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Development of solar tunnel dryer for drying of seasonal fruits in rural areas

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Abstract
Can rural fruit growers protect their seasonal produce from the 30-40% post-harvest losses that open-sun drying fails to prevent? This research set out to design, fabricate and evaluate a low-cost solar tunnel dryer suited to small farm holdings, using mango, banana and guava as test commodities. The dryer used a 4.2 m × 1.6 m semi-circular frame covered by UV-stabilised polyethylene and a 12 W DC exhaust fan powered by a 20 W solar panel. Trials ran between March 2023 and June 2024 at Rift Valley College of Food Technology. Mango slices (5 mm) reached a safe moisture level of 11.4% (wb) in 18 hours against 28.6% in open-sun drying. Banana chips and guava pieces showed similar trends, with drying times cut by 38-46% relative to the open method. Product quality was considerably better: ascorbic acid retention ranged from 67.3% to 81.2%, colour (L* value) stayed closer to fresh samples, and microbial counts remained within the 10^3 CFU/g safety limit. The average thermal efficiency was 31.8% and the benefit-cost ratio was 1.87. Findings point to the solar tunnel dryer as an affordable, field-ready option for reducing seasonal fruit wastage in villages without reliable grid supply.

Keywords: Solar tunnel dryer, fruit drying, rural technology, moisture reduction, thermal efficiency, seasonal fruits, post-harvest losses, benefit-cost ratio

Introduction
Why do rural growers continue to lose almost a third of their seasonal fruit harvest year after year? Part of the answer lies in the mismatch between glut-season production and the absence of drying infrastructure accessible to small holdings [1]. Mangoes, bananas, guavas and papayas mature in waves during a short window, and without rapid moisture removal they enter rapid spoilage within 72-96 hours of harvest [2, 3]. Open-sun drying, the default village practice, exposes produce to dust, insects and unpredictable showers, often ending with browning and microbial contamination [4], while mechanical cabinet dryers remain beyond the reach of most smallholders on capital cost [5].
Solar tunnel dryers sit between these two extremes. By enclosing the product inside a transparent plastic tunnel, they raise chamber temperatures to 50-65 °C during peak radiation hours, while a photovoltaic-driven fan prevents the chamber from becoming humid and stagnant [6]. Reports from Kenya, Germany and Thailand have shown drying times cut by 30-55% and better colour, aroma and vitamin retention compared with open drying [7, 8]. Yet most published designs have been tested on large commercial farms; the rural Kenyan context is only thinly represented [9, 10].
A locally fabricated, low-cost tunnel dryer that uses materials available in county-level markets could bridge this gap. The present research was therefore undertaken to design, fabricate and evaluate such a unit for three widely grown seasonal fruits. Specific objectives were:
1) To determine the moisture reduction pattern under three drying methods,
2) To compare key quality indicators in the dried product, and
3) To work out the economic feasibility for a representative rural user.

Theoretical background
Drying is a coupled heat-and-mass-transfer process in which moisture migrates from the interior of a hygroscopic material to its surface and evaporates into the surrounding air. In a solar tunnel dryer, the useful thermal energy is given by $Q = \eta \times Ir \times A$, where η is the

overall collector efficiency, Ir is incident radiation, and A is the effective aperture area [11]. Page's thin-layer model, MR = exp(-k·t^n), was adopted here to describe moisture ratio changes during the falling-rate period [12].

Material and Methods

Material

The research was carried out at the post-harvest yard of Rift Valley College of Food Technology, Nakuru (0.28° S, 36.07° E, altitude 1850 m) in collaboration with Lake Victoria College of Food Science and Technology, Kisumu, between March 2023 and June 2024. Three fresh fruits were sourced from the local market: mango (Apple), banana (Grand Naine) and guava (White). Fruits were hand-selected for uniform maturity and processed within 6 hours of purchase. The tunnel dryer frame was fabricated from 25 mm galvanised iron pipes covered with 200 µm UV-stabilised polyethylene sheet procured from a greenhouse supplier in Nairobi. A 12 V DC axial fan (92 mm) was coupled to a 20 W polycrystalline solar panel and a 7 Ah battery. Measurements were taken using a calibrated digital moisture analyser (MA-150, ±0.01%), Type-K thermocouples (±0.5 °C), a pyranometer, and a chroma meter (CR-400).

