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Review

Soybean carbohydrate as fermentation feedstock for production of biofuels and value-added chemicals

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ABSTRACT

Being one of the major oilseed crops throughout America and Asia, soybean production has increased rapidly due to the rising demand for oil and protein. Carbohydrates are also major components in soybean. During the soybean processing for producing oil and protein products, large amounts of carbohydrate-rich byproducts or waste are generated. Soy protein products such as soybean meal, soy protein concentrate and soybean milk also contain carbohydrates that have anti-nutritional concerns and decrease the value of these products. Removing these carbohydrates from soy protein products and finding valuable uses for these carbohydrates and other carbohydrate-rich waste/byproducts are highly desirable. Here, the various carbohydrate-rich waste byproducts generated from soybean processing and their compositions are described. Recent developments on their use as fermentation feedstocks for production of biofuels, enzymes and a variety of specialty chemicals are then reviewed and summarized. This review can facilitate knowledge and technology integration for development of a soy-based biorefinery platform.

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1. Introduction

The ability of soy to grow in a wide variety of soil and climatic conditions makes it a versatile crop and one of the most widely grown oilseed crops. Besides production of vegetable oil for human consumption, soy's protein-rich meal has high value as functional and nutritional ingredients for food and feed uses. Oil and protein together make up approximately 60% of the soybean weight; carbohydrate, 26–30%, is another major component [1]. During the processing of soybeans for making the oil and protein products, large amounts of byproducts or waste are also generated, which are rich in carbohydrates [2]. The large amounts of soybean carbohydrates, mainly ended up in these waste or low-value byproducts, are yet to find high-value applications [3]. These waste/byproducts include the hulls separated from beans before oil extraction [4], molasses generated from the production of soy protein concentrate (SPC) [5], and soybean okara created during production of soy protein isolate (SPI) and soybean milk, respectively [6]. A flow diagram is given in Fig. 1 for the various products made by current soybean processing. More detailed description is given in Section 2.1.

Soybean meal, a protein-rich product mainly used as animal feed, also contains large proportions of carbohydrates. Majority of the carbohydrate are structural polysaccharides and galactose-containing oligosaccharides such as stachyose and raffinose, which the animal may lack the necessary endogenous enzymes to digest [7]. Their presence reduces the nutritional value of soybean meal for use in animal feed. Removal of undesirable carbohydrates not only can improve the digestibility but also increase the protein content of soybean meal [8–11]. The carbohydrates separated from soybean meal may also be used for the production of value-added chemicals and fuels [12–15].

Fermentation can be used to convert soybean carbohydrates, either present in carbohydrate-rich waste/byproducts or separated from soybean meal, to more valuable bio-products. Many fermentation processes require or strongly favor the use of monosaccharides as substrate. For these processes, pretreatment and hydrolysis for carbohydrate monomerization are done before or during the fermentation; the latter is termed simultaneous saccharification and fermentation. Some microorganisms can utilize complex soy carbohydrates, containing oligo- and poly-saccharides, directly and are often investigated in solid-state fermentation [16–19]. These fermentation processes using soybean carbohydrate as major feedstock to produce value-added bio-products have been an active area of research but have not been systematically reviewed. In this work, an overview is first given for the current soybean processing and the various waste and byproducts generated. Production of biofuels (ethanol and butanol), commercially important enzymes and specialty chemicals are then described in more detail.

2. Current soybean processing

2.1. Overview of current processing and derivatives

A flow diagram is given in Fig. 1 for the various products made by current soybean processing. Recovery of soybean oil is done by physical and chemical methods such as hard screw pressing, prepress-solvent extraction and direct solvent extraction [20]. Soybean hulls are first removed. The dehulled flakes are then pressed or solvent-extracted for oil, leaving the soybean meal that contains a high percentage of protein [21]. Soybean meal can be used as a source of protein supplements in animal feed and food. To further raise the protein content of soybean meal, water (with or without ethanol) extraction of soluble sugar at pH around the isoelectric point of soy protein is done to produce the soy protein concentrate [22]. Alternatively, soy protein isolate can be produced by dissolving protein at high pH, separating the solution from remaining solids, and then reprecipitating protein from the solution by lowering pH to the isoelectric point [23]. Soybean okara is the solid remainder collected after most protein is made soluble, e.g., in making either soy protein isolate or soybean milk [24]. Soybean okara contains mainly insoluble polysaccharides. On the other hand, soy molasses contains the soluble carbohydrate collected in the aqueous streams during the making of soy protein concentrate and isolate [15]. The principal carbohydrate-rich byproducts from soybean processing include hulls, meal, okara and molasses. Except soybean meal, they are yet to find valuable large-scale industrial applications. Their compositions and/or characteristics are described in the following sections.

2.1.1. Soybean hull

Soybean hull represents almost 8–10% of the whole soybean [13]. Considered as having much less commercial value than the oil and protein, hulls have not received much attention beyond the use as animal feed. They are typically sold as is or as compressed pellets and fed to cattle and pigs. Soybean hull contains mainly cell wall polysaccharides. It has a relatively small amount of lignin (1–4%) compared to other agricultural residues. Lignin is a major hindrance for the hydrolysis of many other lignocellulosic materials to fermentable sugar. The low lignin content makes soybean hulls potentially an easier feedstock for production of biomass-derived chemicals. Composition of soybean hulls on a dry basis is presented in Table 1. The relatively wide content ranges of different components reflect the dependency of nutritional value and chemical composition of soybean hulls on the processing nature and growing conditions (demographic and seasonal).

2.1.2. Soybean meal

Soybean meal is an abundant byproduct after oil extraction. It has become an increasingly more important source of protein in animal diets, particularly for poultry, swine, cattle and fish [25]. It is by far the dominant protein supplement used in livestock and

Table 1
Compositions of soybean hulls, meal, okara and molasses on a dry basis [116–120].

Components	Composition (weight%)			
	Hulls	Meal	Okara	Molasses
Cellulose	29–51	2–4	10–15	–
Hemicellulose	10–20	8–10	5–12	–
Soluble oligosaccharides	5–10	10–12	2–5	55–60
Lignin	1–4	0.5–1	1–2	–
Pectin	6–15	10–12	25–35	–
Protein	9–14	50–52	25–30	8–12
Ash	1–4	5–6	4–5	5–7
Fat	–	2–3	3–7	15–20