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REVIEW ARTICLE

Post-harvest profile, processing and value addition of dried red chillies (*Capsicum annum* L.)

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Abstract Chilli has dominated and retained an important place amongst the spices worldwide. They are dried ripe fruits intuitively consumed as a spice, condiment, culinary, and medicinal purposes. The global consumption pattern is intriguing because of the inherent pungency, aroma, taste, spicy flavour, and therapeutic properties. Predominantly, the colour and pungency decide the quality features and are actively responsible for organized marketing and trade of the dried chillies. India is one of the leading producers and exporters of chilli. The chemical composition of the chillies varies substantially with agro-climatic zones and post-harvest management strategies. The quantum of post-harvest loss of 25–35% hampers the farmer's income and affects the wholesale/retail marketing. This review paper is intended to provide a deep insight into the advancements in various post-harvest unit operations of dried red chillies. A detailed overview of post-harvest operations (drying, grading, destalking, packaging, storage) and processing techniques for value-added products (chilli powder, dried flakes, seeds, oleoresin) is discussed in this paper. The presented information will help the researchers and the industry personnel engaged in the post-harvest processing and value addition of dried red chillies.

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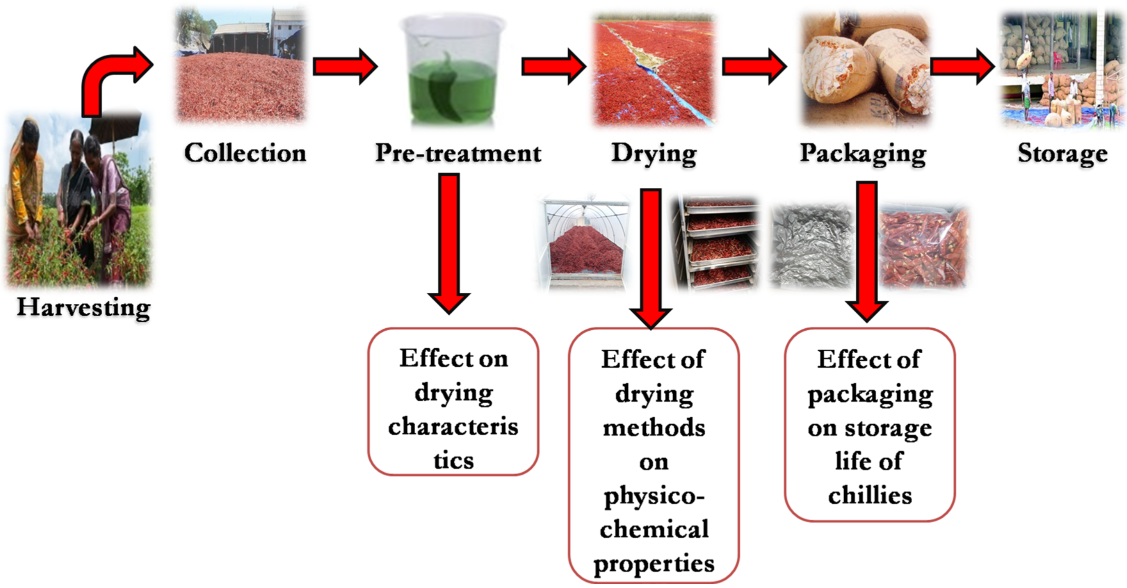
Graphical abstract



Keywords Destalking · Chilli powder · Drying · Mechanization · Oleoresin

Abbreviations

SHUs	Scoville heat units
°C	Centigrade
INR	Indian rupees
µ	Micron
mg	Milli gram
RH	Relative humidity
kcal	Kilo calories
TEC	Total extractable colour
g	Gram
CO_2	Carbon dioxide
d.b.	Dry basis
Meq	Milliequivalent
kg	Kilogram
U/g	Micromole/gram
mm	Milli metre
CP	Cold press extraction
ASTA	American Spice Trade Association
SE	Soxhlet extraction
IS	Indian standard
SCE	Supercritical CO_2 extraction
cm	Centimetre
MAE	Microwave-assisted extraction
w.b.	Wet basis
h	Hour
CE/g	Catechin equivalents per gram
LDPE	Low density polyethylene
DPPH	Diphenyl-1-picrylhydrazyl
d.w.	Dry weight
cv.	Cultivar
ABTS	2,2′-Azino-bis(3-ethylbenzothiazoline-6-sulfonic acid)

Introduction

Chilli has a prominent place amongst the major spices across the globe with the cultivation of beyond 400 different varieties. It refers to the dried ripe fruit of genus '*Capsicum*', also called red pepper, and belongs to the family Solanaceae. It constitutes a main commercial crop utilized as a fresh vegetable, condiment, and culinary supplement. Chillies are an imperative constituent in most global food items as they give colour, taste, flavour, and pungency to the food products. Chillies have very good medicinal properties such as digestive, carminative, thermogenic, antipyretic, stimulant, serdorific, cardiotonic, sialagogue and rubefacient.

Indian chillies are highly cherished due to their inherent commercial features, i.e. colour and pungency. These attributes are significant to define the desired quality characteristics for consumers' acceptance and market price. In India, chilli is recognized with different names such as *Lal Mirch* in Hindi, *Marcha* in Gujarati, *Mensina kai* in Kannada, *Mirchi* in Marathi, *Lalmirch* in Punjabi, *Milagay* in Tamil (Anonymous 2021). Chilli is a Kharif crop with sowing usually done during July-August and harvest during January/February (Satyanarayana and Sukumaran 2002), followed by the commencement of marketing in February–March. The world's hottest chilli "Naga Jolokia", has a pungency level (> 1 million Scoville heat units (SHUs)) is cultivated in the hilly terrain of Assam (India).

Globally, India ranks first in dry chilli production with a 33% share, followed by Thailand (9%), Ethiopia (7.8%), China (7.2%) and Pakistan (3.16%), respectively. Approximately 80% of the country's production is consumed within the country, and about 15–20% of domestic production is exported. India produced around 1.70 million tonnes of chilli from nearly 0.68 million hectares area, among which 4.84 lakh tonnes was exported worth 6.22 lakhs INR (Anonymous 2021). The major chilli producing states are Andhra Pradesh (41.47%), Telangana (19.25%), Madhya Pradesh (12.68%), Karnataka (10.87%), West Bengal (4.19%), Orissa (2.89%), Nagaland (1.71%), Gujarat (1.09%), Tamil Nadu (0.86%), Rajasthan (0.78%), Assam (0.76%), Punjab (0.59%), Uttar Pradesh (0.43%) and Maharashtra (0.14%) (Anonymous 2021).

Owing to its importance as a major spice, processing chillies into a variety of products is a conventional practice. The generalized sequential post-harvest unit operations include cleaning, grading, drying, destalking/destemming, pounding, packaging and storage. The literature about various research studies is plentiful; however, any such review covering detailed information about the post-harvest processing of dried red chillies is lacking. Therefore, the authors have attempted to document and systematically present the available information in this review paper. The illustrated compilation will surely be helpful to the researchers, industrialists and education professionals.

