



Pigments and colour characteristics: Influence of drying methods on Nigerian pepper (*Capsicum frutescens*)

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ARTICLE INFO

Keywords:

Capsicum frutescens
Carotenoids
HPLC.
Extractable colour
Surface colour
Browning index

ABSTRACT

Drying conditions such as temperature and duration leads to pepper modifications that can results into quality degradation. In this study matured red fresh *Capsicum frutescens* var. *Baccatum* (FB) and *Capsicum frutescens* var. *longum* (FL) were dried using sun drying (SFB and SFL) and hot air cabinet drying (CFB and CFL) methods. Effects of drying was investigated on moisture content, water activity, carotenoid (capsorubin, violaxanthin, capsanthin, antheraxanthin and zeaxanthin) and colour characteristic (extractable, surface colour, non-enzymic browning index [NEBI]). Cabinet drying significantly ($P < 0.05$) reduced the moisture content and water activity to 7.7% and 0.41 in CFB and 7.5% and 0.42 in CFL compared to 8.5% and 0.45 in SFB and SFL by sun drying. Capsorubin was the most abundant carotenoid in both species (51 and 29%) and capsanthin (43 and 25%) in FB and FL. Extractable colour loss in FB was 31 and 26% due to sun and cabinet drying, while FL recorded 42 and 24%. The chromatic coordinates (a^* , b^* and L^*) in the fresh *C. frutescens* var. *baccatum* and *C. frutescens* var. *longum* were significantly affected by the drying methods with values ranging from 23 to 28, 20–24 and 36–41 in the dried peppers. The highest NEBI values of 113 and 123 were recorded for the *C. frutescens* var. *baccatum* while the lowest colour difference was recorded in *C. frutescens* var. *longum*. Cabinet drying method provided higher NEBI with CFB having the highest values indicating that cabinet drying may be considered a better drying alternative for dehydration of red pepper due to better colour retention of the dried products.

1. Introduction

Colour an important parameter in food quality is associated with the presence of pigments in tissues. Carotenoid is an important pigment that provides red colour to many food products. However, thermal processing such as drying used to preserve some foods usually result into reduction in their carotenoid concentration, thus causing colour changes. Red colour of pepper derived from the capsanthin and capsorubin components exclusively synthesized during fruit ripening in capsicum are important bioactive substances [1]. Red pepper colour is primarily caused by the xanthophylls capsanthin and capsorubin which make up the largest pigment percentage and have many times the tinctorial strength of red components. The pigment content increases as the fruit ripens and this continues for a period after reaching full maturity. The transition in colour of the fruit from green to red usually takes a few days, during which the colour is brownish due to the co-occurrence of chlorophyll and the red pigments [2]. The amount of pigment in the tissues depends upon factors such as species, variety,

maturity and growing conditions [3]. Carotenoids are increasingly drawing the attention of researchers as a major natural food colour due to their inherent nutritional characteristics and the implied possible role in prevention and protection against degenerative diseases [1,4]. Capsanthin, the major carotenoid in ripe fruits, contributes up to 60% of the total carotenoids. However, excessive heating during thermal processing produces considerable losses in the quality and particularly in the organoleptic properties of foods. Hence, red cultivars of *Capsicum* have been the focus of a number of studies over many years on the composition of carotenoid pigments [4]. Pepper *Capsicum frutescens* is a valuable crop that is grown for cash by farmers all over the world [5]. Nigeria is known to be one of the major producers of pepper in the world accounting for about 50% of the African production [6,7]. Nigeria has good soils and weather that can readily support the growth and production of pepper. Pepper grown in Nigeria is in high demand because of its pungency and good flavour. It can readily be dried, ground and packaged for export. Exportation of pepper in Nigeria has once been reported to be a lucrative business [6,8]. Drying is a primary and

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<https://doi.org/10.1016/j.jafr.2023.100760>

Received 21 March 2023; Received in revised form 20 August 2023; Accepted 24 August 2023

Available online 5 September 2023

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suitable preservation technique of pepper to minimize mould development before storage. Moulds are the main cause of quality deterioration of chili peppers [9]. Therefore, the aim of the study is to investigate the effect of drying methods on the pigments and colour characteristic of two varieties from the species *Capsicum frutescens* varieties baccatum locally known as 'bawa' and longum also known as 'shombo' in Nigeria.

2. Materials and methods

2.1. Materials

Matured pods of *Capsicum frutescens* var *baccatum* and *Capsicum frutescens* var. *Longum* were harvested from farm locations in Ogbomoso, Ibadan, Eruwa in Oyo state and Abeokuta, Ota and Alapoti in Ogun state South western Nigeria. The variety obtained from each location were mixed together and initially stored under refrigerated condition (4 °C) for two days. Ten kilograms was removed from each cultivar of the two species and subjected to sun and hot air cabinet drying. All reagents and solvents used were of analytical grade.

2.2. Dried pepper preparation

Fresh pepper (*C. frutescens*) was washed and the stalk removed. The pod was blanched using hot water at 90 °C for 3 min [10,11] cooled in cold water and drained on a perforated tray before drying. The pepper was subjected hot air cabinet and sun drying. Sun drying was carried out by spreading blanched pepper on a tray in a single layer and exposed to sunlight ranging between 33.6 and 37.5 °C and an average humidity varying from 45 to 68% until constant weights was obtained [12]. This drying process was carried out between the hours of 9.00am to 6.00pm daily for a period of seven days in the month of November 2020. Cabinet drying was carried out by placing the blanched pepper on perforated tray in a forced draft oven (Serwell Instruments Inc., Bangalore, India) which has an area of approximately 0.2 m². A temperature of 60 °C was used throughout the drying period which lasted for about 24 h [12].

2.3. Moisture

Moisture content of the fresh, sun and cabinet dried pepper were determined using AOAC [13] method which entails drying at 60 °C in a hot air oven until insignificant consecutive weight changes.

2.4. Water activity (A_w)

Water activities of the samples were measured using Official Methods of Analysis of the AOAC [13]. at 25 °C with a water activity meter (Aqua Lab Series 3 TE, Pullman, WA, USA).

2.5. Determination of carotenoid profile

Fresh and dried pepper samples were homogenized, weighed and subjected to carotenoid extraction as described by Minguez-Mosquera and Hornero-Mendez [14]. After saponification, the organic layer of the extract was vacuum-dried. HPLC quantification of carotenoid was carried out with Rayleigh-LC100 system equipped with Surveyor Auto Sampler Plus, Surveyor LC Plus quaternary pump and a surveyor photodiode array (PDA) detector. The chromatographic conditions were: Betasil C18 column (particle size 3 µm, and dimension 250 mm × 4.6 × 0.5), 25 °C column temperature, 9.24 mg/mL sample quantity, 460 nm UV detection wavelength. The mobile phase was a mixture of acetonitrile and water (75:25 v/v) and a flow rate of 1.5 mL/min. A 20 µL aliquot was used for each HPLC injection. Capsanthin, capsorubin and violaxanthin were determined by comparison with external standards from Sigma-Aldrich (St Louis, Missouri, USA). Carotenoid identification was based on retention time measured under identical HPLC conditions, while quantitative determination in the pepper samples was

achieved using the peak areas.

