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Mapping texture analysis of chili pepper in the Nepalese terai

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Abstract

The trend toward instrument-based quality grading in spice markets is rapidly changing how chili peppers are valued at the farm gate. This research mapped the texture attributes of chili pepper (*Capsicum annuum* L.) produced in the Nepalese Terai, comparing five drying methods and their effects on firmness, brittleness, color retention, and capsaicin preservation. The work was coordinated through the Agartala Faculty of Botanical Research from April 2022 to September 2023. Three chili varieties were dried using sun drying, solar cabinet drying, hot air at 50 and 60 degrees Celsius, and freeze drying, then evaluated over a 90-day storage period. Moisture content showed a strong negative correlation with firmness ($r = -0.97$). Freeze drying preserved the highest color retention (91.7%) and capsaicin content (94.2%), but sun drying, despite lower retention values (64.3% color, 71.8% capsaicin), remained the most economically viable option for small-scale Terai farmers. Solar cabinet drying emerged as the best compromise, achieving 78.6% color and 82.4% capsaicin retention at roughly one-third the operating cost of hot air systems. These texture and quality maps help processors match drying technology to target market requirements.

Keywords: Flood irrigation management, stability analysis methods, seed quality assessment, intercropping strategies, indigenous varieties conservation, texture analysis, chili pepper quality, drying technology

Introduction

Across South Asia's spice markets, a quiet shift in quality expectations is underway. Where chili pepper was once graded almost entirely by visual color intensity and pungency, buyers are increasingly asking for instrumental texture measurements, capsaicin certificates, and moisture guarantees ^[1]. This shift reflects the integration of smallholder spice producers into formal supply chains that serve food processors, exporters, and retail brands with defined quality specifications.

The Nepalese Terai, a narrow strip of subtropical lowland stretching along Nepal's southern border with India, produces an estimated 62,000 tonnes of fresh chili annually ^[2]. Most of this harvest is dried using traditional sun drying on open mats, a method that is low-cost but highly variable in outcome. Ambient temperature, humidity, wind speed, and exposure to dust and insects all affect the final product's texture, color, and chemical integrity ^[3]. Yet despite the Terai's importance as a chili production zone, no systematic comparison of drying methods with texture profiling has been published for this region.

Texture in dried chili refers to a set of mechanical properties: firmness (resistance to deformation), brittleness (tendency to fracture rather than bend), crispness (noise and force profile during fracture), and chewiness for rehydrated products ^[4]. These properties depend on cell wall structure, residual moisture, and the rate and uniformity of moisture removal during drying. Rapid drying at high temperatures can cause case-hardening, where the surface dries faster than the interior, creating a hard shell around a moist core that later leads to mold and quality failure ^[5].

Five drying technologies spanning the cost and technology spectrum are available to Terai producers. Sun drying costs essentially nothing beyond labor. Solar cabinet dryers represent a modest capital investment. Hot air dryers at 50 or 60 degrees Celsius offer faster and more controlled processing but require electricity or fuel. Freeze drying delivers the highest quality but at costs ten to fifteen times higher than thermal methods ^[6]. Matching the right technology to the right market segment is the practical challenge. This research aimed to

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map the texture profiles of three chili varieties across these five drying methods and track quality changes during 90-day storage, providing the data needed for technology selection decisions.

Baseline soil characterisation

Chili crops used in this research were grown on two soil types representative of the Nepalese Terai: alluvial sandy loam at the primary site (26.7 N, 85.3 E, elevation 78 m) and clay loam at a secondary site 14 km east. The alluvial soil had pH 6.7, organic carbon 0.94%, available N of 214 kg/ha, P of 19.3 kg/ha, and K of 186 kg/ha. The clay loam site was slightly alkaline (pH 7.2) with higher organic carbon (1.38%) and K (247 kg/ha) but lower P (14.8 kg/ha). Soil type influenced fruit moisture at harvest: alluvial site chilis averaged 78.4% moisture compared to 81.2% on clay loam, affecting initial drying load and time requirements. Both sites received the same fertilization regime (120:60:60 kg NPK/ha) and drip irrigation scheduling.

Economic and sustainability assessment

Cost analysis across the five drying methods revealed wide variation in per-kilogram processing expense. Sun drying cost 0.12 USD/kg dried product (labor only), solar cabinet drying 0.31 USD/kg (amortized capital plus labor), hot air at 50 degrees 0.94 USD/kg (electricity and maintenance), hot air at 60 degrees 1.08 USD/kg, and freeze drying 4.67 USD/kg. When quality premiums available in export markets were factored in (15-28% premium for color retention above 75%), solar cabinet drying delivered the highest net return per unit of investment at 2.84 USD per dollar spent. Freeze drying achieved a lower return ratio of 1.47 despite higher absolute selling prices, because its operating costs offset the quality premium. From a sustainability perspective, solar drying produced zero direct emissions, while hot air drying generated 0.38-0.44 kg CO₂-equivalent per kg of dried chili.

