# Corn Processing by-Products

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As an important food crop, corn has an important impact on people's lives. The processing of corn produces many by-products, such as corn gluten meal, corn husk, and corn steep liquor, which are rich in protein, oil, carbohydrates, and other nutrients, all of which are inexpensive. Their accumulation in large quantities during the production process not only results in a burden on the environment but also the loss of potentially valuable food materials that can be processed. In fact, the by-products of corn processing have been partially used in functional foods, nutrients, feed, and other industries. There is no doubt that the secondary utilization of these by-products can not only solve the problem of waste pollution caused by them, but also produce high value-added products and improve the economic benefits of corn.

corn processing by-products development utilization

## 1. Corn Gluten Meal

According to research reports, about 180 kg of corn gluten meal (CGM) can be produced for every ton of corn starch syrup processed. The protein content of CGM is as high as about 60%, mainly consisting of zein, globullins, and glutellins [1][2], all of which are very high-quality plant protein sources. CGM contains a high percentage of hydrophobic amino acids, and the rest of the composition is mainly water, fiber, and fat [3][4]. At present, the deep processing products of CGM are described in the following paragraph.

### 1.1. Corn Peptide

CGM is rich in Glu, Leu, Pro, Ala, Phe, and Asp, and its nutritional value is very rich. However, it has low water solubility and is deficient in essential amino acids such as Lys, His, and Trp, considerably, which limits its nutritional value and its direct application as a food ingredient [5]. In order to further expand the application of CGM in the field of food and health care, it can be modified by enzymatic hydrolysis to prepare small molecule oligopeptides, which have better physiological activity and functional properties [6]. In recent years, research has shown that small-molecule oligopeptides have a beneficial effect on human digestion, absorption, and metabolism [7]. Corn peptides (CPs) are usually small molecular peptide fragments produced by the enzymatic hydrolysis of corn gluten powder under the action of proteases [8]. CPs are usually composed of 2–20 amino acids, and the relative molecular weight is between 300–1000 Da. CPs have the characteristics of easy digestion and absorption, and have shown good application prospects in the fields of food and medicine [9]. In 2010, China's Ministry of Health approved it as a new resource for food [10].

There are many methods for preparing CPs, including enzymatic hydrolysis, microbial fermentation, and chemical synthesis [11]. At present, the more commonly used is enzymatic hydrolysis, which includes single and compound enzymatic hydrolysis. The optimization of enzymatic hydrolysis process for corn gluten meal has been relatively mature. The single enzymatic method mainly refers to the use of alkaline protease, neutral protease, or pepsin by optimal conditions for different catalytic reactions of different enzymes. Compound enzyme refers to the interaction and matching ratio between different enzymes, which optimizes the best ratio method, which is more convenient and efficient than single enzyme digestion, and the yield is also higher.

CPs have antioxidant activity, are anti-hypertension, and prevent alcohol injury, and have other unparalleled physiological functions [12]. Ma et al. found that CPs can effectively reduce the amount of ethanol in the blood after alcoholic intake by plasma alanine and leucine [13]. CPs have been found to have the potential ability to promote alcohol metabolism by activating the liver alcohol dehydrogenase (ADH), which leads to a decrease in blood alcohol concentration [14]. In addition, Wu et al. have reported the protective effect of CPs at a dose of 4 g/day may protect the alcoholic liver injury by regulating lipid metabolism and human oxidative stress responses [15].

In the field of food processing, CPs can improve antioxidant capacity of the foods without any decay in other quality parameters. CPs are rich in hydrophobic amino acids, which can promote the secretion of glucagon and can also be used to make sports drinks and other high-protein beverage products [16]. In addition, adding CPs to fresh milk fermented by probiotics and lactic acid bacteria can significantly improve the viscosity, flavor, taste, and health functions of the fresh milk. CPs have extensive application in the field of health food, and because CPs contain a high proportion of alanine and leucine, the concentration of alanine and leucine in the blood increases, which can enhance the alcohol dehydrogenase and acetaldehyde in the liver. The activity of dehydrogenase promotes the decomposition and metabolism of ethanol in the body to achieve the function of sobering alcohol. For this reason, CPs have been widely developed as foods and beverages with functions such as being anti-alcohol and offering liver protection [17][18]. Secondly, the content of leucine and alanine in CPs are high level and play a key role in the anti-fatigue effect, therefore, CPs have been added in sports food to improve muscle resistance to fatigue, there are functional foods that combine CPs with other biologically active substances in the market, and functional foods made of compound substances have the functions of being anti-fatigue, lowering blood pressure, and promoting anti-aging [19]. The main component, technology method, function, and major findings of corn gluten meal are summarized in **Table 1**.

