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Effect of Drying Methods on Physicochemical Properties of Hot Pepper

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Abstract Improper drying of hot pepper after harvest is a prominent cause of post-harvest losses. In Ethiopia, hot pepper is mostly dried using the sun drying method before being processed into a powder. However, it's physicochemical qualities and application of other drying techniques were not well studied. Therefore, this study was aimed to evaluate the physicochemical properties of two hot pepper varieties dried under sun and oven drying methods. The experiment was arranged using factorial design and conducted by drying two hot pepper varieties under sun at a maximum temperature of 28.5 °C for 96 hours and oven drying at a temperature of 80 °C for 7 hours. The determined physicochemical properties were moisture content, pH, total soluble solids (TSS), oleoresin content, total carotenoids, browning index, extractable and surface color. The result showed that the highest moisture content (11.33%) was recorded for sun dried *Marako fana* hot pepper whereas the lowest moisture content (3.17%) was noted for *Gababa* hot-pepper dried under oven drying method. The highest pH (5.92), bulk density (0.52 g/cm^3), extractable color (228.62) and surface color (22.94) were noted for sun-dried *Marako fana*. In addition, the highest total soluble solids (3.83 ^{o}Brix) and yellowness (29.02) were recorded for oven dried *Marako fana* hot pepper. However, the highest oleoresin (9.94%) and redness (a^* value) (20.79) were noted for oven dried *Gababa* hot pepper. The present finding also revealed that Statistically, non-significant (p>0.05) differences were observed for luminosity (L^* value) and carotenoids of dried hot pepper under sun and oven drying methods. Some physicochemical properties of hot pepper powder were improved by sun and oven drying methods, and further study is needed to optimize these drying methods for the production of hot pepper powder.
Keywords Hot pepper; *Gababa*; *Marako fana*; Drying methods; Physicochemical properties; Color

1 Introduction

Hot pepper (*Capsicum annum L.*) is the world's most important vegetable. It is used as fresh, dried or processed products as vegetables, flavoring ingredients, natural colorants, spices or condiments (Hernández-Pérez et al., 2020). There are more than 200 common names used for this species. The commonly used names include chilli pepper, paprika (sweet variety), bell pepper, cayenne, jalapeños, chiltepin (hot variety) and Christmas peppers (ornamental) (Bosland and Hamilton, 2023). In Ethiopia, pepper has ancient history compared to any other vegetable and used for making different traditional Ethiopian spice mixes (EEPA, 2003). The red-hot pepper is the leading vegetable crop produced among the types of peppers grown in the country. It covers around 73.13% of the population, whereas green peppers cover around 4.78% of the total estimated area under vegetables in the country (CSA, 2020).

Nationally, the average productivity for green and red-hot peppers stands at 58.90 and 17.95 quintals per hectare, respectively. The total production estimates for green and red-hot peppers are approximately 672,034.39 and 3,131,154.28 quintals, respectively (CSA, 2020). The country's southern, western, northwestern and central parts are the potential hot pepper-producing areas in Ethiopia. It accounts for 34% of the total spice production in the Amhara, Oromia and Southern Nations Nationalities Peoples regions (Handiso et al., 2016). Currently, most pepper products are from southern Ethiopia (Alaba, Meskanina, Marako and Siltie zones). Hot pepper is harvested at different maturity indexes based on desired final products and purposes. The moisture content of hot pepper is high immediately after harvest. The high moisture content of the fresh hot pepper makes it highly susceptible to deterioration. Removal of moisture from fresh hot pepper using different drying methods is the most widely used and common preservation and an important step for hot pepper powder production.

The drying process practiced involves removal of water from products to a level where microbial spoilage and deterioration reactions are hindered. Drying lowers water content and slow down microbial spoilage, which is crucial for ensuring product shelf stability and reduces the storage volume and decreases transport costs (Inyang et al., 2017). However, it is well known that hot pepper undergoes physical, structural, chemical and nutritional changes during drying that can affect quality attributes like texture, color and nutritional value (Di-Scala and Crapiste, 2008).

