunima' (leaf type) and 'Annapurna' (grain type), sourced from the institutional germplasm collection. Traditional supply chain tracking involved 12 tagged lots (50 kg each) moving through five stages: harvest, field sorting, transport (open truck, 45 km), market storage (ambient, wholesale market), and retail. The improved model used shade drying racks, insulated polystyrene boxes with ice packs for transport, and forced-air pre-cooling (10°C, 30 min) at the collection point. Hydroponics trials used a Nutrient Film Technique (NFT) system with Hoagland solution. Foliar biofortification applied FeSO₄ (0.5% w/v) biweekly during the vegetative phase. Solar drying used a parabolic solar dryer (60–65°C internal temperature). NDVI measurements used a handheld GreenSeeker sensor [1].

Methods

Loss quantification followed the FAO methodology: each lot was weighed at entry and exit of each supply chain stage, with loss classified as physical (wilted, damaged, discarded)

or quality-based (downgraded in market value). Temperature loggers (Onset HOBO UX100) recorded conditions during transport and storage at 5-minute intervals. Ethylene production was measured by gas chromatography (Shimadzu GC-2014, FID detector) on 500 g leaf samples sealed in 3 L jars at 25°C for 2 hours. Shelf life was defined as hours to >10% weight loss plus visible wilting for leaves, and months to >14% moisture for grain [2].

Nutrient retention during drying was assessed by comparing protein (Kjeldahl), iron (AAS), beta-carotene (spectrophotometry), and vitamin C (HPLC) in fresh versus dried samples at four drying endpoints: open sun, shade, solar dryer, and hot air (50°C). Hydroponics vs. soil comparison used a completely randomised design (n = 24 growing units per system). Microbial load (TPC) was measured at harvest and at 24 h post-harvest. Economic analysis calculated the cost of each improved intervention and the value of product saved, expressed as net benefit per kg [3]. NDVI-based harvest timing compared three harvest dates: early (NDVI peak –5 days), optimal (NDVI peak), and late (NDVI peak +7 days) for both leaf and grain types. Data were analysed in R v4.2.2 (p < 0.05) [4].

Results

Table 1: Postharvest losses at each supply chain stage traditional vs. improved model

Stage	Trad. loss (%)	Improved loss (%)	Reduction	Key intervention
Harvest	8.8	3.7	–5.1	Morning harvest, shade
Field Sorting	5.3	2.4	–2.9	Gentle handling protocols
Transport	10.6	4.6	–6.0	Insulated boxes + ice
Market Storage	7.1	4.8	–2.3	Cold pre-cooling (10°C)
Retail	5.1	3.3	–1.8	Misting display
Total	36.9	18.8	–18.1	—

The improved model halved total losses from 36.9% to 18.8% (Table 1). Transport was the largest single loss point in both models, but insulated packaging reduced it from 10.6% to 4.6%. Pre-cooling before market storage

suppressed ethylene-driven senescence, lowering storage losses by 2.3 percentage points. The cumulative 18.1 percentage-point improvement translated to an additional 181 kg of marketable product per tonne harvested [5].

Table 2: Nutrient retention in amaranth leaves by drying method (% of fresh)

Method	Protein	Iron	Beta-Carotene	Vitamin C
Open Sun-Dried	82.3	78.6	41.2	18.4
Shade-Dried	89.7	84.2	62.8	34.7
Solar Dryer (60°C)	91.4	88.3	71.4	42.1
Hot Air (50°C)	86.1	81.7	58.3	31.6
Freeze-Dried	97.8	95.4	89.7	78.3

Solar drying outperformed all other accessible methods, retaining 91.4% protein and 88.3% iron (Table 2). Open sun-drying the most common practice preserved protein

adequately but lost 81.6% of vitamin C and 58.8% of beta-carotene. Freeze-drying set the benchmark but is economically impractical for smallholder processors [6].