2.6. Capsanthin/capsorubin ratio

This was determined by dividing the amount of capsanthin by the amount of capsorubin in the pepper samples as described by Kim et al. [15] and Hornero-Méndez D and Mínguez-Mosquera [16].

2.7. Extractable colour

The ASTA colour value of pepper sample was determined according to Korkmaz et al. [17] method with slight modification. The amount of 0.1 g samples was extracted with 20 mL acetone for 3 h by using a water bath (axially shaken at 140 rpm) maintained at 25 °C. Then the extract was diluted 1/5 with acetone. The absorbance of the diluted extract was measured against acetone at 460 nm by spectrophotometer (Shimadzu UV160 U). The extractable colour of the samples was expressed in ASTA units Equation (1)

$$\text{ASTA} = A \times 164 \times I_f \times W^{-1} \dots \dots \dots (1)$$

A is absorbance of the extract, I_f is the deviation factor of the spectrophotometer, which was calculated by dividing the theoretical absorbance ($A_t = 0.600$) by the real absorbance (A_s) of standard colour solution (0.001 M $K_2Cr_2O_7$ and 0.09 M $(NH_4)_2Co(SO_4)_2 \cdot 6H_2O$ in 1.8 M H_2SO_4) at 460 nm, and W is the sample weight (g) on dry basis. The colour loss value (%) was calculated according to equation (2):

$$\text{Colour loss} = \frac{C_{vo} - C_{vt}}{C_{vo}} \times 100 \dots \dots \dots (2)$$

where, C_{vo} is the ASTA colour value of fresh pepper and C_{vt} is the ASTA colour value of dried pepper.

2.8. Colour measurement

Colour measurements of the fresh, sun and cabinet dried pepper slices were carried out as described by Azab et al. [18] using a Hunter-Lab Colorimeter (Miniscan® XE Plus 4500 L) with some modification. The instrument (45°/0° geometry, D 65 optical sensor, 10° observer) was calibrated with black and white reference tiles through the tri-stimulus values X, Y, Z, taking as standard values those of the white background (X = 79.01; Y = 83.96; Z = 86.76) tile. The colour values were expressed as L, a, and b. A glass cell containing the fresh, sun and cabinet dried samples was placed above the light source and post-processing. L, a, b values were recorded. Colour measurements were taken in triplicate and average values were taken for further calculation. In addition, the total colour change (ΔE) (Equation (3)), chroma (Equation (4)), hue angle (Equation (5)), and Browning index (Eqs. (6) and (7)) were calculated using measured L^* , $a \times$ and $b \times$ values to determine the colour changes induced by the drying methods as compared with fresh samples:

$$\Delta E = \sqrt{(L_0 - L_t)^2 + (a_0 - a_t)^2 + (b_0 - b_t)^2} \dots \dots \dots (3)$$

where L_0 , a_0 , b_0 are the initial colour measurements of raw pepper samples and L_t , a_t , b_t are the colour measurements at a specified time.

$$\text{Chroma} = (a_t^2 + b_t^2)^{0.5} \dots \dots \dots (4)$$

$$\text{Hue} = \tan^{-1} \left(\frac{b_t}{a_t} \right) \dots \dots \dots (5)$$

$$\text{Browning Index} = \frac{[(100(x - 0.31))]}{0.17} \dots \dots \dots (6)$$

$$x = \frac{(a_t + 1.75L_t)}{(5.645L_t + a - 3.012b_t)} \dots \dots \dots (7)$$

2.9. Statistical analysis

Data analyses was done using statistical package for social sciences software (SPSS, IBM, version 26). Triplicate data were analysed using one-way analysis of variance (ANOVA) and differences within the means were analysed using Duncan multiple comparison test at a confidence level of 95% ($p < 0.05$).

3. Results and discussions

3.1. Moisture content (mc) and water activity (A_w)

The Mc and corresponding A_w values for fresh *Capsicum frutescens* var. *Baccatum* (FB) was 89.62%, 0.9913 and for *Capsicum frutescens* var. *Longum* (FL) 88.88%, 0.9253 respectively (Table 1). There were significant differences ($P < 0.05$) among the varieties with FB having higher values for both parameters compared to FL. The high moisture content and A_w observed in the fresh peppers could be attributed to the high-water content associated with fresh fruits and vegetables. Cabinet drying significantly ($P < 0.05$) reduced the moisture content and water activity to 7.7% and 0.4163 in CFB and 7.57% and 0.4163 in CFL compared to 8.5% and 0.4446 in SFB and SFL by sun drying. The results obtained are in line with Giuffrida et al. [14] who reported similar values for different varieties of *Capsicum* sp. The relationship between water activity and moisture content seems to be identical for both varieties of pepper. Carotenoid loss in red pepper is affected by water activity, package atmosphere, storage temperature, and treatment of pepper [19,20]. The lower the water activity of pepper the longer will be the shelf life due to less availability of free water for biochemical deterioration, maximal stability for carotenoid oxidation is found at A_w of 0.3 [21,22]. The degradation of dried pepper caused by the biochemical reactions and micro-organisms can be arrested at a lower water activity of less than 0.6 [23]. This implied that the A_w of all sun and cabinet dried peppers were in the range (0.4 and 0.5) which will not facilitate deteriorative changes that may affect the pepper quality if properly stored.

3.2. Effect of drying methods on carotenoid

Five main carotenoids identified in the fresh and dried peppers were capsanthin, capsorubin, violaxanthin, antheraxanthin and zeaxanthin. Capsorubin concentration was 51 and 29% and capsanthin 43 and 25% of the total carotenoids in fresh (FB, FL) pepper samples. Zeaxanthin was not detected in FB but higher value of violaxanthin was recorded in FL (Table 2). Hassan et al. [24] reported similar values in selected collections of sweet and hot pepper from *C. annuum* species. It is known that the concentration of carotenoid in fresh pepper varies according to light intensity, temperature, fruit maturity, location where the plant is grown and genotype. Capsorubin, violaxanthin and capsanthin were

Table 1
Moisture content and A_w of pepper samples.

