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Research Article

Physicochemical, bioactive compounds and antioxidant activities of sweet red corn under different drying methods

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Abstract

This study investigated the physicochemical properties, bioactive compounds, and antioxidant activities of sweet red corn under different drying methods. The color characteristics of the corn varied significantly based on the drying method employed. Freeze-drying resulted in the lightest color, while sun drying and hot air drying at different temperatures showed intermediate and varying color parameters. The total phenolic and flavonoid content decreased after drying, with heat drying methods exhibiting a greater decrease compared to freeze-drying. Microstructural analysis revealed changes in cell structure and starch granules, with freeze-dried samples displaying distinct characteristics. The sugar content decreased in all drying methods compared to the fresh sample. The amino acid content also decreased after drying, with heat drying methods affecting certain amino acids more than others. Different phenolic acids and flavonoids were detected, with their concentrations varying depending on the drying method. Fresh corn exhibited the highest antioxidant activity, while freeze-drying retained a significant amount. Sun drying and high-temperature drying methods resulted in decreased antioxidant activity. These findings underscore the importance of selecting appropriate drying techniques to preserve desired attributes and beneficial properties of corn.

Keywords: antioxidants; bioactive compounds; corn; flavonoids; phenolic acids

Introduction

Corn cultivation holds significant importance in Thailand's agricultural sector, positioning the country as a major corn producer in Southeast Asia (Thoudam *et al.*, 2011; Senphan *et al.*, 2019). Corn is not only a rich source of carbohydrates but also contains natural antioxidants like vitamins, carotenoids, flavonoids, phenolic compounds, and anthocyanins, which offer numerous health benefits. These antioxidants help protect against free radicals, reduce the risk of chronic diseases such as heart disease and cancer, promote eye health, and have anti-inflammatory and cognitive-enhancing effects (Lopez-Martinez *et al.*, 2009; Lee *et al.*, 2010; Montilla *et al.*, 2011; Saikaew *et al.*, 2018). Especially, color corn varieties exhibit a higher concentration of antioxidants and demonstrate enhanced antioxidant activity compared to white corn (Lopez-Martinez *et al.*, 2009; Mahan *et al.*, 2013; Saikaew *et al.*, 2018). Sweet corn (*Zea mays*) is a widely cultivated and consumed

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crop known for its pleasant taste and nutritional value (Yang *et al*., 2019). Additionally, there has been a growing interest in sweet red corn varieties due to their vibrant color and potential health benefits associated with the presence of bioactive compounds (Harakotr *et al*., 2022). The 'Siam Ruby Queen' variety of sweet red corn is particularly attractive, with its deep red kernels that are visually appealing and may contain higher levels of bioactive compounds compared to traditional yellow or white corn varieties (Harakotr *et al*., 2014; Hong *et al*., 2020). Drying is a common method employed to preserve agricultural produce, including corn kernels, for extended storage periods and to create value-added products (Mwaurah *et al*., 2020). Different drying techniques can influence the physicochemical properties, bioactive compound content, and antioxidant activities of the dried product (Chumroenphat *et al*., 2021; Siriamornpun *et al*., 2012). Therefore, understanding the impact of various drying methods on sweet red corn is crucial to optimize the preservation of its quality and beneficial compounds. The physicochemical properties of dried corn, such as moisture content, color, pH, and texture, play a vital role in consumer acceptance and food processing applications. Moisture content affects the shelf life of the product and is directly related to its texture and crispness. Color is an essential quality parameter that influences consumer preference, and the red pigmentation in sweet red corn is attributed to the presence of anthocyanins, which are potent antioxidants. pH is an indicator of product stability and can affect taste and microbial growth. Texture is an important sensory attribute that determines the mouthfeel and overall eating experience.

Furthermore, sweet red corn is known to contain bioactive compounds that exhibit potential health benefits, including antioxidant and anti-inflammatory properties. The major bioactive compounds found in sweet red corn include phenolic compounds, flavonoids, and anthocyanins. These compounds are known to scavenge free radicals, protect against oxidative stress, and reduce the risk of chronic diseases, such as cardiovascular diseases and certain types of cancer. However, the drying process can affect the stability and retention of these bioactive compounds, which may impact the potential health benefits of the dried corn product. antioxidant activity is an important indicator of the potential health benefits of sweet red corn and is closely related to its bioactive compound content. Several in vitro assays, such as the 2,2-diphenyl-1-picrylhydrazyl (DPPH) scavenging activity and ferric reducing antioxidant power (FRAP), can be used to assess the antioxidant activities of the dried corn samples.

Therefore, this study aimed to investigate the physicochemical properties, bioactive compound content, and antioxidant activities of sweet red corn ('Siam Ruby Queen') with different drying methods. The findings of this research will contribute to a better understanding of the effects of drying techniques on the quality and nutritional value of sweet red corn and provide valuable insights for optimizing drying strategies to preserve the color, bioactive compounds, and antioxidant potential of this unique corn variety. The purpose of this investigation is to provide information that will assist in recommending that these plants be used more widely. Future studies on the development of food products for functional food should be able to build on the findings of this study.

Materials and Methods

Merck (Darmstadt, Germany) provided all of the chemicals and standards for HPLC, including phenolic acids: protocatechuic, gallic, p-hydroxybenzoic, p-coumaric, chlorogenic acids, sinapic, syringic, ferulic, vanillic, and caffeic); flavonoids (quercetin, myricetin, apigenin, kaempferol and rutin); sugar, and amino acids. All additional high-purity solvents for HPLC analysis were supplied by Merck (Darmstadt, Germany).

