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GENETICALLY MODIFIED STARCH AS AN INDUSTRIAL RAW MATERIAL

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ABSTRACT

Starch is an important raw material for industrial applications, both for food and nonfood purposes. Of particular interest is the use of starch as a nonpetroleum chemical stock for the manufacture of biodegradable polymers. Annual EC starch production is nearing 10 million tons, with 80% from cereals and 20% from potatoes, and grows at 4–5% annually. The potential for genetically modified starch is considered very high. Such starch offers significant advantages: 1) chemical modifications, which are expensive and environmentally hazardous, are replaced; 2) novel carbohydrates can be produced.

STARCH AS AN INDUSTRIAL RAW MATERIAL

Starch is an important raw material for industrial applications, both for food and nonfood purposes, and the market is increasing. Of particular interest is the use of starch as a nonpetroleum chemical feedstock for the manufacture of biodegradable polymers, such as "plastics," and as a noncellulose feedstock in the paper industry. In addition to promising applications outside the food industry, nutritionally and functionally modified starches have great potential as new and improved food additives. The annual starch production within the EC is approaching 10 million tons (MT) and it grows at 4–5% per year with 80% originating from cereals and 20% from potato. Of the consumed starch, 45% is used as native or modified starch in foodstuff, polymers, paper, chemicals, boards, and pharmaceuticals, while the rest is used as starch hydrolysates.

STARCH AND SYNTHESIS OF STARCH

Starch is a mixture of amylose and amylopectin, both glucose polymers. Amylose is a mostly linear polymer of 200–2000 α-1,4-bonded glucose moieties with rare α-1,6 branch points. Amylopectin, on the other hand, is highly α-1,6 branched, with a complex structure of 10^6–10^8 MW and up to 3×10^6 glucose subunits, making it one of the largest biological molecules in nature (Fig. 1; see Ref. 1 for a detailed description of the amylose and amylopectin molecules). In the plant, starch is deposited as starch granules, primarily in amyloplasts of endosperm (seeds), tubers, and roots. Figure 2 shows the central enzymes and the metabolic pathways in starch synthesis (see Refs. 2 and 3 for recent reviews).

In most plants starch consists of 20–30% amylose and 70–80% amylopectin. The structure of the amylose and amylopectin molecules, the amylose/amylopectin ratio, the degree of substitution, and the association of lipids and proteins are responsible for the functional qualities of starch, and thereby affect properties such as gelatinization, retrogradation, viscosity, fermentability, behavior as granules, and behavior as pure and mixed polymer sheets. The size of the starch granules is heterogeneous, with a diameter of 0.5–100 μm. In some cereals, such as barley, starch is composed of a fraction with large granules (A-starch) and a fraction with small granules (B-starch). Of the various forms of modified starches that occur in nature, only phosphorylation of potato starch is understood to some extent.

Concomitant with the increased interest in starch as an industrial raw material is a growing demand for production of modified starch in transgenic plants [4–6].

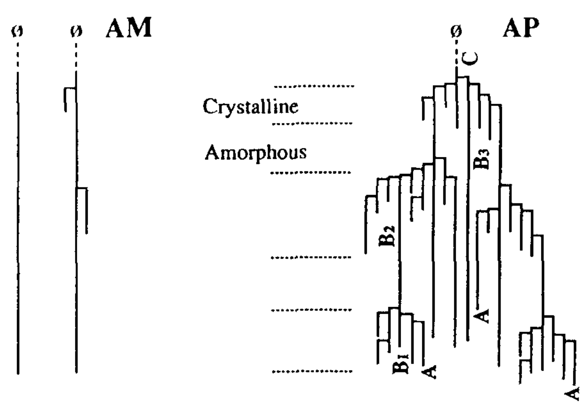

FIG. 1. The structure of amylose (AM) and amylopectin (AP). The crystalline branch clusters and the amorphous regions between the clusters are shown. The A-chains are unbranched whereas B-chains and the single C-chain with the reducing end (∅) are branched. The B-chains are further divided according to length from short B1-chains to long B3-chains (see Ref. 1 for references).