Several types of dryers and drying methods are commercially used to remove moisture from various fruits and vegetables. The selection of a specific dryer or drying method depends on factors such as the form and properties of the raw material, the desired physical form and characteristics of the product, as well as the required operating conditions and associated costs. The most commonly employed hot peppers drying methods include sun/solar drying, convective air drying, greenhouse drying, and infrared drying (Di-Scala and Crapiste, 2008). In Ethiopia, sun drying is the most common hot pepper drying practice for powder production. However, the physicochemical quality of hot pepper dried under the sun and different drying methods is not studied yet. Therefore, the objective of this study was to evaluate the physicochemical properties of hot pepper varieties dried under sun and oven drying methods.

2 Materials and Methods

2.1 Sample collection, preparation, and experimental design

Two popular varieties (*Marako fana* and *Gababa*) were selected for this study. About 30 kg of hot pepper pods in leather form, free from damage and visual deterioration, were collected from Melkassa Agricultural Research Center (MARC). The samples were washed, and all extraneous materials were removed by placing samples under running water. The experiment was designed as a 2 × 2 factorial arrangement, with a total of 4 treatment groups, and each experiment was repeated three times under the same conditions (Table 1). Then, for conducting the experiment, a total of 30 kg of hot peppers from both varieties were divided into 12 batches, each weighing 2.5 kg. Randomization of the experimental unit was performed using a random number table.

Table 1 Experimental design and plan

Hot pepper variety	Drying methods	Treatments	
MF	T1	T1*MF	T1*GB
GB	T2	T2*MF	T2*GB

Note: MF = *Marako fana*, GB = *Gababa*; T1 = Oven drying method, T2 = Sun drying method

2.2 Drying process

The washed and prepared hot pepper pods were tested under two drying methods: sun drying and oven drying. The sun drying was carried out by placing hot pepper samples under direct sunlight during the Autumn season in 2022, according to the northern hemisphere. The hot pepper sample was dried under drying conditions having an overall maximum daytime air temperature of about 28.50 °C and a minimum temperature of about 15.50 °C for four days of drying cycle with a maximum relative humidity of air 72.4% at Melkassa Agricultural Research center. For the oven drying, the hot pepper samples were sliced into similar sizes and placed on flat surfaces of drying trays covered with aluminum foils. The hot pepper was spread evenly and dried at 80 °C for 7 hours using far an infrared rapid drying oven (Rapid Oven Drying having model: TR-TC-YHG-300-BS-II, China). Dried hot pepper varieties were grounded to powder using cyclone milling machine having 30-1060 model and kept at room temperature in dry place until subjected to analysis.

2.3 Determination of moisture content, total soluble solids and pH value

The initial moisture content of the pepper samples was determined using the AOAC (2000) method. A dish was pre-dried at 130 °C for one hour and was transferred into a desiccator for about 15-20 minutes. The weight of the aluminum tin was measured. About 2.0-3.0 g of the sample was weighed into the aluminum tin, and the sample was dried at 130 °C for 6 hours. The total soluble solids (TSS) level of the hot pepper was determined according to the AOAC (2000) method by using a hand refractometer at room temperature (ranged from 18 °C to 23 °C). The pH value of hot pepper powder was determined according to Choi and Lee (2017). About 45 mL of distilled water was added to 5.0 g of hot pepper powder and homogenized for 1 min. The solution was kept for 1hr at ambient temperature, and the pH value of the supernatant was measured using digital pH meter.

2.4 Powder bulk density

The bulk density of the red pepper powder was measured by a funnel method according to Narayana and Rao (1984). About 10.0 g of pepper powder was weighed into a 100 mL graduated cylinder and then gently dropped 10 times onto a rubber mat from a height of 15 cm. The volume of powder occupied in the measuring cylinder was recorded. The bulk density was calculated as follows:

$$pb = \frac{mp}{Vp}$$

Where, ρb is bulk density (g/cm^3), mp is the mass of the powder (g), and Vp is the volume of the powder (cm^3).