TREATMENT		MOISTURE (%)	A_w
FRESH	FB	89.62 $\pm$ 0.016 ^a	0.9913 $\pm$ 0.0003 ^a
	FL	88.88 $\pm$ 0.015 ^a	0.9253 $\pm$ 0.0017 ^a
SUNDRIED	SFB	8.50 $\pm$ 0.028 ^b	0.446 $\pm$ 0.0035 ^b
	SFL	8.54 $\pm$ 0.066 ^b	0.4490 $\pm$ 0.003 ^b
CABINET DRIED	CFB	7.70 $\pm$ 0.054 ^c	0.4163 $\pm$ 0.004 ^c
	CFL	7.57 $\pm$ 0.044 ^c	0.4163 $\pm$ 0.0027 ^c

Values are means $\pm$ standard deviation of three replicate samples. Mean values with different superscripts in the same treatment are significantly different ($P < 0.05$). FB is Fresh *Capsicum frutescens* var. *Baccatum*, FL is Fresh *Capsicum frutescens* var. *Longum*, SFB is sun-dried *Capsicum frutescens* var. *Baccatum*, SFL is sun dried *Capsicum frutescens* var. *Longum*, CFB is cabinet dried pepper *Capsicum frutescens* var. *Baccatum* and CFL is cabinet dried *Capsicum frutescens* var. *Longum*.

significantly different ($P < 0.05$) in the sundried (SFL, SFB) samples with 5.6, 3.2 and 7 mg/100 g in SFB while 7.4, 5.3 and 10 mg/100 g was recorded in SFL. Capsorubin loss of 55.3 and 41% was higher in SFB and SFL compared to 10.4 and 9% capsanthin. This is in agreement with the findings of Ayuso et al. [25]. Increase in antheraxanthin concentration in SFB was observed contrary to other carotenoids lost with the drying methods. Zeaxanthin and antheraxanthin were not detected in sundried (SFB, SFL) pepper samples (Table 2). *C. frutescens* var. *longum* with higher total carotenoid concentration had significantly ($P < 0.05$) higher losses compared to *C. frutescens* var. *Baccatum* with increase in antheraxanthin concentration. CFB had 1.6, 5.2 and 2.3 mg/100 g capsorubin, capsanthin and antheraxanthin compared to 1.1, 8.3, 1.1 and 4.0 mg/100 g in CFL. This result was due to the duration of exposure, temperature and sunlight. There are few reports on the effect of solar drying on capsanthin, but about 79.5% losses may occur in the drying of ground pepper during a longer exposure to sun drying temperature [26]. A fading colour appears upon prolonged exposure to temperature and light, due to isomerization reactions shifting from trans to cis configurations [27,28]. Capsorubin losses due to cabinet drying was 87 and 91% in CFB and CFL while 52 and 24% was recorded for capsanthin. The relatively low concentration of violaxanthin in the dried peppers may be attributed to the transformation to capsorubin. Li et al. [29] reported that violaxanthin can theoretically be transformed into capsorubin by progressive oxygenation. Shirkole et al. [30], reported that the colour degradation of paprika follows a first order kinetics with higher rates at enhanced temperature and water activity during storage. Topuz and Feng [31] also reported that 10 months storage at ambient temperature may results in 42.1% loss in capsanthin in *Capsicum* species.

3.2.1. Effect of drying on capsanthin to capsorubin (caps: caps) ratio in pepper samples

The carotenoid profile of the *Capsicum frutescens* samples was affected by drying consequently affecting the capsanthin to capsorubin (caps: caps) ratio. The result (Fig. 1) showed the caps: caps ratio of 0.88 and 0.86 in fresh (FB, FL) pepper samples. The ratio in the sundried (SFB,SFL) samples was 1.2 and 1.4 respectively. The more stable capsanthin was responsible for the higher concentration of the capsanthin which accounted for the higher ratio after drying. The ratio of 1.8 and 7.7 in cabinet dried (CFB,CFL) pepper samples showed that the capsanthin was stable with cabinet drying. Carotenoid esters, particularly monoesters in pepper (*C. frutescens*) and diesters in paprika (*C. annuum*) showed higher process stability than the non-esterified pigments [32]. However, the susceptibility of the mono- and diesters such as capsanthin, zeaxanthin, capsorubin and β -cryptoxanthin established comparable processing stability as stability of the esterified pigments seemed to be related to their more lipophilic nature which protects the carotenoids from thermal degradation [17,33,34]. The caps-to-caps ratio of 1.8 and 7.7 in cabinet dried (CFB, CFL) showed that the capsanthin in the *C. frutescens* var. *longum* belongs to the esterified group hence the thermal stability. As reported, carotenoids esterified with lauric, myristic and palmitic acids exhibited a lower susceptibility to degradation than their non-esterified forms because esterified pigments with their content of saturated fatty acids are more stable, being less prone to photo- and thermo-oxidative degradation [35]. Available literature on processing and storage stability of carotenoid esters are scarce and sometimes contradictory. The results of this study confirmed a lower susceptibility of capsanthin to thermal degradation during drying.

3.3. Effect of drying on the extractable colour of pepper samples

The drying methods brought about changes in the extractable colour and colour loss of the peppers as shown in Fig. 2a and b. Surface colour does not necessarily depend on the total amounts of pigments as colour in pepper samples is also evaluated using extractable colour expressed in ASTA units. Extractable colour is the official method used by the American Spice Trade Association ASTA [36,37]. The ASTA colour

Table 2

Effect of drying on carotenoids profile in pepper samples.

Samples	Capsorubin (mg/100 g)	Violaxanthin (mg/100 g)	Capsanthin (mg/100 g)	Antheraxanthin (mg/100 g)	Zeaxanthin (mg/100 g)	Total Carotenoid (mg/100 g)
FB	12.5 ^a ±0.16	4.3 ^{bc} ±0.56	11.0 ^a ±0.08	2.1 ^{bc} ±0.76	ND	25.6 ^c ±0.32
FL	12.5 ^a ±0.96	12.5 ^a ±0.70	10.8 ^a ±0.06	2.7 ^b ±0.02	4.7 ^a ±0.16	43.1 ^a ±0.20
SFB	5.6 ^c ±0.14	3.2 ^c ±0.04	7.0 ^d ±0.02	14 ^a ±0.64	ND	29.5 ^b ±0.10
SFL	7.4 ^b ±0.46	5.3 ^b ±0.22	10 ^b ±0.32	ND	3.2 ^c ±0.06	25.7 ^c ±0.00
CFB	1.6 ^d ±0.2	ND	5.2 ^c ±0.24	2.3 ^{bc} ±0.34	ND	9.1 ^c ±0.26
CFL	1.1 ^d ±0.16	ND	8.3 ^c ±0.06	1.1 ^{cd} ±0.16	4 ^b ±0.24	14.3 ^d ±0.50

Values are means ± standard deviation of three replicate samples. Mean values with different superscripts in the same treatment are significantly different ($P < 0.05$). FB is Fresh *Capsicum frutescens* var. *Baccatum*, FL is Fresh *Capsicum frutescens* var. *Longum*, SFB is sun-dried *Capsicum frutescens* var. *Baccatum*, SFL is sun dried *Capsicum frutescens* var. *Longum*, CFB is cabinet dried pepper *Capsicum frutescens* var. *Baccatum* and CFL is cabinet dried *Capsicum frutescens* var. *Longum* and ND is not detected.

