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Research Article

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Nutritional Profiling and Characterization of Different Varieties of Corn Silk

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Abstract

Corn silk has been used in traditional Chinese medicine for thousands of years, but it is still considered more of an agricultural waste. This study aimed to assess the nutritional and phytochemical properties of corn silk of 4 different kharif varieties - PIONEER, JKMH, AHC, and K25 at the different growth stages (stage 1 to stage 5). JKMH exhibited the highest values ($p < 0.05$) for moisture 84.36 ± 0.17% wb and ash content 3.04 ± 0.08% in stage 1, while AHC stage I had the highest protein content of 8.16 ± 0.02 g. PIONEER showed the highest flavonoid and ascorbic acid content of 38.94 ± 2.97 mg QE/100 g and 88 ± 1.41 mg/100 g respectively on reaching the mature stage along with the highest antioxidant activity in Free radical scavenging activity (FRSA) (36.8 ± 0.86%) and CUPRAC (26.04 ± 1.2 µmol trolox/g). The variety PIONEER was estimated to be the best variety for developing value-added products due to its nutritional and phytochemical properties. The Fourier transform infrared spectroscopy (FTIR) spectra revealed the presence of various functional groups and bonds such as the O-H group, N-H bond, C-N group, and C=O bond. Differential scanning colorimetry displayed the on-set temperature (T_{onset}) as 32.09 °C and end-set temperature (T_{endset}) as 94.59 °C for endothermic reactions of corn silk powder and on-set temperature (T_{onset}) as 334.09 °C and end-set temperature (T_{endset}) as 369.87 °C for exothermic reactions. Thus, corn silk has great potential in making value added products because of its nutritional and antioxidant properties, rather than just being dumped as an agricultural waste material.

Keywords

Corn silk, Nutritional, Phytochemical, Growth stages, Antioxidant activity, Flavonoid

Introduction

Corn silk is referred to as the yellowish thread-like strands found inside the maize husk. It is scientifically known as stigma maydis [1]. These are long and silky, with the color ranging from yellowish to reddish. Corn silk has been used in traditional medicine for the treatment of various medical problems because of its high medicinal properties in different parts of the world [2]. There are a variety of bioactive compounds such as proteins, vitamins, and minerals, carbohydrates, fixed and volatile oils, steroids, and other natural antioxidants such as flavonoids present in silk [3]. There is presence of other compounds like polysaccharides, alkaloids, glycoproteins, terpenes, saponins, tannins, and organic acids [4, 5]. It is used for the treatment of problems like malaria, urinary tract infections (UTIs), and prostate problems. Corn silk also exhibits anti-inflammatory, anti-depressant, and anti-cancer effects [6]. High serum levels of triglycerides, low-density

lipoprotein, total cholesterol, and low levels of high-density lipoprotein can be treated with the help of corn silk [7]. The anti-diabetic effect is also exhibited as it elevates insulin levels and boosts the recovery of pancreatic beta cells [8]. Corn silk also contains compounds that function as diuretics and aid in the reduction of inflammatory responses [9]. Corn silk exhibits strong antioxidant activity due to the presence of flavonoids which show scavenging action [10] and helps lower blood pressure as it exhibits anti-ACE activity (angiotensin converting enzyme) [11].

Due to the beneficial properties of corn silk, it has been used to make a variety of other value-added products. Corn silk tea has been produced which helps to lower blood pressure [12]. It has also been used to make beef patties and low-fat meatballs [13].

Given that many studies have continuously investigated the potential health benefits of corn silk, which was previously thought to be a waste material, the current study aims to investigate the nutritional profile and bioactive composition of selected varieties of corn silk grown in Punjab region along with the characterization of the best suited variety. The selected variety of corn silk powder or its extract can be used to develop a variety of value-added products like candies, beverages, and patties.

Materials and Method

Sample collection and preparation

The different kharif varieties of corn viz. PIONEER, JKMH, AHC, and K25 were grown at the agriculture farm of Lovely Professional University, Phagwara, Punjab, India. The average growth period of maize crops was 90 - 120 days. The reproductive stage of corn has various stages namely silking stage (R1 - 60 days after emergence), blister stage (R2 - 72 days after emergence), milking stage (R3 - 80 days after emergence), dough stage (R4 - 86 days after emergence), dent stage (R5 - 96 days after emergence) and physiological maturity stage (R6 - 115 days after emergence). Intermittent sample collection was carried out on the following days at different stages as shown in figure 1. The only stages used in the experiment were from stages 1 to 5 as stage 6 is not processible and consumable. The corn silk was cleaned and washed with potable water. Blanching was done for 60 second at 100 °C for preventing any chemical changes and color retention which was followed by tray drying for 4 h at 50 °C (Labfit India Pvt Ltd., Mumbai, India) until persistent weight was achieved to obtain the dry powder. A commercial mechanical grinder (rex 500, bajaj electrical and electronics Pvt. Ltd., Punjab, India) was used to grind the dried corn silk, followed by sieving using an electric sieve shaker (8" sieve shaker SS-15, Gilson Company, Inc., Lewis Center, OH, USA) with 22 mesh-sieve size. Sealed zip-lock pouches (Wellworth Packers Pvt. Ltd., Delhi, India) were used to store the corn silk powder at a temperature of 4 - 7 °C for further use.

Nutritional composition of corn silk powder

Determination of the chemical composition (carbohydrates, fat, protein, ash, and moisture) of corn silk powder was done with the values being expressed in the unit g/100 g. The soxhlet method was used for the determination of the fat content [14]. Ash content was determined using the dry ashing method. The oven-dry method was used for the determination of moisture content [14]. The carbohydrate content of the samples was determined using the difference method [15]. Kjeldahl's method was used to determine the protein content, in which the final values were found by multiplication of factor 6.25 with the nitrogen content [12].

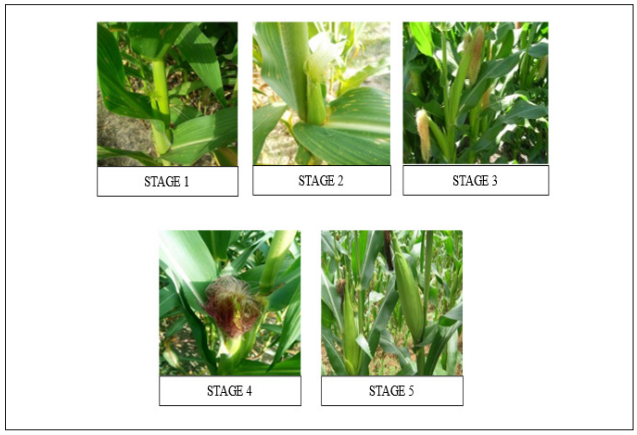


Figure 1: Pictorial presentation of different stages of corn silk (stage 1 to stage 5).