Sample preparation

Fresh sweet red corn samples were obtained from the northeastern region of Thailand (November-December 2018). The fresh sweet red corn was stored at 4 °C for comparison with the dried samples after drying with the procedures to be evaluated. All of the evaluated techniques were used to dry 500 g quantities of corn. Each drying process lowered the moisture level to less than 7%. The following were the drying technique conditions: Freeze dried (FD), sweet red corn was frozen at -50 °C for 12 hours before drying in Scanvac Cool Safe equipment (model 100-9 Pro, LaboGene ApS, Denmark). The vacuum was adjusted to 20 Pa absolute and the heating plate and cold trap were both cooled to 100 °C. Hot air dried (HD) employed an electric thermo-static drying hot-air oven (type FED 115, WTB Binder, Germany) with temperature settings of 40 °C, 60 °C, and 80 °C. Sun dried (SD), sweet red corn slices were sun-dried for 3-5 days at 35-45 °C. Before testing, samples were crushed, sieved with a 40-mesh sieve wire, and stored at -20 °C (Figure 1).

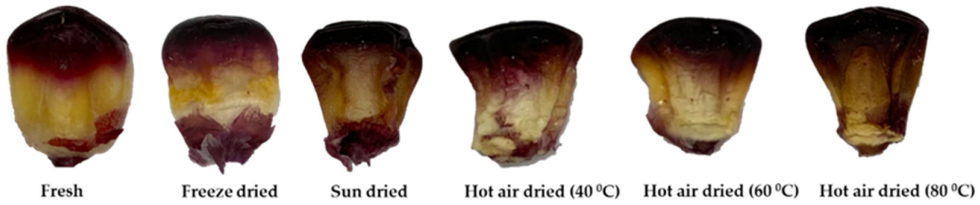

Figure 1 Sweet red corn after drying with different methods

Color determination

The sample of sweet red corn color was analysed using a Minolta CR-300 Chroma Meter (Konica Minolta, Osaka, Japan) on L*, *a**, and *b** scales. L* values indicated brightness, *a** values represented redness/greenness, and *b** values showed yellowness/blueness. The equipment was calibrated using a white standard. Each treatment had ten separately measured samples, and their average was computed. Color difference *ΔE* was estimated using L*, *a** and *b** parameters (Siriamornpun *et al*., 2012; Saensouk *et al*., 2022) provided details on the color scales.

Total phenolic contents (TPC) and total flavonoids contents (TFC)

TPC and TFC were determined using the method of Saensouk *et al*. (2022). The Folin-Ciocalteu reagent was used to measure the TPC of the sample, and the absorbance was measured at 725 nm with gallic acid as a reference. The TFC was measured by mixing 25 µL of extracted sample with 100 µL of purified water and 10 µL of 5% $NaNO_2$ solution in a 96-well plate. After 5 minutes of shaking, 15 µL of 10% $AlCl_3{\cdot}6H_2O$ solution was added, followed by 50 µL of 1 M NaOH and 50 µL of filtered water. The absorbance was measured at 510 nm immediately after mixing, and the results were expressed as rutin equivalent (mg RE/g db).

Microstructure of fresh and dried sweet corn

Investigation of fresh and dried sweet red corn slice slides was prepared using a Carl Zeiss light microscope, and images were digitized with Zeiss xioCamlCc3 software. Structural alterations were assessed with a Hitachi SEM (TM-4000plus) after gold coating of samples for vacuum mode examination.

Sugar contents

Sugar extraction was performed by mixing 0.1 g of powdered dry samples and fresh samples with 5 mL of distilled water, incubating for 30 minutes at 80°C, and then extracting the sugar after analysing the supernatants by HPLC (Shimadzu 20 series) after filtration through a 0.22 mm filter, according to Harakotr *et al*. (2022).

Phenolic acid and flavonoid compounds by HPLC

The individual of phenolic acids and flavonoid compounds were extracted following the method described by Chumroenphat *et al*. (2021). In brief, 1.0 g of each sample was mixed with 20 mL of a 1:100 (v/v) HCl:methanol solution and shaken at 37 °C for 12 hours. The sample was filtered on Whatman No. 1 paper after shaking, and the pellets were re-extracted using the same procedure. The mixed filtrates were vacuum-dried at 40 °C and redissolved in 5 mL of a 50:50 methanol:water solution. HPLC analysis, using a Shimadzu system with an InertSustain® C18 column and detected at 280 nm and 370 nm for flavonoids and 280 nm and 320 nm for phenolic acids, was performed following the methodology of Siriamornpun *et al*. (2012). External standards were used for comparison during the analysis.

Amino acid contents by LC/MS/MS

Amino acids were extracted using a previous method (Saensouk *et al*., 2022) and analysed by LC/MS/MS using a Shimadzu LCMS-8030 triple-quadrupole mass spectrometer (Kyoto, Japan) with an InertSustain® C18 column (2.1 x 150 mm, 3 μm) in ESI mode. The isocratic elution employed a mobile phase of solvent A (0.1% v/v formic acid in water) and solvent B (0.1% v/v formic acid in water/methanol, 50:50 v/v) at 0.2 mL/min flow rate and 40°C column temperature. The data presented amino acid content in mg/100 g dry basis with SD (n = 3).