Anatomy

Peduncle refers to the stem that attaches fruit to the plant. The calyx is that portion of the stem that connects to the topmost part of the chilli fruit. Seeds are the plant's reproductive part, and the Capsaicin glands are the primary source of hotness. Pericarp comprises the fruit's overall cover and consists of principal biochemical parameters (colour and pungency). Apex is the terminal part of the fruit having rounded tip morphology. Different chilli varieties have a variable degree of roundness. Whole chillies generally consist of about 53% pericarp, 40% seeds and 7% stalk and calyx (Satyanarayana and Sukumaran 2002) with modest variation among the cultivars. Jalgaonkar and Mahawar (2017) have evaluated the physico-chemical properties of selected chilli cultivars, and reported that the pericarp content was

Table 1 Nutritional composition of different chilli cultivars

Parameters	Naga King chilli	Big bird's eye chiili	Small birds eye chilli	Guntur chilli
				
Moisture (g/100 g)	89.67 ± 1.03	87.84 ± 2.06	87.66 ± 1.54	88.23 ± 1.40
Protein (g/100 g)	1.59 ± 0.10	1.52 ± 0.02	1.28 ± 0.08	0.91 ± 0.02
Fat (g/100 g)	0.82 ± 0.03	1.71 ± 0.04	1.99 ± 0.14	1.18 ± 0.06
Ash (g/100 g)	0.73 ± 0.02	0.82 ± 0.05	0.69 ± 0.07	0.75 ± 0.06
Soluble dietary fiber (g/100 g)	0.63 ± 0.01	0.68 ± 0.09	0.66 ± 0.07	0.73 ± 0.07
Insoluble dietary fiber (g/100 g)	4.20 ± 0.29	5.47 ± 0.46	5.48 ± 0.52	5.52 ± 0.50
Total dietary fiber (g/100 g)	4.83 ± 0.19	6.15 ± 0.21	6.14 ± 0.17	6.25 ± 0.38
Carbohydrate (g/100 g)	2.36 ± 0.07	1.96 ± 0.09	2.24 ± 0.08	2.71 ± 0.06
Energy (KJ)	24.44 ± 1.03	30.67 ± 0.74	32.45 ± 1.81	26.56 ± 0.93
Iron (mg/100 g)	1.98 ± 0.13	0.48 ± 0.06	0.34 ± 0.06	0.79 ± 0.06
Zinc (mg/100 g)	0.11 ± 0.01	0.18 ± 0.03	0.15 ± 0.03	0.18 ± 0.02
Phosphorus (mg/100 g)	40.08 ± 1.73	46.69 ± 1.59	30.02 ± 1.59	34.66 ± 0.98
Copper (mg/100 g)	0.08 ± 0.01	0.09 ± 0.02	0.08 ± 0.01	0.16 ± 0.01
Manganese (mg/100 g)	0.19 ± 0.04	0.13 ± 0.01	0.15 ± 0.02	0.21 ± 0.02
Calcium (mg/100 g)	8.79 ± 0.95	20.44 ± 1.70	17.93 ± 2.35	16.04 ± 0.78
Magnesium (mg/100 g)	17.59 ± 0.97	28.78 ± 1.06	25.05 ± 1.48	20.03 ± 0.86
Capsaicin (g/100 g)	0.46 ± 0.12	0.08 ± 0.01	0.17 ± 0.01	0.02 ± 0.01
Scoville Heat Unit	87,959	21,869	38,901	7639

Source: Ananthan et al. (2014)

37.52% (cv. Byadgi), 88.98% (cv. Guntur), and 62.23% (cv. Guntur brown), respectively. It was also observed that the seed content was highest (51.50%) in Byadgi chilli, followed by Guntur Brown (30.80%), and Guntur (3.95%). Whereas, the stalk content of Guntur, Guntur Brown, and Byadgi chilli was 7.07, 6.97 and 10.98%, respectively.

Nutritional composition

Dried chillies contain ample vitamin C (64 mg/100 g). Also, it comprises an excellent amount of other antioxidants compounds like vitamin A, vitamin B-complex such as thiamine (vitamin B1), pyridoxine (vitamin B6), niacin (vitamin B3) and riboflavin (vitamin B2) and flavonoids like β-carotene, β-cryptoxanthin, zeaxanthin, and lutein. In addition, chillies are rich in phosphorus, potassium, iron, calcium and sodium. The nutritional composition per 100 g of dry chilli is moisture (6.5 g), energy (415 kcal), protein (14.0 g), carbohydrates (58.2 g), ash (7.2 g), calcium (0.1 g), phosphorus (320 mg), sodium (10 mg), potassium (2100 mg), iron (9.9 mg), thiamine (0.59 mg), riboflavin (1.66 mg), niacin (14.2 mg), ascorbic acid (64 mg), vitamin A activity (5180 retinol equivalents), calorific value (246 kcal) and flavour compounds (Capsaicin, dihydro capsaicin) as reported by Chakrabarty et al. (2017). The nutritional composition of different chilli cultivars is appended in Table 1.

Engineering properties of chillies

Plentiful reported studies are deliberating about the evaluation and significance of physical and engineering properties of different dried chilli cultivars' as a function of their moisture content. Such reported information has obvious importance in the design and development aspects of post-harvest machineries'. Kaleemullah and Kailappan (2003) recommended the shape of chilli as oblong because the cylindricity index (0.69) was higher than sphericity (0.61). The authors also reported that the mass of one hundred chillies at 329.44% (d.b.) moisture content was 0.389 kg, whereas the corresponding value at 10.24% (d.b.) moisture was 0.099 kg. In addition, a negative correlation between the axial dimensions and moisture content was observed. A positive relationship was highlighted between moisture content and bulk density; moisture content and apparent density, whereas the angle of repose showed a non-linear trend with moisture content. Decrease in porosity (44.37–43.15%) was observed with reducing moisture content (329.44–250.21% d.b.); however, further reduction in moisture levels (250.21–10.24% d.b) showed a rise in porosity (43.15–51.84%). The static and kinetic coefficient of friction were maximum (0.591–0.497 and 0.563–0.468) on mild steel surface followed by galvanized iron (0.558–0.470 and 0.529–0.435), aluminium (0.527–0.418 and 0.503–0.397), stainless steel (0.488–0.371 and 0.461–0.325) and hardboard (0.433–0.303 and 0.401–0.273) for moisture levels 329.44 and 10.24% d.b., respectively. A linear relationship was noticed between the coefficient of friction on all the surfaces and moisture level. The geometric mean diameter, arithmetic mean diameter, and surface area of the Guntur brown cultivar was highest (44.70 mm, 19.91 mm and 0.17 mm^2), followed by the Byadgi (43.80 mm, 19.57 mm and 0.17 mm^2) and Guntur (37.98 mm, 17.72 mm and 0.18 mm^2) cultivars, respectively (Jalgaonkar and Mahawar 2017).

Harvesting

Harvesting of matured/ripened chilli is preferably done in the morning hours to avoid loss due to field heat and storage heat. The purpose of chilli for growing decides the time and stage of harvesting. For dry chilli and chilli powder, dark red coloured fruits at the moisture content of 65–80% are harvested with 5–6 pickings at an interval of 14–21 days. Approximately 125 workers are required to handle the total chilli picking per hectare. For green chilli powder preparation, the use of chilli harvested 20 days after fruit set was suggested (Panda 2010). It is recommended to harvest all the ripe red chillies as soon as they appear on the plant, which is processed to achieve the best spice colour quality. Applying fruit ripening agents during pre or post-harvest treatment may enhance the quantity of ripe red fruit. Usually, chillies are harvested manually, either by bare hands or secateurs.