Mineral analysis

Thermo iCAP 7000 Duo ICP OES (Thermo Fisher Scientific, Bremen, Germany) was used for the determination of the mineral content of the corn silk powder samples [14]. Pure argon gas (Himalayan Gases, Baddi, India) is used for plasma. PTFE vessels using a Multiwave Pro microwave oven (Anton Par, Graz, Austria) were used for the process of microwave digestion. For the preparation of all solutions, deionized water ASM Type I (18.2 mΩ, Aurium mini, Sartorius, Germany) was used. Nitric acid (HNO_3 69%, Loba Chemie Pvt Ltd., Mumbai, India) was used for the digestion of the materials. The analytical solutions (Alfa Aesar, Specure, MA, USA) were made using standard solution dilutions (1000 µg ml^{-1}) of Ag, Al, B, Ba, Bi, Ca, Cd, Co, Cr, Cu, Fe, Ga, In, K, Li, Mg, Mn, Na, Ni, Pb, Sr, TI and Zn. 0.5 g of weighed samples along with 7 ml of HNO_3 were taken in the PFTE vessels. A five-step heating program was followed for the microwave-assisted digestion: (i) ramp for 10 min to 150 °C; (ii) hold for 10 min at 150 °C; (iii) ramp for 10 min to 180 °C; (iv) hold for 10 min at 180 °C; and (v) ramp for 21 min to 55 °C cooling temperature. After cooling the containers to room temperature, the solutions were shifted to polyethylene tubes and ultrapure water ASM type I was added to make the volume up to 30 ml. After digestion of collected samples, auxiliary gas flow of 0.5 l/min, sample flow of 0.50 l/min, analysis pump rate of 50 rpm, nebulizer gas flow of 0.5 l/min, plasma gas flow of 12 l/min, radio frequency power of 1250 W, stabilization time of 5 s, integration time of 15 s and nebulization pressure of 20 psi were used for the ICP OES quantification procedure which was carried out in axial view of plasma. Monitoring was done for sodium (588.995, 589.592 nm), magnesium (279.553 nm), potassium

(766.940 nm), calcium (293.366, 396.847 nm), manganese (257.610 nm), copper (324.754 nm) and iron (259.940 nm).

Extraction of ethanolic extract

Corn silk samples were macerated with 80% ethanol (v/v) in a 1:10 ratio. A falcon tube was filled with the macerated mixture and for 10 min, the mixture was continually agitated using a shaker (Heidolph Promax 2020, Schwabach, Germany). Whatman no. 4 filter paper with a pore size of 20 - 25 m was used to remove the particles. The final volume of the solution was determined by the amount of ethanol present in the tube.

Antioxidant content of corn silk samples

The total phenolic content of corn silk samples was determined by the method explained by Singh et al. [16] using the Folin-Ciocalteu colorimetric method and gallic acid was used as standard. The values were expressed as mg GAE/100 g. Flavonoid content was estimated by the method given by Sadh et al. [17] by using Quercetin as standard and the flavonoid was expressed as mg QE/100 g. Ascorbic acid content was determined by 2, 6-dichlorophenol indo phenol titration method [18]. Ascorbic acid content was calculated by the formula given in equation 1.

$$\text{Amount of ascorbic acid mg/100 g sample} = \frac{\text{Dye factor}}{\text{V1ml}} * \frac{\text{V2}}{\text{5 ml}} * \frac{\text{100 ml}}{\text{Weight of sample}} * 100 \quad (1)$$

Where, V1 = Volume of dye consumed by standard ascorbic acid; V2 = Volume of dye consumed by dye solution

Antioxidant activity

Free radical scavenging activity

The antioxidant activity in terms of % inhibition was determined using the method used by Singh et al. [19]. The following equation 2 was used to determine the antioxidant activity:

$$\text{Antioxidant activity (\%)} = \frac{A_0 - A}{A_0} * 100 \quad (2)$$

where, A_0 = Absorbance of DPPH as blank; A = Absorbance of sample

Ferric reducing antioxidant power (FRAP)

The FRAP activity is based on the mechanism of reaction on the reduction of Fe^{3+} TPTZ complex (colorless complex) to Fe^{2+} -tripyridyltriazine (blue-colored complex) formed by the action of electron-donating antioxidants at low pH. The 3.995 µl of corn silk extract (prepared with 80% ethanol in 1:10 ratio) was mixed with 5 ml of FRAP (300 mmol acetate buffer + 10 ml TPTZ in 40 mmol HCl + 20 mmol of $FeCl_{3}{\cdot}_{6}H_2O$). The following reaction is measured at an absorbance of 593 nm. The FRAP values were expressed as mg of trolox equivalent (TEAC) per gram of sample [20].

Cupric ion reducing antioxidant capacity (CUPRAC)

The cupric ion reduction antioxidant capacity was evaluated using the Al-Rimawi et al. [21] technique. To generate a final volume of 4.1 ml, 100 µl of sample extract was mixed with 1 ml each of 10 mM copper chloride solution, 7.5 mM neocuproine alcoholic solution (99.9% ethanol), 1 M (pH 7.0) ammonium acetate buffer solution, and 1 ml distilled water. The absorbance was measured at 450 nm against the reagent blank after 30 min. Different concentrations of trolox were used to create a standard curve. The results were given in terms of µmol trolox/g.

Characterization of corn silk powder

FTIR

About 5 mg of dried corn silk powder sample was used for the FTIR analysis (Shimadzu 8400S FTIR spectrometer, fitted with KBr beam splitter), along with 5 mg of KBr [22]. The spectrum range used in the spectrophotometer was 400 - 4000 cm^{-1} and the maximum resolution was -0.85 cm^{-1}. Stuart's guidelines were used to analyze the obtained spectra of the samples.

Differential scanning calorimetry

A differential scanning calorimeter (Shimadzu DSC-50 system, Kyoto, Japan) was used for the thermal investigation of corn silk powder [23]. To obtain the thermograms, 2 mg samples were crumpled in a 30 °C to 450 °C heated aluminum pan with continual nitrogen purging of 20 ml/min and ramping of 10 °C/min.

Statistical analysis

Triplicates (n=3) were used to conduct the experiment. SPSS V. 22 (SPSS Inc, Chicago, IL, USA) was used to carry out statistical analysis. The data was expressed in terms of mean ± standard deviation. The data was evaluated using Duncan's multiple tests and one-way analysis of variance (ANOVA). p values < 0.5 were taken into consideration [24].

