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SUGAR PROFILES OF SEEDLINGS OF *ZEA MAYS* AND SEVERAL WEEDY PANICOID GRASSES

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Key Word Index—*Zea mays*; *Panicum miliaceum*; *Setaria faberii*; *Sorghum bicolor*; Poaceae; seedlings; sugars; glucose; fructose; sucrose.

Abstract—Sugar profiles were obtained for root, shoot and endosperm tissues from four-day-old seedlings of *Zea mays*, *Setaria faberii*, *Panicum miliaceum* and *Sorghum bicolor*, and pronounced differences were observed. Sugars in *S. faberii* roots were especially low compared to *Z. mays*, with no detectable glucose or fructose (< 0.01%) and only ~ 0.03% sucrose in the former species compared to ~ 1% fructose, 9–16% glucose and 3–4% sucrose in the latter. *Panicum miliaceum* roots contained < 0.1% sucrose and glucose, and the shoots contained ~ 1/10 as much glucose as *Z. mays*.

INTRODUCTION

Recognition of biochemical diversity within a plant family is helpful as a taxonomic tool [1, 2] and could be the starting point for design of selective growth regulators useful as herbicides. Individual enzymes are the target of some recently developed drugs for animals [3, 4]. However, there is no evidence that such an approach has been used in the development of herbicides, except for a recent report documenting the differential inhibition of PEP carboxylase from C_3 and C_4 plants by phenoxy herbicides [5]. A severe limitation is imposed on this approach by the small amount of information that is available concerning the comparative biochemistry of plants. Furthermore, comparative studies commonly emphasize secondary substances such as flavonoids and methyl cyclitols [1, 6] whose function is not known or whose presence is not essential for plant growth and development. The importance of research that could lead eventually to new kinds of herbicides is underscored by the appearance of weeds resistant to chemicals that are the mainstay of present day control programs [7, 8].

Poaceae is an example of a large and morphologically diverse family where several examples of metabolic differences are known. Some species of Poaceae possess the C_4 and others the C_3 photosynthetic carbon pathway [9]. Some temperate zone perennials accumulate fructans as reserve materials [10], and the unusual oligosaccharide raffinose is a minor constituent in *Sorghum* seeds [11]. However, at present there are no metabolic discriminators for many species in this family.

This paper is concerned with possible metabolite differences among several genera of Poaceae, subfamily Panicoideae. Contrasting metabolite profiles would be indicative of underlying biochemical differences [12]. The species selected for study were *Zea mays* L. (maize), *Panicum miliaceum* L. (wild proso millet), *Setaria faberii* Herrm. (giant foxtail) and *Sorghum bicolor* (L.) Moench. (shattercane). The latter three are problem weeds in *Z. mays*, with *S. faberii* being widespread already and *P. miliaceum* increasing [13, 14].

RESULTS AND DISCUSSION

Substantial quantitative differences in the sugar profiles are seen when *Z. mays* roots and shoots are compared to those of the other species. The glucose content of *Z. mays* tissues was especially high compared to glucose in the other seedlings (Fig. 1A and B). This difference was most pronounced in the root tissues. The two *Z. mays* cultivars contained 9–16% glucose, while *S. faberii* contained no detectable glucose (< 0.01%), *P. miliaceum* contained ~ 0.02% and *S. bicolor* ~ 0.5%. Furthermore, *Z. mays* shoots contained 10–15-times more glucose than did shoots of *P. miliaceum*, with smaller differences noted for the other two species. There were also large differences in levels of root fructose and sucrose when *Z. mays* was compared with certain of the other species, with some differences observed for shoots. *Setaria faberii* roots contained no detectable fructose (< 0.01%) compared to 0.8–1.1% in *Z. mays*. Roots of *S. faberii* contained only ~ 0.03% sucrose and *P. miliaceum* ~ 0.09% compared to 3–4% in *Z. mays*. A several-fold difference in shoot sucrose level was present, with *Z. mays* at 4% and the other species at 1% or less.