Antioxidant activity

•DPPH free-radical scavenging

The DPPH radical scavengers in the extracts were identified as described in a prior study (Chumroenphat et al., 2021). The absorbance was measured using a microplate reader (Varioskan Lux, Thermo Fisher Scientific, USA) at 517 nm. The results are expressed in milligrams of Trolox equivalents (TE) per gram of dry basis (mg TE/g db).

•Ferric reducing/antioxidant power assay (FRAP)

The FRAP processes were carried out in accordance with a previously published approach (Saensouk *et al*., 2022). In the 96-well plate of the microplate reader, the absorbance was measured in comparison to a control at 593 nm. The FRAP readings were given in milligrams of $FeSO_4$ per gram of dry basis (mg $FeSO_4$/g db).

Statistical analysis

All data were analysed using a statistical software package. A one-way analysis of variance (ANOVA) was performed to determine the significance of differences between the treatment groups. The mean ± standard deviation (SD) of three replicates was reported for all data. Statistical significance was defined as $p < 0.05$.

Results and Discussion

The physicochemical, bioactive component, and antioxidant activity of sweet red corn were investigated using various drying processes. Its samples come from a single source, a location, and a season. In the sections that follow, several drying processes with varying physicochemical, bioactive compound, and antioxidant properties will be investigated.

Changes in color, total phenolic content and total flavonoid content with different drying methods

The comparison of sweet red corn with different drying methods, distinct color characteristics were observed as shown in Table 1. The brightness is shown by the L*value when evaluated to positive and negative

values; the redness, greenness, and positive and negative values were recognized by the *a** values, while the yellowness and blueness were determined by the *b** values (Siriamornpun *et al*., 2012). Freeze-drying resulted in the lightest color, with significantly higher L* values (74.46±0.50), indicating a lighter appearance compared to the fresh sample. It also exhibited the lowest *a** values (4.91±0.15), indicating reduced redness. Sun drying produced an intermediate color, with slightly lighter L* values (48.56±0.83) and lower *a** values (9.52±0.16) compared to the fresh sample. Hot air drying at 40 °C, 60 °C, and 80 °C showed variations in color parameters. Drying at 60 °C resulted the highest L* value (65.11±0.99), while drying at 80 °C resulted in the highest *a** (10.82±0.25) and *b** (22.60±0.32) values. Overall, these findings highlight the influence of drying methods on color characteristics, enabling selection based on desired color attributes. The *ΔE* values indicate the overall color difference between the drying methods. The freeze-dried samples had the highest *ΔE* value (73.64±1.00), suggesting the most significant difference in color compared to the fresh sample. The sun-dried samples had a relatively smaller *ΔE* value (48.46±0.81), indicating a smaller color difference compared to the fresh sample. Hot air drying at different temperatures also showed varying *ΔE* values. These findings provide insights into the impact of different drying methods and temperatures on the color characteristics of the samples. The choice of drying method and temperature can influence the resulting color attributes, and understanding these changes is important for optimizing drying strategies to preserve desired color characteristics in the final product.

Table 1. Color parameters of dried sweet red corn by different drying methods

Parameter	Drying method					
	Fresh	FD	SD	HD40	HD60	HD80
L*	6.59±1.26e	74.46±0.50 a	48.56±0.83 d	56.13±1.31 c	65.11±0.99 b	56.46±0.61 c
*a**	33.26±2.19 a	4.91±0.15 f	9.52±0.16 c	7.89±0.39 d	6.69±0.31 e	10.82±0.25 b
*b**	11.31±2.15 d	12.71±0.20 d	14.68±0.62 c	19.43±1.18 b	15.13±0.58 c	22.60±0.32 a
ΔE	-	73.64±1.00 a	48.46±0.81 d	56.32±1.07 c	64.46±0.96 b	55.93±0.96 c

The mean ± standard deviation (SD) of triplicate measurements (n = 10) are presented for all data. Freeze-dried (FD), sun-dried (SD), and hot air-dried (HD) samples are denoted by different letters. Means with different letters are significantly different at $p < 0.05$ within the same row.

Changed on total phenolic content (TPC) and total flavonoid content (TFC)

Total phenolic content (TPC) and total flavonoid content (TFC) are measures of the concentration of certain plant compounds in a sample, which can have potential health benefits. Corn, like many other plant-based foods, contains phenolic compounds and flavonoids. These compounds have antioxidant properties and may have a positive impact on human health, including reducing the risk of chronic diseases. Studies have shown that the TPC and TFC content in corn can vary depending on factors such as the variety of corn, the part of the plant (e.g. kernels, husk, cob, etc.), and the growing and harvesting conditions. Generally, corn kernels have lower TPC and TFC compared to other parts of the plant. The result of TPC and TFC on different drying methods as show in Table 2. The highest content of total phenolic acids was found in fresh sample followed by FD (134 mg GAE/g db), HD80 (124 mg GAE/g db), FD (107 mg GAE/g db), SD (103 mg GAE/g db) and HD60 and SD, respectively. The results agreed with the total flavonoid content (TFC) analysis, which revealed that the TFC was highest in the fresh corn samples, followed by those subjected to hot air drying at 80 °C (HD80). There were no significant differences in TFC between the FD, SD, HD60 and SD. According to these findings, heat treatment decreased the TFC and TPC values in Fresh samples, which is consistent with previous research (Chumroenphat *et al*., 2021). Normally, phytochemical substances are reduced during heat processing. Our results agree with the previous research that found that a longer drying duration had an effect on many chemical changes, such as the decomposition of phenolic compounds,