Results and Discussion

Nutritional composition of corn silk

A decrease ($p < 0.05$) in the moisture content was observed for the variety PIONEER from 82.99 ± 0.296% to 74.20 ± 1.33%, as it reaches the fifth stage of development. JKMH depicted the highest value of moisture content upon reaching maturity (76.19 ± 0.13% wb). All the varieties exhibited low moisture content in their mature stages as depicted in table 1, the lowest shown by AHC (70.25 ± 0.16% wb). This result was similar to the result of a study by Rahman and Rosli [25] in which the moisture content of immature silk is higher than mature silk.

A decrease ($p < 0.05$) in the ash content could be seen for all the varieties as shown in table 1. PIONEER exhibited the highest value (0.70 ± 0.26%) as it approached maturity while K25 showed the lowest value (0.33 ± 0.04%). The value for ash content was similar in the immature stage to the value found in a study carried out by Habu et al. [26] which was 3.78 ± 0.02%.

A decreased trend ($p < 0.05$) in the protein content was

Table 1: Nutritional composition of corn silk varieties at different growth stages.

Corn silk varieties and stages	Moisture (% wb)	Ash (%)	Protein (g)	Fat (g)	Carbohydrate (g)
PIONEER 1	82.99 ± 0.296^{e}	2.14 ± 0.06^{k}	6.58 ± 0.56^{ab}	2.78 ± 0.15^{ab}	5.50 ± 0.04^{i}
PIONEER 2	80.22 ± 0.17^{f}	1.83 ± 0.21^{j}	5.16 ± 0.02^{cd}	1.83 ± 0.07^{c}	10.95 ± 0.08^{b}
PIONEER 3	79.33 ± 0.78^{h}	1.07 ± 0.10^{ghij}	4.89 ± 0.42^{def}	1.16 ± 0.07^{ef}	13.54 ± 1.38^{b}
PIONEER 4	76.81 ± 0.48^{ijk}	0.83 ± 0.07^{efg}	3.63 ± 0.49^{efg}	0.87 ± 0.01^{g}	17.85 ± 0.90^{h}
PIONEER 5	74.20 ± 1.33^{kl}	0.70 ± 0.26^{cdef}	2.52 ± 0.50^{g}	0.73 ± 0.03^{i}	21.83 ± 2.12^{j}
JKMH 1	84.36 ± 0.17^{g}	3.04 ± 0.08^{ij}	6.35 ± 0.22^{a}	1.38 ± 0.14^{bc}	4.86 ± 0.01^{j}
JKMH 2	82.10 ± 0.01^{h}	2.32 ± 0.18^{fghi}	5.52 ± 0.49^{cd}	1.04 ± 0.08^{cd}	9.01 ± 0.40^{b}
JKMH 3	81.01 ± 0.48^{jk}	1.81 ± 0.09^{cdef}	4.58 ± 0.55^{efg}	0.91 ± 0.06^{ef}	11.67 ± 1.20^{a}
JKMH 4	78.78 ± 0.01^{mn}	1.33 ± 0.16^{bc}	3.19 ± 0.13^{efgh}	0.75 ± 0.04^{gh}	15.94 ± 1.20^{i}
JKMH 5	76.19 ± 0.13^{p}	0.49 ± 0.37^{a}	2.44 ± 0.35^{fg}	0.54 ± 0.01^{i}	20.32 ± 0.14^{i}
AHC 1	75.65 ± 0.30^{g}	1.34 ± 0.07^{hij}	8.16 ± 0.02^{a}	0.86 ± 0.02^{c}	13.97 ± 0.20^{l}
AHC 2	74.71 ± 0.76^{hi}	1.16 ± 0.07^{ghi}	7.88 ± 0.14^{cd}	0.70 ± 0.01^{de}	15.55 ± 0.56^{c}
AHC 3	72.78 ± 0.83^{ij}	0.88 ± 0.01^{fgh}	6.22 ± 0.04^{de}	0.63 ± 0.03^{g}	19.48 ± 0.90^{k}
AHC 4	72.27 ± 0.41^{mn}	0.73 ± 0.02^{cd}	5.44 ± 0.35^{efgh}	0.54 ± 0.03^{gh}	14.13 ± 0.50^{g}
AHC 5	70.25 ± 0.16^{no}	0.50 ± 0.01^{bc}	3.57 ± 0.56^{fg}	0.43 ± 0.02^{i}	21.00 ± 0.05^{m}
K25 1	79.10 ± 0.62^{a}	1.03 ± 0.04^{m}	6.53 ± 0.48^{a}	1.13 ± 0.09^{a}	25.24 ± 0.84^{i}
K25 2	76.65 ± 0.69^{b}	0.91 ± 0.09^{lm}	5.42 ± 0.36^{c}	0.87 ± 0.03^{de}	16.14 ± 1.19^{fg}
K25 3	74.16 ± 0.10^{b}	0.70 ± 0.06^{lm}	3.71 ± 0.22^{de}	0.75 ± 0.04^{f}	20.67 ± 0.02^{de}
K25 4	72.88 ± 1.03^{c}	0.50 ± 0.01^{k}	2.48 ± 0.41^{fgh}	0.67 ± 0.01^{g}	23.46 ± 0.64^{c}
K25 5	71.05 ± 0.22^{d}	0.33 ± 0.04^{k}	1.89 ± 0.31^{fg}	0.55 ± 0.05^{h}	26.18 ± 0.63^{d}

Note: The values are represented in mean ± standard deviation derived for triplicate experiments (n = 3). The values denoted with different superscripts differ significantly at $p < 0.05$ in a column.

seen for all the varieties with the highest value shown by PIONEER (2.52 ± 0.50 g) as it reached from stage 1 to stage 5. The values for other varieties are depicted in table 1. The protein content was significantly low as compared to the results of the protein content of about 18.725 ± 0.79% in a study carried out by Habu et al. [26].

A significant decrease ($p < 0.05$) in the fat content was seen in all the varieties as they reached maturity. The highest value was shown by PIONEER of 0.73 ± 0.03 g at stage 5. These findings are similar to results of fat content found in other studies which show that the fat content can vary from 0.29 - 4.74 g [10].