The colour and pungency are the main quality parameters for dried chillies. The concentration of capsaicin compounds are responsible for the pungency of chillies, which can be expressed in terms of Scoville Heat Units (SHU). Chillies are also classified based on the level of pungency i.e. mild (900–1995 SHU), medium (2010–19,995 SHU), hot (19,995–99,000 SHU), and extra hot (> 99,000 SHU), respectively (Paramkusam 2017). The nature of pungency has been established as a mixture of seven holologous branched chain alkyl vanillyl amides, named capsaicinoids. The pungency level is uneven and is concentrated more in the placenta (Anu and Peter 2000). American Spice Trade Association (ASTA) colour value indicates the total extractable colour of chilli (Paramkusam 2017). In whole chillies, the proportion of unripe or marked fruits shall not exceed 2% (m/m), and the ratio of broken fruits and fragments shall not exceed 5% (m/m) (IS 2322:2010). Various specifications of different Indian chilli varieties, including the region of cultivation, harvesting season, market availability, colour and capsaicin, is expressed in Table 2.

Table 2 Specifications for Indian chilli varieties *Source*: Anonymous (2021)

Varieties	States	Harvesting season	Characteristics	Availability in market	ASTA colour value	Capsaicine (%)
Birds eye chilli (Dhani)	Mizoram and some areas of Manipur	October to December	Blood red in colour, highly pungent	Kolkata	41.70	0.589
Byadagi	Dharwad	January to March	Red in colour with less pungency or without pungency	Hubli-Dharwad	159.90	Negligible
Ellachipur Sannam-S4 Type	Amaravathi (Maharashtra)	September to December	Reddish colour and very hot	Mumbai, Delhi, Ahmedabad, Nagpur	70.40	0.20
Guntur Sannam- S4 Type	Guntur, Warangal, Khammam in Andhra Pradesh	December to May	Skin thick, hot and red	Guntur	32.11	0.226
Hindpur-S7	Hindpur (Andhra Pradesh)	December to March	Red in colour, hot and highly pungent	Hindpur	33.00	0.24
Jwala	Kheda, Mehsana in south Gujarat	September to December	Highly pungent, light red in colour, short and the seeds are compact	Unjha	–	0.40
Kanthari-White	Kerala and some parts of Tamil Nadu	–	Short and ivory white in colour with high pungency	–	2.96	0.504
Kashmir Chilli	Himachal Pradesh, Jammu & Kashmir and also in sub-tropical regions of North India during winter season	November to February	Long, fleshy, deep red in colour	North India	54.10	0.325
Madhya Pradesh G. T. Sannam	Indore, Malkapur Chikli and Elachpur areas of Madhya Pradesh	January to March	Red in colour and pungent	Madhya Pradesh	–	–

Table 3 Types of post-harvest losses in dry red chillies *Source*: Satyanarayana and Sukumaran (2002)

Types of post-harvest losses	Reason	Prevention
Discoloration	Prolonged exposure to sun during drying operation Harvesting of immature pods	Adoption of improved drying methods Harvesting of mature pods
Mould growth	Adoption of improper drying methods Storage at less than optimal temperature and relative humidity	Adoption of improved drying methods Desired storage conditions needs to be maintained
Loss of seed (seed bleeding)	Loose stem or pod borer Physical injury/Splitting Improper packaging	Handling with care Appropriate packaging Selection of a better variety
Wrinkling of pods	Prolonged exposure to open sun during drying Over drying Delayed picking/over ripening on plant	Adoption of improved drying techniques Drying at optimum temperature and time Timely picking from plant

Post-harvest losses

The annual post-harvest losses in India are 6% (cereals), 8% (pulses), 10% (oilseeds), and 15% (fruits and vegetables) having an estimated value of one lakh crore INR (Jha et al. 2015). Nanda et al. (2012) have also assessed the post-harvest losses of different crops, and mentioned the collective post-harvest losses in chilli as 5.6% (3.9% in farm operations, and 1.7% in storage). Different types of post-harvest losses that occurred in chillies deteriorated its quality and ultimately reduced its market value. It is estimated that at the producer's level, around 15–25% of losses occurred due to improper moisture content, 1–10% takes place due to spoilage in field condition, 5–10% due to farm to assembling

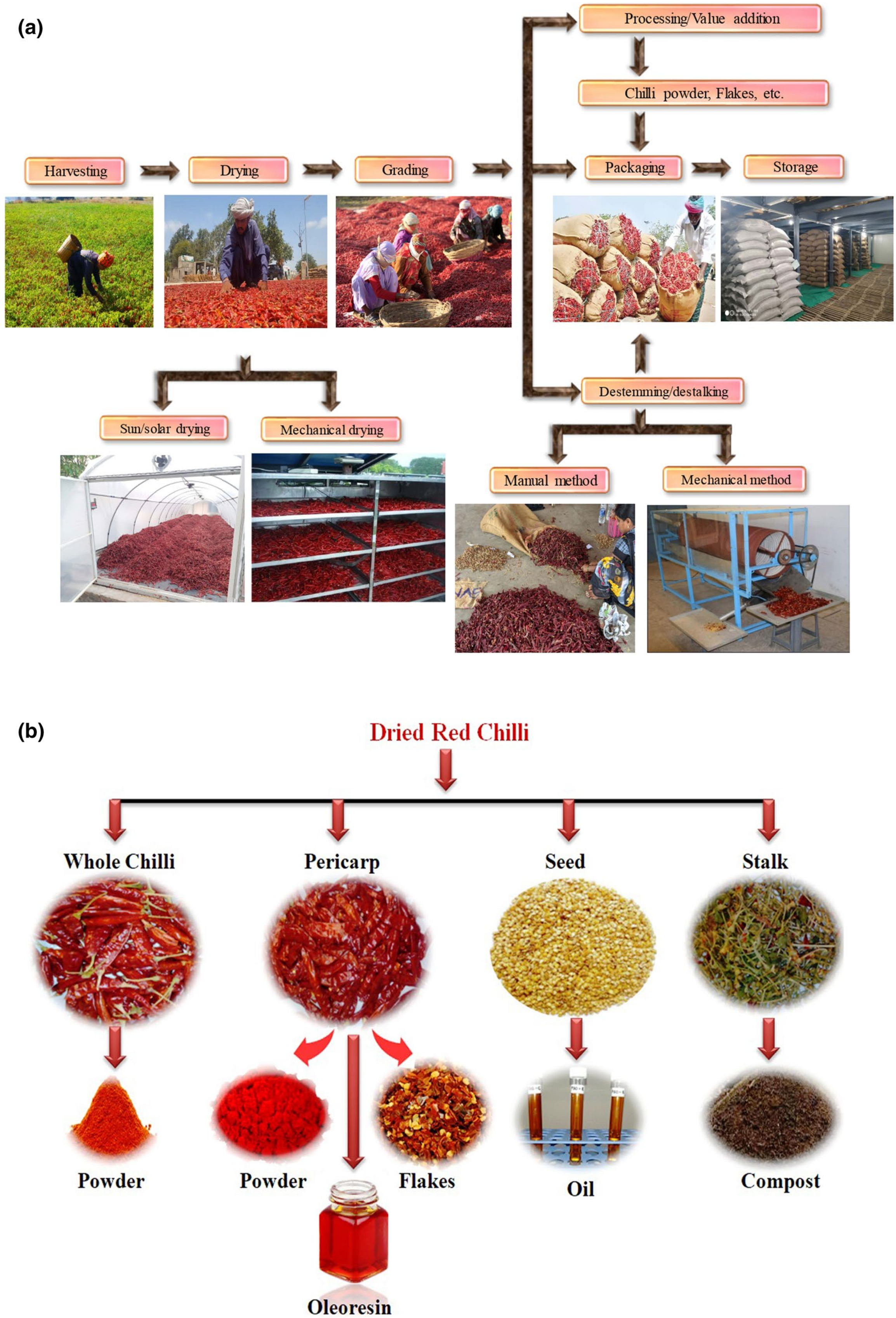


Fig. 1 **a** Unit operations in dry chilli processing **b** value added products from dried red chilli

and 2–5% due to assembling to distribution operation (Anonymous 2002). The types of post-harvest losses, along with their possible reason and prevention, are listed under Table 3.