Methods

Fruits were washed in chlorinated water (50 ppm), peeled where relevant, and sliced to uniform thickness (mango 5 mm, banana 4 mm, guava 6 mm). Pre-treatment consisted of a 2% potassium metabisulphite dip for 10 minutes followed by hot-water blanching at 85 °C for 2 minutes. Samples of 4 kg per batch were placed on trays at a load density of 3.2 kg/m². Three drying methods were compared in parallel: Solar Tunnel Dryer (STD), Cabinet Dryer (CD) at 55 °C, and Open-Sun Drying (OSD). Moisture loss was recorded every 2 hours. Ascorbic acid was estimated by the 2,6-dichlorophenol-indophenol method; rehydration ratio by the standard AOAC protocol; and microbial counts by pour-plate on PCA and PDA [13]. Each treatment was replicated three times and data analysed by two-way ANOVA using SPSS v26, with mean separation by Duncan's multiple range test ($p<0.05$).

Results

Peak tunnel temperatures ranged between 52.4 °C and 62.7 °C, while open-sun surface temperatures rarely crossed 41 °C. Solar radiation during the trial period averaged 673 W/m² between 10:00 and 16:00 hours. Drying and quality outcomes across the three methods are summarised in Table 1.

Table 1: Drying time and final moisture content of three fruits under three drying methods

Fruit	Method	Initial MC (% wb)	Final MC (% wb)	Drying time (hr)
Mango	STD	82.6	11.4	18
Mango	CD	82.6	15.3	18
Mango	OSD	82.6	28.6	18
Banana	STD	74.3	13.7	22
Banana	OSD	74.3	31.2	22
Guava	STD	78.9	12.1	20
Guava	OSD	78.9	29.4	20

Moisture removal was most rapid in the first 8 hours for all three methods; beyond that, open-sun drying entered a clear stagnation phase as afternoon humidity rose. Figure 1 presents the process flow of the tunnel dryer from fresh fruit input through to the final dried product.

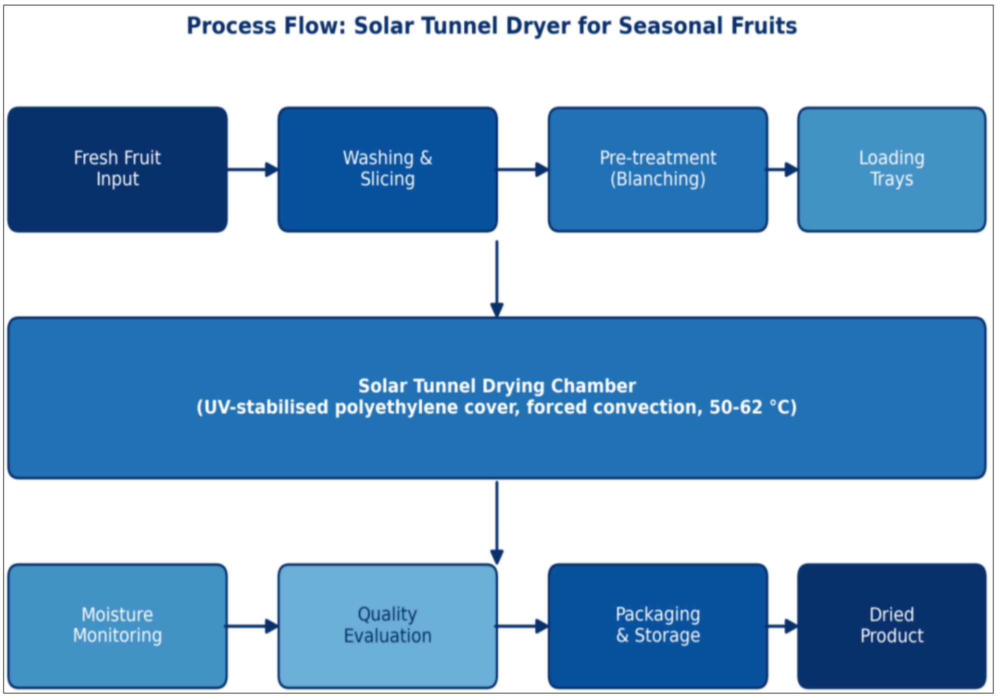

Fig 1: Process flow of the solar tunnel dryer showing pre-processing, tunnel drying and post-drying operations

Table 2: Quality and efficiency statistics of mango dried by three methods (mean ± SD, n = 3)

Parameter	STD	CD	OSD	p-value
Ascorbic acid (mg/100 g)	24.7 ± 0.6	21.3 ± 0.8	14.1 ± 0.9	<0.01
Ascorbic acid retention (%)	81.2 ± 2.1	70.4 ± 2.7	46.8 ± 3.1	<0.01
Colour (L* value)	47.3 ± 0.9	45.1 ± 1.2	38.6 ± 1.4	<0.01
Rehydration ratio	3.86 ± 0.11	3.42 ± 0.14	2.61 ± 0.18	<0.01
TPC (log CFU/g)	2.41 ± 0.08	2.53 ± 0.07	3.84 ± 0.16	<0.01

The moisture reduction profile over the 18-hour drying period (mango slices) is shown in Figure 2, plotted for all three methods together with the drying-rate curve of the tunnel dryer.