Corn silk contains various polysaccharides (carbohydrates) which can improve glucose tolerance, thus helping in the treatment of type II diabetes mellitus [27]. These can prove highly beneficial for human health. There was an increase ($p < 0.05$) in the carbohydrate content for all the varieties as they became mature. The highest value of 26.18 ± 0.63 g was shown by K25 at the mature stage while JKMH displayed the lowest value of 20.32 ± 0.14 g. This value is significantly lower as compared to the result of a study carried out by Shahzad et al. [28] in which carbohydrate content was found to be 54.21 ± 0.45 g. The study done by Habu et al. [26] in Nigeria showed similar results for carbohydrate content in the mature stage which was 28.84 ± 0.1 g. The values of carbohydrates, fat, and protein are comparable to the values of the study carried out by Zilic et al. [3] in which the content of carbohydrate was 27.80 g, fat was 0.36 g and protein was 5.78 g. In another study carried out by Mendoza et al. [29], the fat content was found to be in the range of 0.9 - 1.8%, carbohydrate content was between 65.1 - 70.9%, and protein content was between 14.1 - 19.1%.

Mineral analysis

All the minerals found in corn silk are essential for important functions in the body. In the case of minerals like sodium, potassium, manganese, and iron, silk of all the varieties exhibited higher values at mature stages whereas the contents of magnesium, calcium, and copper were higher in the immature stages. The highest potassium content was exhibited by PIONEER at maturity (1439.29 ± 1.17 µg/g). The sodium content considerably increased ($p < 0.05$) from stage 1 to stage 5 for PIONEER, JKMH and AHC from 763.80 ± 1.26 µg/g to 1079.15 ± 0.94 µg/g, 573.57 ± 0.24 µg/g to 906.32 ± 1.48 µg/g and 396.87 ± 1.23 µg/g to 618.31 ± 1.47 µg/g respectively while it declined for K25 from 2581.04 ± 0.47 µg/g to 2151.60 ± 0.20 µg/g. The magnesium content significantly declined upon reaching maturity. The values of other minerals like calcium, potassium, iron, copper, and manganese differed in the different growth stages as depicted in table 2. The mineral content is found to be comparatively lower than the mineral content in the experiment carried out by Shahzad et al. [28]. This can be due to the fact that a variety of factors affect the amount of minerals present in corn silk such as soil type, irrigation, environment, and fertilizers. The sodium and magnesium content were higher in mature stages as compared to the earlier stages which was similar to the result of study carried out by Zilic et al. [3]. However, the findings related to calcium and potassium contrasted in result. The values for potassium and magnesium were significantly higher in the study carried out by Rahman and Rosli [25] where the potassium was 26281.67 ± 1379.7 µg/g and magnesium were 1219.17 ±

Table 2: Mineral analysis of corn silk varieties at various stages.

Corn silk varieties and stages	Sodium (µg/g)	Magnesium (µg/g)	Potassium (µg/g)	Calcium (µg/g)	Manganese (µg/g)	Copper (µg/g)	Iron (µg/g)
PIONEER 1	763.80 ± 1.26^{jk}	642.96 ± 1.19^{j}	1113.18 ± 0.41^{e}	889.42 ± 1.33^{a}	13.41 ± 1.5^{abcde}	10.14 ± 0.46^{cdefg}	7.38 ± 1.68^{h}
PIONEER 2	899.10 ± 1.45^{h}	612.38 ± 0.24^{k}	1145.47 ± 2.12^{d}	845.21 ± 1.07^{b}	14.81 ± 1.61^{abcd}	9.58 ± 1.28^{cdefg}	9.50 ± 0.45^{gh}
PIONEER 3	875.20 ± 0.81^{hi}	523.55 ± 0.52^{m}	1297.45 ± 1.46^{c}	790.39 ± 2.28^{de}	16.45 ± 2.02^{abc}	8.10 ± 0.56^{defg}	12.26 ± 1.37^{efgh}
PIONEER 4	1007.48 ± 1.65^{g}	489.39 ± 1.3^{n}	1313.38 ± 0.51^{b}	755.83 ± 0.92^{f}	18.44 ± 0.93^{ab}	7.00 ± 1.87^{efg}	15.60 ± 1.12^{cdefg}
PIONEER 5	1079.15 ± 0.94^{f}	351.53 ± 2.17^{0}	1439.29 ± 1.17^{a}	700.38 ± 1.72^{g}	20.31 ± 0.14^{a}	6.03 ± 1.16^{fg}	16.39 ± 0.87^{cdefg}
JKMH 1	573.57 ± 0.24^{l}	292.08 ± 1.79^{p}	676.80 ± 2.11^{n}	696.96 ± 1.87^{g}	10.08 ± 1.17^{cdefg}	22.43 ± 1.44 ^{a}	9.95 ± 0.94^{fgh}
JKMH 2	696.97 ± 1.62^{k}	242.08 ± 0.77^{q}	747.20 ± 1.81^{j}	646.09 ± 0.99^{h}	11.65 ± 1.51^{bcdefg}	19.82 ± 0.49^{ab}	10.98 ± 1.12^{efgh}
JKMH 3	772.09 ± 0.94^{j}	211.36 ± 0.83^{r}	883.17 ± 0.94^{h}	636.13 ± 0.72^{hi}	12.99 ± 0.84^{bcdef}	19.76 ± 1.36^{ab}	12.76 ± 0.49^{efgh}
JKMH 4	812.11 ± 1.29^{ij}	195.76 ± 1.76^{s}	902.99 ± 1.2^{g}	593.45 ± 0.83^{j}	15.18 ± 0.6^{abcd}	16.93 ± 0.93^{abc}	14.14 ± 1.14^{defgh}
JKMH 5	906.32 ± 1.48^{h}	170.95 ± 0.94^{t}	1012.69 ± 0.34^{f}	576.32 ± 0.75^{j}	15.50 ± 1.07^{abc}	14.68 ± 0.44^{abcde}	16.01 ± 0.76^{cdefg}
AHC 1	396.87 ± 1.23^{n}	831.17 ± 1.14^{e}	599.95 ± 1.64^{p}	829.99 ± 1.51^{bc}	10.73 ± 1.16^{cdefg}	18.56 ± 1.06^{ab}	10.66 ± 1.33^{fgh}
AHC 2	499.45 ± 0.42^{m}	784.28 ± 2^{g}	646.54 ± 0.92^{o}	812.89 ± 0.45^{cd}	10.97 ± 0.97^{cdefg}	16.57 ± 0.47^{abc}	11.22 ± 0.82^{efgh}
AHC 3	558.80 ± 1.28^{lm}	716.94 ± 1.96^{h}	698.61 ± 0.42^{m}	787.81 ± 1.24^{de}	11.82 ± 0.5^{bcdefg}	15.66 ± 1.46^{abcd}	13.90 ± 1.01^{defgh}
AHC 4	597.49 ± 2.45^{l}	682.84 ± 1.14^{i}	706.82 ± 2.1^{l}	768.59 ± 1.63^{ef}	13.50 ± 1.21^{abcde}	13.47 ± 0.37^{bcdef}	15.68 ± 1.34^{cdefg}
AHC 5	618.31 ± 1.47^{l}	605.60 ± 1.93^{l}	753.28 ± 0.7^{j}	711.86 ± 0.76^{g}	14.64 ± 1.09^{abcd}	10.68 ± 0.94^{cdefg}	17.41 ± 0.47^{cdef}
K25 1	2581.04 ± 0.47^{a}	1456.25 ± 1.08 ^{a}	683.88 ± 0.86^{n}	752.04 ± 0.89^{f}	5.79 ± 1.33^{g}	6.56 ± 0.52^{fg}	18.39 ± 1.15^{cde}
K25 2	2471.29 ± 0.28^{b}	1007.13 ± 1.06^{b}	703.34 ± 1.06^{lm}	698.24 ± 0.86^{g}	6.31 ± 1.84^{fg}	6.49 ± 2.13^{fg}	20.73 ± 0.22^{bcd}
K25 3	2361.93 ± 1.72^{c}	963.57 ± 2.29^{c}	726.00 ± 1.18^{k}	722.80 ± 1.64^{g}	7.15 ± 1.67^{efg}	5.40 ± 2.02^{g}	22.30 ± 0.25^{abc}
K25 4	2254.28 ± 0.5^{d}	876.19 ± 0.87^{d}	753.97 ± 1.16^{j}	635.32 ± 1.51^{hi}	7.33 ± 1.86^{efg}	4.82 ± 0.96^{g}	25.81 ± 1.9^{ab}
K25 5	2151.60 ± 0.20^{e}	813.32 ± 0.46^{f}	801.27 ± 0.15^{i}	606.19 ± 1.11^{ij}	8.37 ± 0.28^{defg}	3.39 ± 1.6^{g}	28.24 ± 0.86^{a}

