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Nutritional composition, extraction, and utilization of corn silk

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Abstract
Corn silk is the thread-like part of the maize plant which has been used for various purposes in traditional medicines and home remedies. It is rich in several nutrients and bioactive compounds such as flavonoids, phenolic acids, alkaloids, saponins that possess various health benefits. Corn silk is known to have anti-diabetic, anti-cancerous, diuretic, anti-inflammatory and anti-microbial properties. Massive production of corn leads to the bulk production of corn silk as well. However, this nutritionally dense compound is usually regarded as waste. The utilization of corn silk in the production of various products is increasing day by day. Valorization of corn silk is not only helping in managing agricultural waste but is also adding up the nutritional and functional value of the products.

Keywords: Corn silk, bioactive compounds, health benefits, extraction, utilization

1. Introduction
Corn silk (*Stigma maydis*) is the thread like part of the maize flower which is obtained as a by-product of corn cultivation. Corn silk (CS) is usually known for its antioxidant capacity that can prevent the oxidation process and it is being widely studied about its health-related benefits (Rahman and Rosli, 2014) [29]. It has several bioactive compounds such as steroids, alkaloids, anthocyanins, saponins, carotenoids and phenolic compounds which have cooperative effects on physical health (Limmatvapirat *et al.* 2020) [21]. Some bioactive compounds possess pharmacological activities because of their antioxidant and free radical scavenging capacity. (Žilić *et al.* 2016) [48]. Many countries have been using corn silk for the treatment of numerous health diseases such as prostate disorders, kidney stones, obesity, urinary infections and bedwetting. Corn silk has also proven to be successful in treating conditions like diarrhea and stomach upsets, which are ascribed to be caused by the infection from Staphylococcus aureus and Salmonella spp. (Emmanuel *et al.* 2016) [10].
CS contain flavonoids that are also responsible for their antimicrobial property because they dislocate the cell membrane in a way that denature bacterial proteins (Abirami *et al.* 2021) [1].
The presence of water-soluble pigment anthocyanin in colored corn not only exhibits higher antioxidant activity but also is responsible for anti-inflammatory and anticarcinogenic effects (Saikaew *et al.* 2018) [31]. The presence of phenolic compounds, alkaloids, polyphenols, saponins and steroids in the silk possesses an antiseptic and antimicrobial nature against some particular sets of microorganisms. Its antioxidant activities could inhibit persistent high-risk human papillomavirus (HR-HPV) infection which plays a key role in the growth of cervical cancer (Li *et al.* 2020) [19]. Many studies claim that the corn silk extract is beneficial in decreasing hyperglycemia and its flavonoid extract significantly reduces the serum LDL-C, triglycerides and total cholesterol levels. The ethanolic extract of corn silk has proven to possess hypotensive effects and also act as a diuretic. Besides this, corn silk can increase the levels of antioxidant enzymes and inhibit lipid peroxidation (Wang *et al.* 2017) [46].
However, corn silk is usually discarded as waste during the processing but it can be used for the formulation of various products. This will not only increase the income of farmers but can also add nutritional density and diversity to the diet of people (Singh *et al.* 2020) [39]. For example, it can be commercially used as a major ingredient for the production of value-added products like corn silk tea, snacks, cosmetics and medicines (Sarepoua *et al.* 2015) [32]. At present, there are more than 1000 kinds of corn by-products that are being used in chemical, fermentation, food and other industries (Jiao *et al.* 2022) [14].