anthocyanin and solute movement of the food constituents, as well as on physical appearance. Additionally, the composition and amount of phenolic acids may change as a result of the drying process at high temperatures. In particular, around 80 °C, certain phenolic acids may degrade and produce other phenolic compounds. Some phenolic structures are thermally unstable and can reorganize or breakdown to generate other phenolic groups, which is what is thought to be the cause of this transition. Such temperature-related alterations in the phenolic profile might affect the total phenol content, possibly increasing it (Aprodu *et al*., 2020).

Table 2. Total phenolic contents and total flavonoid contents of sweet red corn with different drying methods

Drying methods	TPC (mgGAE/g db)	TFC (mgRE/g db)
Fresh	93.97±1.21 d	12.59±0.21 a
FD	107.98±5.25 c	3.53±0.13 c
SD	103.11±3.01 c	3.80±0.14 c
HD40	134.84±4.29 a	3.65±0.14 c
HD60	104.67±4.50 c	3.70±0.14 c
HD80	124.40±2.84 b	6.22±0.36 b

The mean ± standard deviation (SD) of three duplicate measurements (n = 3) are presented for all data. The total phenolic content (TPC) and total flavonoid content (TFC) are denoted by TPC and TFC, respectively. Freeze-dried (FD), sun-dried (SD), and hot air-dried (HD) samples are denoted by different letters. Means with different letters (a, b, c, d) within the same column are significantly different at $p < 0.05$.

Changed on microstructure of fresh and dried sweet corn

The microstructure of fresh (a-c) and drained (d-h) sweet corn with different drying methods were shown in Figure 2. According to our findings, the visible purple color of the pericarp covered the entire corn grain display on Figure 2 (a-b). The purple was the result of an abundance of anthocyanins in the pericarp and aleurone layers of corn, with different compositions and contents (Li *et al*., 2019). As reported by the authors, the pericarp-pigmented corn has significantly higher anthocyanin contents than aleurone-pigmented corn, due to a greater number of pigmented cell layers in the peri-carp compared to a single-layered aleurone(Hong *et al*., 2020; Lao and Giusti, 2016; Nankar *et al*., 2016; Li *et al*., 2019). Figure 2 (d-h) displays the structure of corn after drying at various temperatures as observed by scanning electron microscopy (SEM), in compared to the structure of fresh corn (Figure 2 c). The results show that, the microstructure of fresh tissue (Figure 2 c) shows the cells are enclosed in thin, highly pitted walls, and the starch granules are fully empty in parenchyma cell of the fresh tissue. In contrast, the three drying methods (sun drying: SD; freeze drying: FD; and hot air drying at 40, 60 80 0C: HD40, HD60, and HD80) were different when compared with fresh tissue, as shown in Figure 2 (d-h). Additionally, microstructure of FD was showing the starch granules clearly in parenchyma cell and the thin of cell wall was cracked. This is because water is sublimated in the freeze-drying process by the direct transfer of water from frozen sample to vapor, which can destroy a thin coating of cell wall (Carapelle *et al*., 2001; Woo and Mujumdar, 2010). Whilst the heat drying methods of sun drying and hot air drying produced similarity of microstructure due to temperature and moisture gradients that produced cell-wall rupture, folding, and deformation throughout the drying process(Chumroenphat *et al*., 2021). Moreover, in all samples, the interior matrix of the grains, which indicates the coupling of starch and protein bodies, was also different (Bhuiyan *et al*., 2010).