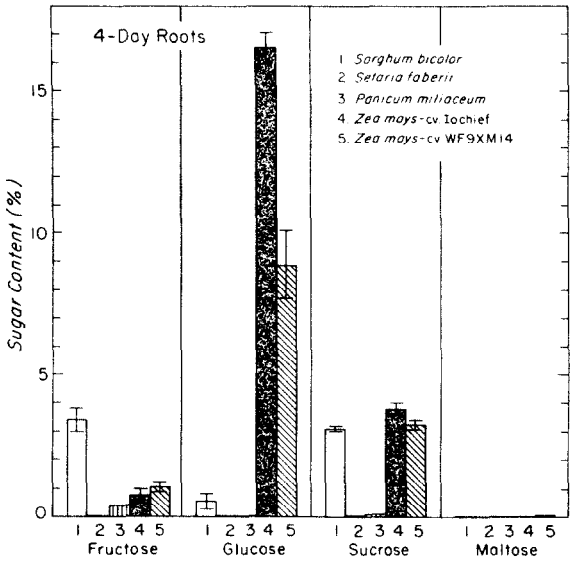
It is likely that the elevated sugars observed in *Z. mays* roots and shoots resulted from a more plentiful supply of carbohydrate reserves in this large-seeded species which had higher endosperm glucose and maltose levels than the other species (Fig. 1C). This difference was especially pronounced in the sugary cultivar, which had about 20-times more glucose and 5–10-times more maltose than the others. It remains to be determined whether the elevated sugars in the growing parts of *Z. mays* seedlings are sequestered in vacuoles and whether metabolites derived from these sugars are also elevated compared to the other species.

The experiment described above was repeated with additional batches of 4-day-old seedlings. The same procedures were used except that each seedling was quick frozen in liquid nitrogen immediately after it was dissected. The frozen material was lyophilized, and ethanol extracts were made from the dried samples. These modifi-

cations were adopted to ensure that the high glucose in *Z. mays* roots and shoots was not an artifact caused by enzymic degradation of sucrose during extraction of the living tissues by hot ethanol and that a similar enzymic attack on phytoglycogen or starch in the sugary endosperm tissues was not responsible for elevated glucose and maltose found there. The *Z. mays* roots again contained abundant glucose with none detectable in root extracts from the other species, and the maize shoots contained several-fold more glucose than the other shoots. The sugary endosperms again contained 6% maltose, and glucose was approximately 16%, with low levels of these sugars in the other endosperm samples as before.

EXPERIMENTAL

Plant material. Both sugary and starchy maize hybrids were included to insure that diverse germplasm was characterized. The starchy cultivar (WF9 × M14) was obtained from Dr. Robert Lambert, Department of Agronomy, University of Illinois, and the sugary cultivar (Iochief) was obtained from the Crookham Company, Caldwell, Idaho. Seeds of *S. bicolor* (shattercane) and *S. faberii* (giant foxtail) were obtained from F & J Seed Service, Woodstock, Illinois. The *P. miliaceum* (wild proso millet) seed was obtained from Dr. Herbert Hopen, Department of Horticulture, University of Illinois at Urbana-Champaign and was collected in Boone County, Illinois. Samples were dried in the oven, and average seed weight in mg was as follows: WF9 × M14, 246; Iochief, 158; shattercane, 16.2; giant foxtail, 1.5; wild proso millet, 3.8. Household Clorox (5.25% $NaClO_3$) was diluted 10-fold, and seeds were surface sterilized for 5 min in this soln. Seeds were then rinsed with distilled water and planted on absorbent paper in Pyrex trays. The papers were moistened with distilled water, and the trays were covered with aluminum foil. Samples of root, shoot and endosperm tissues were taken for analysis from rapidly growing seedlings germinated 4 days in the dark at 30°. Average root and shoot lengths in cm (± s.d.) at the time of harvest were as follows: Iochief (15.5 ± 3.2, 10.7 ± 2.6), WF9 × M14 (7.3 ± 2.1, 8.9 ± 4.2), *S. bicolor* (6.8 ± 1.4, 17.2 ± 3.8), *P. miliaceum* (7.1 ± 1.2, 8.4 ± 2.2), *S. faberii* (3.1 ± 0.5, 5.9 ± 0.9). Dry wts were determined on separate samples after 48 hr at 60° in a forced air oven.