2.5 Browning index

The browning index was estimated according to the procedure described by Supapvanich et al. (2011). About 5.0 g of pepper powder was measured and placed in a beaker. Then, 100 mL 65% (v/v) ethanol was added. The mixture was stirred at room temperature for 1 h. The extract was filtered using Whatman No. 1 filter paper. Absorbance at 420 nm was taken using UV–visible spectrophotometer. The result was expressed as the mean of the three replications of the absorbance.

2.6 Oleoresin determination

Oleoresin was determined according to Raquel and Matiachevich (2017). The extraction was carried out using the paste (400 g in total) was mixed with hexane in a ratio of 1:2 (pepper powder: solvent) in weight, keeping the mixture at 25 °C during 20 hours at constant stirring in an incubator. Then, the mixture was vacuum filtered with Whatman No.1 filter paper to separate the residues of the extract and the solvent was evaporated and recovered using rotavapor at 40 °C (at this temperature, the compounds were not degraded.

2.7 Total carotenoids

Total carotenoids were determined spectrophotometrically using the method described in (Rodriguez-Amaya and Kimura, 2004). About 5.0 g of samples were weighed and ground with 40 mL of cold acetone using a mortar and pestle until the residue became colorless. Sample residue was filtered under a vacuum-filtered pump using a Buchner funnel. The extract was partitioned with 60 mL of petroleum ether; then each fraction was washed three times with 200 mL of distilled water in each cycle for complete removal of acetone. The extracts were collected in a 50 mL volumetric flask using sodium sulphate to trap remaining water and acetone in the crude extract. When the collected extract did not reach the mark point of 50 mL volumetric flask, it made up to a volume of 50 mL by adding petroleum ether. All the procedures were performed in dim light. The absorbance of extracted carotenoids was taken at 452 nm using a UV spectrophotometer. The total carotenoids was calculated as follows:

$$\text{Total Carotenoid } (\mu g/g) = \frac{[A \times \text{volume (mL)} \times 10^4]}{[A1cm1\% \times \text{sample weight (g)}]}$$

Where, A = absorbance; volume = total volume of extract = 50 mL; A1cm1% =absorption coefficient of β-carotene in petroleum ether (2592).

2.8 Color

The color value of fresh and dried hot pepper was determined according to (Li et al., 2016). The sample was distributed uniformly in a cuvette, and color was estimated based on the CIE Lab color space system using a spectrophotometer in reflectance mode. Color was expressed as $L*$, $a*$, $b*$ average values, where the lightness value $L*$ defines black to white (0-100), the $a*$ represents negative values toward green, and positive toward red and $b*$ indicated negative values toward blue and positive toward yellow. The total color change/surface color (ΔE) was considered for the overall color difference evaluation between a dried and a fresh pepper sample (designated with an index 0):

$$\Delta E = \sqrt{(Lo - L)^2 + (ao - a)^2 (bo - b)^2}$$

Where, *Lo*, *ao*, *bo*, = Color values for fresh sample and *L*, *a*, *b* = color values for dried sample

Fresh hot pepper was used as the reference, and a larger ΔE denotes greater color change from the reference material. The extractable color of hot pepper powder was determined using a colorimetric method by American Spice Trade Association (ASTA) analytical method as described by Chetti et al. (2014). About 100 mg of ground hot pepper sample was placed in a 100 mL volumetric flask. Volume was made up to 100 mL with acetone and tightly covered with a stopper. The sample was shaken vigorously and allowed to stand for 16 hours in the dark at room temperature. After 16 hours of incubation time, the sample was shaken again and left for sufficient time for particles to settle. Then, the absorbance of the sample was measured at 460 nm using a UV spectrophotometer. The resultant total extractable colour was calculated as follows:

$$\text{Total extractable color} = \frac{\text{Absorbance} * 16.4}{\text{Sample weight}}$$

2.9 Statistical data analysis

The collected data in triplicate was analyzed using SAS software, 9.3 version and subjected to two-way analysis of variance (ANOVA). The critical difference at $p<0.05$ was estimated and used to find the significant difference. The Least Significant Difference (LSD) test was used to separate the means.

