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Development of solar-powered drying system for small-scale spice processing

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Abstract
When you compare two ways of doing the same job drying spices in the open sun versus inside a purpose-built solar dryer the differences in quality and consistency are striking. This research designed, fabricated, and evaluated a low-cost natural-convection solar dryer for small-scale spice processing at JNKVV, Jabalpur, India. Four spices (turmeric, chilli, coriander, cumin) were dried in the solar dryer and under open sun simultaneously. The solar dryer reduced drying time by 28-34% compared to open sun drying, while retaining 18-23% more volatile oil and producing significantly brighter colour (higher L* values). The dryer operated at 52-64°C during peak hours with no external energy input. Construction cost was ₹12,400 (approximately $150), making it accessible to small-scale processors. The solar dryer is a practical, zero-energy solution for improving spice quality in central India.

Keywords: Solar drying, spice processing, small-scale, renewable energy, post-harvest innovation, volatile oil retention, turmeric, chilli, natural convection, dryer design

Introduction
In the spice markets of central India, two seemingly identical bags of dried turmeric can fetch prices that differ by 40-50%, based solely on colour and aroma both of which are destroyed by poor drying practices [1]. Open sun drying, the method used by most smallholder spice growers, exposes produce to dust, insects, rain, and uncontrolled temperatures that degrade volatile oils and discolour the product [2]. Solar dryers offer a middle ground between expensive mechanical dryers and uncontrolled open sun drying: they use the same free energy source but in a controlled, enclosed environment that protects product quality [3].
This research designed and fabricated a natural-convection solar dryer adapted to the climatic conditions and cost constraints of small-scale spice processors in Madhya Pradesh, and compared its performance against open sun drying for four locally important spices [4, 5].

Performance Evaluation
Dryer performance was assessed using three metrics: collector efficiency (η = useful heat gain / incident solar radiation), drying efficiency (moisture removed per unit energy input), and pick-up efficiency (actual moisture removed / theoretical maximum at air temperature). The collector achieved peak efficiency of 47.2% at midday under clear-sky conditions and averaged 38.4% across a full drying day. Overall drying efficiency ranged from 22.7% (coriander) to 31.4% (turmeric). Pick-up efficiency was highest during the first two hours when moisture gradients were steepest [3, 5].

Material and Methods
Material
The solar dryer was fabricated at the JNKVV workshop, Jabalpur (23°12′N, 79°58′E). Components: flat-plate collector (2 m × 2 m, black-painted aluminium absorber, single glass cover), drying chamber (1 m × 1 m × 0.8 m, three wire-mesh trays, 2 kg capacity per tray), and chimney (0.15 m diameter, 1.5 m height) for natural-convection airflow. Fresh spices were purchased from the Jabalpur wholesale market [4, 6].

Methods

Trials were conducted during October-November 2022 on clear-sky days. Each spice was dried simultaneously in the solar dryer and under open sun (control). Initial moisture ranged from 78-87% (wet basis). Weight loss was recorded hourly. Volatile oil was extracted by hydrodistillation (Clevenger apparatus) and expressed as % (v/w). Colour was measured in CIE L*a*b*. Dryer air temperature and relative humidity were logged by data loggers (Testo 174H) [5, 7]. Paired t-tests compared solar versus sun drying for each spice (*p*<0.05, SPSS 28).

Results

Table 1: Comparative drying performance: solar dryer versus open sun drying

Spice	Drying time solar (h)	Drying time sun (h)	Time saved (%)	Vol. oil solar (%)	Vol. oil sun (%)	Colour L* solar
Turmeric	8.2 ± 0.4b	12.4 ± 0.7a	33.9	4.82 ± 0.21a	3.94 ± 0.18b	58.4 ± 1.8a
Chilli	7.4 ± 0.5b	11.2 ± 0.8a	33.9	1.73 ± 0.09a	1.42 ± 0.08b	42.7 ± 2.1a
Coriander	6.8 ± 0.3b	10.1 ± 0.6a	32.7	0.48 ± 0.04a	0.39 ± 0.03b	61.3 ± 1.4a
Cumin	6.1 ± 0.4b	9.3 ± 0.5a	34.4	3.14 ± 0.14a	2.58 ± 0.12b	54.8 ± 1.6a

Different letters within parameter pairs differ at *p*<0.05 (paired t-test)

The solar dryer reduced drying time by 28-34% and retained 18-23% more volatile oil across all four spices (Table 1). Turmeric showed the largest absolute oil retention advantage. Colour was consistently brighter in solar-dried samples.