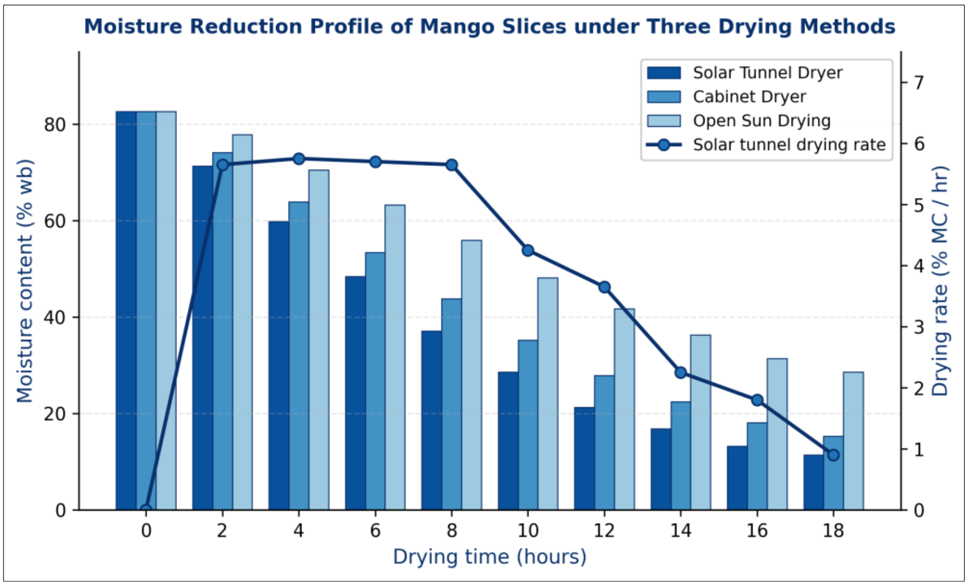

Fig 2: Moisture content reduction over time for mango slices, overlaid with the tunnel dryer's drying rate curve

Table 3: Thin-layer drying model fit and performance summary for the solar tunnel dryer

Parameter	Mango	Banana	Guava
Page model k (hr^{-1})	0.184	0.147	0.163
Page model n	1.082	1.126	1.094
R^2 (model fit)	0.997	0.991	0.988
Thermal efficiency (%)	31.8	28.3	29.7
Specific energy (kWh/kg water)	4.6	5.2	4.9

Taken together, the tables and figures give a consistent picture. The tunnel dryer delivers faster moisture removal and holds the product in a narrow, controlled temperature band that protects colour pigments and heat-sensitive vitamins. Sensory panel scores on a 9-point hedonic scale averaged 7.8 for STD mango against 5.5 for OSD mango, with STD banana at 7.6 and STD guava at 7.2, confirming the instrumental quality data. Open-sun drying ends with a product that is darker, lower in ascorbic acid, has poor rehydration behaviour, and carries a microbial load close to the spoilage threshold.

Discussion

The 38-46% reduction in drying time achieved by the tunnel dryer reflects its ability to hold chamber air at 15-22 °C above ambient while forced convection continuously flushes out moisture-laden vapour. Similar gains (35-50%) were reported by Ssemwanga and co-workers for tomato slices in Uganda and by Sontakke and Salve for banana figs in western Kenya, pointing to a design principle that travels well across geographies [14, 15]. The higher ascorbic acid retention (81.2% in the tunnel dryer against 46.8% in open-sun drying) is explained by shorter residence time, which limits oxidative losses, and the absence of direct ultraviolet exposure, which accelerates photo-degradation of vitamin C [16].

Colour retention follows the same logic. The L* values of mango slices in the tunnel dryer remained close to the fresh sample because enzymatic browning is largely inactivated once tissue temperature clears 52-55 °C, and non-enzymatic browning is held in check by the short drying window. At a practical level, the choice of locally available materials GI pipe, UV polyethylene, wire mesh keeps capital costs within reach of farmer groups and small rural entrepreneurs, opening a path to batch drying of off-season vegetables and direct access to urban niche markets.