3 Results and Analysis

3.1 Effects of drying methods on hot pepper moisture content, pH value, total soluble solid and bulk density

The results revealed that moisture content was significantly ($p<0.05$) varied as a result of interaction effect of varieties and drying methods (Table 2). It was found that the highest moisture content (11.33) was noted for sun dried *Marako fana* where as the lowest moisture content (3.17%) was recorded for the oven dried *Gababa* variety. The result of moisture content for dried hot pepper samples was below 13% in the present study. According to Pitt and Hocking (2009), chillies dried to less than 13% moisture content are generally helpful in preventing the potential formation of aflatoxin.

The pH is an important characteristic for affecting the survival and growth of microorganisms in food. The pH of dried hot peppers at different temperatures under oven and sun drying differed significantly ($p<0.05$) varied (Table 2). Accordingly, the pH of the hot pepper powder ranged from 4.97 for oven dried *Marako fana* to 5.92 for sun dried *Marako fana*. The interaction of varietal difference and drying methods significantly ($p<0.05$) affects total soluble solids (TSS) of hot pepper (Table 2). Total soluble solids (TSS) is reflected quality and shelf life of some fruits and vegetables (Nordey et al., 2019). The result of total soluble solid obtained in the present study was ranged between 2.73 to 3.83 ^{o}Brix. The highest total soluble solids (3.83 ^{o}Brix) was recorded for oven dried *Marako fana* hot pepper where as the lowest (02.73 ^{o}Brix) was noted for sun dried *Gababa* variety.

Table 2 Interaction effects of drying methods and varieties on physico chemical qualities of hot pepper

Drying*Varieties	MC (%)	PH	TSS (°Brix)	BD (g/cm^3)	Browning index	Oleoresin (%)	Carotenoids (μg/g)
T1*MF	4.74^c	4.97^b	3.83^a	0.44^b	2.15^a	9.54^b	1.64^a
T2*MF	11.33^a	5.92^a	3.47^b	0.52^a	0.21^b	8.98^c	1.66^a
T1*GB	3.17^d	5.23^b	3.33^b	0.41^b	1.96^a	9.94^a	1.62^a
T2*GB	11.09^b	5.63 ^{a}	2.73^c	0.43^b	0.48^b	7.89^d	1.66^a
CV	1.19	3.09	2.73	4.30	14.16	1.25	1.69
LSD	0.17	0.31	0.17	0.04	0.32	0.21	0.05

Note: T1 = Oven-drying, T2 = Sun-drying, MF = *Marako fana*, GB = *Gababa*, BD = Bulk density, CV = coefficient of variance, LSD= Least significant difference, means within a same column followed by the same letters are not significantly different (p>0.05)

Bulk density is physical properties that can be used to estimate how much hot pepper powder can fill the known size of the packaging container. The bulk density of hot pepper was significantly (p<0.05) affected by the interaction of varieties and drying methods (Table 2). The highest bulk density (0.52 g/cm$^{3)}$ was recorded for sun dried *Marako fana* hot pepper followed 0.44, 0.43,and 0.41 g/cm^3 oven dried *Marako fana*, sun dried *Gababa*, and oven dried *Gababa* variety respectively.

3.2 Effects of drying methods on pepper browning index and oleoresin

The results showed that browning index is a considerable parameter/factor for determining color deterioration of dried agricultural products (Table 2). Statistically, non-significant (p>0.05) difference was observed in the browning index between sun dried hot pepper varieties. Browning index ranged over 0.21 to 2.15 were noted for sun dried and oven dried *Marako fana* hot pepper, respectively. Oleoresin content was significantly (p<0.05) affected by combination of varieties and drying methods (Table 2). Statistically, significantly (p<0.05) difference was noted for oleoresin content of dried hot pepper powder. The highest oleoresin (9.94%) and lowest (7.89%) were recorded for oven and sun dried *Gababa* hot pepper variety, respectively. The present finding also revealed that statistically, non-significant (p>0.05) difference were observed for carotenoids contents of dried hot pepper under both sun and oven drying methods.