Post-harvest management

Chilli crop yield, pungency level, the colour of the fruit, and disease occurrence are affected by the stress level that chilli faces in the field, which eventually affects the post-harvest quality due to poor post-harvest management practices. Hence, entire unit operations from harvesting to packaging at the field relate to the product's commercial value. The combination of various unit operations followed in dry chillies processing are shown in Fig. 1a.

The maturity of chilli decides the pungency level, initial colour and retention properties. Pods left to ripen and to wither on plant parts are superior in these qualities to those picked when fully coloured but succulent. The perishability of chillies is higher, and hence it's processing, value addition and storage are considered essential to farmers, processors, exporters and consumers. Since the initial moisture content of freshly harvested red chilli is 65–80%, it becomes difficult to process or store. It is estimated that the shelf life at this moisture content is about 2–3 days at ambient conditions and 15 days at low-temperature storage conditions (Chitravathi et al. 2015). To enhance the storage life of chillies and avoid the development of microflora and subsequent quality loss due to spoilage, reducing the moisture content is mandatory and simultaneously maintaining better aeration to the chillies after harvesting (Samreen and Rao 2017).

Drying

Drying is the most prominent unit operation during dried chilli processing as it determines the product quality and its market significance. Traditionally, in most chilli-producing countries, red chillies were dried directly under the sun due to possible reasons, *viz*., natural and sustainable sources of drying, cost-effectiveness, and field-level drying. With the retention of the fruit quality, any drying technique exhibiting all these advantages may pave the way for the farmer to practice comfortably and effectively. With the advancement in research and development activities, advanced drying techniques were adopted for drying chillies that include sun drying, solar drying, greenhouse type solar drying, heat pump drying, microwave drying, fluidized bed drying, etc. These drying technologies have reportedly improved the quality of the end product by significantly reducing the drying time, resulting in the preservation of the nutrient, colour, and volatile compounds. Pre-treatments are recommended to increase the drying rate and enhance the quality of dried products. Different pre-treatment applied and various drying techniques resulted in lesser drying time while maintaining qualities of dried chilli are listed in Table 4.

Sorting and grading

Quality grading is a pertinent task that needs to be followed to develop any product's modern trade, marketing, and economy. Grading of chillies is one of the main criteria for effective marketing in the local market and has become a prerequisite for international markets due to its worldwide commercialization. External inspection is usually done according to size, colour, moisture content, and the stalk of the pods. The consumers categorize the variety of chillies as per their destined purpose. The end-users are primarily classified into domestic retail users and wholesale industrial users. For powder preparation, chillies with fleshy skin, uniform red colour, pungency, and fewer seeds are preferred by industrial people. There are multiple local and conventional grading practices followed by farmers, village merchants, and itinerant merchants. Visual assessment is used to decide the quality and, thereby, price in open and closed auctions. However, such methods have no well-defined grading standards (Karpate and Saxena 2009).

Grading is done at the producer/processing industries mainly for sorting chillies based on size and colour and discarding unripe, spoiled, damaged, and discoloured chillies. Generally, deep red and light red coloured chillies containing fewer seeds fetch a premium price. Good fruit length, high pungency, shining red colour, and the calyx's strong attachment are other vital factors for a higher price. Whole dried chillies are characterized commercially by their length as ≤ 4 cm, $4 < 8$ cm, $8 < 12$ cm, $12 < 16$ cm, > 16 cm named as size code 1, size code 2, size code 3, size code 4, size code 5, respectively. Chillies are also classified depending on the pungency level in terms of total capsaicinoids (μg/g dry weight) as mild (60–133), medium (134–1333), hot (1333–6600), extra hot (> 6600), respectively as described by Paramkusam (2017).

There is limited technological advancement related to the sorting and grading of dried red chillies. On this line, Shetty et al. (2020) had proposed an automated system that uses image processing techniques and an artificial neural network to grade dry red chillies. Hue saturation value colour model-based algorithm with the efficiency of 80.5% was developed and used to measure the various morphological characteristics and then cluster chillies into multiple grades. The accuracy of the computer-extracted parameters could be higher since the manual approach of measurement did not account for the curves and curls in the sample.

Table 4 Different pre-treatment and drying techniques used for drying of chillies

Drying methods	IMC (w.b.)	FMC (w.b.)	DT (°C)	Drying time (h)	Dryer description	Pre-treatments	Findings	References
Tray drying	86.31	8	60	16	Forced air circulation	Blanching in 2% acetic acid solution for 2 min at 100 °C and by soaking immediately in the chemical solution of 0.3% $Na_2S_2O_5$ combined with 1% $CaCl_2$ for 10 min	32% retention in phenolic compounds observed due to pre-treatment Highest value of pungency index (2.425 ± 0.042) was observed as compared to untreated chilli (0.887 ± 0.004)	Kamal et al. (2019)
Solar poly tunnel and tray drying	80	9.4	35.3–43.5 (Solar poly tunnel) and 56–60 (Tray)	20 (tray), 40 (solar poly tunnel)	Tray dryer (90 × 60 × 90 cm) Solar poly tunnel dryer (3 × 2 × 3 m)	Shredding of chilli, hot water blanching (3 min) followed by dipping in 0.20% potassium meta bisulphite solution + 0.50% citric acid for 5 min	Drying was faster (18 h) in pretreated samples compared to untreated ones (22.60 h) Solar poly tunnel dryer produced bright red coloured powder with relatively higher sugar, and ascorbic acid content	Sharma et al. (2015)
Solar tunnel dryer	77	7	37–60	144-168	Natural convection type, 37.5 m^2 in area, with UV stabilized 200µ polyethylene film, 5 chimneys on the top, 2 exhaust fans and 5 vents towards the bottom to remove the moist air	Hot water blanching (90 °C for 3 min) followed by cooling and draining	Thermal efficiency: 12.25%	Arjoo and Yadav (2017)
Solar drying and low temperature drying system	74	13.5	50 (Solar drying) and 27–30 (low temperature drying)	52	Drying system consisted of humidity control unit (ultrasonic), air-conditioner, temperature and RH sensor, heating coil and microcontroller unit	–	Moisture condensation rate: 2.16 kg water/h Specific energy consumption: 0.75 MJ/kg	Nimrotham et al. (2017)

Table 4 (continued)