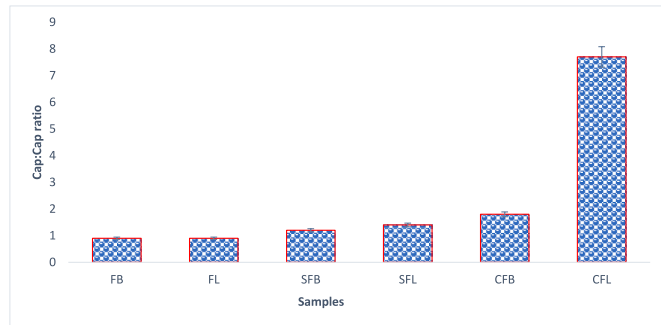


Fig. 1. Capsanthin to Capsorubin (Cap: Cap) ratio of dry-treated peppers. Values are means ± standard deviation of three replicate samples. FB is Fresh *Capsicum frutescens* var. *Baccatum*, FL is Fresh *Capsicum frutescens* var. *Longum*, SFB is sun-dried *Capsicum frutescens* var. *Baccatum*, SFL is sun dried *Capsicum frutescens* var. *Longum*, CFB is cabinet dried pepper *Capsicum frutescens* var. *Baccatum* and CFL is cabinet dried *Capsicum frutescens* var. *Longum*.

values in fresh (FB, FL) samples was 380.48 and 350.22 respectively. These values significantly differ ($P < 0.05$) with the drying methods as FB recorded 32 and 26% losses due to sun and cabinet drying, while FL recorded 42 and 24%. There was higher loss in *C. frutescens* var. *longum* variety compared to *C. frutescens* var. *Baccatum*. The ASTA value of red pepper is affected by the quality of raw fruit, drying condition, number of seed, packaging, storage temperature and area of cultivation. Cabinet drying method indicated better colour retention based on ASTA values in both varieties, however CFB had significantly ($P < 0.05$) higher ASTA values compared to the other dried samples. Findings from this research showed that cabinet drying provided greater colour retention than sun drying. ASTA colour values of Korean red pepper powders have been shown to reduce by 50% after 42 days of exposure to sunlight [38,39]. The difference obtained with this work is probably due to variety, different climatic conditions, harvesting and drying method: In this

study, the cabinet drying temperature was set at 60 °C consequently the difference observed between samples can be ascribed to the cultivar. Major colour change in red pepper during drying was also due to the increase in the content of brown pigments associated with Maillard reactions which proceeds at a much higher temperature (60 °C) in the cabinet dryer compared to the sun drying temperature [40]. Brown pigments in dried red peppers is due to their content of reducing sugars and amino acids [39,41]. Red pepper contains appreciable amounts of reducing sugars and amino acids which Korkmaz et al. [17] reported is responsible for the susceptibility of dried pepper to Maillard reaction. According to Addala et al. [42] there is a significant colour loss in stored pepper products at elevated conditions and a good correlation between moisture, water activity and ASTA have been established.

3.4. Effect of drying on colour characteristic of pepper

3.4.1. Chromatic coordinates (redness, yellowness and lightness)

Chromatic coordinates redness (a^*), yellowness (b^*) and lightness (L^*) of fresh red pepper were affected by the drying methods (Fig. 3a–c). FB exhibited significantly ($P < 0.05$) higher colour retention irrespective of the drying methods compared to the FL. This may be due to degradation of pigments and formation of brown colour that may be caused by the drying temperature. Surface colour of red pepper is related to carotenoid content, particularly capsanthin which is the main red pigment [43]. The cabinet dried samples (CFB, CFL) had redness (a^*) values of 28.28 and 25.64, yellowness (b^*) 22.47 and 36.65 and lightness (L^*) 38.28 and 36.65. In this study, the loss in redness which was significantly higher in FL was due to alterations in carotenoid profile. L^* value reduced with sun and cabinet drying methods with *C. frutescens* var. *baccatum* having a higher value as shown in Fig. 3c. Since L^* is a measure of the colour in the light-dark axis, this reduction indicated that the samples became darker with drying. It has been observed that the variation in the brightness of heat-treated samples can be taken as an indication of browning reaction [44]. Pigment oxidation and decomposition may also be associated with higher exposure to oxygen as well

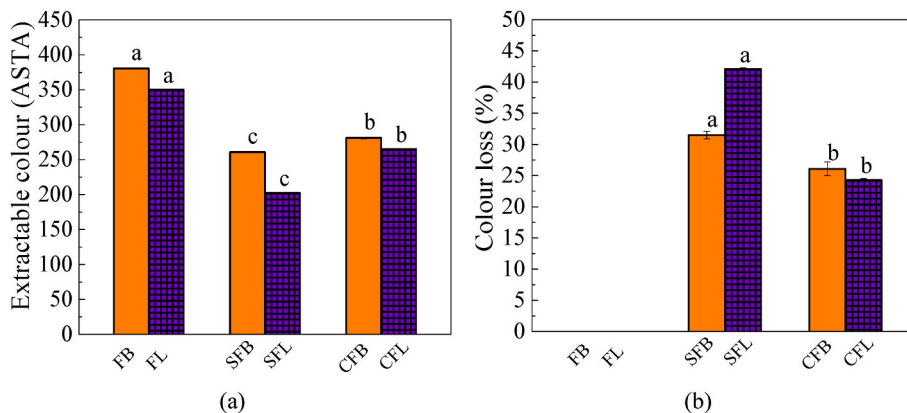


Fig. 2. Extractable colour (a) and colour loss (b) of dried pepper samples.

Mean values are represented with each bar and standard deviations are represented with error bars. Different superscripts above bars in the same treatment are significantly different ($P < 0.05$). FB is Fresh *Capsicum frutescens* var. *Baccatum*, FL is Fresh *Capsicum frutescens* var. *Longum*, SFB is sun-dried *Capsicum frutescens* var. *Baccatum*, SFL is sun dried *Capsicum frutescens* var. *Longum*, CFB is cabinet dried pepper *Capsicum frutescens* var. *Baccatum* and CFL is cabinet dried *Capsicum frutescens* var. *Longum*. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