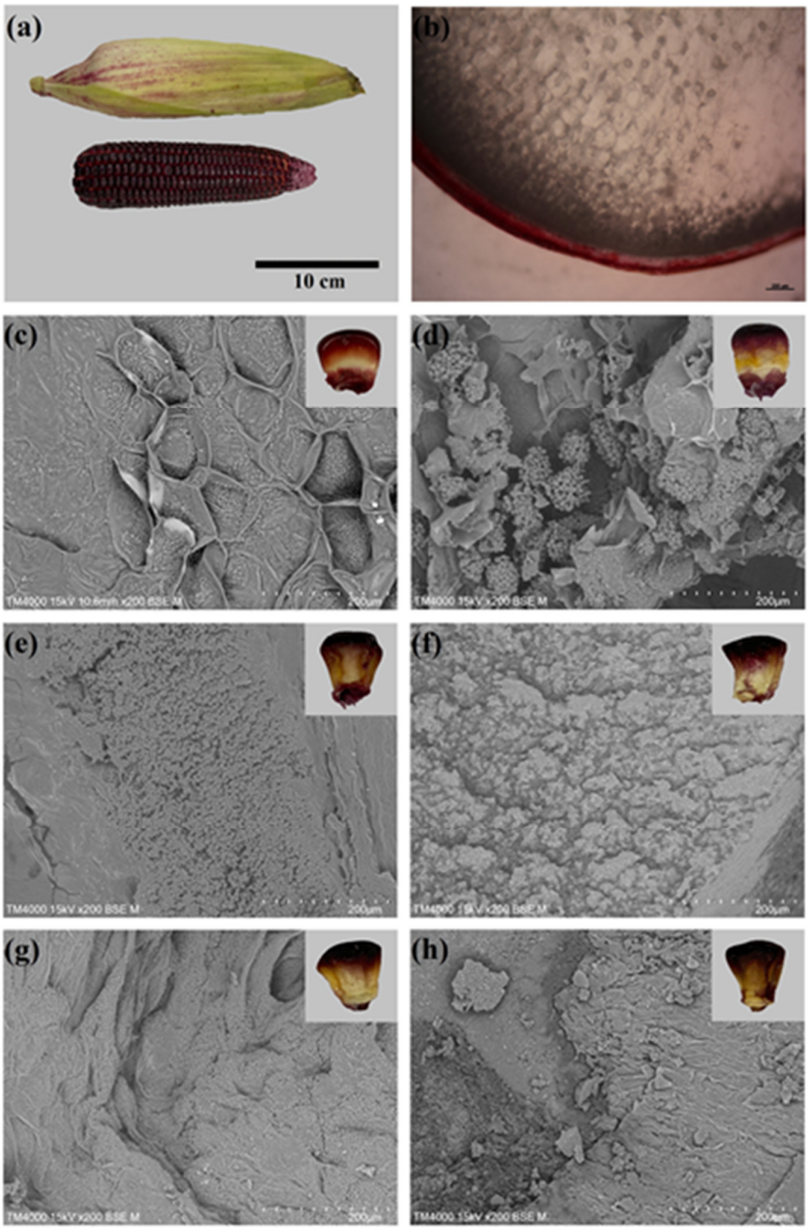

Figure 2 Microstructure of fresh and dried sweet red corn. a: sweet red corn; b: fresh observe with LM; c: fresh observe with SEM; d: freeze dried by SEM; e: sun dried by SEM; f: hot air oven dried 40 °C by SEM; g: hot air oven dried 60 °C by SEM; h: hot air oven dried 80 °C by SEM. Image of fresh sweet red corn sections using light micros-copy (×20); image of fresh and dried sweet red corn using scanning electron micrographs: different drying (×200)

Sugar contents

The composition of soluble sugars in corn was discovered to be mostly composed of sucrose, glucose, and fructose, respectively(Chumroenphat *et al*., 2021). Sucrose was the most abundant soluble saccharide among all endosperm sugar components (Harakotr *et al*., 2022). On the other hand, this investigation found maltose, a disaccharide of sugar was important sugar in corn (Mousavi *et al*., 2024). This molecule shares structural similarities with the disaccharide sucrose. Maltose is sweeter than sucrose, which is how it differs

from the latter (Nishi *et al*., 2016). Maltose is composed of two units of glucose, whereas sucrose is composed of glucose and fructose. The results show that sugar content decreased significantly in all drying methods over a 6-time comparison with a fresh sample. The total sugar content of fresh and dried sample display in glucose, fructose, sucrose and maltose are shown in Table 3. The fresh sample had the highest total sugar was 603 µg/g db and with the following order: fresh>HD80 and HD40, SD and FD were no significantly. For HD60 was lowest content of total sugar, these results could be explained by 60°C for liquid faction; along with the addition of amylolytic enzymes (amylase) to hydrolyse starch into glucose (Vohra *et al*., 2014) and the hydrolyzation of sucrose by invertases or synthases into glucose and fructose during the drying process (Harakotr *et al*., 2022; Reyes *et al*., 1982).

Table 3. Contents of sugars analyses in sweet red corn with different drying methods

Parameter	Sugar content (µg/g db)					
	Fresh	FD	SD	HD40	HD60	HD80
Sucrose	113.12±0.11 a	15.87±1.07 d	18.75±1.22 c	21.63±1.05 b	16.99±0.16 d	19.63±0.44 c
Glucose	337.66±3.67 a	56.31±1.91 c	56.08±2.27 c	57.42±1.10 c	49.62±0.30 d	68.89±1.84 b
Fructose	119.65±0.23 a	15.91±0.02 cd	17.00±1.14 c	14.52±0.23 d	14.75±1.44 d	20.61±0.36 b
Maltose	33.24±0.58 a	7.62±0.42 c	7.97±0.04 c	8.13±0.51 c	7.74±0.15 c	8.89±0.05 b
Total	603.67±4.59	95.71±3.42C	99.8±4.67 C	101.70±2.89C	89.10±2.05D	118.02±2.69 B

Values are expressed as mean ± SD of triplicate measurements (n = 3). FD: Freeze dried; HD: Hot air dried; SD: Sun dried. Means with different letters (a, b, c, d) are significantly different at $p < 0.05$ within the same row. Means with different letters (A, B, C, D) within the same row in the parameter are significantly different at $p < 0.05$.