Drying methods	IMC (w.b.)	FMC (w.b.)	DT (°C)	Drying time (h)	Dryer description	Pre-treatments	Findings	References
Solar dryer	90	10	64.30	32	Forced convection indirect type double pass solar dryer, collector area 10 m^2, loading density 3.66 kg/m^2	–	Drying efficiency: 24.04% Vitamin C: 2020 mg/kg Contamination by aflatoxin B1: < 0.250 µg/kg Dryer cost: Rs. 1.97 lakh Drying cost: Rs. 5–6/kg Payback period: 3.26 years	Banout et al. (2011)
Solar greenhouse dryer	63.8	8.01	50–55	120	Forced ventilation, 30 m^2 area, 6 mm thick polycarbonate sheet, photovoltaic panels to drive DC exhaust fans, Drying rate: 3.7–6.5 kg/h Drying capacity: 50 kg	–	Quality of red chillies was superior to open sun drying	Samreen and Rao (2017)
Green house type solar drying	74	9	35–58	72	Parabolic shape and covered with polycarbonate sheets, 8 × 20 m^2 area with 9 DC fans powered by three 50 W solar cell modules for ventilation Dryer capacity: 1000 kg	–	Dryer cost: Rs. 18.89 lakh Production: 11,500 kg/year Payback period: 2 years	Kaewkiew et al. (2012)
Infrared and hot air rotary drying	74	8	50, 55, 60, 65, 70	13.5, 8, 5, 4, 2	Four IR heaters (250 W) and one fin coil heater (1 kW) Rotation facility provides uniform drying with fluidize bed effect	–	Optimal drying performance (65 °C) in terms of 0.54–0.56 mg/ml (capsaicin), 20.79–22.16 (a*), 2.21–2.57 kWh (power)	Mihindukulasuriya and Jayasuriya (2015)

Table 4 (continued)

Drying methods	IMC (w.b.)	FMC (w.b.)	DT (°C)	Drying time (h)	Dryer description	Pre-treatments	Findings	References
Far infrared radiation (FIR) assisted microwave vacuum drying	85.5	4–5	Radiation power: 100, 200, 300 W	1.5–3.86 (100 W) 0.56–1.66 (200 W) 0.5 to 1.3 (300 W)	Dryer consisted of microwave oven (2450 MHz and 800 W) 500 W far-infrared heater equipped with dryer Microwave leakage < 0.5 W/m^2	Blanching using hot water (90 °C for 3 min) followed by cooling and draining	Optimum drying condition (300 W microwave power with applied FIR power (300 W) with minimum shrinkage coefficient (0.0218 ± 0.0005), least colour changes, hardness (8.5 N) with highest rehydration ability (1.49)	Saengraya et al. (2015)
Vacuum heat pump drying	76–77	13	50, 55, 60, 65	7	5.2 kW heat pump to supply heat to the drying chamber 1.2 kW liquid ring vacuum pump to control the pressure in the drying chamber	–	Shrinkage percentage (18.18–30.05) Rehydration ratio (1.19–1.38) Change in colour (1.2–13.3) Optimum drying temperature (60 °C)	Artnaseaw et al. (2010)
Solar assisted heat pump dryer	82.5	10	53	26	Dryer dimensions (4.42 × 1 m) Greenhouse cover: Polycarbonate (5 mm thick) Surface area: 10 m^2 Working fluid: R-22 Compressor: 2.50 kW		Drying efficiency: 31.2% Pick-up efficiency: 45.1% Specific energy consumption: 2.40 kWh/kg Net present value of system: 915.60 USD Payback period: 1.9 years	Naemsai et al. (2019)
Natural convective solar dryer	72.27	7.6 (SSD) 10.1 (SC)	41.6 (SSD) 43.13 (SC)		Integrated with SSD and SC as thermal storage medium		Drying efficiency: 18.79% (SSD), 11.89% (SC) Effective diffusivity: 1.227×10^{-10} m^2 /s (SSD) 9.262×10^{-11} m^2 /s (SC) Specific energy consumption: 3.340 (SSD), 5.281 (SC)	Ndukwu et al. (2017)

Table 4 (continued)

Drying methods	IMC (w.b.)	FMC (w.b.)	DT (°C)	Drying time (h)	Dryer description	Pre-treatments	Findings	References
Solar drying combined with $CaCl_2$ desiccant	76	< 5	42.1 to 43.8	57	Drying box size (50 × 50 × 70 cm) Collector size (150 × 100 × 15 cm) Collector material component: Plat absorber-glass wool-aluminum composite Slope angle: 30°	Chilli fruit (13–17 cm length, 4–6 g weight) subjected to washing, sorting, destemming, and cutting in half	The dried pepper powder of whole chilli had higher beta-carotene (20.38 mg/100 g), ash (5.81%), and vitamin C (24 mg/100 g) as that of half chilli	Romauli et al. (2021)
Solar assisted heat pump dryer	4.08	0.08	70.5	11	Dryer integrated with biomass furnace Solar collector area:1.8 m^2 Working fluid: R-22 Capacity: 22 kg	–	Specific moisture evaporation rate:0.14 kg/kWh Drying rate: 1.57 kg/h Thermal efficiency: 9.03%	Yahya (2016)

Where IMC, Initial moisture content (% w.b.); FMC, Final moisture content (% w.b.); DT, Drying temperature (°C); SSD, Sodium sulfate decahydrate; SC, Sodium chloride

Destalking/Destemming

Chilli is very hot among the spices, and its value decides by the pungency, the active principle of which 'capsaicin', anamide derivative of vanillylamine and 8-methylnon-trans-6 enoic acid. The presence of this particular 'capsaicin' makes its destalking (cutting of stem) an arduous and cumbersome process. At the commercial level, chilli is mostly consumed as powder; however, in southern states of the country, whole destalked chilli is used to prepare dishes like *chutney*, *sambhar*, etc. Destalking is considered of paramount importance for both these circumstances and is typically done after adequate drying and before storage/marketing. Also, for the industries where chillies are preferred for export purposes, removing the stalk is considered mandatory by the buyers. Some processing industries also perform manual destalking, which has very low efficiency and is a time-consuming exercise. Chilli being hot spice with a high pungency level, it becomes hard for the labourers involved in destalking. The contract women labourers engaged in destalking can destalk 12–15 kg chillies/day with the labour charge of 3–4/kg INR (Pandey et al. 2013). Destemming is a massive process, and approximately 106 lakh labour days are required to handle the country's total chilli production of 16 lakh metric tonnes (Kumar 2016). According to an estimate, about 320 crore INR annually is being spent in India to destem/destalk the chillies. The chilli stalks have no commercial value, hence being burnt or used for composting. The stem is one of the significant contaminants during value addition as it adds fungi, mites, and fibre materials into the prepared products. The grading criteria for stalkless chillies (without calyx and stalk) includes the maximum tolerance limits for different characteristics i.e. pods with stalk (1% by count); pods with calyx (5% by count); moisture (11 ± 0.5% w.b.), loose seed (5%); foreign matter (0.5%). Further, the general characteristics includes that the chillies shall (a) be the dried form of ripened fruits (b) be free of contaminants like visible mould or insects (c) be in good condition for human consumption (d) be of 1 year's crop and free from extraneous colouring matter, oil and other detrimental substances as mentioned by De (2003).

As evident from the literature, it is corroborated that manual practice of destalking is prevalent; however, there have been attempts executed to mechanize or enhance the efficiency of the existing destalking of the fresh and dried chillies. The machine operation, working mechanism with their corresponding capacity and efficiency are elaborated in Table 5.