Note: The values are represented in mean ± standard deviation derived for triplicate experiments (n = 3). The values denoted with different superscripts differ significantly at $p < 0.05$ in a column.

143.07 µg/g in the immature stage as compared to our results.

Antioxidant content

Tests for total phenolic content, total flavonoid content, and ascorbic acid were performed to determine the antioxidant content. The different varieties have varying antioxidant content and antioxidant activity as seen in table 3 and table 4.

Total phenolic content

Phenols are highly beneficial for the human body as they can help against cardiovascular conditions, inflammation, abnormal lipid profile, diabetes, oxidative stress, and blood pressure [30]. Cardiac glycosides, anthocyanins, hesperidin, and allantoins are some of the phenols found in corn silk. A significant decline ($p < 0.05$) in the phenol content was seen for all the varieties as they approached stage 1 to stage 5 as shown in table 3. For PIONEER, the value reduced from 41.79 ± 1.08 mg GAE/100 g to 25.89 ± 1.26 mg GAE/100 g as it reached maturity. For JKMH and AHC, the value decreased from 47.82 ± 0.54 mg GAE/100 g to 28.84 ± 0.9 mg GAE/100 g and 50.51 ± 0.72 mg GAE/100 g to 36.66 ± 0.72 mg GAE/100 g respectively. A similar trend was seen for K25 as its value declined from 35.25 ± 0.54 mg GAE/100 g to 16.28 ± 1.26 mg GAE/100 g. AHC exhibited the highest phenolic content on reaching the final stage. The phenolic content was higher in the immature stages as compared to the mature stages. The result was consistent with the result of a study carried out by Simla et al. [31] in which the phenolic content was found to be higher in the early stages. The values were lower as compared to another study on corn silk using different extraction techniques carried out by Faiza et al. [32], the phenolic content ranged from 92.63 ± 6.25 mg GAE/100 g to 131.23 ± 6.45 mg GAE/100 g for immature corn silk while it was lower 79.06 ± 3.21 mg GAE/100 g to 102.37 ± 3.25 mg GAE/100 g for mature silk. The value of phenolic content was also similar to the findings of experiment carried out by El-Sawi et al. [33], in which the total phenolic content was found to be 45.391 mg GAE/g.

Total flavonoid content

Flavonoids can prove highly beneficial for human health as they have been shown to reduce the mortality rate due to cancer and cardiovascular diseases. They can also lower the risk of developing type II diabetes mellitus [34]. Some of the flavonoids found in corn silk include maysin, rutin, catechin, protocatechin, and quercetin. The values for flavonoid content showed a steady decline ($p < 0.05$) for all the varieties as they grew from the immature to the mature stage as shown in table 3. PIONEER showed the highest amount of flavonoid content on reaching stage 5 (38.94 ± 0.97 mg QE/100 g) among all the varieties. ACH exhibited the lowest value amongst all upon reaching maturity at 9.86 ± 0.55 mg QE/100 g. For JKMH and K25, a reduction in the value was seen from 48.42 ± 1.48 mg QE/100 g to 25.13 ± 2.04 mg QE/100 g and 40 ± 1.11 mg QE/100 g to 23.42 ± 0.37 mg QE/100 g respectively. The phytochemical properties of corn silk vary in the different growth stages as seen in table 3. This result matched with the result of the experiment carried out by Sarepoua et al. [35] in which the phytochemical content varied throughout the growth stages. The flavonoid content is affected by parameters such as solvent polarity, region of cultivation, maturity stage, and corn hybrid. The flavonoid content of corn hybrids used in this study was higher at the immature stage as compared to the values in the study carried out by Limmatvapirat et al. [20] in which flavonoid content ranged from 11.25 ± 0.31 mg RE/g to 22.46 ± 0.48 mg RE/g. However, the experiment

Table 3: Antioxidant content in different varieties at various growth stages of corn silk.

