Analysis of Temperature and Drying Time Effects Using Tray Dryer on Physicochemical Characteristics of Red Cayenne Pepper (Capsicum frutescens L.): Mini Review

Ana Nadiya Afinatul Fishi[1]*, Saepul Adnan[2], Faathira Nuur Qodrina[3], Muhammad Rizki Maulana Setiawan[4], Nabiqi Zulfaa Rachman[5], Putri Auliya Rahmawati[6], Dedeh Rosmaniar Sofia[7]

[1,2,3,4,5,6]Food Technology, Faculty of Science and Technology, Universitas Muhammadiyah Bandung, Bandung, West Java, Indonesia

[7]Departement of Agro-industrial Technology, Faculty of Agrotechnology, Universitas Al-Ghifari, Bandung, West Java, Indonesia

ABSTRACT

Red cayenne pepper (Capsicum frutescens) was a high-value horticultural commodity with a high moisture content (60–85%), which made it highly susceptible to postharvest deterioration. Drying was widely employed to extend shelf life while retaining bioactive compounds, including capsaicin, vitamin C, and carotenoids. This literature review aimed to evaluate the effects of drying temperature and duration using tray-dryer technology on the physicochemical quality of red cayenne pepper in whole and powdered forms. The reviewed studies showed that drying temperatures above 60°C accelerated vitamin C and carotenoid degradation through thermal degradation and oxidation and enhanced non-enzymatic browning, resulting in undesirable color changes. In contrast, lower temperatures prolonged the drying process and potentially increased the risk of microbial growth. Although capsaicin was relatively stable to heat, prolonged exposure to elevated temperatures could decrease pungency. Overall, drying at 50–60°C with an appropriate drying duration was identified as a suitable condition for achieving a safe moisture content (<10%) while retaining nutritional quality, color stability, and sensory characteristics. The findings indicated that careful control of drying temperature and duration was essential for maintaining the physicochemical and functional quality of dried and powdered red cayenne pepper. These findings provided a basis for optimizing tray-drying conditions for the production of stable, high-quality red cayenne pepper products.

Keywords: Red Cayenne Pepper, Tray Dryer, Drying Temperature

INTRODUCTION

Red cayenne pepper (Capsicum frutescens L.) is one of the horticultural commodities with high economic value, yet it is highly susceptible to postharvest damage due to its high moisture content, ranging from 70% to 80% (Atika Yahdiyani Ikhsani, 2015). This is further supported by (Alhanannasir et al., 2024) and (Agarry et al., 2022), who note that once harvested, the water content of chili peppers increases to around 60–85%, giving them a shelf life of only about 2 to 3 days after harvest. To reduce losses and extend shelf life without damaging active compounds such as capsaicin, drying has become the most commonly applied solution. Drying is the reduction of moisture content with the aid of natural or artificial heat energy (Lailatul Dinda Saputri et al., 2022). The purpose of drying is to lower the moisture content of the material by adding heat to drive water out of the material, thereby giving the chili a longer shelf life (Theresya Narotama Nia Anggraeni Sutrisni, 2021).

According to research on red chili (Capsicum annuum L.) conducted by (Tomi L. Olatunji, 2018), global production of C. annuum in 2014 was estimated at 409,000 tons, projected to increase to around 454,000 tons in 2015. Global chili consumption was estimated at around 400,000 tons and has increased progressively, with consumption growth rates in Asia and the Middle East at 3%–4%. Globally, the consumption growth rate is 2%–3% per year. Among red chili producers, Indonesia is one of the largest, on par with India at 16%, and below Vietnam, which produces at 35%.

Red cayenne pepper (Capsicum frutescens) is not merely an ordinary kitchen spice commodity, but a significant source of bioactive compounds for health. Its most distinctive main content is capsaicin, an alkaloid compound that provides a spicy sensation while also acting as a thermogenic and anti-inflammatory agent. In addition to capsaicin, red cayenne pepper is rich in essential vitamins, particularly vitamin C, whose levels often exceed those of citrus fruits, as well as vitamin A in the form of beta-carotene, which functions as a natural antioxidant. The intense red color of this fruit also indicates the presence of carotenoid pigments such as capsanthin and capsorubin, which are effective in neutralizing free radicals (Sestry Misfadhila et al., 2022).