Table 5 Machineries developed for destalking of fresh and dried red chillies

Type of chilli	Operation	Mechanism	Capacity/Efficiency	References
Fresh chilli	Mechanized	Neural network and image processing	Static (97%), and working (95.3%)	Huynh et al. (2021)
Fresh chili pepper	Mechanized	Processing speed: 1–5 pepper/s	94 – 30%	Sawantranon and Chansuwan (2019)
Dried red chilli	Mechanized	Rotary with cutting	6.5 kg/h; 85–87%	Jalgaonkar et al. (2022)
Fresh chilli	Semi-automatic	–	Destalking rate (88.37%), damaging rate (6.34%), specific power consumption (20.15 Wh/kg) and capacity (13.9 kg/h) at belt conveyor velocity (0.13–0.18 m/s)	Phong et al. (2017)
Fresh red chilli	Mechanized	Puller, angled belt, mechanical positioning and cup de-stemming	Puller (62%), angled belt (35%), mechanical positioning (54%), cup (73%)	Herbon et al. (2010)

Packaging

Dried chillies being hygroscopic in nature, can absorb moisture from the atmosphere, and therefore the selection of appropriate packaging material and technique is significant for interim storage and distant marketing. As a conventional practice, bulk packaging of well-dried chilli pods in gunny bags is performed for transporting up to the market. Usually, the gunny bags hold about 30 kg of dried chillies, and to accommodate more quantity in each bag, chillies are pressed by compaction. Further, for more compression, manually, it is rammed by labour, increasing the filling capacity to 50 kg per bag (Pandey et al. 2013). Such packaging practice is unhealthy, unhygienic and non-scientific. Researchers have directed their efforts towards improvement in the existing packaging techniques for enhancement of shelf life and maintenance of quality attributes are described in this section:

Naik et al. (2001) evaluated the quality (colour and capsaicin) of dried whole chillies affected by packaging (250 g) in 75µ HDPE and 12µ metallized polyester/37µ LDPE pouches. They reported that packed chillies had better colour after 180 days under refrigerated storage (4–5 °C) than ambient storage. Also, better colour retention was found in chillies stored in metallized polyester polyethene pouches.

Indiramma (2004) emphasized that the low bulk density of dry red chillies poses a problem during packaging. Around 78% volume reduction compared to the original was observed by compressing chillies at 10% moisture during the bailing process with a pressure of 2.5 kg/cm^2. This compression did not cause any damage to the product, whereas compressing the chillies below 8% moisture level can cause breakage loss due to brittleness. Bulk compressed packaging bags of 10–23 kg capacity made up of 75 µ polyethene were used. Such type of packaging reportedly protects against moisture, insects, and contamination from external sources.

Chetti et al. (2014) conducted experiments on the quality estimation of long-term (24 months) stored red chillies influenced by vacuum packaging. In this study, the chilli fruits at moisture level (10 and 12%) were vacuum packed as well as in jute bags followed by storing under ambient (25 ± 2 °C) and cold conditions (4 ± 1 °C) both kept at light and dark environment. Vacuum packaged chillies stored under cold storage had the least variation in quality parameters *viz*. change of moisture, capsaicin, oleoresin, and total extractable colour. The vacuum-packed chillies stored at 12% moisture content recorded better quality parameters over 10% moisture.

Iqbal et al. (2015) evaluated the stability of capsaicinoids and antioxidants of dried peppers *cv*. sky red, maha and wonder king under different packaging (jute, low-density polyethene) and storage conditions (20, 25, 30 °C) for 5 months. A significant reduction was observed in ascorbic acid (22.6%), phenolic compounds (19.0%), carotenoids (17%) and capsaicinoids (12.7%), respectively, during storage with a more pronounced effect at a higher temperature. The degradation rate was reported to be higher for peppers packed in jute bags than for those wrapped with LDPE. Despite the sensitivity of capsaicinoids and antioxidants towards atmospheric conditions, the packaging material and ambient storage helped in the preservation of about 77–87% of the compounds.

Storage

Storage conditions greatly influence the colour of the dried chillies though it did not majorly affect its pungency. Colour is one of the primary fascinating factors for a producer's price. Hence, conserving the colour is a final determinant in whole chilli processing before it reaches the consumers, which can be necessarily achieved during the storage period. Comparatively, the effect of packaging and storage are more prominent than the effect of drying temperature. Cold storage is the preferred mode of storage during the summer season, imparting colour retention and protection against infestation. Generally, the conditions (5–8 °C and 55–60% RH) are recommended for cold storage and are extensively followed by farmers in India to obtain premium quality chillies. If the cold storage temperature goes beyond 5 °C, condensation occurs, resulting in discolouration and decay of pods. Presently, the farmers prefer storing the harvested chillies for not more than 9 months unless the market prices are low. The cold storages usually are with a plinth area of 1000–2000 m^2 with 4–6 floors. Each floor is to a height of 3–4 m, and the evaporators are placed on each floor for uniform distribution of temperature. The bottom of each floor is made of wooden planks, and only steps are used to reach various levels of storage godown. The walls and roof of the cold storage godowns are constructed with brick and concrete. The latest ones are constructed with polyurethane foam lined with a metal sheet with improved insulation (Satyanarayan and Sukumaran 2002).

Duman (2010) evaluated the effect of storage (hermetically sealed/ vacuum storage) on the quality indices of one tonne Turkish red chili peppers. The results suggested that the dried chillies stored under vacuum-hermetic storage (8–22 °C, 38–42% RH, absolute pressure 80–100 mm Hg) had retained the quality characteristics such as colour, pungency, and aflatoxin of red chili peppers for 6 months. Chetti et al. (2014) suggested that vacuum packaging in impervious film found to be superior technology to preserve chilli up to 24 months storage at ambient (25 ± 2 °C) and cool (4 ± 1 °C) conditions. Cold storage of chilli showed least decline in total extractable colour, oleoresin extractable colour and capsaicin content. Addala et al. (2015) recommended the controlled atmospheric storage (22 °C and 45% RH + ethoxyquin) for paprika products that showed a significantly lower extractable colour loss. It was also observed that the samples stored at high temperature and humidity degraded rapidly as compared to those stored in room conditions.

Quality parameters considered during procurement

As already described, pungency and colour are excellent quality characteristics for dried red chillies. Pungency has been the combined effect of combining seven hologous branched-chain alkyl vanillyl amides, named capsaicinoids. The distribution of these pungency-causing components is uneven in the fruit and is highest in the placenta (Anu and Peter 2000). The red colour is attributed to the carotenoid pigments (capsanthin and capsorubin) comprising 60% of the total carotenoids. Other major pigments are Betacarotene Violaxanthin, Neoxanthin, and Lutein (Anu and Peter 2000). The following parameters are considered as the preferable qualities aspects of the dried chillies detrimental for overall sound quality and accordingly price fixation:

- Properly dried to the safe moisture content below 10% (w.b.)
- Good shining wrinkle, no bleaching/discolouration on the surface.
- Bright uniform red colour.
- Good pungency level.
- Medium size fruit with a moderately thin pericarp.
- Firm pedicle/stalk.
- Few seeds in fruit.
- Free from contamination.

Value addition of dried red chillies

The value addition can be classified into two phases. The first is the manufacturing process that involves cleaning, drying, grading, sieving and packing chilli. The second phase consists in processing to obtain various products, *viz.*, chilli powder, chilli flakes, chilli oleoresin, seed oil, etc. (Fig. 1b). Overall, value addition builds up profit to farmers and easies to transport catches more attraction of consumers, and it adds flavour to the product.