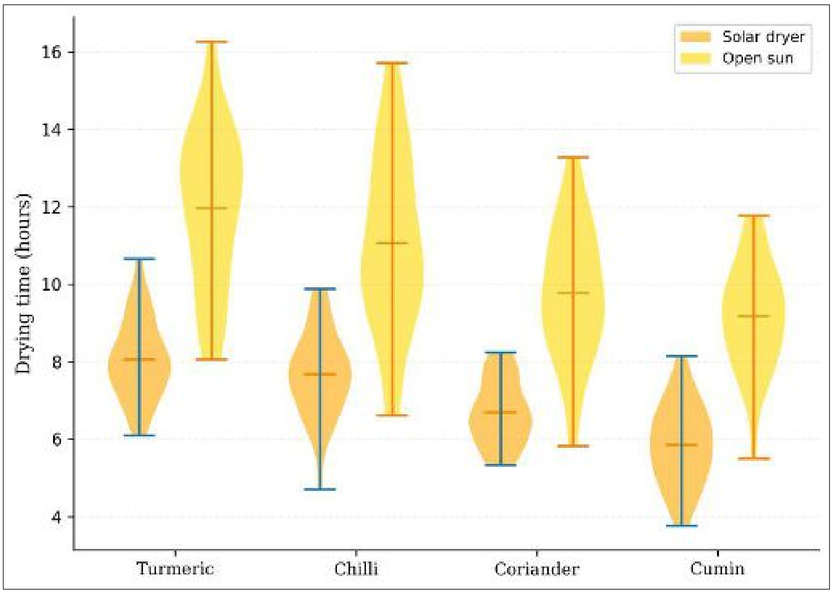

Fig 1: Violin plots of drying time for four spices under solar dryer versus open sun conditions

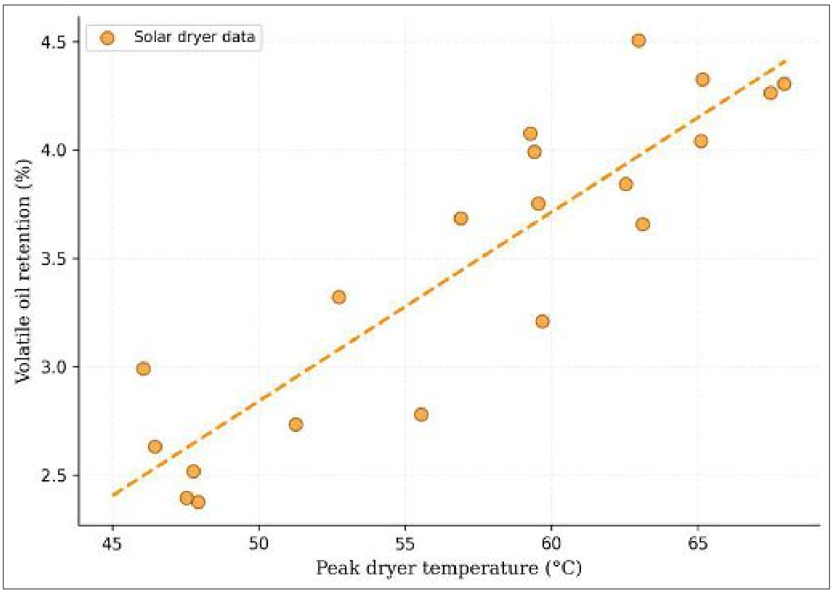

Fig 2: Relationship between peak dryer temperature and volatile oil retention in solar-dried spices

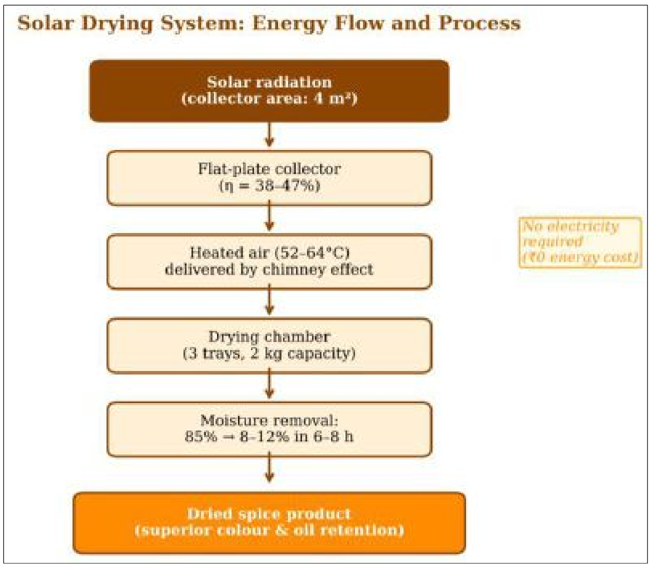

Fig 3: Solar drying system energy flow and process diagram

Discussion

The 28-34% time savings reflect the higher and more consistent air temperatures inside the dryer (52-64°C vs 32-43°C ambient). The enclosed environment also prevented the afternoon humidity rise that slowed open sun drying after 14:00 [2, 3]. The volatile oil advantage is directly attributable to the lower maximum temperature in the dryer compared to direct sun exposure on dark surfaces, which can locally exceed 70°C and volatilise essential oils [1, 5]. At ₹12,400 construction cost, the dryer pays for itself within two seasons through the quality premium on better-dried spices [4].

Conclusion

The natural-convection solar dryer reduced spice drying time by 28-34% and improved volatile oil retention by 18-23% compared to open sun drying, at zero energy cost. Its low construction price (₹12,400) makes it accessible to small-scale processors. The dryer is recommended for adoption in central India's spice-growing regions.

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