2. Production of corn silk: Corn is a starchy cereal plant that is widely used as human food, biofuel and livestock feed around the world. It is extensively grown in many countries including the USA, China, Brazil and India. According to the United States Department of Agriculture 2020, USA, China, Argentina and Brazil account for 64.63% of total production and a large fraction of it is consumed domestically (Wang *et al.* 2021) [45]. The processing of corn results in a production of a high amount of cornsilk but a new and efficient method should be opted for its valorization (Pashazadeh *et al.* 2021) [28]. It has been reported in the literature that the communal yield of different corn silk varieties lies between 123 to 283 kg per hectare. North America and Latin America hold the first position in the production of corn silk followed by the European countries. China is also progressing to become the producer and consumer of corn silk extract (Singh *et al.* 2022) [36, 37, 38]. According to the Global Corn Silk Market Report 2022, higher corn production will lead to easy accessibility of corn silk extract. Due to the growth of several diseases and the increase in health awareness among consumers, there has been an increase in the demand for health products and dietary supplements which will lead to the growth of the pharmaceutical industry in the future.

3. Nutritional Composition: Corn silk has numerous biochemical nutrient compounds like proteins, carbohydrates, vitamins, mineral salts, alkaloids, tannins, volatile chemicals, steroids and flavonoids. It is also rich in B complex vitamins, vitamin A, vitamin K and minerals like sodium and potassium (Bhuvaneshwari and Sivakami, 2015) [3]. However, the nutritional composition of the silk varies with the genotype and it is found that corn silks at the silking stage are far a better source of phenolic compounds than those at the mature stage (Zilic *et al.* 2016) [48]. Several studies have been conducted to determine the nutritional composition, mineral content, flavonoid, polyphenolic content and antioxidant activity of corn silk. It was found that the number of flavonoids, anthocyanins and phenolic compounds was comparatively good in association with their organic activities (Limmatvapirat *et al.* 2020) [21]. Mostly, the samples used for the nutritional analysis were first dried. Drying reduces the weight and moisture content of the sample and also it is one of the most cost-effective methods of food preservation. Drying of corn silk is purposely done because at high temperatures the determination of natural antioxidants from plant material is quite effective (Bhuvaneshwari and Sivakami, 2015) [3]. Several studies used different methods for sample preparation. According to Singh *et al.* 2022 [36, 37, 38], the collected sample was firstly blanched at 100 °C for 60 s followed by the tray drying at 50 °C for 4 h and according to Thaiwong, 2020 [43] the corn silk sample was directly dried at 40 °C, 50 °C and 60 °C in a hot air oven.

Nutritional analysis of corn silk powder conducted by Singh *et al.* 2022 [36, 37, 38], showed the amount of moisture content to be 7.89±0.49 g/100 g and carbohydrate content to be 56.16±0.66 g/100 including high levels of pectin, glucan, cellulose, hemicellulose, and lignin. The total fat content was about 0.55% and fiber was around 14.82±0.84 g/100 g. The amount of macro minerals like calcium (1338 µg/g), magnesium (1169 µg/g), sodium (3654.21 µg/g), potassium (1135.7 µg/g) were quite optimum and that of micro minerals like manganese, iron, copper and zinc was found to be in the range of 11.1 µg/g, 41.7 µg/g, 11.9 µg/g, and 83.7 µg/g respectively. Whereas, Rahman and Rosli, (2014) [29] compared the nutritional content between the mature and immature silk and found that the moisture content in mature silk (84.42%) was lower than that of immature silks (89.31%) and the amount of carbohydrates of mature silk was slightly higher than immature silks (27.80%). The lipid (1.27%) and protein (12.96%) content of immature silks was higher than that of immature silks which corresponds to 0.66% and (8.95%) respectively. TDF of both mature (51.24 g/100g) and immature corn (48.50 g/100g) was higher). Besides this, Rahman and Rosli, (2014) [29] determined the mineral content using an atomic absorption spectrophotometer and found a varied range of calcium (1087 µg/g), magnesium (1219 µg/g), potassium (35671 µg/g), sodium (266 µg/g), copper (5.60 µg/g), iron (4.50 µg/g), manganese (35.5 µg/g) and zinc (46.3 µg/g) in both mature and immature corn silks. An average range of amount of nutrients present in the corn silk is shown in Table 3.