Red chilli powder

Red chilli powder is an intriguing constituent of Indian and international cuisines as it is responsible for the distinctive bright red colour and pungency feature. Powdered chillies are achieved by subjecting the pure, clean, dried, ripe chilli fruits for pounding. Chillies shall be grounded to the desired fineness level such that it completely passes through a 500 µm IS sieve (IS 2322:2010). The permissible constraints for chilli powder are moisture content (≤ 10%), scoville index (≥ 24,000), total ash (≤ 8%), acid insoluble ash (≤ 1.3%), crude fibre (≤ 30%), non-volatile ether extract (≥ 12%) (IS 2322:2010). Also, the powder should have its characteristic red colour, pungent taste, and flavour. For export purpose, grading of chilli powder is usually done based on granule size as coarse (500–600 µm), medium (300–500 µm), and fine (200–300 µm). Maximum 2% of edible vegetable oil by weight can be incorporated in chilli powder with a proper label mentioning about quantity and nature of oil utilized. The main contaminants found in chilli powder are brick powder, lead soluble salts, and oil-soluble tar. Such contaminants can cause health disorders such as

Table 6 Machineries used for production of chilli powder

Machineries used	Specification	Findings	References
Plate mill Pin mill	Moisture content of chilli was kept as 14 ± 0.5% (d.b.) during grinding Pin mill consisted of rotating disk having diameter of 0.23 m operated using 4 kW motor Plate mill consisted of 0.18 m diameter iron grooved plate operated by 1.5 kW motor	Best machinery combination of one pass through pin mill without the screen and other two passes through plate mill was obtained to produce chilli powder of 500 µm particle size 0.095 kWh energy was required to produce chilli powder	Bandara et al. (2015)
Cryogenic grinder (CG) Low temperature pulverizer (LTP) Spice pulverizer (SP)	–	Moisture content of chilli powder ground in CG, LTP and SP was 10.08, 9.11 and 8.91 (% d.b.), respectively. Retention of colour value, nutrients was found in the order CG > LTP > SP. About 0.017% capsaicin content in CG followed by LTP (0.012%) and SP (0.007%) Operating cost was 0.98 INR/kg (SP), 1.34 INR/kg (LTP), and 4.92 INR/kg (CG), respectively.	Mallappa et al. (2015)
Evaporative water cooling grinding	Moisture content of chilli was 7.95 ± 0.26% (d.b.) during grinding Main components includes water atomizing unit, dehumidified air supplying unit and grinding unit with vibratory hopper Main purpose to reduce the temperature by absorbing heat increase	During grinding, 12 ± 1.53 °C reduction in the temperature was observed at 30 kg/h of feed rate and 2.1 kg/h of water spray rate. 15% more recovery of capsaicin was reported Water activity of all the grinding samples was within the acceptable range	Bandara et al. (2017)
Hand pounding (HP) Ambient grinding in ball mill (AG) Cryo-grinding in ball mill (CG)	Moisture content of chilli was 11.10% (d.b.) during grinding In CG liquid nitrogen (LN_2) used as a cryogen HP, AG and CG carried at different grinding temperature of 30 ± 2 °C, 30 ± 2 °C, and − 90 ± 3 °C, respectively.	CG showed finer particle size, higher uniformity and larger specific surface area of ground powder than that of HP and AG. Better colour retention, smoother and more regular surface along with higher mineral content (K) in CG ground powder	Singh et al. (2018)

stomach disorders, metal toxicity, cancer, lead poisoning, heart disease, and liver damage, etc.

Wang et al. (2009) reported that during the storage of dehydrated peppers, capsaicin and dihydrocapsaicin content got diminished. The authors suggested that heating red chilli powder to 100–190 °C for 15 min had no significant effect on capsaicinoids, while heating at > 190 °C resulted in the degradation of capsaicin and dihydrocapsaicin. The decrease in capsaicin and dihydrocapsaicin was 17.50% and 16.05%, while heating at 200 °C, 53.18% and 54.91% at 230 °C, 94.32% and 93.19% at 260 °C, respectively. The study also suggested that storing the peppers at low temperatures (2–5 °C) has improved the retention of capsaicinoids during storage. In contrast, the mode of packaging (air/vacuum) did not affect the storage stability.

Akusu (2019) conducted a study analyzing the effect of packaging materials on ground pepper's shelf life and quality attributes. The results demonstrated that quality attributes of chilli powder *viz*. moisture (7.94–8.28%) and carbohydrate (33.21–35.77%) increased, while protein (10.20–9.43%), fat (16.97–16.17%), ash (5.58–5.01%) and crude fibre (26.11–25.29%) decreased during ambient storage of 60 days. The polypropylene packaging (30µ and 20µ) was adjudged better for extended storage of ground pepper and retention of carotenoids, colour, and pungency.

Making chilli powder is mechanized primarily, and various grinding techniques are mentioned in the literature. The detailed information about the different mechanisms/machineries used to prepare chilli powder is presented in Table 6.

Red chilli flakes

Chilli flakes can be obtained by adequately removing the peduncles, and seeds from fresh red chilli. Chillies can be longitudinally crushed or manually cut into 2 or 3 pieces after cleaning with water. The slices to be dehydrated by sun drying (33 ± 5 °C) until moisture decreases below 15% (d.b). Subsequent to drying, the slices can be grounded by a mill to obtain the final size of flakes in the range from 1 to 5 mm. Chilli flakes are among the crucial ingredients, and are nowadays used for garnishing over many processed foods to give a spicy taste.

Oleoresin

According to FAO, chilli oleoresin is obtained by solvent extraction of paprika, which consists of the fruit pods powder, without or with the seeds having dark red viscous liquid (Anonymous 2002). It contains major colouring principles namely capsanthin ($C_{40}H_{56}O_3$) with other coloured compounds such as capsorubin, canthaxanthin, cryptoxanthin, zeaxanthin, and lutein, as well as other carotenoids. The main flavouring compound present in oleoresins is capsaicin ($C_{18}H_27O_3$) which is used in pharmaceutical applications such as vapor rubs, pain balms, linaments, prickly heat powders, ointments for cold, sore throat, chest congestion, and skin ointments.

To extract oleoresins, trichloroethylene, acetone, propan-2-ol, methanol, ethanol, hexane solvents are used. The organic solvent can be recovered afterwards from the oleoresin. Spice oleoresins need to be followed export standards. Solvent residues in the oleoresins should not exceed 30 ppm. Sarojam et al. (2020) reported that crude oleoresins yield of different varieties of chillies collected from the Guntur market (India) was varied from 3.32 to 8.82%. Maximum yield (8.82%) was noticed in the Teja (S-17) variety whereas, the wonder hot variety showed a minimum yield of 3.32%.

Oleoresins are insoluble in water and glycerin, and are soluble/dispersible in oil and fat. They can be used directly in fatty products like oil-based dressings and sauces, processed meats, canned foods, etc. High pungent and low colour oleoresin can be used for pharmaceutical, nutraceutical and cosmetic industries (Satyanarayana and Sukumaran 2002).