Although extensive research has been conducted on chili drying, comprehensive literature data integrating the effects of air velocity and relative humidity on mass transfer coefficients, as well as energy-exergy analysis, remains very limited (Agarry et al., 2022). Therefore, combining experimental studies with mathematical modeling is necessary not only to predict drying profiles across various temperature ranges, but also to develop new models that can improve energy efficiency in the food processing industry.

There are quite a number of processing methods aimed at extending the shelf life of red cayenne pepper, one of which is the drying method mentioned above. This method has certainly been widely applied across many industrial sectors, not only for red cayenne pepper. This preservation method offers its own advantages along with effectiveness in maintaining the quality of the resulting product, combined with the many technique variations available within a single method, which must be adjusted to production needs, thus requiring an in-depth study of drying methods. The type of drying method focused on in this literature review is the Tray Dryer.

Chemical Components of Cayenne Pepper

The level of pungency in chili is influenced by the content of capsaicinoid compounds (particularly capsaicin and dihydrocapsaicin). Capsicum frutescens (cayenne pepper) has a higher capsaicinoid content than other chili varieties. Cayenne pepper also has a higher vitamin C content compared to red chili, as well as fruits such as mango, orange, pineapple, apple, tomato, and starfruit, among others. In addition, the phytochemical compounds in cayenne pepper are diverse, including tannins, flavonoids, alkaloids, anthraquinones, phenols, saponins, glycosides, terpenoids, limonoids, and carotenoids (Kusnadi, 2019).

Effect of Tray Dryer Drying on the Nutritional Content of Cayenne Pepper

The use of the tray dryer method in drying red cayenne pepper has a significant effect on nutrient retention, mainly due to constant heat exposure and air circulation. The nutrient component most affected is Vitamin C (ascorbic acid), which is highly labile and easily oxidized by heat and oxygen. At excessively high drying temperatures (above 60°C), the rate of Vitamin C degradation increases drastically due to damage to its molecular structure. However, the use of a tray dryer with proper temperature settings and shorter drying times can actually minimize nutrient loss compared to traditional sun drying, which is uncontrolled and directly exposed to UV light (Tanggasari J. &., 2025).

Recent experimental evidence indicates that moderate drying temperatures, particularly around 50–60 °C, may provide a suitable balance between drying efficiency and quality retention in chili peppers; however, this range should not be regarded as a universal optimum. In red cayenne pepper (*Capsicum frutescens* L.), drying at 50, 60, and 70 °C showed that increasing temperature and drying time affected vitamin C, β-carotene, and capsaicin retention, with 60 °C for 20 h identified as the optimum condition under the specific experimental conditions, whereas higher-temperature treatment resulted in greater losses of some quality attributes (Lourenza & Murdianto, 2026). Similarly, another study on *C. frutescens* reported better vitamin C retention at 50 °C, demonstrating that the optimal temperature may vary depending on the targeted quality attribute (Murni & Tanggasari, 2025). Supporting evidence from red chili (*Capsicum annuum* L.) also showed reduced carotenoid and capsaicinoid retention when the drying temperature increased from 40 to 60 °C across several drying methods (Krzykowski et al., 2024). Therefore, temperatures above 60 °C may increase the risk of degradation of heat-sensitive or quality-related compounds under certain processing conditions, but the appropriate drying temperature should be determined according to cultivar, drying technology, sample characteristics, drying duration, and the specific quality attributes targeted.

On the other hand, capsaicin, the compound responsible for the pungent taste, tends to be thermostable, so the effect of tray dryer temperature on pungency is usually not as significant as its effect on micronutrient content. Overall, optimizing temperature and time parameters in the tray dryer is crucial: too low a temperature prolongs drying time, triggering microbial growth, while too high a temperature damages the integrity of nutrients and bioactive compounds in the chili (Tanggasari, 2023).