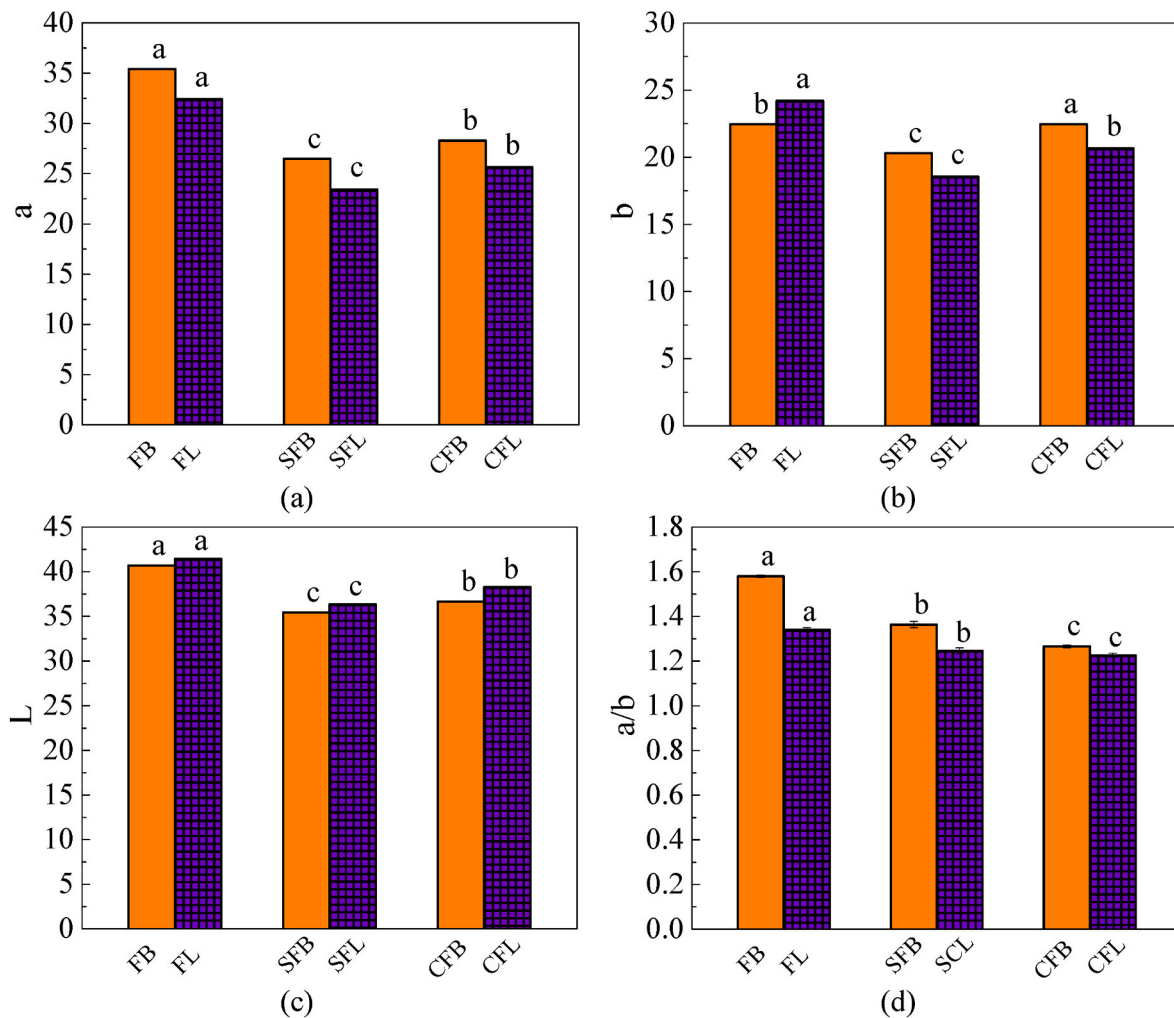


Fig. 3. Colour characterisation of dried pepper

Mean values are represented with each bar and standard deviations are represented with error bars. Different superscripts above bars in the same treatment are significantly different ($P < 0.05$). FB is Fresh *Capsicum frutescens* var. *Baccatum*, FL is Fresh *Capsicum frutescens* var. *Longum*, SFB is sun-dried *Capsicum frutescens* var. *Baccatum*, SFL is sun dried *Capsicum frutescens* var. *Longum*, CFB is cabinet dried pepper *Capsicum frutescens* var. *Baccatum* and CFL is cabinet dried *Capsicum frutescens* var. *Longum*. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

as longer period of vaporization from the pepper surface. Generally, carotenoids decomposed easily via oxidation and isomerization reactions, especially when exposed to high oxygen, temperature, and light [24]. These changes are higher in products having high moisture content [45].

3.4.2. Hue value

The hue value is considered to be one of the most sensitive measures of colour change, which must be taken into account during thermal processing of capsicum for getting a quality product. The hue (H) values for fresh (FB, FL) pepper sample are 32.36 and 36.77°. The H values for the sundried *C. frutescens* var. *baccatum* (37.47°) and *C. frutescens* var.

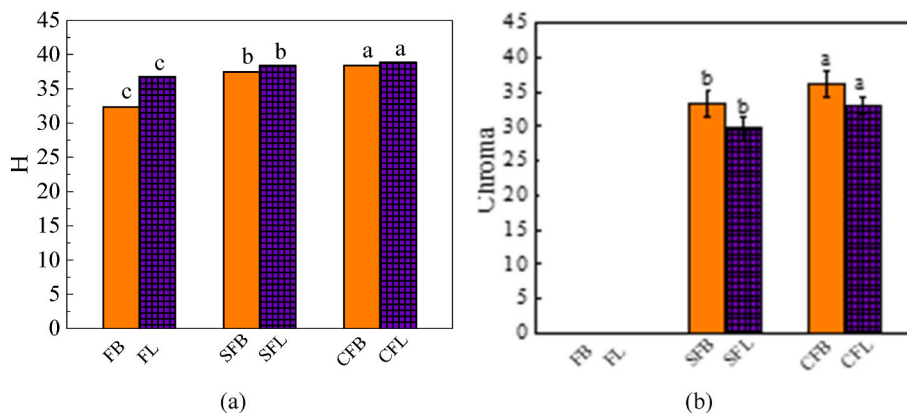


Fig. 4. Effect of drying methods on (a) Hue and (b) Chroma values

Mean values are represented with each bar and standard deviations are represented with error bars. Different superscripts above bars in the same treatment are significantly different ($P < 0.05$). FB is Fresh *Capsicum frutescens* var. *Baccatum*, FL is Fresh *Capsicum frutescens* var. *Longum*, SFB is sun-dried *Capsicum frutescens* var. *Baccatum*, SFL is sun dried *Capsicum frutescens* var. *Longum*, CFB is cabinet dried pepper *Capsicum frutescens* var. *Baccatum* and CFL is cabinet dried *Capsicum frutescens* var. *Longum*.

longum (38.38°) was lower compared to cabinet dried *C. frutescens* var *baccatum* (38.88°) and *C. frutescens* var *longum* (38.40°) as shown in Fig. 4a. The hue value was higher in the *C. frutescens* var *longum* than the *C. frutescens* var *baccatum* indicating a higher loss in redness due to drying in the cultivar. This trend is comparable to the findings of Swain et al. [46] in colour degradation of yellow sweet pepper (*Capsicum annuum*.) undergoing microwave assisted convective drying. A hue angle of 0° is red and 90° yellow; therefore, the closer the value to 90°, the more orange a powder will appear [47].

3.4.3. Chroma value

The chroma values for SFB and CFB were 33.33 and 36.12, while SFL and CFL had 29.70 and 32.93, respectively (Fig. 4b). The chroma value expresses the vividness and dullness of fruits and vegetables. A low chroma value indicates a dull colour, while an increase in this value indicates a vivid colour. The higher values in the cultivar *baccatum* indicated a greater colour saturation and stability compared to the *longum* [43]. Chroma values represents colour saturation of the samples, with high values representing vivid colour and is proportional to the strength of the colour. Other investigators have reported similar observations [48].