Corn silk varieties and stages	Polyphenol content (mg GAE/100 g)	Flavonoid content (mg QE/100 g)	Ascorbic acid (mg/100 g)
PIONEER 1	41.79 ± 1.08^{c}	65.13 ± 0.79^{a}	131.5 ± 2.12^{a}
PIONEER 2	39.10 ± 0.9^{d}	56.31 ± 1.48^{b}	118 ± 1.24^{b}
PIONEER 3	35.64 ± 0.72^{ef}	50.92 ± 1.41^{c}	109 ± 1.41^{cd}
PIONEER 4	30.51 ± 0.36^{g}	46.18 ± 1.67^{d}	93 ± 0.82^{fg}
PIONEER 5	25.89 ± 1.26^{i}	38.94 ± 0.97^{e}	88 ± 1.41^{gh}
JKMH 1	47.82 ± 0.54^{b}	48.42 ± 1.48^{cd}	99.5 ± 2.12^{ef}
JKMH 2	41.79 ± 1.08^{c}	45.94 ± 0.93^{d}	92.5 ± 1.53^{fg}
JKMH 3	37.05 ± 1.26^{de}	40.26 ± 0.74^{e}	82 ± 1.41^{hi}
JKMH 4	34.10 ± 0.72^{f}	31.57 ± 0.37^{f}	68.5 ± 2.12^{j}
JKMH 5	28.84 ± 0.9^{gh}	25.13 ± 2.04^{hi}	63 ± 0.65^{j}
AHC 1	50.51 ± 0.72^{a}	31.05 ± 0.74^{fg}	114.5 ± 0.94^{bc}
AHC 2	46.92 ± 0.72^{b}	25.52 ± 1.11^{hi}	103 ± 2.02^{de}
AHC 3	43.33 ± 0.36^{c}	21.31 ± 1.48^{j}	98.5 ± 2.12^{ef}
AHC 4	39.10 ± 0.9^{d}	12.36 ± 1.97^{k}	92.5 ± 1.53^{fg}
AHC 5	36.66 ± 0.72^{def}	9.86 ± 0.55^{k}	77.5 ± 0.7^{i}
K25 1	35.25 ± 0.54^{ef}	40 ± 1.11^{e}	89 ± 1.41^{g}
K25 2	30.89 ± 0.18^{g}	36.71 ± 0.18^{e}	78 ± 1.41^{i}
K25 3	27.54 ± 0.9^{hi}	31.18 ± 1.3^{fg}	67.5 ± 2.12^{j}
K25 4	21.79 ± 1.81^{j}	27.76 ± 1.67^{gh}	44.5 ± 1.36^{k}
K25 5	16.28 ± 1.26^{k}	23.42 ± 0.37^{ij}	38 ± 1.41^{l}

Note: Whereas stage 1 - silking stage (R1 - 60 days after emergence), stage 2 - blister stage (72 days after emergence), stage 3 - milking stage (80 days after emergence), stage 4 - dough stage (86 days after emergence), stage 5 - dent stage (96 days after emergence). The values are represented in mean ± standard deviation derived for triplicate experiments (n = 3). The values denoted with different superscripts differ significantly at $p < 0.05$ in a column.

done by Faiza et al. [32] showed no significant difference in the flavonoid content of mature and immature corn silk. The value of flavonoid content (26.75 mg CE/g) obtained from an experiment carried out by El-Sawi et al. [33] was also similar to our findings.

Ascorbic acid

Ascorbic acid is not synthesized in the human body, so is essential in diet. It provides an array of benefits as it can help against cardiovascular disorders, infections, and cancer, and acts as a strong antioxidant and co-factor in metabolic reactions [36]. A similar trend for flavonoid and phenolic content was seen for ascorbic acid also. The highest value on reaching maturity was shown by PIONEER at 88 ± 1.41 mg/100 g. There was a drop in the value for JKMH on reaching maturity from 99.5 ± 2.12 mg/100 g to 62 ± 0.65 mg/100 g. Similarly, the value for AHC decreased ($p < 0.05$) from 114.5 ± 0.94 mg/100 g to 77.5 ± 0.7 mg/100 g. The least value was exhibited by K25 at 38 ± 1.41 mg/100 g on reaching stage 5. This result was similar to the result of an experiment carried out by Singh et al. [16] in which the ascorbic acid content reduced from the immature stage (324 ± 1.57 mg/100 g) to maturity (108 ± 1.23 mg/100 g).

Antioxidant activity

FRSA

A decrement ($p < 0.05$) in the antioxidant activity was seen in all the varieties of corn silk as they reached maturity as depicted in figure 2. PIONEER and JKMH exhibited the highest value (58.58 ± 0.43%) in stage 1, but it gradually decreased to 36.8 ± 0.86% and 32.2 ± 0.43% in stage 5 respectively. AHC and K25 displayed a similar value in stage 5 as shown in table 4. The antioxidant activity of corn silk is exhibited due to the presence of certain phytochemicals like phenolics, flavonoids, and polysaccharides [20]. This result is in agreement with the result of an experiment carried out by Singh et al. [16] in which the scavenging activity decreased upon reaching maturity. This decrease in antioxidant activity is due to the reduced content of antioxidants in the mature stage. In another study by Singh et al. [14], the FRAP activity of corn silk powder of variety G5417 was found to be 45.4 ± 0.92% which is higher as compared to PIONEER and JKMH.

FRAP

FRAP is based on the reduction of Fe(III) to Fe(II) by the antioxidants present in the sample. A violent blue color is

Table 4: Antioxidant activity in different varieties at various growth stages of corn silk.

Corn silk varieties and stages	FRSA (%)	FRAP (mg TEAC/g)	CUPRAC (µmol trolox/g)
PIONEER 1	58.58 ± 0.43^{a}	57.28 ± 0.9^{cd}	53.55 ± 0.92^{a}
PIONEER 2	52.14 ± 0.86^{bc}	52.64 ± 2.03^{ef}	46.24 ± 1.27^{b}
PIONEER 3	50.61 ± 0.43^{cd}	46.24 ± 2.03^{h}	39.78 ± 2.12^{c}
PIONEER 4	44.17 ± 0.86^{e}	23.52 ± 1.13^{m}	29.66 ± 0.7^{ef}
PIONEER 5	36.8 ± 0.8^{6f}g	20.32 ± 1.13^{n}	26.04 ± 1.^{2}g
JKMH 1	58.58 ± 0.43^{a}	52 ± 1.13^{f}	48.24 ± 1.04^{b}
JKMH 2	53.98 ± 0.86^{b}	48.8 ± 1.13^{gh}	41.11 ± 1.16^{c}
JKMH 3	53.06 ± 1.3^{bc}	45.92 ± 1.58^{h}	34.11 ± 1.88^{d}
JKMH 4	43.55 ± 1.73^{e}	37.76 ± 1.35^{j}	26.86 ± 2.16^{fg}
JKMH 5	32.2 ± 0.43^{hi}	30.08 ± 1.35^{l}	19.52 ± 0.79^{h}
AHC 1	44.78^{e}	68.48 ± 1.81^{a}	24.82 ± 1.78^{g}
AHC 2	30.67 ± 1.73^{i}	62.88 ± 0.67^{b}	19.8 ± 0.5^{h}
AHC 3	25.46 ± 1.3^{j}	58.72 ± 1.58^{c}	16.2 ± 0.98^{i}
AHC 4	22.08 ± 1.73^{k}	50.24 ± 0.9^{fg}	13.07 ± 0.73^{j}
AHC 5	17.79 ± 0.86^{l}	29.28 ± 0.67^{l}	9.92 ± 0.66^{k}
K25 1	47.85 ± 0.86^{d}	61.76 ± 1.35^{b}	30.57 ± 1.29^{e}
K25 2	39.26 ± 0.86^{f}	55.52 ± 1.58^{de}	26.28 ± 0.53^{g}
K25 3	34.04 ± 2.16^{gh}	49.92 ± 1.81^{fg}	21.05 ± 0.45^{h}
K25 4	24.53 ± 1.73^{jk}	40.8 ± 1.13^{i}	16.4 ± 1.52^{i}
K25 5	17.48 ± 1.9^{l}	33.92 ± 1.81^{k}	13.17 ± 1.02^{j}