Chili Powder

Chili powder is a form of fresh chili preservation obtained through drying and grinding stages until it becomes powder. Chili powder particle size is generally classified into three categories: coarse (500–600 µm), medium (300–500 µm), and fine (200–300 µm), which pass through the sieving process. In powder form, chili has a higher economic added value because it is more practical to use and simplifies packaging and distribution. To produce high-quality chili powder, certain quality standards must be met, including moisture content ≤10%, a minimum pungency index of 24,000 Scoville Heat Units (SHU), ash content ≤8%, and crude fiber ≤30% (Jalgaonkar et al., 2024). The pungency level of chili powder is also categorized based on SHU value: not spicy (900–1,999 SHU), mildly spicy (2,000–19,999 SHU), spicy (20,000–100,000 SHU), and very spicy (>100,000 SHU). In addition, based on SNI 3389:2023, chili powder that meets quality standards must have a maximum moisture content of 11%, be free of pests and diseases, contain no added sulfur dioxide (SO_2), and have a characteristic chili aroma (Badan Standardisasi Nasional, 2023).

According to Dendang et al. (2018), the optimal quality of chili powder is influenced by process parameter settings such as drying time and temperature, pressure, and the drying method used. The use of high temperatures can indeed accelerate the drying process, but has the potential to reduce the nutrient content of the final product. Therefore, further study is needed on the effects of various drying methods on the physicochemical characteristics of chili powder to obtain the most effective process conditions for maintaining product quality.

Effect of Tray Dryer Drying on the Physicochemical Properties of Fresh Red Cayenne Pepper

The drying process using a tray dryer is a dehydration method that utilizes convective hot air flow to move water from within the tissue of red cayenne pepper to the surrounding environment. Physically, the parameters most affected are color and texture. According to Hawa et al. (2019), high drying temperatures cause non-enzymatic browning, or the Maillard reaction, in which amino groups react with reducing sugars, turning the bright red color of the chili darker or brownish. In addition, cell shrinkage due to rapid water loss damages the chili's capillary structure, which directly reduces the product's rehydration capacity when it is reused in food processing.

In terms of chemical characteristics, vitamin C content and carotenoid pigments are the components most sensitive to heat. Vitamin C (ascorbic acid) is thermolabile and easily oxidized. Research by Arslan & Özcan (2011) showed that using temperatures above 60°C in a tray dryer can significantly reduce vitamin C levels compared to low-temperature drying methods. On the other hand, capsaicin, the compound responsible for the pungent taste, tends to have better thermal stability. However, excessively long drying durations in a tray dryer still risk reducing pungency intensity due to long-term thermal degradation.

The balance between drying temperature and time is crucial for maintaining the antioxidant activity of red cayenne pepper. The decrease in total carotenoids during the drying process often occurs due to exposure to oxygen and heat, which breaks the double bonds in the pigment molecules. Therefore, optimizing the drying temperature within the range of 50°C to 60°C is considered the ideal standard for minimizing physicochemical damage while achieving a safe moisture content below 10%, in order to extend product shelf life without losing its original nutritional and sensory identity (Toontom et al., 2012). Comparison of drying conditions and their effects on physicochemical and bioactive characteristics of chili pepper reported was shown at Table 1.

Organoleptic Analysis and Chili Powder

The organoleptic quality of red cayenne pepper dried using a tray dryer is greatly influenced by the interaction between temperature and duration of heat exposure. In terms of color, the drying process ideally preserves carotenoid pigments to keep the chili bright red; however, using temperatures above 60°C often triggers non-enzymatic browning (Maillard reaction) and pigment oxidation, causing the powder's color to become dark red or dull. This decrease in brightness and redness values is the main visual indicator for determining the extent of thermal damage occurring in the chili tissue (Saputri, 2022).