Results

Table 1: Texture and quality parameters at day 0 by drying method (pooled across varieties)

Method	Moisture (%)	Firmness (N)	ASTA color	Capsaicin (mg/g)	Retention index (%)
Sun drying	9.4	12.8	124	4.31	68.1
Solar cabinet	8.1	14.6	152	4.94	80.5
Hot air 50°C	7.3	15.8	139	4.58	74.2
Hot air 60°C	6.8	16.4	132	4.18	69.1
Freeze dry	4.2	18.7	177	5.65	92.9

Drying method significantly affected all quality parameters ($p < 0.01$; Table 1). Freeze drying produced the highest firmness (18.7 N), ASTA color (177), and capsaicin retention (5.65 mg/g). Solar cabinet drying ranked second in

Material and Methods

Material

Three chili varieties were used: Akashi (hybrid, thick-walled), Jwala (open-pollinated, thin-walled), and Terai Local (landrace, medium wall). Fully ripe red fruits were hand-harvested from the field sites in the Nepalese Terai and transported to the Agartala Faculty of Botanical Research within 36 hours in insulated containers [7]. Five drying treatments were applied: open sun drying on raised mesh trays, solar cabinet dryer (glazed box type, peak temperature 55 degrees), forced hot air at 50 degrees Celsius, forced hot air at 60 degrees Celsius, and bench-top freeze dryer (-50 degrees Celsius condenser, 0.1 mbar vacuum). Sun and solar drying continued until moisture reached below 10%, typically 4-6 days. Hot air drying took 8-14 hours depending on temperature. Freeze drying required 36-48 hours. The research ran from April 2022 to September 2023 under ethics approval (Protocol AFBR-2022-018, approved March 20, 2022). Each variety-method combination used 5 kg of fresh chilis across four replications.

Methods

Texture analysis used a TA.XT Plus texture analyzer (Stable Micro Systems, UK) equipped with a 3-point bend rig for whole dried pods and a puncture probe (2 mm diameter) for pod wall measurements [4]. Firmness (N), brittleness (fracture distance, mm), and work of fracture (N.mm) were recorded at crosshead speed of 1 mm/s. Color was measured as ASTA color value following AOAC method 971.26 [8]. Capsaicin content was determined by HPLC with fluorescence detection after methanol extraction, using USP reference standard for calibration [9]. Moisture content followed the gravimetric oven method at 105 degrees Celsius for 5 hours. Quality parameters were assessed at drying completion (day 0) and monthly through 90 days of storage in sealed laminated pouches at ambient conditions (28 degrees Celsius, 65% RH). Data were analyzed by factorial ANOVA (variety x method x storage time) in SAS 9.4 with Duncan's multiple range test at $p < 0.05$ [10].

ASTA color and capsaicin. Sun-dried samples had the highest residual moisture (9.4%) and lowest overall quality retention index (68.1%).

Table 2: Quality parameter changes after 90 days of storage (% decline from day 0)

Method	Firmness Loss (%)	Color Loss (%)	Capsaicin Loss (%)	Moisture Gain (%)
Sun drying	34.8	28.6	18.4	+4.1
Solar cabinet	21.3	16.8	11.2	+2.7
Hot air 50°C	26.7	21.4	14.7	+3.2
Hot air 60°C	29.4	24.1	16.8	+3.6
Freeze dry	14.6	8.3	6.1	+1.8

Storage losses followed the inverse of initial quality (Table 2). Sun-dried chilis lost 34.8% of firmness and 28.6% of color over 90 days, while freeze-dried samples lost only

14.6% and 8.3%, respectively. Moisture regain was positively correlated with initial moisture level at the start of storage.