It is reported that the corn silk extract shows the highest scavenging activity which could neutralize about 78% of DPPH free radical compound and this is assumed to be related to the presence of high phenolic and flavonoid content in the extract (Irawaty *et al.* 2018) [13]. In a study conducted by Thaiwong, 2020 [43], it was found that drying of CS at 40 °C showed the highest values of total phenolic compounds (39.51±1.89 µg GAE/mL) and drying it at 50 °C showed the highest value of flavonoid content (517.54±10.21 mg CE/mL). In another study, Singh *et al.* 2022 [36, 37, 38] found the presence of total phenolic content to be 94.10±0.26 mg GAE/g and that of flavonoid to be around 163.93±0.83 mg QE/100 g. Therefore, the range of phenolic and flavonoid content of dried CS lies between 80.8 to 117.1 µg GAE/g and 36.27 to 40.83 mg CE/g dw respectively.

Table 1: Nutritional composition of corn silk powder/100 g

Sr. No.	Nutritional compound	Amount in corn silk powder	References
1.	Moisture	4-7%	(Singh *et al.* 2022) [36, 37, 38] (Rahman and Rosli, 2014) [29] (Bhuvaneshwari and Sivakami, 2015) [3]
2.	Fat	0.5-1.2%	
3.	CHO	27-56%	
4.	Protein	12-15%	
5.	Fibre	14-51 g/100g	
6.	Calcium	1080-1338 µg/g	
7.	Magnesium	1169-1219 µg/g	
8.	Sodium	266-3654 µg/g	
9.	Potassium	1135-35671 µg/g	
10.	Copper	5-11 µg/g	
11.	Iron	4-41 µg/g	
12.	Manganese	11-35 µg/g	
13.	Zinc	46 46-83 µg/g	

4. Health benefits: Corn silk (CS) generally considered as a waste material is beneficial for the human population as it poses several health benefits due to the presence of several digestible bioactive compounds in it (Mada and Saini, 2020) [39]. Various chemical constituents discovered so far in these stigmas have been found to form essential components of a balanced diet required by human beings for prosperous well-being (Zilic *et al.* 2016) [48]. Being rich in flavonoids and phenolic compounds, it acts as an excellent source of antioxidants and thereby enhances the scavenging of harmful free radicals formed as a result of different biological processes (Vijitha & Saranya, 2017) [44]. Studies by Chen *et al.* in 2013 [5] also evidenced the protective role of corn silk against several chronic diseases related to kidney, skin, body inflammation, arthritis and gout.

Extracts of CS have also been found to help reduce the deteriorating effects of diabetes, hypertension and high blood pressure (Shi *et al.* 2019) [33]. In addition to these, CS has also been found to regulate cell death by modulation of different signalling cascades thereby supporting the nervous system (Somvat *et al.* 2018) [41]. The risk of many fatal diseases such as cancer, diabetes, asthma, heart failure, hypoglycemia, obesity, etc. has been found to increase in the majority of the human population due to unhealthy lifestyles and improper intake of food products. Various preparations having CS extracts in them in minimal quantities have been found to minimize risk of these fatal diseases among human beings (Hasanudin *et al.* 2012) [12]. Moreover, CS powders are being sprinkled on food as flavouring and garnishing agents indirectly adding to its qualitative value. In children, the problems related to urogenital tract, kidney & gallbladder stones, prostate disorders, etc. have also been cured through the intake of CS extracts in one or another form (Smorowska *et al.* 2021) [40].