Comparative analysis of recent studies indicates that drying temperature and drying duration should not be considered independently when evaluating the quality of dried chili pepper. Increasing the drying temperature generally accelerates moisture removal and shortens the required drying time; however, prolonged exposure to elevated temperatures may intensify the degradation of heat-sensitive bioactive compounds. Recent studies on Capsicum have reported reductions in vitamin C and capsaicinoids under more severe thermal conditions, whereas milder drying conditions tend to provide better retention of sensitive compounds. In addition to chemical composition, thermal drying can modify color attributes and flavor characteristics, indicating that optimization should consider both drying efficiency and quality retention rather than moisture reduction alone. In terms of texture, drying changes the chili's cell structure from soft and watery to hard, brittle, and easily crushed. This occurs due to massive water evaporation from the cell vacuoles, causing cell wall shrinkage and creating air cavities within the tissue. This very dry texture is highly beneficial for the grinding process into powder, because the lower the moisture content, the finer the resulting particles and the lower the risk of caking during storage (Saputri, 2022). Meanwhile, the fresh, pungent aroma characteristic of red cayenne pepper tends to shift toward a dried spice aroma or a slightly smoky (roasted) scent. The volatile compounds or essential oils responsible for the fresh aroma are highly sensitive to heat and easily evaporate during air circulation within the drying racks. Therefore, setting the temperature too high can cause a significant loss of the original aroma profile, although the pungent compound (capsaicin) remains stable and does not affect the perception of sharpness on the tongue (Saputri, 2022).

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Table 1. Comparison of drying conditions and their effects on physicochemical and bioactive characteristics of chili pepper reported in recent studies

Reference	Pepper species	Drying system	Temperature	Drying time	Moisture content / endpoint	Vitamin C	Carotenoids	Capsaicin / capsaicinoids	Color	Main finding
Susilawati & Tanggasari (2023)	Capsicum frutescens L.	Tray dryer	45 °C	6 h	77.10%	0.65%	NR	244.4072 ppm; 730.776 SHU	NR	Highest vitamin C and capsaicin among the tested temperatures
			50 °C	6 h	54.10%	0.52%	NR	229.2425 ppm; 710.84 SHU	NR	Higher temperature reduced moisture and vitamin C
			55 °C	6 h	50.30%	0.54%	NR	226.1886 ppm; 720.721 SHU	NR	Lowest moisture content and highest weight loss
Lourenza & Murdianto (2026)	Capsicum frutescens L.	Food dehydrator / tray-type system	50 °C	16 h	40.05 ± 1.73%	931.84 ± 7.20 µg/g	47.89 ± 9.53 µg/g β-carotene	760.73 ± 2.82 ppm	L*=47.08; a*=23.76; b*=39.62	High residual moisture and highest vitamin C retention
			50 °C	20 h	14.57 ± 0.21%	893.29 ± 4.53 µg/g	108.29 ± 11.77 µg/g	683.52 ± 18.16 ppm	L*=54.04; a*=22.66; b*=43.03	Longer drying substantially reduced moisture
			50 °C	24 h	12.92 ± 0.60%	867.21 ± 13.24 µg/g	128.92 ± 44.48 µg/g	735.31 ± 12.95 ppm	L*=51.99; a*=21.72; b*=42.93	Vitamin C continued to decline with time
			60 °C	16 h	7.40 ± 0.34%	841.59 ± 14.78 µg/g	193.48 ± 47.63 µg/g	960.36 ± 76.86 ppm	L*=55.03; a*=27.24; b*=53.35	Faster drying with higher capsaicin concentration
			60 °C	20 h	5.40 ± 0.39%	795.56 ± 11.02 µg/g	219.91 ± 19.88 µg/g	998.96 ± 77.17 ppm	L*=58.20; a*=25.38; b*=52.64	Overall optimum reported by the authors
			60 °C	24 h	4.70 ± 0.18%	766.53 ± 0.00 µg/g	225.19 ± 21.57 µg/g	885.97 ± 21.58 ppm	L*=59.22; a*=24.10; b*=52.32	Prolonged drying reduced vitamin C and capsaicin
			70 °C	16 h	3.54 ± 0.20%	745.22 ± 14.37 µg/g	236.58 ± 46.97 µg/g	844.54 ± 43.54 ppm	L*=58.20; a*=25.38; b*=52.64	Very rapid moisture removal
			70 °C	20 h	2.44 ± 0.09%	708.71 ± 20.44 µg/g	230.90 ± 40.67 µg/g	736.56 ± 64.60 ppm	L*=59.60; a*=26.05; b*=52.73	Further thermal exposure reduced vitamin C and capsaicin
			70 °C	24 h	1.75 ± 0.06%	595.56 ± 67.45 µg/g	215.94 ± 43.34 µg/g	698.59 ± 56.28 ppm	L*=59.23; a*=25.19; b*=53.38	Lowest moisture and vitamin C
Susanto (2018)	Capsicum frutescens L.	Tray dryer	Tray-drying treatment	Until 11% moisture	11% target	NR	NR	Hotness intensity evaluated	Qualitatively discussed; no instrumental color values reported	Tray drying successfully reached the 11% moisture target; blanching improved drying rate and rehydration characteristics
Widhiantari et al. (2025)†	Capsicum frutescens L.	Rotary-rack hybrid dryer	43–47, 48–52, 53–57 °C	Up to 14 h	6.43% at 53–57 °C with blanching	NR	NR	NR	Qualitatively discussed; no instrumental color values reported	Blanching accelerated drying; 53–57 °C with blanching produced the lowest moisture