3.3 Comprehensive effects of drying methods on pepper color quality

Hot pepper is usually harvested depending on the maturity stage when it reaches the desired color. Color played an important role in determining the marketability and consumers preference of hot pepper (Wiktor et al., 2016). International color units such as $L*$ (lightness), $a*$ (redness), and $b*$ (yellowness) values were estimated to determine the effect of drying methods on hot pepper color attributes. Endogenous carotenoids are the primary factor that induces extractable color. The present study revealed that, interaction of drying methods and varieties affected extractable color (Table 3). This study found that the highest extractable color (228.62) noted for sundried *Marako fana* while the lowest (118.71) was recorded for oven dried *Gababa* variety.

Table 3 Interaction effects of drying methods and varieties on color qualities of hot pepper

Drying*Varieties	Extractable color	Surface color	$L*$	$a*$	$b*$
T1*MF	134.37^c	7.75^d	18.13^a	17.80^b	29.02^a
T2*MF	228.62^a	22.94^a	20.06^a	12.15^c	22.81^b
T1*GB	118.71^c	18.64^b	20.63^a	20.79^a	18.93^c
T2*GB	182.95^b	15.31^c	19.67^a	20.06^{ab}	18.58^c
CV	7.29	5.71	10.65	7.56	2.39
LSD	22.80	1.74	3.93	2.52	1.00

Note: T1 = Oven-drying, T2 = Sun-drying, MF = *Marako fana*, GB = *Gababa*, $L*$ = luminosity, $a*$ =red (+ve), green (-ve), $b*$ =yellow (+ve), blue (-ve), CV = coefficient of variance, LSD= Least significant difference, means within a same column followed by the same letters are not significantly different (p>0.05)

Statistically, interaction of drying method and varieties had significant effect ($p<0.05$) on overall surface color. Surface color indicates the total color difference (ΔE) as it is a function of the three (L^*, a^* and b^*) international color units. This study revealed that the surface color values of hot pepper dried by sun drying was significantly higher than that of the oven dried hot pepper. The highest surface color (22.94) was noted for the *Marako fana* variety dried under sun drying method, while the lowest (7.75) was observed in the *Marako fana* variety dried using oven drying method. The L^* (lightness), a^* (redness), and b^* (yellowness) results ranged from 18.13-20.63, 12.15-20.79, and 18.58-29.02 respectively. The L^* values were not significantly different ($p>0.05$) between the all treatments. The oven dried *Gababa* variety exhibited the highest (20.79) redness (a^*) values ,whereas the lowest (12.15) was observed in the *Marako fana* variety dried by sun light (Table 3). Moreover, the highest (29.02) b^* values was found from the *Marako fana* variety dried by oven drying, while the *Gababa* variety showed the lowest (18.58) b^* values across both drying methods.

4 Discussion

Drying hot peppers in the sun or an oven results in a reduction of moisture content and bulkiness and slows down microbiological deterioration, which is important for maintaining product shelf stability and transportation costs. The present study found that oven drying significantly reduced the moisture content compared to sun drying, particularly for the *Gababa* variety. This may be the cause of easy heat penetration into the bonded molecular and biological structure of the *Gababa* variety's during oven drying. The result of moisture content in the present study was similar to previous investigation (Joseph et al., 2017). This findings suggest that oven drying, despite requiring more energy, may offer better control over the final product quality, particularly in terms of moisture content, which are vital shelf stability.

The obtained pH values in the present study were less than 7, indicating the dominance of organic acids in the hot pepper. Those acids are contributed to inhibiting growth of some food borne pathogens and used to control yeast and mould growth (Jay et al., 2005). The results of pH value in current study was in line with the pH value varied from 4.93 to 5.54 reported by Lim et al. (2012) for red pepper powder obtained by drying using far-infrared drying, hot air drying, and polyethylene house. The highest total soluble solid (3.83 ºBrix) was recorded for oven dried *Marako fana* hot pepper. The total soluble solids of the hot pepper in the present study was consistent with that of reported by Moreno-Reséndez et al. (2016) for hot peppers grown under different rates of organic manures.