3.4.4. Total colour difference

Total colour difference (ΔE) which is the degree of colour variation between two samples represents the overall surface colour change and it is a function of the chromatic coordinates. The values for cabinet dried (CFB, CFL) pepper samples were significantly lower than the sundried (SFB, SFL) as shown in Fig. 5a, these lower values implied a better colour retention. The surface colour of cabinet dried pepper was closer to fresh (FB, FL) samples. The degree of colour difference between two samples based on total colour change can be interpreted in the following way: ΔE in the range of 0–0.5 indicates an imperceptible difference in colour, 0.5–1.5 a slight difference, 1.5–3.0 a just noticeable difference, 3.0–6.0 a marked difference, 6.0–12.0 an extremely marked difference, and above 12.0 a colour of a different shade [49,50]. In this work there are visible differences in colour for all dried samples compared to the fresh pepper samples and more pronounced with sun drying method. Previous researchers reported that high moisture levels (>80%) of fresh red pepper fruits allow the fruits to have longer metabolic activity during sun drying at mild temperatures and therefore yield dried products with equal or more carotenoid content than the fresh pepper [51,52]. The sun drying method used in this research significantly altered the surface colour of the final products as the prolonged time of drying led to higher ΔE values, indicating that cabinet drying may be considered a better drying alternative for dehydration of red pepper due to better colour retention. This result was consistent with a previous findings that temperature and duration of drying were important factors for colour degradation during drying [53]. Furthermore, browning reaction (BI) and carotenoid changes were considered as the main causes of surface colour changes,

since the trends of BI and extractable colour were consistent with the ΔE value changes [54]. Reason for this may be that some other components apart from browning substances and carotenoids, such as vitamins, carbohydrates and amino acids in the material, affect the final product colour [54].

3.4.5. Browning index

Another important factor that is related to the colour of dried pepper is browning reactions, a reaction that occurs in products containing groups of sugars and amino acids [55,56]. The cultivars and drying methods had significant effect on the browning index values (Fig. 5b). The cabinet drying method provided higher BI with CFB having the highest values. This indicated that the fresh *Capsicum frutescens* var. *Baccatum* was more vulnerable to colour change through non enzymatic browning than the fresh *Capsicum frutescens* var. *Longum* with lower BI values. However, the BI index for the sundried (SFB, SFL) samples were not significantly different. According to Kaur and Kaur [57], for minimum browning, the peppers should be stored at water activities below 0.3 and in the form of whole pods or coarse powder with seeds.

4. Conclusions

The influence of drying methods has been qualitatively and quantitatively demonstrated on the pigment and colour characteristic of *C. frutescens* var *baccatum* and *C. frutescens* var. *Longum*. The water activity of the sun and cabinet dried pepper samples are in the range that will not facilitate deteriorative changes that may affect the pepper quality if properly stored. Five main carotenoids identified in the fresh and dried peppers were capsanthin, capsorubin, violaxanthin, antheraxanthin and zeaxanthin. Capsorubin was the predominant in both pepper cultivars accounting for a higher percentage however capsanthin was relatively more stable under the drying conditions. Major colour change in red pepper during drying was also due to the increase in the content of brown pigments associated with Maillard reactions which proceeds at higher temperature of the cabinet dryer compared to the sun drying temperature. Chromatic coordinates redness a^* , yellowness b^* and lightness L^* of fresh red pepper were affected by the drying methods. The sun drying method used in this research altered the surface colour of the final products as the prolonged time of drying led to higher ΔE values indicating that cabinet drying may be considered a better drying alternative for dehydration of red pepper due to better colour retention.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

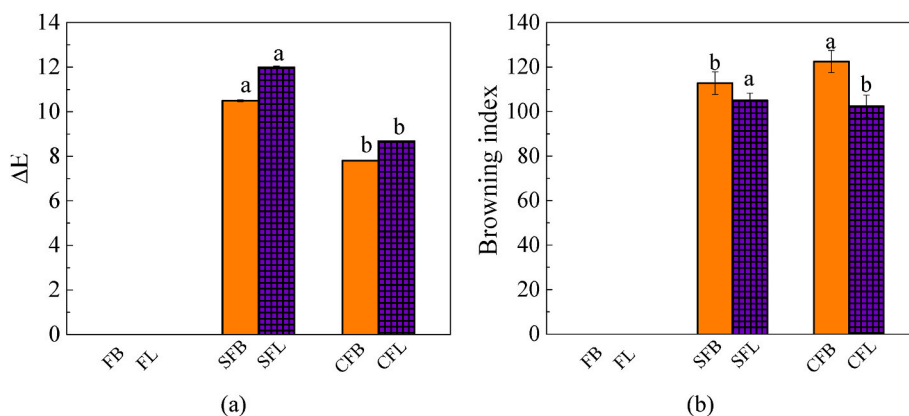


Fig. 5. Browning index (a) and chroma values (b) of dry-treated peppers.

Mean values are represented with each bar and standard deviations are represented with error bars. Different superscripts above bars in the same treatment are significantly different ($P < 0.05$). FB is Fresh *Capsicum frutescens* var. *Baccatum*, FL is Fresh *Capsicum frutescens* var. *Longum*, SFB is sun-dried *Capsicum frutescens* var. *Baccatum*, SFL is sun dried *Capsicum frutescens* var. *Longum*, CFB is cabinet dried pepper *Capsicum frutescens* var. *Baccatum* and CFL is cabinet dried *Capsicum frutescens* var. *Longum*.

Data availability

No data was used for the research described in the article.