CS possesses anti-inflammatory, anti-pancreatic, anti-microbial (anti-fungal, anti-viral, anti-bacterial), anti-fatigue and anti-atherosclerosis along with anti-diabetic properties (Tao *et al.* 2020) [42]. In another study, corn silk extract is found to possess protection against convulsions due to the presence of flavonoids. Flavonoids are the secondary metabolites that can modulate the GABAA-CL channel complex in the central nervous system and thus act as anticonvulsants (Okokon *et al.* 2018) [25]. The effect of corn silk extract was studied in the hyperglycaemic mice and it showed a positive effect in improving glycaemic metabolism due to an increase of insulin and recovery of injured β-cells. The study also showed depreciation in TC, TG and LDL-c when the effects of flavonoids from corn silk were examined on hyperglycaemic mice (Wang *et al.* 2017) [46]. Scientifically, it has been examined that glycaemic metabolism in corn silk has been improved because it inhibits α-amylase activity and retard the digestion of starch as well as restrain the increase of post-meal blood sugar (Mada and Saini, 2020) [39]. Corn silk is also known to reduce high blood pressure as it can regulate the electrolytes by releasing potassium and sodium in the urine (Elbossaty, 2020) [9].

5. Extraction techniques: Preparation of plant material for extraction is one of the most important steps in research because the abundance of the available compounds depends on it. Preparatory steps include weighing, volume measurement, mixing, diluting, heating, cooling, fractionation, purification, and preservation. The sample formation for the analysis includes several important steps like pre-washing, drying or freeze-drying, and grinding followed by extraction and qualitative and quantitative analysis (Krakowska *et al.* 2022) [16].

One of the conventional extraction methods used is maceration, in which the plant material is soaked in a solvent at room temperature. Plant extracts are then collected from the bottom of the vessel. Percolation is conducted by passing a solvent through plant materials at a controlled rate. In heat reflux extraction and Soxhlet extraction, bioactive compounds can be extracted using the reflux technique (Chuo *et al.* 2020). Besides these, the other modern techniques used for plant material extraction involve ultrasound-assisted extraction (UAE), microwave-assisted (MAE), supercritical fluid extraction (SFE), or accelerated solvent extraction (ASE) extraction. The UAE is based on the working principle of utilization of ultrasound waves at a frequency between 20-100 MHz. These waves accelerate the diffusion of solvents into the plant material with the development of bubbles inside the solvent (Ligor *et al.* 2018) [20]. Whereas in MAE oscillating electromagnetic fields of suitable frequency offer an instant delivery of energy to the solvent because of the homogenous, successive and efficient heating of the solid matrix and solvent. This method is very fast and it has been used to extract several nutraceuticals such as essential oil, lipids, dietary supplements and others (Chaturvedi, 2018) [4].

Corn silk extract has been widely used to know its nutritional composition and to determine the presence of bioactive compounds. Several methods have been used to prepare the corn silk extract and studies have shown that the methanolic extract gives the highest extraction of phytochemicals than the ethanolic extract (Dardouk *et al.* 2019) [8]. According to Singh *et al.* 2022 [36, 37, 38], the corn silk extraction was prepared by using 80% (v/v) ethanol and distilled water. Firstly, the sample was weighed and macerated with 80% ethanol at a low temperature (0 °C) and then it was centrifuged at 8000 rpm for 15 min. In another study, the CS extract was prepared by dissolving it in 200ml of 100% methanol (MeOH) followed by pulverization (Oyabambi *et al.* 2021) [27]. According to Krusong *et al.* 2020 [17], baby corn silks were dried at 45-50 °C and then its extract was prepared by adding 5 g of sample in 100 mL of distilled water followed by heating at 95 °C for 5 min. After that, the extract was filtered and reconstituted with 5 mL distilled water. Ethanol-based corn silk extract that was used to determine the phytochemical properties and antimicrobial activities proved to be best in exhibiting maximum antimicrobial activity against G-ve bacteria and G+ve (Morshed and Islam, 2015) [24].