Amino acid content on different drying methods

Corn is a good source of protein and contains all the essential and non-essential amino acids (Li *et al*., 2022). Whilst corn is dried, the amino acid content can be affected by various factors, such as the drying temperature, the length of time it is dried, and the storage conditions after drying (Setiawan *et al*., 2010). This study showed the different drying methods beneficial to amino acids, including 10 essential amino acids (arginine, histidine, isoleucine, leucine, lysine, methionine, phenylalanine, threonine, tryptophan, and valine) and 10 non-essential amino acids (alanine, asparagine, aspartic acid, cysteine, glutamine, glutamic acid, glycine, proline, serine and tyrosine). The result shows that cysteine cannot be found in sweet red corn, but another amino acid can be found in corn in all drying methods and the amino acid content decreased after drying (Table 4). Furthermore, the comparative content of essential and non-essential amino acids was found to be higher in essential amino acids than non-essential amino acids. In particular, methionine had the highest content found in fresh, and FD had a certain total amino acid content higher than other drying methods. Which was similar to a previous study, reporting that high-temperature drying can cause a loss of certain amino acids, particularly lysine and tryptophan, which are more heat-sensitive than other amino acids (Chumroenphat *et al*., 2021). To preserve the amino acid content in corn during drying, it is important to use low-temperature drying methods and to monitor the drying process carefully to avoid over-drying. Additionally, proper storage conditions after drying, such as keeping the corn in a cool and dry environment, can help to maintain the amino acid content. However, the amount of amino acids, is influenced by drying conditions such as microwave, vacuum, far-infrared radiation, etc. and needs evaluation (Xu *et al*., 2016; Zhao *et al*., 2020; Akhtaruzzaman *et al.*, 2021).

Table 4. Contents of amino acids in sweet red corn with different drying methods

Parameter	Amino acid (mg/100g db)					
	Fresh	FD	SD	HA40	HA60	HA80
Essential						
Arginine	11.16±0.09e	3.46±0.07e	4.43±0.08f	3.97±0.15e	4.74±0.18g	3.21±0.03e
Histidine	8.31±0.33h	11.60±0.81c	5.03±0.14e	3.75±0.20e	5.60±0.38f	1.04±0.03g
Isoleucine	8.89±0.10g	11.00±0.46c	10.38±0.14b	7.68±0.18b	7.79±0.19c	0.89±0.11g
Leucine	7.79±0.13h	9.43±0.38cd	9.01±0.37d	6.60±0.17d	6.58±0.20d	3.72±0.22d
Lysine	19.21±0.29c	7.28±0.21d	3.91±0.06g	2.68±0.11g	5.41±0.07f	0.49±0.03e
Methionine	66.11±2.37a	49.83±4.05a	10.67±1.2b	12.29±0.29a	10.36±0.43b	8.65±0.47c
Phenylalanine	13.55±0.31d	11.34±0.51c	9.84±0.09c	7.21±0.27c	6.01±0.31e	17.02±0.46b
Threonine	9.63±0.27f	3.88±0.21e	3.48±0.14h	3.14±0.08f	5.30±0.11f	1.87±0.03f
Tryptophan	4.83±0.09j	3.42±0.14e	3.19±0.04i	2.27±0.04h	3.40±0.17h	33.77±0.42a
Valine	33.30±1.69b	18.9±0.61b	15.77±1.25a	12.47±0.38a	13.60±0.30a	0.13±0.01f
Sum-Essential	182.80±4.15A	130.15±6.17B	75.73±2.26C	62.04±1.69E	68.80±0.77D	70.78±1.41CD
Non-Essential						
Alanine	115.98±12.35a	30.38±1.69a	14.05±0.87b	18.94±0.34a	16.67±0.59b	19.05±0.51a
Asparagine	5.46±0.02h	1.20±0.01f	2.04±0.03h	1.38±0.02h	3.63±0.03g	1.64±0.03d
Aspartic acid	12.66±0.23f	4.37±0.02d	9.04±0.35e	7.30±0.38e	8.70±0.46d	1.42±0.02e
Cysteine	ND	ND	ND	ND	ND	ND
Glutamine	28.82±0.63b	11.94±0.10b	17.35±0.09a	15.96±0.08b	20.58±0.03a	2.56±0.1c
Glutamic acid	18.82±1.74e	7.90±0.17c	4.06±0.11f	2.63±0.1f	4.05±0.06f	0.72±0.03g
Glycine	4.22±0.33i	1.00±0.10g	1.39±0.05i	0.97±0.04i	1.16±0.04i	0.25±0.05i
Proline	22.12±1.04d	11.38±0.80b	12.44±0.38c	13.30±0.96c	8.21±0.21e	9.12±0.47b
Serine	9.97±0.08g	2.85±0.04e	2.61±0.01g	2.07±0.03g	1.91±0.00h	0.96±0.00f
Tyrosine	26.98±0.58c	11.14±0.39b	9.69±0.22d	8.57±0.26d	9.46±0.27c	0.37±0.02h
Sum-non-Essential	245.03±13.23A	82.17±2.31B	72.68±0.89CD	71.11±0.75D	74.37±0.19CD	36.08±0.07E
Total amino acids	427.83±17.24A	212.32±8.47B	148.41±2.77C	133.15±8.47E	143.17±0.86D	106.86±1.37F

Values are expressed as mean ± SD of triplicate measurements (n = 3). ND: Not detected; FD: Freeze dried; HD: Hot air dried; SD: Sun dried. Means with different letters (a, b, c, d) are significantly different at $p < 0.05$ within the same column. Means with different letters (A, B, C, D) within the same row in the parameter are significantly different at $p < 0.05$.