Fernández-Ronco et al. (2013) reported that ultrasound-assisted technique has resulted in lesser extraction time of oleoresin from *Capsicum annuum* compared with maceration. In the study, the highest oleoresin recovery (84 wt%) was obtained using hexane at 298 K (extraction temperature and 1:4.3 (powder: solvent). Kostrzewa et al. (2020) extracted carotenoids from sweet paprika using supercritical CO_2 and reported that process conditions *viz*. pressure (43–45 MPa), temperature (319–323 K), and time (54–60 min) resulted in the enhanced recovery of carotenoids (84%).

Capsanthin

Nowadays, plenty of restriction is being applied by many countries on the application of artificial colour. In the circumstances of expected banning of the coal-tar based synthetic food colours, colour extracted from chilli might have excellent potential as a "natural plant colourant" in the food industry.

Extractable colour signifies the total pigment specifically when powder addition as an ingredient/colourant in oil-based products. Anu and Peter (2000), in their study, reported that the total extractable colour (TEC) was highest in destalked chilli powder (1066.30 ± 0.18 ASTA units) than whole chilli powder (905.15 ± 0.12 ASTA units).

Jalgaonkar et al. (2022) reported that destalking has resulted in about a 12.29% increase in TEC as stalk in the whole chilli while grinding has deteriorated the TEC. The total carotenoid content was also higher for destalked chilli powder (90.90 ± 1.45 mg/100 g) than whole chilli powder (85.91 ± 0.35 mg/100 g). The results corroborated that destalking of chilli before processing is prominent to obtain a superior chemical composition.

Chilli seed

Chilli seeds are the by-products obtained when preparing process products like crushed chillies and chilli powder. The seeds are principally consumed for oil extraction, which can be carried out using expeller, solvent extraction, supercritical CO_2 extraction, and microwave-assisted extraction techniques. It can have extensive applications to be used as edible oil, pickling, and industrial purpose. Seed cake is the by-product of the oil extraction process. Oil extraction from the chilli processing by-products would make the processing industries more efficient and productive.

The seed contains 16–25% of oil, which predominantly comprises 68–72% linoleic acid, 13–15% palmitic acid, 9–11% oleic acid, 2.15% stearic acid, 0.8% free fatty acid as oleic acid %, 136 iodine value, 194 saponification value, and 4.2 Meq O_2/kg oil peroxide value (Reddy and Sarojine, 1987). Also, various minerals and vitamins A, D, E and K are present in the seed and particularly beneficial to healthcare and anti-ageing. To increase the chilli powder yield and reduce its pungency level, sometimes chilli powder is mixed with red chilli powder.

Yilmaz et al. (2015) carried out roasting and enzyme treatment to chilli seeds before oil extraction by cold pressing methods. The seed roasting was accomplished using a hot air oven (150 °C for 25 min). In the enzyme treatment, the seeds were incubated with 100 U/g seed hemicellulose and 0.25 U/g seed protease. Cold pressing was reported to be inferior oil sensory properties, consumer acceptability with a low oil yield. The positive effect of pre-roasting yielded higher oil recovery with enhanced sensory characteristics. The corresponding oil yield was 5.12 ± 0.08% (control), 6.65 ± 1.02% (roasted) and 5.41 ± 0.62% (enzymatic), respectively.

Chouaibi et al. (2019) extracted the oil from seeds of red pepper using four different extraction methods such as cold press extraction (CP), soxhlet extraction (SE), supercritical CO_2 extraction (SCE), and microwave-assisted extraction (MAE). Oil yield and capsaicin content in oil extracted by MAE showed the highest value (32.87 ± 0.07% and 18.14 ± 0.12 mg/kg oil) followed by SCE (25.27 ± 0.12% and 18.02 ± 0.15 mg/kg oil), SE (18.39 ± 0.10% and 6.68 ± 0.10 mg/kg oil) and CP (14.60 ± 0.25% and 3.45 ± 0.05 mg/kg oil), respectively. MAE showed the highest total tocopherols content. Oxidative stability was found high (11.26 h) in MAE seed oil whereas, it was low (1.25 h) in SE seed oil.

Seed meals contain a good amount of protein (19.29 ± 0.25%) and some minerals (potassium, zinc, iron, boron, magnesium, calcium, copper, aluminium, sodium). However, some anti-nutritional factors such as tannins (1.66 ± 0.03 mg CE/g meal) and phytic acid (11.36 ± 0.01 mg P/g meal) were also present, in minute quantity than similar kinds of meals. Most importantly, the meals displayed some functional properties, for instance, emulsion stability (43.52 ± 0.75%), water-holding capacity (2.46 ± 0.07 g water/g meal), oil holding properties (1.38 ± 0.04 g oil/g meal), emulsifying activity (45.92 ± 0.75%), foaming capacity (116.67 ± 23.56%) and foam stability (74.00 ± 11.31%) (Yilmaz et al. 2017). Also, the authors have emphasized that meals obtained after oil extraction using the cold pressing method possess superior quality because of mild operating conditions and the absence of solvents/chemicals and can be used for human consumption.

Zhang et al. (2019) studied the effect of roasting on the qualitative parameters of oil. The findings suggested that oil obtained from roasted seeds had more excellent oxidative stability during storage (60 °C for 1 month) than unroasted seeds. Vitamin E of unroasted pepper seed oil was reduced significantly (66.8 to 8.7 mg/ 100 g) after 15 days of storage. On the contrary, vitamin E of seed oil after roasting was reduced from 87.1 to 30.1 mg/100 g (120 °C), 62.7 to 42.6 mg/100 g (160 °C) and 56.4 to 39.2 mg/100 g (200 °C), respectively. The results emphasized the role of roasting on the increased stability of vitamin E.

Chilli stalk

Chilli's stalks (calyx) are generally removed as waste during food processing. The stalk contains strong antioxidant activity with a high amount of total flavonoids, total phenols, and capsaicin (Chen et al. 2012). Higher scavenging activity was found in red pepper stalk than pericarp and placenta, with increased effectiveness in ABTS, DPPH, and nitric oxide scavenging radicals. Also, high content of total phenols (19.43–27.08 mg GAE/g d.w.), total flavonoids (12.68–19.71 mg NAE/g d.w.), and capsaicin (1.17–15.23 mg/g d.w.) were contained in the extract obtained from the stalk. This demonstrated that red pepper stalk as a potent antioxidant could be used natural antioxidant as an alternative in kimchi or other foods (Chen et al. 2012). On a similar line, Olatide et al. (2019) used chilli stalks for yoghurt production as a source of non-dairy lactic acid bacteria in the milk fermentation due to the presence of microorganisms in the stalk decreased pH and increased titratable acidity in yoghurt. The chilli stalks after their removal have no commercial value and hence are burnt or used for composting (Pandey et al. 2013).

Conclusion and future prospective

The production and per capita consumption of dry chillies have increased steadily across the globe. Dried chillies' demonstrative and superlative features make them a key ingredient in distinct food cuisines and medicines. Though post-harvest mechanization has sufficiently nurtured the spice processing sector in displacing manual labour, there still exists a void for developing efficient processing technology for different chilli varieties. In the current perspective of an open and competitive global market, the chilli producing and consuming countries need to follow standardized process protocols to meet the international standards for the production and export of better quality value-added products. Unit operations such as drying, destalking, packaging, storage, and product development have many challenges and scope for a well-organized value chain of dried chillies. Consolidation of post-harvest technologies for implementation in chilli growing countries may drastically bring down post-harvest losses and meet international demand, tailored as per the importer's requirement.

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