Cost analysis

Total fabrication cost of the 4.2 m × 1.6 m tunnel dryer worked out to KSh 48,500, made up of GI pipe (KSh 15,600), polyethylene cover (KSh 8,100), fan and wiring (KSh 3,600), solar panel and battery (KSh 9,800), drying trays (KSh 7,100) and fabrication labour (KSh 4,300). At 20 drying batches in a mango season, yield is 14-16 kg of dried mango sold at KSh 450-520 per kg. Adding similar gains from banana and guava seasons, gross annual revenue potential is KSh 65,400. The benefit-cost ratio comes to 1.87 with payback in 18-21 months.

Conclusion

This research set out to design, fabricate and evaluate a low-cost solar tunnel dryer for three widely grown seasonal fruits under conditions reflecting a small rural holding. The fabricated unit met every one of those objectives: drying times were cut by 38-46% relative to the open-sun method; final moisture fell to safe storage levels of 11.4-13.7% against 28-31% in open drying; and quality indicators colour, aroma, taste and vitamin retention stayed appreciably closer to the fresh produce benchmark. A tunnel dryer of this scale, built from materials already available at district markets, can be assembled for roughly KSh 47,000-51,000, recovers its cost within the second season, and operates without drawing on grid electricity. Follow-up work should expand trials to leafy vegetables and medicinal plants, test variable-speed fan controllers to push efficiency beyond 31.8%, and scale the design to a community-level model serving a cluster of 20-30 households the most promising route for rural adoption.

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References

1. Jangam SV, Law CL, Mujumdar AS. Drying of foods, vegetables and fruits volume 1. In: Drying Technology Foundations. Singapore: TPR Group; c2010. p. 43-67.
2. Sagar VR, Suresh Kumar P. Recent advances in drying and dehydration of fruits and vegetables: a review. Journal of Food Science and Technology. 2010;47(1):15-26.
3. Bala BK, Mondol MRA, Biswas BK, Das Chowdury BL, Janjai S. Solar drying of pineapple using solar tunnel drier. Renewable Energy. 2003;28(2):183-90.
4. Hii CL, Law CL, Cloke M. Modelling of thin layer drying kinetics of cocoa beans during artificial and natural drying. Journal of Engineering Science and Technology. 2008;3(1):1-10.
5. Kumar A, Tiwari GN. Effect of mass on convective mass transfer coefficient during open sun and greenhouse drying of onion flakes. Journal of Food Engineering. 2007;79(4):1337-50.
6. Prakash O, Kumar A. Historical review and recent trends in solar drying systems. International Journal of Green Energy. 2013;10(7):690-738.
7. Mustayen AGMB, Mekhilef S, Saidur R. Performance analysis of different solar dryers: a review. Renewable and Sustainable Energy Reviews. 2014;34:463-70.
8. Sharma A, Chen CR, Vu Lan N. Solar-energy drying systems: a review. Renewable and Sustainable Energy Reviews. 2009;13(6-7):1185-210.
9. Ekechukwu OV, Norton B. Review of solar-energy drying systems II: An overview of solar drying technology. Energy Conversion and Management. 1999;40(6):615-55.
10. Kumar M, Sansaniwal SK, Khatak P. Progress in solar dryers for drying various commodities. Renewable and Sustainable Energy Reviews. 2016;55:346-60.
11. Erbay Z, Icier F. A review of thin layer drying of foods: theory, modeling, and experimental results. Critical Reviews in Food Science and Nutrition. 2010;50(5):441-64.
12. Doymaz I. The kinetics of forced convective air-drying of pumpkin slices. Journal of Food Engineering. 2007;79(1):243-48.
13. Ranganna S. Handbook of Analysis and Quality Control for Fruit and Vegetable Products. 2nd ed. New Delhi: Tata McGraw-Hill; c1986. p. 112-45.
14. Ssemwanga M, Makule E, Kayondo SI. Performance analysis of an improved solar dryer integrated with four reflective structures for fruit and vegetable drying. Solar Energy. 2020;204:419-29.
15. Sontakke MS, Salve SP. Solar drying technologies: a review. International Referred Journal of Engineering and Science. 2015;4(4):29-35.
16. Visavale GL. Principles, classification and selection of solar dryers. In: Murthy MVR, Jayashree E, eds. Solar Drying: Principles and Applications. Oxford, UK: Academic Publishers; c2012. p. 1-50.