*NR = not reported

DISCUSSION

The red cayenne pepper plant (Capsicum frutescens L.) is known for its pungent flavor derived from capsaicinoid content. In addition, red cayenne pepper is rich in nutrients and vitamins, including calories, protein, fat, carbohydrates, calcium, vitamin A, B1, and vitamin C (Maria Afnita Lelang et al., 2019), as well as rich in antioxidants such as carotenoid, flavonoid, and phenolic compounds (Nur Hasanah, 2022). The capsaicinoid compound group produces a warm to hot sensation upon contact with the skin, which clinically plays an important role in relieving pain (as an analgesic) and in cancer prevention (as an anticancer agent) (Nur Hasanah, 2022). The nutritional content of cayenne pepper (jemprit) based on research by (Rahayu, 2016) is presented in Table 2.

Red cayenne pepper (Capsicum frutescens L.) contains a diverse range of nutritional and bioactive compounds, including carotenoids, vitamin C, capsaicinoids, sugars, phenolic compounds, vitamin E, and dietary fiber. However, the concentration of these compounds can vary considerably among genotypes, indicating that the nutritional characteristics of C. frutescens are strongly influenced by genetic diversity. A study involving 30 C. frutescens germplasms reported substantial variation in total carotenoids (0.007–0.377 mg/L), total sugars (6.008–11.900 mg/g), total phenols (1.363–2.905 mg/g), vitamin E (13.965–217.334 µg/g), and total dietary fiber (5.400–15.140 g/100 g). Among these components, vitamin E showed particularly high variability, suggesting that the selection of specific germplasm may be important when targeting peppers with enhanced nutritional value.

Table 2. Nutritional and bioactive composition of red cayenne pepper (Capsicum frutescens L.)

Nutritional / bioactive component	**Content reported for *C. frutescens***	**Unit**	**Basis / material**	**Reference**
Moisture	71.49 ± 0.69	g/100 g	Fresh fruit	Recent comparative study of *C. frutescens* and *C. annuum*
Protein	1.88 ± 0.06	g/100 g	Fresh fruit	Comparative study, 2025/2026
Dietary fiber	5.18 ± 0.06	g/100 g	Fresh fruit	Comparative study, 2025/2026
Iron (Fe)	4.91	mg/100 g	Fresh fruit	Comparative study, 2025/2026
Potassium (K)	5.21	mg/100 g	Fresh fruit	Comparative study, 2025/2026
Zinc (Zn)	0.2	mg/100 g	Fresh fruit	Comparative study, 2025/2026
Total carotenoids	0.007–0.377	mg/L	Fruit samples from 30 *C. frutescens* germplasms	Zhang et al., 2025
Total sugars	6.008–11.900	mg/g	Fruit samples from 30 germplasms	Zhang et al., 2025
Total phenolics	1.363–2.905	mg/g	Fruit samples from 30 germplasms	Zhang et al., 2025
Vitamin E	13.965–217.334	µg/g	Fruit samples from 30 germplasms	Zhang et al., 2025
Total dietary fiber	5.400–15.140	g/100 g	Fruit samples from 30 germplasms	Zhang et al., 2025
Vitamin C	0.10–8.04	mg/g	513 Capsicum germplasms; *C. frutescens* subset	Li et al., 2023
β-Carotene	16.37–224.97	µg/g	513 Capsicum	Li et al., 2023

			germplasms; *C. frutescens* subset	
Capsaicin	0–1219.90	mg/100 g	513 Capsicum germplasms; *C. frutescens* subset	Li et al., 2023
Total soluble solids	5.00–16.20	°Brix	513 Capsicum germplasms; *C. frutescens* subset	Li et al., 2023