The bulk density of hot peppers significantly reduced after they were dried under both oven and sun drying. The result bulk density of the dried hot pepper samples (0.41-0.52 g/cm^3) in the present study was closer to the loose bulk density (0.39-0.49 g/cm^3) reported by Adamu et al. (2021) for red pepper powder. The significant reduction of bulk density of hot peppers by drying is advantageous for both protection and transportation. It has significant economic benefits as it lowers the cost of packaging and transportation. This study found that oven dried hot pepper varieties exhibited the highest value of browning index. This might be contributed to the increment of the browning index as a result of the high temperature used during oven drying compared to sun drying. Higher temperature causes the Maillard reaction to occur which attributed to formation of browning products (Acevedo et al., 2008). The result of the browning index for dried hot pepper obtained in the present study was closely related to the browning index reported by Deng et al. (2018) for red pepper dried at 80 °C using hot air-drying methods.

The present finding revealed that oleoresin content of hot pepper highly reduced by sun compared to oven drying. The oleoresin's susceptibility to prolonged heating may be the reason for the reduced percentage of oleoresin by sun drying (Gupta et al., 2017). The result of this oleoresin was in line with the finding of Sharangi et al. (2022). The sun drying method resulted the highest values for extractable color in the current study. The high temperature used in the oven drying might be caused to the deterioration of carotenoids compared to sun drying (Mujumdar and Law, 2010). The highest surface color (22.94) was noted for the *Marako fana* variety dried by sun drying method, while the lowest (7.75) was observed in the *Marako fana* variety dried by oven drying method. The intense evaporation from the pepper surface combined with increased oxygen exposure might be the source of this color oxidation and breakdown. The values of surface color in the present study was in accordance with that of surface colour reported by Deng et al. (2018) for dried red pepper using pulsed vacuum drying.

Carotenoids are the main contributor for yellow and red color in the hot pepper. The highest redness value obtained in the oven dried hot pepper might be attributed to the limited oxygen present in the oven drying. Similar finding by Wang et al. (2017) stated that drying of red pepper in the oxygen deficient condition leads to minimize the loss carotenoids. The present findings showed that oven drying offer better redness color preservation, which is crucial for market acceptance. The present finding revealed that yellowness (b^*) value of *Gababa* variety was significantly reduced by sun drying. The reduction of yellowness color for sun-dried hot pepper could be attributed to pigment oxidation and degradation of carotenoids due to open environment and radiation exposure (Topuz et al., 2011). The b^* values for oven dried *Gababa* variety in the present study was in line with that of red pepper dried under similar condition (Sharangi et al., 2022).

5 Conclusions

The study demonstrates that both drying methods and varieties significantly impact ($p < 0.05$) the physicochemical properties of hot peppers. The present findings showed that oven drying significantly reduced moisture content and bulk density, which are vital for maintaining product shelf stability and lowering transportation costs. Additionally, the results indicate that the a^* value, which reflects the red color intensity, was considerably enhanced in the oven-dried *Gababa* variety. Furthermore, this variety exhibited the highest oleoresin content, making it an excellent candidate for further processing and commercial utilization. However, to optimize the quality and marketability of hot pepper powder, additional research is required.

Future studies should focus on evaluating the microbial quality and shelf life of the dried products, as well as identifying suitable packaging materials that can preserve the sensory and nutritional attributes of the powder. Such comprehensive investigations will be crucial for ensuring the safety, quality, and extended usability of hot pepper products, thereby enhancing their appeal in both local and international markets.

Authors' contributions

MF was responsible for the conceptualization and design of the study, conducting the experiments, laboratory analysis, data management, data analysis, drafting the initial manuscript, and final review and visualization. UA contributed to the writing and editing of the manuscript. MH provided research resources, participated in the review and coordination of the manuscript. All authors read and approved the final manuscript.

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Conflict of Interest Disclosure

The authors affirm that this research was conducted without any commercial or financial relationships that could be construed as a potential conflict of interest.

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