Phenolic acid and flavonoid compounds by HPLC

The contents of ten individual phenolic acids in sweet corn were detected by HPLC (Table 5). These results indicated that the highest values of total phenolic acids were found in HD80, HD40, SD, FD, HD60, and fresh, at 596, 578, 515, 509, and 442 μg/g db, respectively. This justifies the heat drying method because it can increase the concentration of some phenolic acids, such as vanillin, gallic acid, protocatechuic acid, *p*-hydroxybenzoic acid, and *p*-coumaric acid. Whilst, vanillic acid, caffeic acid and sinapic acid decreased when drying with heat. Furthermore, the highest ferulic acid content was found at HD60, and it decomposed when heated to 80 °C. Remarkably, vanillin was increased from 8 (fresh) to 1671 μg/g db (HD80) in about 209 folds (Table5). These results could be explained by the bioconversion of glucose to vanillin due to the lower glucose content in dried samples compared with fresh samples. Moreover, as reported by the authors, vanillin production by fermentation used the bioconversion of ferulic acid produced from rice bran via the endogenous route of *Streptomyces setonii* (Hansen, 2021). While, eugenol and curcumin have also been raw materials of vanillin by bioconversion (Chumroenphat *et al*., 2021; Gallage and Møller, 2015; Nagpure and Gupta, 2011). Widely used vanillin is useful in a flavoring claimed as natural in a commercial food or beverage composition.

The flavonoid compound contents (rutin, quercetin, apigenin and myricetin) in sweet red corn with different drying methods are shown in Table 5. The results show that the total flavonoid compounds ranged from 787 to 4433 μg/g db in HD60 and the fresh sample, respectively. The individual flavonoid compounds

were myricetin, found highest in fresh at 3403 μg/g db and quercetin found in SD and HD40 but not significantly, while HD60 and HD80 were absent of quercetin but nonetheless could detect other individual flavonoids (rutin, myricetin and apigenin). In the case of quercetin it is unstable and leads to further degradation during the drying process under oxygen conditions (Buchner *et al*., 2006; Chaaban *et al*., 2017). However, individual phenolic and flavonoid compounds were reported in several varieties of corn, such as purple corn (*Zea mays* L.) (Maxican), where eight phenolic acids was ferulic acid identified with HPLC (Lopez-Martinez *et al*., 2009). Whereas purple corn in the USA reported 11 phenolic acids and flavonoids, including gallic acid, catechin, chlorogenic acid, caffeic acid, rutin, ferulic acid, hesperidin, morin, quercetin, naringenin, and kaempferol. (Ramos-Escudero *et al*., 2012). In Thailand, Harakotr *et al*. (2014) reported phenolic acids including protocatechuic acid, p-hydroxybenzoic acid, vanillic acid, caffeic acid, p-coumaric acid, and ferulic acid in purple waxy corn (Harakotr *et al*., 2014). In general, previously reported biological activities were reported.

Table 5 Contents of phenolic acid, flavonoids analyses in sweet red corn with different drying methods

Parameter	Drying method					
	Fresh	FD	SD	HD40	HD60	HD80
Phenolic acid content (μg/g db)						
Gallic acid	4.88±0.51 cd	7.92±0.17 c	20.88±1.94 b	8.26±0.04 c	21.89±0.23 b	187.83±1.55 a
Protocatechuic acid	ND	16.35±2.38 c	19.43±1.31 b	ND	ND	54.62±1.80 a
P-hydroxybenzoic acid	ND	14.23±0.29 c	17.14±0.80 b	ND	ND	79.48±1.53 a
Vanillic acid	192.72±2.90 a	39.09±2.20 d	53.61±1.80 b	48.04±1.58 c	56.03±1.12 b	ND
Caffeic acid	187.12±1.80 a	36.69±2.94 d	44.31±4.90 c	49.59±3.71 b	24.48±0.83 e	ND
Syringic acid	3.13±0.13 e	8.52±0.66 c	12.76±0.44 a	9.36±0.25 b	9.87±0.17 b	12.33±0.93 a
Vanillin	8.17±0.14 h	373.28±10.61 e	393.10±7.25 e	459.42±12.70 d	357.78±0.10 f	1671.19±30.28 a
P-coumaric acid	ND	1.64±0.14 c	4.94±0.20 b	0.38±0.03 d	0.54±0.01 d	10.03±0.81 a
Ferulic acid	18.25±0.28 c	13.25±0.35 d	12.80±0.24 d	8.14±0.37 e	39.07±0.83 a	0.39±0.12 f
Sinapic acid	27.31±0.92 a	4.07±0.24 c	ND	12.77±0.39 b	ND	0.20±0.01 d
Total	441.58±0.95 F	515.04±1.97 D	578.97±1.90 C	595.96±2.34 B	509.66±0.41 E	2016.07±4.63 A
Flavonoid content (μg/g db)						
Rutin	851.57±0.52 a	174.57±0.07 c	225.14±0.82 b	174.63±0.50 c	122.70±0.44 e	168.73±0.14 d
Myricetin	3403.41±4.05 a	941.16±1.72 b	918.84±3.70 c	680.94±1.15 d	639.09±1.15 e	594.48±1.37 f
Quercetin	23.50±0.14 a	6.76±0.03 d	5.72±0.02 d	5.43±0.01 d	ND	ND
Apigenin	154.89±1.66 a	71.32±1.24 c	64.24±0.64 d	35.40±0.05 e	25.41±0.02 f	137.15±0.11 b
Total	4433.37±6.37A	1193.81±3.06C	1213.94±5.18 B	896.40±1.71 E	787.20±1.61 F	900.36±1.62 D

Values are expressed as mean ± SD of triplicate measurements (n = 3). ND: Not detected; FD: Freeze dried; HD: Hot air dried; SD: Sun dried. Means with different letters (A, B, C, D) are significantly different at $p < 0.05$ within the same row in the parameter. Means with different letters (a, b, c, d) are significantly different at $p < 0.05$ within the same row.