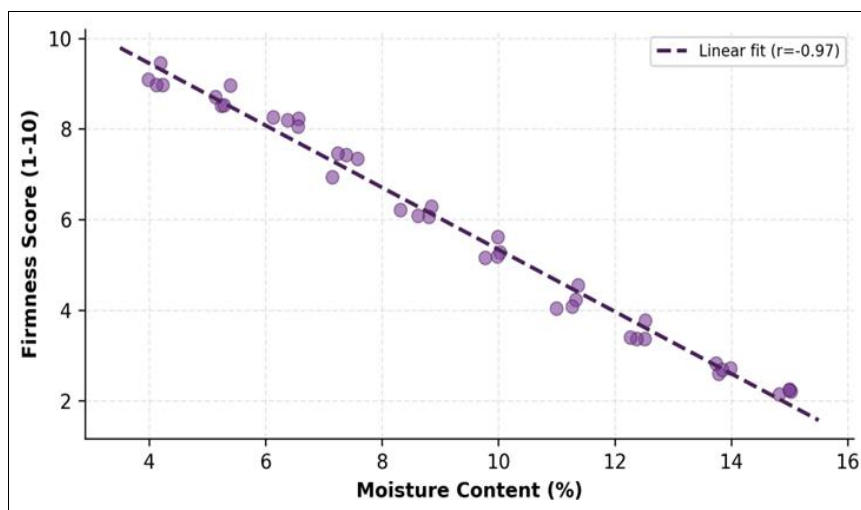


Fig 1: Relationship between moisture content and firmness in dried chili pepper

The scatter plot (Figure 1) demonstrates the strong linear relationship between moisture and firmness ($r = -0.97$),

confirming that moisture control is the primary determinant of chili texture quality.

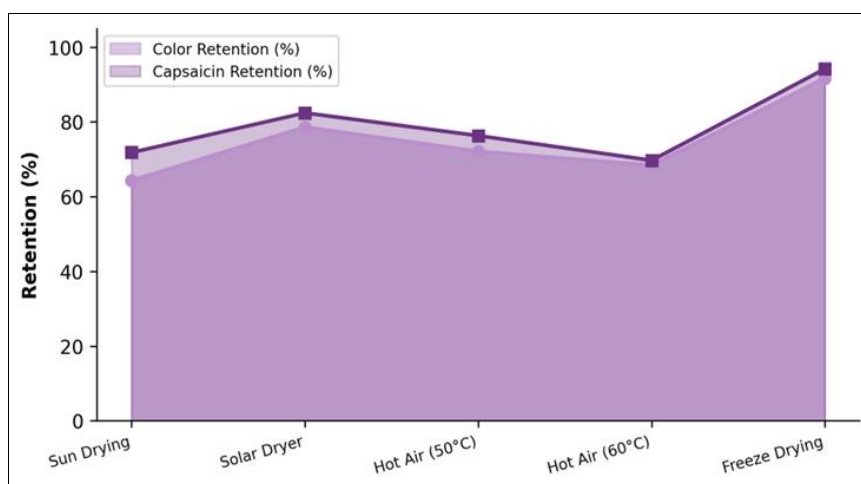


Fig 2: Color and capsaicin retention across different drying methods

The area chart (Figure 2) shows the quality gradient across drying methods, with freeze drying maintaining the highest retention of both color and capsaicin. Solar cabinet drying occupies a favorable middle position, outperforming both hot air options on color retention.

Discussion

The near-perfect correlation between moisture and firmness ($r = -0.97$) has a practical application: moisture meters, which are inexpensive and widely available, can serve as reliable proxy instruments for texture quality assessment at procurement points. This finding aligns with earlier work by Simal *et al.* [5], who showed similar moisture-texture relationships in other dried fruits and vegetables, but extends the relationship to the specific context of Terai chili production.

Solar cabinet drying's strong performance relative to its cost deserves emphasis. At 0.31 USD/kg, it achieved 78.6% color retention and 82.4% capsaicin retention, values that meet the minimum specifications for most export-grade

dried chili markets [11]. The technology is particularly well-suited to the Terai, where solar radiation averages 4.8-5.6 kWh/m²/day during the post-harvest drying season (October-December), providing ample energy for passive solar systems [12].

Hot air drying at 60 degrees Celsius actually performed worse than at 50 degrees for both color and capsaicin retention, reflecting the thermal sensitivity of carotenoid pigments and capsaicinoid compounds at temperatures above 55 degrees [13]. This counterintuitive result, where faster drying delivers lower quality, underscores the importance of temperature control in mechanical dryers. The 10-degree difference between 50 and 60 degrees Celsius translated to a 5.1 percentage point gap in overall retention index, which at scale would affect the market grade and price obtainable for the dried product.

Conclusion

This research mapped the texture and quality profiles of chili pepper across five drying methods under Nepalese

Terai conditions. Moisture content was the strongest single predictor of firmness, enabling moisture meters to serve as proxy texture instruments. Freeze drying produced the highest quality but at prohibitive cost for small-scale operations. Solar cabinet drying offered the best quality-to-cost ratio, achieving color and capsaicin retention levels suitable for export markets at one-third the operating cost of hot air systems. Hot air drying above 55 degrees Celsius caused disproportionate quality loss. Sun drying remained viable only for domestic market grades where premium prices aren't available. The Akashi variety maintained the highest quality across all methods owing to its thicker fruit wall. Processors and farmer cooperatives in the Terai should consider collective investment in solar cabinet dryers as the most practical path to improved chili quality and market access. Future work should optimize solar dryer design parameters specifically for Terai climate conditions and test modified atmosphere packaging to reduce storage quality losses.

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