References

- [1] R. Arimboor, R.B. Natarajan, K.R. Menon, Red pepper (*Capsicum annuum*) carotenoids as a source of natural food colours: analysis and stability: a review, *J. Food Sci. Technol.* 52 (2015) 1258–1271, <https://doi.org/10.1007/s13197-014-1260-7>.
- [2] Z. Ye, Z. Shang, M. Li, X. Zhang, H. Ren, X. Hu, J. Yi, Effect of ripening and variety on the physiochemical quality and flavour of fermented Chinese chili pepper (Paojiao), *Food Chem.* 368 (2022), 130797.
- [3] N. Mohd Hassan, N.A. Yusof, A.F. Yahaya, N.N. Mohd Rozali, R. Othman, Carotenoids of capsicum fruits: pigment profile and health-promoting functional attributes, *Antioxidants* 8 (10) (2019) 469.
- [4] T. Hernández-Pérez, M.D.R. Gómez-García, M.E. Valverde, O. Paredes-López, *Capsicum annuum* (hot pepper): an ancient Latin-American crop with outstanding bioactive compounds and nutraceutical potential, *Rev. Compr. Rev. Food Sci. Food Safety* 19 (6) (2020) 2972–2993.
- [5] L. Aliyu, R.A. Yahaya, U.L. Arunah, I.M. Haruna, Response of two chilli pepper varieties (*Capsicum frutescens* L.) to harvesting frequency, Available online at *Elixir Int. J. Agric.* 42 (2012) 6493–6495.
- [6] O.O. Idowu-Agida, E.I. Nwaguma, I.B. Adeoye, Cost implication of wet and dry season pepper production in Ibadan, Southwestern Nigeria, *Agric. Biol. J. N. Am.* 1 (4) (2010) 495–500.
- [7] A.T. Lawal, A.Y. Gaya, A. Alhassan, I. Sulei, F.S. Abdulwahab, H. Umar, Marketing analysis of chilli pepper in kano state markets, Nigeria, *FUDMA J. Sci.* 5 (4) (2021) 38–43.
- [8] M. Joyce, J. David, J. Titus, Structure of red pepper marketing in Adamawa State, Nigeria, *Int. J. Vet. Sci. Agric. Res.* 1 (3) (2019) 16–21.
- [9] T. Calado, A. Venâncio, L. Abrunhosa, Irradiation for mould and mycotoxin control: a review, *Compr. Rev. Food Sci. Food Saf.* 5 (2014 Sep) 1049–1061.
- [10] T.Y. Tunde-Akintunde, G.O. Ogunlakin, Influence of drying conditions on the effective moisture diffusivity and energy requirements during the drying of pretreated and untreated pumpkin, *Energy Convers. Manag.* 52 (2) (2011) 1107–1113.
- [11] S.B. Anoraga, I. Sabarisman, M. Ainuri, Effect of different pre-treatment on dried chilli (*Capsicum annuum* L.) quality, *IntOP Conf. Series: Earth Environ. Sci.* 131 (1) (2018), 012014. IOP Publishing.
- [12] V.K. Maurya, K.M. Gothandam, V. Ranjan, A. Shakya, S. Pareek, Effect of drying methods (microwave vacuum, freeze, hot air and sun drying) on physical, chemical and nutritional attributes of five pepper (*Capsicum annuum* var. *annuum*) cultivars, *J. Sci. Food Agric.* 98 (9) (2018) 3492–3500.
- [13] Method 925.10, Official Methods of Analysis, seventeenth ed., AOAC International, Gaithersburg, MD, 2000.
- [14] M.I. Mínguez-Mosquera, D. Hornero-Méndez, Formation and transformation of pigments during the fruit ripening of *Capsicum annuum* cv. Bola and Agridulce, *J. Agric. Food Chem.* 42 (1) (1994 Jan) 38–44.
- [15] J. Song, Q. Wei, X. Wang, D. Li, C. Liu, M. Zhang, L. Meng, Degradation of carotenoids in dehydrated pumpkins as affected by different storage conditions, *Food Res. Int.* 107 (2018 May 1) 130–136.
- [16] D. Hornero-Méndez, M.I. Mínguez-Mosquera, Rapid spectrophotometric determination of red and yellow isochromic carotenoid fractions in paprika and red pepper oleoresins, *J. Agric. Food Chem.* 49 (8) (2001) 3584–3588.
- [17] A. Korkmaz, A.F. Atasoy, A.A. Hayaloglu, The effects of production methods on the color characteristics, capsacinoids content and antioxidant capacity of pepper spices (*C. annuum* L.), *Food Chem.* 341 (2021), 128184.
- [18] D.E. Azab, R.I. Almoselhy, M.H. Mahmoud, Improving the quality characteristics of low fat toffee by using mango kernel fat, pectin, and high-speed homogenizer, *J. Food Process. Preserv.* (2022 Oct 12), e17235.
- [19] A.J. Meléndez-Martínez, A.I. Mandić, F. Bantis, V. Böhm, G.I. Borge, M. Brčić, A. Bysted, M.P. Cano, M.G. Dias, A. Elgersma, M. Fikselová, A comprehensive review on carotenoids in foods and feeds: status quo, applications, patents, and research needs, *Crit. Rev. Food Sci. Nutr.* 62 (8) (2022) 1999–2049.
- [20] J.W. Rhim, S.I. Hong, Effect of water activity and temperature on the color change of red pepper (*Capsicum annuum* L.) powder, *Food Sci. Biotechnol.* 20 (1) (2011) 215.
- [21] T.P. Labuza, B. Altunakar, Water activity prediction and moisture sorption isotherms, in: *Water Activity in Foods: Fundamentals and Applications*, 2020, pp. 161–205.
- [22] C.K. Tuyen, M.H. Nguyen, P.D. Roach, Effects of spray drying conditions on the physicochemical and antioxidant properties of the Gac (*Momordica cochinchinensis*) fruit aril powder, *J. Food Eng.* 98 (3) (2010) 385–392.
- [23] B.M. Ghodki, T.K. Goswami, Effect of grinding temperatures on particle and physicochemical characteristics of black pepper powder, *Powder Technol.* 299 (2016) 168–177.
- [24] N. Mohd Hassan, N.A. Yusof, A.F. Yahaya, N.N. Mohd Rozali, R. Othman, Carotenoids of capsicum fruits: pigment profile and health-promoting functional attributes, *Antioxidants* 8 (10) (2019) 469.
- [25] M.C. Ayuso, M.J. Bernalte, M. Lozano, M.I. García, V. Montero de Espinosa, M. M. Pérez, M.T. Hernández, N. Somogyi, Quality characteristics of different red pepper cultivars (*Capsicum annuum* L.) for hot paprika production, *Eur. Food Res. Technol.* 227 (2008) 557–563.
- [26] A. Topuz, F. Ozdemir, Assessment of carotenoids, capsacinoids and ascorbic acid composition of some selected pepper cultivars (*Capsicum annuum* L.) grown in Turkey, *J. Food Compos. Anal.* 20 (2007) 596–602.
- [27] L. Lemmens, K. De Vleeschouwer, K.R. Moelants, L.J. Colle, A.M. Van Loey, M. E. Hendrickx, β -Carotene isomerization kinetics during thermal treatments of carrot puree, *J. Agric. Food Chem.* 58 (11) (2010) 6816–6824.
- [28] D. Giuffrida, P. Dugo, G. Torre, C. Bignardi, A. Cavazza, C. Corradini, G. Dugo, Evaluation of carotenoid and capsacinoids contents in powder of red chili peppers during one year of storage, *Food Res. Int.* 65 (2014) 163–170.
- [29] Q.H. Li, S.P. Yang, Y.N. Yu, A. Khan, P.L. Feng, M. Ali, D.K. Shao, Y.Y. Wang, R. X. Zhang, W.X. Gai, R. Han, Comprehensive transcriptome-based characterization of differentially expressed genes involved in carotenoid biosynthesis of different ripening stages of *Capsicum*, *Sci. Hortic.* 288 (2021), 110311.