**Table 1.** The main component, technology method, function, and major findings of corn gluten meal.

| Component | Technology Method | Function | Major Findings | Reference |
|---|---|---|---|---|
| Corn peptide | There are many methods for preparing CPs, including enzymatic hydrolysis, microbial fermentation, and chemical synthesis. At present, the more commonly used is enzymatic hydrolysis, and enzymatic | CPs have antioxidant activity, anti-hypertension, metabolic alcohol, and other unparalleled physiological functions | CPs can effectively reduce the amount of ethanol in the blood after alcoholic intake by plasma alanine and leucine | [12] |
| | | | CPs have been found to have the potential ability to promote alcohol metabolism by | [13] |

| Component | Technology Method | Function | Major Findings | Reference |
|---|---|---|---|---|
| | hydrolysis is carried out through the optimal conditions for catalytic reactions of different enzymes | | activating the liver alcohol dehydrogenase (ADH) | |
| | | | CPs may protect the alcoholic liver injury by regulating lipid metabolism and human oxidative stress response | [14][15][16] |
| | | CPs has sobering alcohol function | As CPs contain a high proportion of alanine and leucine, the concentration of alanine and leucine in the blood increases, which can enhance the alcohol dehydrogenase and acetaldehyde in the liver. The activity of dehydrogenase promotes the decomposition and metabolism of ethanol | [17][18][19] |
| Zeaxanthin | Zeaxanthin in the CGM is currently following two extraction methods: (1) Organic solvent method; (2) Ultrasonic microwave extraction method | The human body cannot synthesize zeaxanthin and lutein, which must be consumed through diet | Zeaxanthin can prevent cataracts by inhibiting oxidative damage | [20] |

## 1.2. Zeaxanthin

Zeaxanthin is an important carotenoid derivative, which was first found in corn. Zeaxanthin (3,3′-dihydroxy-β-carotene) is a polyene molecule containing nine alternating conjugated double and single carbon bonds, with both ends of the carbon skeleton connected to a hydroxyl ionone ring. The 3′ chiral carbon atoms in both rings allow for three possible stereoisomers of zeaxanthin, including (3S, 3′S)-zeaxanthin, meso-zeaxanthin and (3R, 3′R)-zeaxanthin. The molecular formula of zeaxanthin is $C_{40}H_{56}O_2$ and the molecular weight is 568.88 Da [20]. Zeaxanthin and lutein are a pair of isomers, and the only difference is that the position of the double bond in the ionone ring is different. Zeaxanthin and lutein are widely found in human eyeballs [21], the pancreas, liver, and other tissues and organs that play an important role in human health [22][23]. Zeaxanthin and lutein are concentrated in the macular area of the central retina of the human eye. The human body cannot synthesize zeaxanthin and lutein, which must be consumed through diet [24]. In CGM, the content of zeaxanthin is about 0.20–0.37 mg/g [25].

Zeaxanthin in the CGM currently follows two extraction methods: (1) The organic solvent method, which can be used to extract zeaxanthin from CGM in organic solvents by utilizing the property of zeaxanthin dissolved in organic solvents. In consideration of the safety of organic solvents, ethanol is mostly selected as the extraction solvent of zeaxanthin. (2) Ultrasonic microwave extraction method. Through ultrasonic oscillation, air-conditioning effect, mechanical effect, thermal effect, etc., the internal structure and state of CGM are changed to increase the penetration of organic solvents into the cell wall, thereby enhancing the extraction efficiency [26].

Zeaxanthin has strong antioxidant and blue light absorbing properties, and is often added as a natural food additive to margarine, butter, beverages, meat, and egg products for the prevention and treatment of eye diseases such as age-related macular degeneration (AMD) and cataracts [27][28][29]. Zeaxanthin is the main macular pigment in the retina of the human body. It absorbs high-energy blue light energy through its own antioxidant activity, thereby preventing the occurrence of human retinal damage [30][31][32]. Zeaxanthin also has a certain anti-cataract effect, and cataracts is the main cause of vision loss in the elderly, as the lens in the eye become turbid. Studies have found that zeaxanthin can prevent cataracts by inhibiting oxidative damage [33]. In addition, because two six-membered carbon rings of zeaxanthin contain one oxygen-containing group, the chemical structure of zeaxanthin has greater stability, with strong coloring ability, and it is widely used in food additives and feed additives [34][35]. In addition, the molecular structure of zeaxanthin shows that there are 11 conjugated double bonds, which enable it to block the chain transmission of free radicals, thus having strong antioxidant activity, and it is often developed as a functional product.