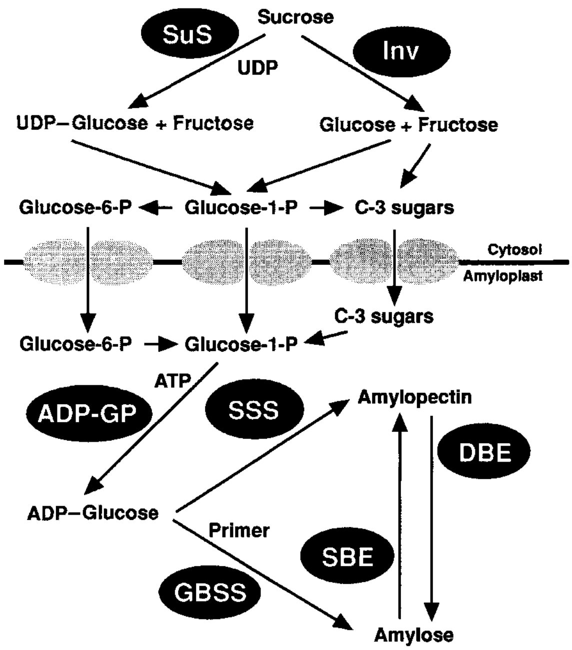

FIG. 2. Schematic representation of the metabolic pathway for starch synthesis in nonphotosynthetic tissues. SuS = sucrose synthetase, Inv = sucrose invertase, ADP-GP = ADP-glucose pyrophosphorylase, SSS = soluble starch synthase, GBSS = granule-bound starch synthase, SBE = starch branching enzyme, DBE = debranching enzyme.

This approach offers the possibility to replace much of the postharvest chemical modifications, which are environmentally hazardous, expensive, and time-consuming. It also makes possible the production, *in planta*, of novel carbohydrates. A desirable product in transgenic plants would be all- or high-amylose starch for the polymer industry. This could be achieved by inactivation of all *sbe* genes (encoding SBE). Selective inactivation of *sbe* genes would be expected to result in starches with altered branching patterns. Other examples of postharvest modifications that could be replaced by a transgenic approach are production of crosslinked starch for increased stability, production of starch with well-defined granule sizes, and substitutions (hydroxypropylation, methylation, carboxylation, phosphorylation, etc.). Production of novel carbohydrates in transgenic plants has been demonstrated by the synthesis of cyclic dextrines from starch [5].

CEREAL AND POTATO STARCH—A COMPARISON

Cereals are important crop and starch sources. The industry for processing of cereals such as corn, rice, wheat, and barley is at hand and very well developed. The storage and handling characteristics for cereal seeds are excellent, and superior to those of tubers like potato. This suggests that production costs, and thereby shelf prices, for bioengineered cereal starch will be competitive. The annual production of barley is less than that for corn, rice, or wheat; around 167 MT worldwide and 48 MT in the EC. (Corresponding numbers for wheat are 565 and 85 MT, respectively). Over 60% of the barley production in the EC is used in the starch-consuming industry. However, barley is globally an important crop for food, feed, and malt production. Barley is also a sturdy plant that can grow in marginal areas. In addition, barley is a diploid species (as opposed to, e.g., potato and wheat) and genetically flexible. Finally, knowledge in barley genetics and breeding is high, and large collections of barley mutants are available. Particle-gun mediated transformation of cereals, including corn, rice, wheat, and barley, has been reported [7, 8].

The annual production of potato is approximately 260 MT worldwide and 45 MT in the EC. Potato is a very important starch source due to the large yield in tubers. The incorporated phosphate groups in the amylopectin chains contribute to the mild taste of potato starch and to its ability to form clear, transparent solutions and gels, and thus renders it an attractive starch in the food industry. Transformation of potato with *Agrobacterium tumefaciens* is well established, and transgenic potatoes with altered starch composition and yield have been described [5].

CONCLUSION

Production of modified starch in transgenic plants has great future potential, especially given the fact that crude oil and cellulose resources are shrinking, and also taking into account the increasing environmental awareness.

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