- [30] S.S. Shirkole, R. Jayabalan, P.P. Sutar, Dry Sterilization of paprika (*Capsicum annuum* L.) by short time-intensive microwave-infrared radiation: establishment of process using glass transition, sorption, and quality degradation kinetic parameters, *Innovat. Food Sci. Emerg. Technol.* 62 (2020), 102345.
- [31] A. Topuz, H. Feng, M. Kushad, The effect of drying method and storage on color characteristics of paprika, *LWT—Food Sci. Technol.* 42 (10) (2009) 1667–1673.
- [32] C.S. Souza, H.G. Daoud, S.A. Duah, S. Vinogradov, G. Palotás, A. Neményi, L. Helyes, Z. Pék, Stability of carotenoids, carotenoid esters, tocopherols and capsacinoids in new chili pepper hybrids during natural and thermal drying, *LWT (Lebensm.-Wiss. & Technol.)* 163 (2022), 113520.
- [33] D.B. Rodriguez-Amaya, Natural Food Pigments and Colorants. Bioactive Molecules in Food, Springer, Cham, 2019, pp. 867–901.
- [34] A. Solovchenko, E.M. Yahia, C. Chen, Pigments. In: *Postharvest Physiology and Biochemistry of Fruits and Vegetables*, Woodhead publishing, 2019, pp. 225–252.
- [35] R. Velázquez, M.G. Córdoba, A. Hernández, R. Casquete, E. Aranda, T. Bartolome, A. Martín, Effects of use of modified traditional driers in making smoked paprika “Pimentón de La Vera”, *On Pepper Qual. Mitig. PAH Contam. J. Food Compos. Anal.* 110 (2022), 104566.
- [36] A.N. Tepić, B.L. Vujčić, Colour change in pepper (*Capsicum annuum*) during storage, *Acta Period. Technol.* (35) (2004) 59–64.
- [37] R. Velázquez, M.G. Córdoba, A. Hernández, R. Casquete, E. Aranda, T. Bartolome, A. Martín, Effects of use of modified traditional driers in making smoked paprika “Pimentón de La Vera”, *On Pepper Qual. Mitig. PAH Contam. J. Food Compos. Anal.* 110 (2022), 104566.
- [38] R. Casquete, R. Velázquez, A. Hernandez, M. de Guia Cordoba, E. Aranda, T. Bartolome, A. Martín, Evaluation of the quality and shelf-life of cayenne (*Capsicum* spp.), *LWT (Lebensm.-Wiss. & Technol.)* 145 (2021), 111338.
- [39] S. Kim, J. Park, I.K. Hwang, Composition of main carotenoids in Korean red pepper (*Capsicum annuum*, L) and changes of pigment stability during the drying and storage process, *J. Food Sci.* 69 (1) (2004) FCT39–44.
- [40] H.D. Adamu, C.C. Ariahu, B.D. Igbabul, Quality characteristics of hot pepper (*Capsicum chinense*) powder in relation to the drying and milling regimes, *Agric. Eng. Int.: CIGR Journal* 23 (4) (2021).
- [41] R.Y. Zhang, H.M. Liu, Y.X. Ma, X.D. Wang, Effects of roasting on composition of chili seed and storage stability of chili seed oil, *Food Sci. Biotechnol.* (2019) 1475–1486.
- [42] R. Addala, M. Vasavada, J. Dong, S. Subramanian, Effect of storage conditions on rate of color degradation of paprika based products, *J. Food Process. Technol.* 6 (3) (2015).
- [43] W. Pola, S. Sugaya, V. Srilaong, C. Wongs-Aree, S. Photchanachai, Color appearance and physico-chemical changes in dried chili as affected by modified atmosphere packaging and temperature during storage, *J. Food Process. Preserv.* 45 (11) (2021), e15967.
- [44] R. Kaur, K. Kaur, P. Ahluwalia, Effect of drying temperatures and storage on chemical and bioactive attributes of dried tomato and sweet pepper, *LWT (Lebensm.-Wiss. & Technol.)* 117 (2020), 108604.
- [45] H. Pinar, N. Çetin, B. Ciftci, K. Karaman, M. Kaplan, Biochemical composition, drying kinetics and chromatic parameters of red pepper as affected by cultivars and drying methods, *J. Food Compos. Anal.* 102 (2021), 103976.
- [46] S. Swain, D.V. Samuel, L.M. Bal, A. Kar, Thermal kinetics of colour degradation of yellow sweet pepper (*Capsicum Annuum* L.) undergoing microwave assisted convective drying, *Int. J. Food Prop.* 17 (9) (2014) 1946–1964.
- [47] Y. Hendrawan, R. Utami, D.Y. Nurseta, S. Nuryani, D.M. Maharani, Classification of total carotene and quality of chili pepper (*Capsicum frutescens*) based on image analysis, *IntOP Conf. Series: Earth Environ. Sci.* 733 (1) (2021), 012005. IOP Publishing.
- [48] X. Feng, Q. Yu, B. Li, J. Kan, Comparative analysis of carotenoids and metabolite characteristics in discolored red pepper and normal red pepper based on non-targeted metabolomics, *LWT (Lebensm.-Wiss. & Technol.)* 153 (2022), 112398.
- [49] X.H. Yang, L.Z. Deng, A.S. Mujumdar, H.W. Xiao, Q. Zhang, Z. Kan, Evolution and modeling of colour changes of red pepper (*Capsicum annuum* L.) during hot air drying, *J. Food Eng.* 231 (2018) 101–108.
- [50] S. Kim, T. Youl Ha, J. Park, Characteristics of pigment composition and colour value by the difference of harvesting times in Korean red pepper varieties (*Capsicum annuum*, L.), *Int. J. Food Sci. & Technol.* 43 (5) (2008) 915–920.
- [51] G. Guclu, D. Keser, H. Kelebek, M. Keskin, Y.E. Sekerli, Y. Soysal, S. Selli, Impact of production and drying methods on the volatile and phenolic characteristics of fresh and powdered sweet red peppers, *Food Chem.* 338 (2021 Feb 15), 128129.
- [52] D. Hornero-Méndez, R. Gómez-Ladrón de Guevara, M.I. Mínguez-Mosquera, Carotenoid biosynthesis changes in five red pepper (*Capsicum annuum* L.) cultivars during ripening. Cultivar selection for breeding, *J. Agric. Food Chem.* 48 (9) (2000) 3857–3864.

- [53] E. Kennao, A. Kumari, M. Singh, S.A. Hossain, A. Das, P.K. Wasnik, B.K. Bharti, Effect of drying on physicochemical characteristics of Bhut Jolokia (chilli pepper), *J. Food Process. Technol.* 11 (823) (2020) 1–8.
- [54] K. Ma, S. Horn, F. Debaste, B. Haut, S. In, Experimental characterization of the drying of kaptop red pepper (*Piper nigrum* L.), *Foods* 9 (11) (2020) 1532.
- [55] M. Cefola, I. D'Antuono, B. Pace, N. Calabrese, A. Carito, V. Linsalata, A. Cardinali, Biochemical relationships and browning index for assessing the storage suitability of artichoke genotypes, *Food Res. Int.* 48 (2) (2012) 397–403.
- [56] F. Liu, X. Cao, H. Wang, X. Liao, Changes of tomato powder qualities during storage, *Powder Technol.* 204 (1) (2010) 159–166.
- [57] R. Kaur, K. Kaur, Preservation of sweet pepper purees: effect on chemical, bioactive and microbial quality, *J. Food Sci. Technol.* 58 (2021) 3655–3660.