In addition to these nutritional constituents, C. frutescens is characterized by the presence of carotenoids, vitamin C, and capsaicinoids, which contribute to its nutritional, functional, and sensory properties. Analysis of 513 Capsicum accessions, including C. frutescens, demonstrated broad variation in carotenoid, β-carotene, vitamin C, and capsaicinoid contents. The C. frutescens accessions had lower average vitamin C, carotenoid, and β-carotene contents than C. annuum, whereas capsaicinoid concentration varied substantially among accessions. These findings indicate that the nutritional profile of red cayenne pepper should be interpreted as a range rather than as a single fixed composition.

The variation in nutritional composition is particularly relevant to drying processes. Vitamin C and carotenoids are susceptible to degradation during thermal processing, whereas capsaicinoids are comparatively more resistant but can also change depending on processing conditions. Therefore, the nutritional composition of fresh red cayenne pepper provides an important baseline for evaluating the effects of drying temperature and drying duration. In the context of tray-drying or hot-air drying, changes in moisture content should consequently be evaluated together with the retention of vitamin C, carotenoids, capsaicinoids, and color characteristics rather than being considered solely as a measure of drying efficiency.

The treatment given to cayenne pepper certainly affects the substances or compounds it contains. The drying method, which uses heat over a mathematically determined duration, affects the content of cayenne pepper, particularly vitamin C content, which is known to be sensitive to heat, and vitamin A, which is sensitive to oxidation (A. Putri Salwa Dita Maharani et al., 2024). Vitamin C is the least stable of all vitamins and is easily degraded during processing and storage (Rasdi Adungka, 2024).

Findings from research on the effect of the drying process using a dehydrator on the physicochemical content of red cayenne pepper (Rasdi Adungka, 2024) indicate that variations in drying temperature and time affect the decrease in vitamin C content in cayenne pepper. In that study, 100 g of fresh red cayenne pepper contained 25.83 g of vitamin C; after drying at temperature variations of 60°C, 70°C, and 80°C for 8 hours, this decreased to 20.30 g at 60°C, 20.58 g at 70°C, and 18.36 g at 80°C. The study also found changes in capsaicin content, which relates to the pungency produced by dried cayenne pepper: before drying it contained 1.73 g/100 g, and after drying it became 1.11 g at 60°C, 1.05 g at 70°C, and 0.96 g at 80°C.

Effects were not limited to these two components; physical changes also occurred, namely weight loss due to decreased moisture content in red cayenne pepper. Based on the study, weight loss from an initial 100 g sample was 82.10 g at 60°C, 97.56 g at 70°C, and 98.11 g at 80°C. This weight loss occurred because part of the water in the material evaporated during the drying process, and the higher the drying temperature, the faster the airflow during drying, further accelerating evaporation and thus affecting weight loss in cayenne pepper (Rasdi Adungka, 2024). This demonstrates that drying can affect the physicochemical content of red cayenne pepper.

CONCLUSION

Red cayenne pepper (Capsicum frutescens) is a commodity with high moisture content that is susceptible to postharvest damage, making the drying process an important method for extending shelf life while maintaining nutritional value and sensory characteristics. Based on this literature review, temperature and drying duration parameters using the tray dryer method have a significant effect on the physicochemical characteristics of cayenne pepper, both in whole and powdered forms. Excessively high drying temperatures can accelerate vitamin C degradation, reduce carotenoid content, and trigger non-enzymatic browning reactions that affect the color and organoleptic quality of the product.

Conversely, temperatures that are too low prolong drying time and potentially increase the risk of microbial growth due to moisture content not yet reaching a safe limit. Capsaicin compounds are relatively more heat-stable than vitamin C, but excessive drying duration can still reduce pungency intensity. Optimizing temperature within the range of 50–60°C with appropriate time settings is considered capable of producing moisture content below 10% while maintaining the nutritional quality, color, and aroma of the chili. Thus, controlling temperature and duration parameters in the tray dryer method is a key factor in producing dried chili and chili powder with optimal physicochemical quality that meets industry standards.

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