6. Utilisation and application: CS can be utilized in vast sectors of marketing industries whether it be food, fodder, pharmaceutical, cosmetics etc. owing to its highly versatile nutritional composition. Dermatologists tested CS extract on Melan-A cells and it decreased melanin production by 37.2% therefore, CS powder is being added to skin products and cosmetics which can help to purify the skin, minimize the size of pores and can act as a brightener and highlighter (Dardouk *et al.* 2019) [8]. Besides this, some studies have found that the cornsilk ethyl acetate extract holds a higher SPF value than its methanol extract. The presence of phenolic compounds and high antioxidant content in corn silk makes it suitable to be used as a natural sunscreen because of its photoprotective nature (Laeliocattleya, 2019) [18]. Silver nanoparticles biosynthesized in an aqueous medium of corn silk extract can prevent bacterial infection because they exhibit antibacterial activity against several bacterial strains. Also, the nanocomposites of corn silk extract promote high bone differentiation which can be used for bone tissue regeneration (Makvandi *et al.* 2020) [23]. Nanocomposites made from corn silk extract is used for the efficient degradation of chemically and biologically resistant dyes in a short time (Khodaei and Dehghan, 2019) [15]. Corn silk water extract has an inhibitive property against the corrosion of mild steel. It acts as an effective inhibitor due to the hetero atoms N, O, and S present in its phytochemical composition (Orubite and Ngobiri, 2017) [26].

Further, the polysaccharide extracts of CS have been used for the development of medications for the treatment and prevention of cancers. Hence, the application of CS extract for the treatment of various diseases and disorders is increasing appreciably (Saheed *et al.* 2015) [30]. Corn silk powder when used in meatballs, improved its nutritional values due to the presence of higher ash and fiber content in it. It also increased the juiciness and shrinkage of meatballs but the cooking yield was decreased because of the loss in moisture and fat content during cooking processes (Aukkanit *et al.* 2015) [2]. Corn silk is rich in fiber and has a higher bioavailability as compared to corn. CS powder when used for making traditional Indian snack Laddu, not only improved the fiber and energy content but also, increased the nutritive value and added value to the product (Singh and Raghuvanshi, 2021) [35]. Some of the common corn silk products and their potential utility and applications are shown in Table 6.

Table 2: Utilisation and applications of corn silk

Sr. No.	Name of CS product	Potential utility	Reference
1.	Corn beef patties	High cooking yield, protein value & reduction in fat content.	Aukkanit *et al.* 2015 [2]
2.	CS tea	Prevention of hypertension & high blood pressure.	Shi *et al.* 2019 [33]
3.	CS decoction	Sprayed over plants for resistance against insects.	Hajinasiri *et al.* 2016 [49]
4.	CS face powder	Added in face masks for detoxification & beautification.	Dardouk *et al.* 2019 [8]
5.	CS gel	As skin brightener & minimization of skin pores	Dardouk *et al.* 2019 [8]
6.	Ethyl acetate CS extract	Protection of skin from UV-A & B radiations i.e potent sunscreen.	Laeliocattleya, 2019 [18]
7.	CS aqueous extract	Inhibition of corrosion of mild steel in hydrochloric acid	Orubite and Ngobiri, 2017 [26]
8.	CS laddu	Nutritious & inexpensive snack rich in fibres	Singh and Raghuvanshi, 2021 [35]
9.	CS extract	Synthesis of gold nanoparticles for removal of dye pollutants from industrial wastes.	Khodaei and Dehghan, 2019 [15]
10.	CS-Ag nanoparticles	Anti-bacterial & bone regeneration	Makvandi *et al.* 2020 [23]

7. Conclusion

It can be stated that corn silk is a valuable agricultural ingredient that is found to be rich in several nutrients and bioactive compounds. However, its underutilization is a major concern and many researchers are undergoing to put this valuable ingredient into use. Many scientists have discovered that it is a rich source of antioxidant and possess several health benefits. Different extraction methods have been used to understand its physiological properties such as anti-diuretic, anti-diabetes, anti-cancerous, antimicrobial and others. Several products have been already manufactured but their commercial application is still lacking. Utilization and of corn silk will not only add to the commercial value but will also increase the valorization of the agricultural produce that is generally discarded as a waste. Hence, more comprehensive research is required to put this valuable ingredient into application.

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