## 2. Corn Husks

Corn husks are the most abundant and least valuable by-product of corn industrial processing, accounting for 10% to 14% of the total fiber content of corn [36]. Corn husks contain 382 g cellulose, 445 g hemicellulose, 66 g lignin, 19 g protein, and 28 g ash per kg of dry matter [37]. Because it is rich in arabinoxylan (70%), it is used to produce xylo-oligosaccharides and dietary fiber. In addition, corn husks are rich in phenolic acids, 90% of which are ferulic acid, which is mainly distributed in the cell walls of aleurone and pericarp layers. Ferulic acid in corn husks exists in free, soluble, and insoluble forms. With a ratio of 1:10:1000, ferulic acid has a strong antioxidant capacity, which can regulate the oxidation state of cells and prevent biological macromolecules such as DNA and proteins from oxidative damage. Compared with the husks of grains such as rice, wheat, and sorghum, the content of phytic acid in corn husks that affects human mineral metabolism is relatively small [38]. Untreated corn husk has no significant beneficial effect on the human health, and excessive consumption of corn husk often leads to human gastrointestinal discomfort because of its insoluble dietary fiber. Therefore, the deep processing of husks can increase the nutritive and economic value of corn.

## 3. Corn Steep Liquor

The first step of corn deep processing is to foam the corn, which will produce a large amount of soaking water. In order to break the -S-S- bond in the protein, the protein network in the corn kernel is broken in order to release the wrapped starch. The corn kernels should be soaked in an aqueous solution of sodium bisulfite first, and the viscous liquid obtained by concentrating the soaking solution is corn steep liquor (CSL) [39]. China is a big producer of corn starch. Most cornstarch on the domestic market is produced by a wet process, and a large amount of CSL will be produced during the production process. CSL contains a lot of protein, soluble sugar, and sulphide compounds; at present, corn steep liquor has not been used effectively, but is directly discarded, which not only increases the production cost of corn starch, and causes a lot of waste of resources, but also has a great impact on the development of the corn industry and causes environmental pollution and destroys the ecological environment.

Therefore, the development of comprehensive utilization of CSL is of great significance to the recovery and secondary development of corn steep liquor, which is of great significance for increasing the added value of corn industry products and reducing environmental pollution.

CSL is the main by-product of corn starch production by the wet process. It is a viscous, acidic slurry with an aromatic smell and yellowish-brown color. It is considered a rich and cheap source of carbon, nitrogen, amino acids and minerals, and has a broad application prospect in the development of the biological process. Some studies have shown that using CSL as a nitrogen source to produce microbial metabolites (such as citric acid, amylopectin, enzyme, and bioenergy) has a very good effect [40]. The crude protein content of CSL is approximately 20% and the solids content is approximately 50%. Therefore, it can be used as an excellent animal feed ingredient; in addition, CSL is rich in sucrose, nutrients, and elements such as Ca, Mg, Al, Fe, Mn, Mo, P, and S, which provide a good source of organic nitrogen and carbon for microbial growth [41]. Selim, MT et al. studied the Lactic acid concentration of about 44.6 g/L with a high yield (0.89 g/g) obtained using 60 g/L of CSL sugar, inoculum size 10% (*v*/*v*), 45 degrees C, and sodium hydroxide or calcium carbonate as a neutralizing agent [42]. Biosurfactants extracted from CSL can be used in dairy production. These results demonstrate that adding this biosurfactant to drinkable yogurt can promote the growth of Lactobacillus casei, which is considered to be a probiotic bacterium [43]. Phytic acid, also known as inositol hexaphosphate, can bind with calcium ions to form calcium phytate, which has a very good therapeutic effect on gastritis, diarrhea, and rickets. The extraction of plant calcium from CSL has a simple operation, a short cycle, and is low cost. At present, the technology for extracting calcium phytate from corn steep liquor is relatively mature [44][45].

## 4. Corn Germ

Corn kernels are composed of the seed coat, endosperm, and embryo. Corn germ is a part of the corn embryo, which is located below the corn kernel and is mainly involved in the growth and development of corn (Different Strategies to Obtain Corn (*Zea mays* L.) Germ Extracts with Enhanced Antioxidant Properties, Design of corn germ extractor based on S7-1200 PLC). Corn germ is the beginning of the growth and development of corn, and its weight only accounts for about 13% of corn, but it is very rich in nutritional value and rich in a variety of nutrients (Corn germ with pericarp in relation to whole corn: nutrient contents, food and protein efficiency, and protein digestibility-corrected amino acid score), concentrating more than 80% of fat and inorganic salt, 60% of sugar and 20% of the protein in the whole corn, and also contains phospholipids, sterols, and other nutritional ingredients [46]. Cornstarch is industrially separated from corn kernels through a process called dry or wet milling, leaving corn germ as the main residue [47]. Corn germ has been studied as a feed for ruminants due to its desirable nutritional properties [48]. The inclusion of whole corn germ in ruminant diets aims to increase energy density and polyunsaturated fatty acids, to obtain higher levels of conjugated linoleic acid (CLA) in the meat, which are beneficial to human health [49]. The addition of 120 g/kg dry matter corn germ into the diet of lambs did not affect the carcass characteristics, physicochemical composition, and sensory properties of the meat. When corn germ dosage was 76.7 g/kg dry matter, the distribution of polyunsaturated fatty acids in lamb meat was the best [50]. Corn germ can be used at low levels in the diet of broilers without compromising their productive rates [51].