Note: The values are represented in mean ± standard deviation derived for triplicate experiments (n = 3). The values denoted with different superscripts differ significantly at $p < 0.05$ in a column.

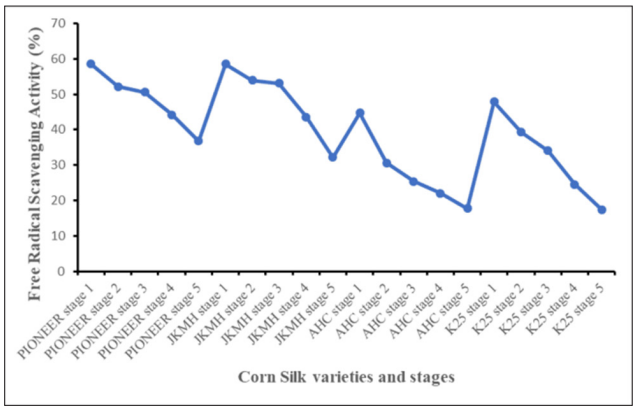


Figure 2: FRSA activity of corn silk varieties at different stages.

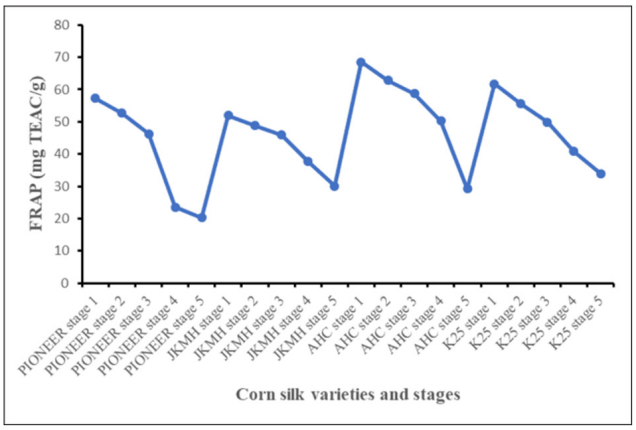


Figure 3: FRAP activity of corn silk varieties at different stages.

obtained when TPTZ reacts with Fe(II) ions [37]. There was a significant reduction ($p < 0.05$) in the antioxidant activity of all the varieties on reaching stage 5 as depicted in table 4 and figure 3. AHC showed the highest value in stage 1 (68.48 ± 1.81 mg TEAC/g), but it declined to 29.28 ± 0.67 TEAC/g in stage 5. K25 exhibited the highest value (33.92 ± 1.81 TEAC/g) on reaching maturity. The values for PIONEER and JKMH declined from 57.28 ± 0.9 TEAC/g to 20.32 ± 1.13 TEAC/g and 52 ± 1.13 TEAC/g to 30.08 ± 1.35 TEAC/g respectively. This result contrasted with the result of a study carried out by Lapcik et al. [5] in which the highest FRAP activity was displayed by the corn silk in the mature stage while the immature stage corn silk had lower activity. However, the obtained result

was comparable to the study done by Faiza et al. [32], where the immature silk had higher FRAP activity (43.25 ± 2.29 µM Fe + 2/g) than the mature silk (34.70 ± 1.10 µM Fe + 2/g). In another study by Singh et al. [16] the highest FRAP activity was found to be in the immature stage and it declined significantly in later growth stages.

Cupric ion reducing antioxidant capacity (CUPRAC)

A similar trend was seen for CUPRAC as all the varieties exhibited a decline ($p < 0.05$) in antioxidant capacity on reaching the mature stage as shown in figure 4. PIONEER had the highest value in stage 1 (53.55 ± 0.92 µmol trolox/g) but it reduced to 26.04 ± 1.2 µmol trolox/g in stage 5. The value for JKMH decreased from 48.24 ± 1.04 µmol trolox/g to 19.52 ± 0.79 µmol trolox/g upon entering the mature stage. AHC displayed the lowest value (9.92 ± 0.66 µmol trolox/g) on reaching maturity. For K25, a drop in the value from 30.57 ± 1.29 µmol trolox/g to 13.17 ± 1.02 µmol trolox/g was seen. This result differed from the result of a study by Lapcik et al. [5] where there was no significant difference in the CUPRAC value of immature (0.89 ± 0.09) and mature stages (1.21 ± 0.13).

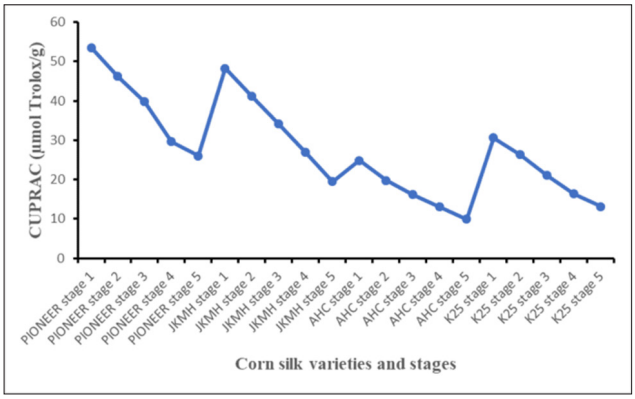


Figure 4: CUPRAC activity of corn silk varieties at different stages.

Characterization of corn silk powder

According to the nutritional and phytochemical properties, PIONEER seems to be the best variety for further utilization, so its further characterization was done.