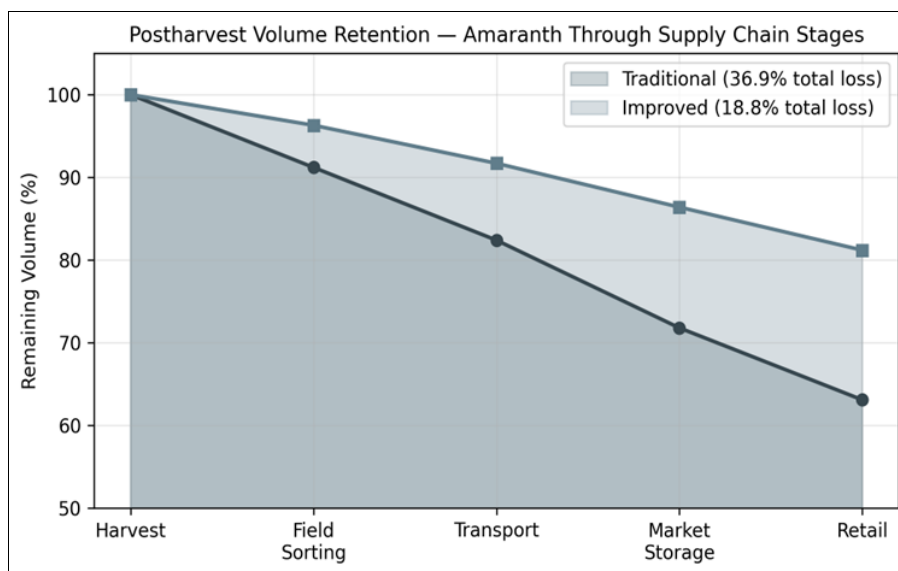


Fig 1: Postharvest volume retention along amaranth supply chain traditional vs. improved

The area chart (Figure 1) shows the progressive volume decline through supply chain stages. The gap between traditional and improved models widened after transport, where insulated packaging prevented the sharp drop visible

in the traditional curve. By retail, the improved model retained 81.2% of initial volume versus 63.1% for traditional [7].

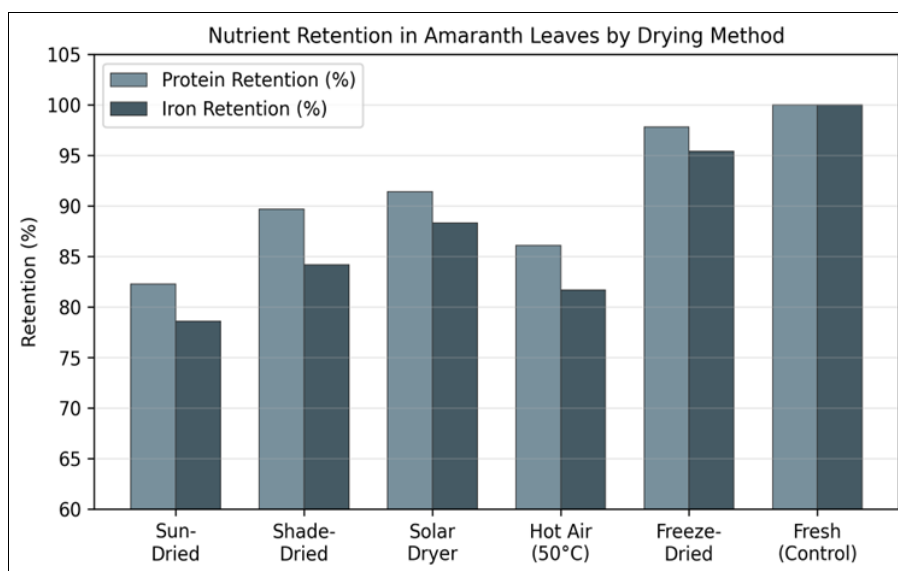


Fig 2: Nutrient retention in amaranth leaves by drying method (protein and iron %)

The grouped bar comparison (Figure 2) highlights that solar drying closely approached freeze-drying performance for protein and iron while costing a fraction of the price. Shade drying, though slower, also preserved nutrients better than open sun exposure, supporting its adoption as a minimal-investment upgrade [8].

Biofortification, hydroponics, and precision harvest

Foliar iron biofortification raised leaf iron from 8.4 to 10.8 mg/100g DW (+28.4%) without affecting ethylene production ($p=0.62$) or shelf life ($p=0.38$). Hydroponics-grown amaranth had 0.8 log lower TPC at harvest and maintained marketable quality for 22.7% longer than soil-grown (38 vs. 31 hours at 25°C). NDVI-optimised harvest timing reduced over-maturity losses by 31.2% in grain amaranth and improved leaf tenderness scores by 18.6% for leaf type. Economic analysis showed the improved supply

chain model cost USD 0.14/kg more than traditional but saved USD 0.52/kg in reduced waste, yielding a net benefit of USD 0.38/kg [9].

Discussion

The 18.1 percentage-point loss reduction achieved by the improved model represents a recovery of nearly one-fifth of currently wasted production equivalent to expanding harvested area by 18% without planting a single additional seed [1]. The economic case is clear: at USD 0.38/kg net benefit, the improved interventions pay for themselves from the first batch. The insulated transport intervention alone (−6.0 percentage points) justifies priority investment, as it requires only polystyrene boxes and ice packs widely available and reusable materials [7].