## 5. Fuel Ethanol by-Product

Corn distiller grains (DDGS) are produced by a mixed fermentation of corn seeds, selected yeast, and enzymes in a fuel ethanol plant. DDGS is mainly composed of dried distillate (DDG) and soluble concentrate (DDS), which is rich in protein, amino acids, vitamins, and other nutrients. Each 100 kg of corn can produce 34.1 kg of ethanol and 31.6 kg of DDGS. The yield is large but the price is low. Due to the high acidity and high viscosity of corn distillers grains, the COD (Chemical Oxygen Demand) value can reach 30,000–50,000 mg/L, and the BOD (Biochemical Oxygen Demand) value can reach 20,000–30,000 mg/L, and if the waste is directly discharged, it will not only cause serious pollution to the environment but also be a great waste of resources, so it should be fully utilized [52]. **Figure 1** is a typical process flow chart of ethanol production by the corn whole grain method.

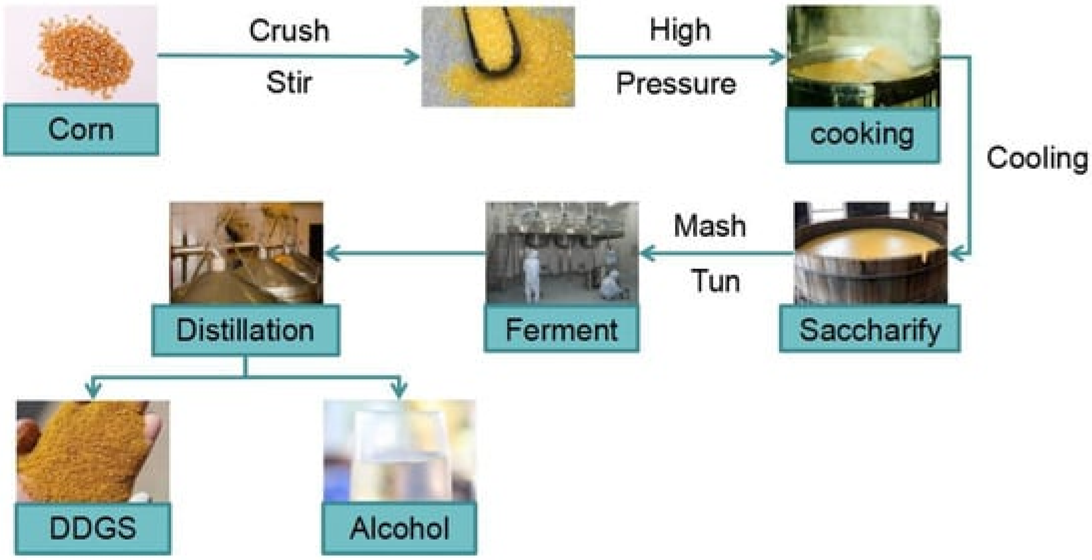

**Figure 1.** Process flow diagram of ethanol and DDGS production.

There is also much research on the application of corn DDGS in livestock and poultry. For example, two groups of Silurus glanis were fed for two consecutive weeks with DDGS in one group and no DDGS in the other. The results showed that the apparent digestibility of corn DDGS is beneficial to Silurus Glanis, and 30% DDGS can be added into the Silurus Glanis’ diet without affecting the growth performance and nutrient utilization of Silurus Glanis [53]. Determination of the effect of different levels of corn DDGS feed on broiler amino acid digestibility showed that higher levels of DDGS could reduce broiler amino acid digestibility [54]. Some scholars have used a combination of alkaline and enzymatic methods to extract cellulose from corn kernels and DDGS. The minimum crude cellulose yield of corn kernels and DDGS is 1.7% and 7.2%, respectively, and the cellulose content is 72% and 81%, respectively. When extracting solids with 35–81% cellulose content, the obtained cellulose can hold up to nine times its weight, so it can be used as an absorbent. Cellulose is also used as paper, composites, lubricants, and nutritional supplements [55].

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