FTIR

The vibrational and rotational modes of functional groups of corn silk powder of PIONEER stage 1 are depicted in figure 5. The peak at the wavelength 3284.88 cm^{-1} suggested the presence of the O-H group. The peak at 2920.32 cm^{-1} represents the C-H stretching vibration. The peak at 2100.55 cm^{-1} presents the C≡O bond. The presence of the C=O bond of the aldehyde group is represented by the peak at wavelength 1730.21 cm^{-1}. The peak at the wavelength 1627.07 cm^{-1} indicates N-H bending vibration, thus showing the presence of proteins. The peak lying at wavelength 1367.58 cm^{-1} indicates the C=O group. The peak at wavelength 1028.09 cm^{-1} represents the presence of the C-N group. The peak at 520.8 cm^{-1} shows the presence of a disulfide bond. The results are similar to the results of the study carried out by Petrovic et al. [38] in which the characterization of corn silk was done to study its adsorption property for Cu^{+2} and Zn^{+2} ions. The peaks varied after the interaction of corn silk with the metal ions. In another experiment carried out by Limmatvapirat et al. [20] on baby corn silk extracts, peaks were obtained at similar wavelengths for two different hybrids Pacific 271 and Zeba SG 17 at 3279.1 and 3261.5 cm^{-1} which indicated the presence of O-H group. Peaks were also obtained at wavelengths 2921.7 cm^{-1} and 2924.0 cm^{-1} for Pacific 271 and Zeba SG 17 respectively which were similar to the peak at 2920.32 cm^{-1} obtained in our study.

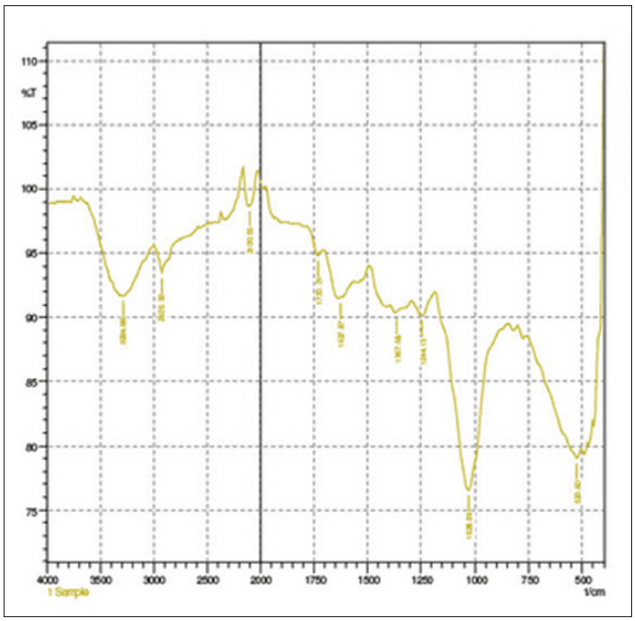


Figure 5: FTIR spectra of corn silk powder (PIONEER stage 1).

Differential scanning calorimetry

The different thermal properties of corn silk could be found using DSC such as enthalpy change, purity of material, and denaturation temperature as seen in figure 6 [39]. The parameters for PIONEER stage 1 for endothermic reactions were found to be on-set temperature (T_{onset}) as 32.09 °C, end-set temperature (T_{endset}) as 94.59 °C, denaturation peak temperature (T_{peak}) as 58.44 °C and ΔH as 118.54 J/g. For exothermic reactions, the values were found to be on-set temperature (T_{onset}) as 334.09 °C, end-set temperature (T_{endset}) as 369.87 °C, denaturation peak temperature (T_{peak}) as 350.04 °C and ΔH as -7.769 J/g. The obtained values are significantly different from the values obtained by the study carried out by Singh et al. [14] to characterize *Zea mays* G5417 in which the on-set temperature (T_{onset}) was found to be 21.09 °C, end-set temperature (T_{endset}) as 102.80 °C, denaturation peak temperature (T_{peak}) as 70.06 °C and ΔH as 172.1638 J/g for endothermic reaction. For exothermic reaction, the values were observed to be on-set temperature (T_{onset}) as 252.02 °C, end-set temperature (T_{endset}) as 296.80 °C, denaturation peak temperature (T_{peak}) as 277.48 °C and ΔH as -33.6161 J/g which were lower as compared to PIONEER.

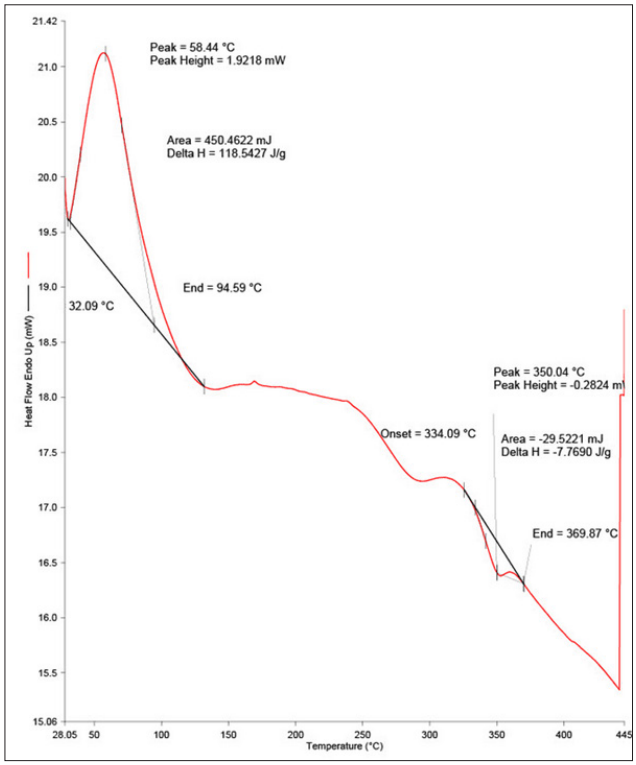


Figure 6: DSC thermograph of corn silk powder (PIONEER stage 1).

Conclusion

All the varieties of corn silk had varying nutritional and phytochemical properties at different growth stages. The antioxidant content tested by flavonoid, phenolic, and ascorbic acid content was greater in the immature stages than in the mature stages. Similarly, the antioxidant activity tested by FRSA, FRAP, and CUPRAC was greater in immature stages. This indicates that the antioxidant activity of corn silk is directly proportional to the amount of its antioxidant or phytochemical content. The variety PIONEER displayed the best nutritional and antioxidant properties which makes it the most feasible for making other corn silk-based products. Corn silk powder or its extract can be used to make a variety of products like patties, laddus, noodles, tea, and other beverages.

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Conflict of Interest

None.

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