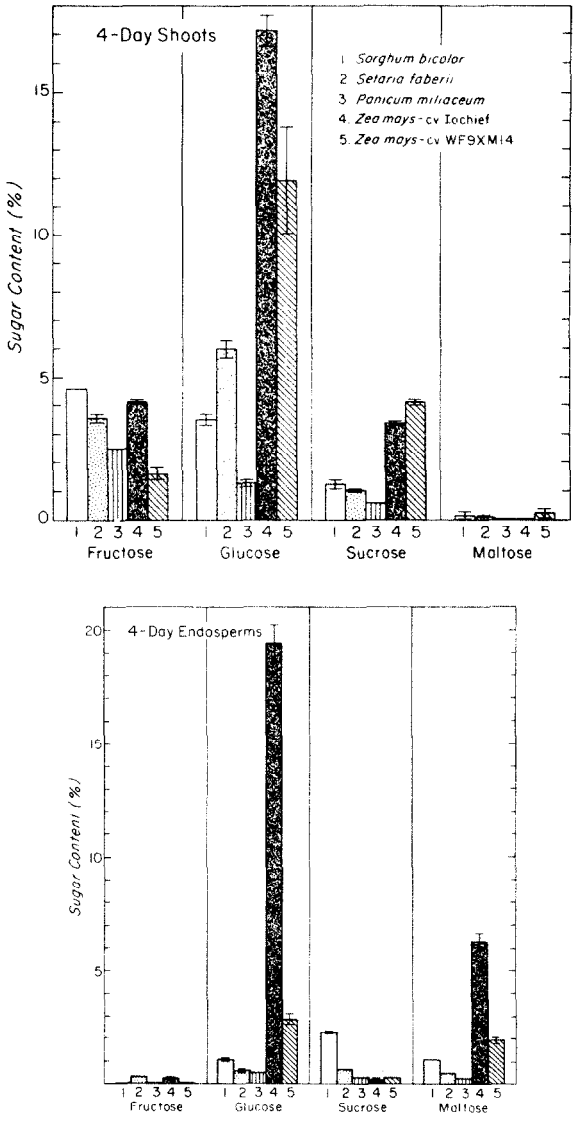


Fig. 1. Sugar profiles of maize seedlings and several wild species of Poaceae. Seeds were germinated four days in the dark at 30°. Values are expressed as percentages of tissue dry weights. Each bar is the average of two determinations, and the differences between pairs of determinations are indicated by the vertical lines. The bars are identified as follows: 1. *Sorghum bicolor* (L.) Moench. (shattercane); 2. *Setaria faberii* Herrm. (giant foxtail); 3. *Panicum miliaceum* L. (wild proso millet); 4. *Zea mays* L. (cv. Iochief, a sugary maize hybrid); 5. *Zea mays* L. (cv. WF9 × M14, a starchy maize hybrid). A, Roots (top). B, Shoots (middle). C, Endosperms (bottom).

Sugar extraction and analysis. The samples (1.0–3.0 g fr. wt) were extracted immediately after harvest with a Sorvall Omni mixer in 8 ml boiling 80% EtOH and centrifuged (6 min) at 17000 *g*. The supernatants were saved, each pellet was rinsed × 3 with 3 ml 80% EtOH, and supernatants were combined to give a final vol. of 15 ml for each sample. A portion of each extract was evaporated to dryness under red. pres. and then dissolved in one-fifth of the initial vol., using 80% EtOH. Two samples of each concd extract (usually 0.1 and 0.2 ml) were dried, the TMS-oxime derivatives prepared, using a total of 0.1 ml of reagent per sample,

and subjected to GC [15]. One μl samples were injected into the 3% OV-17 column with He carrier gas set at 20 ml/min and initial oven temp. at 160°. After 2 min the oven temp. was increased to 1°/min for 6.5 min to obtain good separation of monosaccharides, and then the temp. gradient was increased to 10°/min to 275° in order to elute disaccharides quickly.

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