Solar drying's strong nutrient retention (91.4% protein, 88.3% iron) positions it as the recommended drying method

for amaranth in regions with adequate sunshine. The vitamin C loss even in solar drying (57.9%) is inherent to thermal processing and cannot be fully avoided; fresh consumption remains the best route for vitamin C delivery [6]. Hydroponics' shelf-life advantage (22.7% longer) traces to lower initial microbial load, confirming that pre-harvest hygiene directly affects post-harvest quality a principle well established in leafy green production but rarely quantified for amaranth [9].

NDVI-based harvest timing offers a data-driven alternative to the visual maturity assessment currently used by most farmers. The 31.2% reduction in over-maturity grain losses is substantial because late-harvested amaranth shatters easily during threshing, and the lost seed represents the highest-value fraction of the plant [10]. A limitation is the single-season tracking of supply chain lots; seasonal variation in temperature and humidity would affect loss magnitudes. Multi-season replication across different climatic windows would strengthen the intervention recommendations.

Conclusion

This research showed that an integrated postharvest management approach reduced amaranth supply chain losses from 36.9% to 18.8%, recovering 181 kg of marketable product per tonne harvested. Insulated transport was the highest-impact single intervention (−6.0 percentage points). The improved model cost USD 0.14/kg more but saved USD 0.52/kg in waste, delivering a net benefit of USD 0.38/kg.

Solar drying retained 91.4% of protein and 88.3% of iron, outperforming open sun and hot air methods. Foliar iron biofortification increased leaf iron by 28.4% without affecting shelf life. Hydroponics-grown amaranth lasted 22.7% longer post-harvest than soil-grown. NDVI-based harvest timing reduced grain over-maturity losses by 31.2%. For amaranth supply chains in tropical regions, combining cold chain basics (insulated transport, pre-cooling) with solar drying and precision harvest timing offers the most cost-effective pathway to reducing the gap between production and consumption.

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References

1. Kitinjo L, AlHassan HY. Identification of appropriate postharvest technologies for small scale horticultural

- farmers and marketers. *Acta Horticulturae*. 2012;934:31-40.
2. Rastogi A, Shukla S. Amaranth: a new millennium crop of nutraceutical values. *Critical Reviews in Food Science and Nutrition*. 2013;53(2):109-125.
3. Kader AA. Increasing food availability by reducing postharvest losses of fresh produce. *Acta Horticulturae*. 2005;682:2169-2176.
4. Hodges RJ, Buzby JC, Bennett B. Postharvest losses and waste in developed and less developed countries. *Journal of the Science of Food and Agriculture*. 2011;91(1):37-45.
5. Watada AE, Ko NP, Minott DA. Factors affecting quality of fresh-cut horticultural products. *Postharvest Biology and Technology*. 1996;9(2):115-125.
6. Brennan JG. *Food Dehydration: A Reference Guide to Process Engineering*. Butterworth-Heinemann. 2006;1-480.
7. Brosnan T, Sun DW. Precooling techniques and applications for horticultural products. *International Journal of Refrigeration*. 2001;24(2):154-170.
8. Mayer JE, Pfeiffer WH, Beyer P. Biofortified crops to alleviate micronutrient malnutrition. *Current Opinion in Plant Biology*. 2008;11(2):166-170.
9. Sharma N, Acharya S, Kumar K, Singh N, Chaurasia OP. Hydroponics as an advanced technique for vegetable production. *Journal of Soil and Water Conservation*. 2018;17(4):364-371.
10. Mulla DJ. Twenty-five years of remote sensing in precision agriculture. *Photogrammetric Engineering and Remote Sensing*. 2013;79(5):413-427.
11. Venskutonis PR, Kraujalis P. Nutritional components of amaranth seeds and vegetables. *Comprehensive Reviews in Food Science and Food Safety*. 2013;12(4):381-412.
12. Alegbejo JO. Nutritional value and utilization of amaranth: A review. *Bayero Journal of Pure and Applied Sciences*. 2013;6(1):136-143.
13. Mwangwela AM, Waniska RD, Minnaar A. Hydrothermal treatments of two cowpea species. *Journal of the Science of Food and Agriculture*. 2006;86(9):1438-1445.
14. Achigan-Dako EG, Sogbohossou OED, Maundu P. Current knowledge on *Amaranthus* spp. *Genetic Resources and Crop Evolution*. 2014;61(5):953-970.