Antioxidant activity

Corn may have health benefits since it includes a variety of bioactive substances, including antioxidants. Free radicals, which are extremely reactive chemicals that can disrupt cellular components and contribute to the onset of chronic diseases, can cause oxidative damage to cells, which is why antioxidants are so important in preventing this damage. The DPPH (2,2-diphenyl-1-picrylhydrazyl) assay and the FRAP (Ferric Reducing Antioxidant Power) assay are two frequently used techniques for determining the antioxidant activity of substances, including those found in corn. The results obtained from the DPPH and FRAP assays for the different drying methods of corn provide insights into the impact of drying on the antioxidant activity of corn samples. When comparing the drying methods, it was observed that fresh corn exhibited the highest antioxidant activity, while freeze-drying (FD) retained relatively higher antioxidant activity compared to sun-drying (SD) and hot air drying (HD) at different temperatures. Hot air drying at higher temperatures generally results in lower antioxidant activity. The results obtained showed that fresh corn exhibited the highest

antioxidant activity, as demonstrated by the highest values in both the DPPH and FRAP were 18.7 mg TE/g db and 116.1 mg $FeSO_4$/g db, (Table 6) respectively.

Table 6 Antioxidant activities measured by means of DPPH radical scavenging and FRAP analyses in sweet red corn with drying methods

Drying methods	DPPH (mg TE /g db)	FRAP (mg $FeSO_4$/ g db)
Fresh	18.72±0.56 a	116.15±0.93 a
FD	5.91±0.22 c	42.81±1.51 c
SD	6.74±0.42 b	41.67±2.70 c
HD40	5.64±0.45 c	39.52±1.73 c
HD60	5.21±0.22 c	35.35±1.98 d
HD80	4.69±0.20 d	52.62±2.08 b

The mean ± standard deviation (SD) of triplicate measurements (n = 3) are presented for all data. FRAP and DPPH denote ferric reducing antioxidant activities and DPPH radical scavenging activities, respectively. FD, HD, and SD denote freeze-dried, hot air-dried, and sun-dried samples, respectively. Means with different letters (a, b, c, d) within the same column are significantly different at $p < 0.05$.

Additionally, FD retained a significant amount of antioxidant activity compared to fresh corn, although there was a notable decrease. The antioxidant activity of FD corn was lower in both the DPPH (5.9 mg TE/g db) and FRAP (42.8 mg $FeSO_4$/g db) assays. Moreover, Sun-dried (SD) corn and hot air drying at different temperatures (HD40, HD60, HD80) showed lower antioxidant activity compared to fresh corn and freeze-dried corn. The DPPH values ranged from 6.7 to 4.6 mg TE/g db, and the FRAP values ranged from 41.6 to 52.6 mg $FeSO_4$/g db, depending on the drying method and temperature. Based on these results, it can be concluded that the choice of drying method has a significant impact on the antioxidant activity of corn. Fresh corn demonstrated the highest antioxidant capacity, while freeze-drying retained a considerable amount of antioxidant activity. Sun-drying and hot air drying at higher temperatures led to a decrease in antioxidant activity. Therefore, freeze-drying can be considered a favourable method for preserving the antioxidant activity of corn, while sun-drying and high-temperature drying methods may result in a decline in antioxidant capacity. These findings emphasize the importance of selecting appropriate drying techniques to maintain the beneficial antioxidant properties of corn.

Conclusions

Our study of the effects on corn has demonstrated that drying methods differ in the ways in which they affect microstructure and bioactive compounds in corn, as well as its antioxidant activities. The microstructure of the freeze-dried corn was comparable to that of the fresh material. Essential amino acids were discovered to have a greater comparative content than non-essential amino acids. Methionine was particularly present in fresh, and FD had an individual total amino acid content that was greater than that of other method of drying. In addition, compared to all other samples dried by other methods, the freeze-dried material exhibited a greater amount of bioactive compounds and anti-oxidant activity. While the SD and HD produced comparable microstructures. On the other hand, the sample that was freeze-dried exhibited a greater concentration of phytochemical, bioactive compounds and antioxidant activity when compared to all other samples that were dried using different methods. This justifies FD providing the highest amounts of TPC and TFC. Additionally, vanillin, the highest of the phenolic acids, was increased at heat drying with bioconversion from drying processing, and some of the phenolic acids were decomposed. The flavonoid compounds decreased with drying compared to frees, especially quercetin, which was unstable at HD60 and HD80. According to the target constituents, such as phenolics, flavonoids, or amino acids, each drying technique may be suitable for certain substances. The results of this study should be helpful in designing a drying process that produces dried corn

while maintaining food quality, high bioactivity, and high antioxidant levels by preventing phytochemical degradation.

Authors' Contributions

OK and TC performed the conception and design of study. TC: analysis and/or interpretation of data designed. OK and TC wrote the manuscript and reviewed the final manuscript for journal submission. All authors read and approved the final manuscript.

Ethical approval (for researches involving animals or humans)

Not applicable.

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Conflict of Interests

The authors declare that there are no conflicts of interest related to this article.

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