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Changes in potato starch quality during growth

D.H. CHRISTENSEN AND MARIANNE H. MADSEN

Danish Institute of Plant and Soil Science, Department of Forage Crops and Potatoes, Research Centre Foulum, P.O. Box 21, DK-8830 Tjele, Denmark

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Summary

Potato starch quality parameters (amylose concentration, glucose-6-phosphate content and granule size) were analyzed in relation to the harvesting date and tuber size of four cultivars. A significant increase in the glucose-6-phosphate content and granule size of starch was observed during tuber growth, whereas the amylose concentration was constant. Granule size increased markedly, whereas glucose-6-phosphate content showed slightly increasing values with increasing tuber size. Amylose concentration showed no correlation with tuber size. We conclude that the changes in the granule size, glucose-6-phosphate and amylose content of potato starch during growth are independent of each other.

Introduction

Potato is one of the world's three most important sources of starch, the others being maize and wheat. In northern temperate regions potato is the only crop grown for starch production. Starch is used in the food industry as thickener and in the non-food industry for more than 500 different products (Kempf, 1986). The rheological properties of starch solutions, which are important in relation to their application, depend on the physical and chemical characteristics of the starch, e.g. granule size, amylose concentration, molecular size and degree of branching. Furthermore, potato starch contains covalently-bound phosphate in the amylopectin molecules, which provide some of its unique properties with regard to gelatinization temperatures and cross linking ability. The organic bound phosphate is mainly present as glucose-6-phosphate (Glc-6-P) and glucose-3-phosphate (Hizukuri et al., 1970; Muhrbeck & Tellier, 1991; Bay-Smidt et al., 1994).

The physical and chemical properties of starch in various plant species change during growth (Banks et al., 1973; Boyer et al., 1976; Noda et al., 1992). Such changes have been only rarely investigated in potatoes. During tuber enlargement starch is synthesized in amyloplasts as round to oval granules. In maize and sweet potatoes granule size increases throughout growth (Boyer et al., 1976; Noda et al., 1992); potatoes apparently show the same developmental pattern (Putz & Tegge, 1980).

In maize and barley starch amylose increases during growth (Boyer et al., 1976; Banks et al., 1973). In sweet potato an increase in amylose content was only observed at an early growth stage (Noda et al., 1992). In potato the amylose concentration was found to be constant during growth (Halsall et al., 1948), but this was contradicted by

Geddes et al. (1965), who found increasing concentrations of amylose throughout growth.

The importance of the stage of development to the phosphorus concentration in potato starch is disputed. Samotus & Schwimmer (1962) found that the content of organic bound phosphorus increased during tuber development, while Nielsen et al. (1994) concluded that the phosphorus content was constant during the period of growth, as they found no correlation between tuber size and phosphorus content.

The objective of this study was to examine the changes and correlation in physical and chemical properties of potato starch during growth, using four cultivars and analyzing granule size, Glc-6-P content and amylose concentration.

Materials and methods

Plant material. Field experiment was conducted on a fine sandy soil (2.6% soil organic matter, 4% clay, pH 5.9, containing 1.11 mg K and 0.82 mg P kg^{-1} dry matter) at Tylstrup Field Station, Northern Jutland, Denmark, using a split-plot experimental design with cultivars as split treatment. The plots were 18.75 m^2 (75 plants). Seed tubers were planted on 4 April 1993. The weather was warm and dry during May and June, followed by colder weather for the rest of the growing period. The plants were fertilized with 160 kg N, 17 kg P and 150 kg K per ha, and were irrigated with 30 mm water at 25–30 mm water deficit. Three maincrop starch cultivars (Oleva, Saturna and Senator) and one late starch cultivar (Dianella) were used. Tubers were harvested eight times during the growing season; the first harvest 69 days after planting (DAP) and then at 14-day intervals. The tubers were divided into seven size grades: 20–30 mm, 30–40 mm, 40–50 mm, 50–60 mm, 60–65 mm, 65–75 mm and >75 mm, and 1.0 kg from each size grade was used for starch isolation within 1 day of harvest. In addition, approximately 5 kg tubers from each size grade were weighed in air and under water to estimate the starch content (Anon., 1993).

Starch isolation. Starch from 1.0 kg washed potatoes was separated from the pulp in a juice centrifuge (Prototype 753, Moulinex A/S). The starch suspension was passed twice through a 125 µm sieve with a total addition of 3.0 l deionised water and allowed to precipitate 30 min. after each sieving. To remove impurities the starch was washed with 0.9 l deionised water followed by vacuum filtration three times and afterwards dried at 30 °C to approximately 10% moisture content. The dried starch was grounded in a mill with a 0.4 mm mesh (Cyclotec 1093 Sample Mill, Tecator, Höganäs, Sweden).

Measurements. The size of the starch granules was determined by an image analyser (Leitz Texture-Analysis-System). Starch was stained with Lugol's solution (Merck, 2 g KI + 1 g I_2 in 300 ml H_2O) and resuspended in 20% polyethyleneglycol 4000 (Merck, Molecular weight 3500–4500) to improve the counting procedure. Approximately 1000 granules were measured from each sample. The values presented are means of the size distributions. An enzymatic assay was used to determine the Glc-6-P content (Bay-Smidt et al., 1994), and the amylose concentration was determined by a spectrophotometric method (Hovenkamp-Hermelink et al., 1988).

Data analysis. The figures presented in Table 1 and Fig. 1 were weighted according to the yield of starch in the different tuber sizes. A two-factorial analysis of variance with the interaction between cultivar and harvesting date as residual was used to examine the effect of cultivar and harvesting date.
The effect of tuber size was analyzed with a three factorial analysis of variance using the interaction between cultivar, harvesting date and tuber size as residual. Unweighted data were used.

Results and discussion

The stage of development of the potato tubers, represented by their harvesting date, had a decisive influence on granule size, which increased significantly during growth independently of the cultivar (Table 1, Fig. 1). The largest increase in average granule diameter was observed during the first half of the experimental period. This correlates very well with the fact that tuber yield (results not shown) and starch content (Table 1) also increased rapidly until about 111 DAP. From 111–139 DAP no or only a small increase in granule size was observed in cvs Oleva and Saturna, while the granule size of the other cultivars was still increasing. This period of constant granule size seems to be a common characteristic of some cultivars, as it also has been observed in Bintje (Putz & Tegge, 1980). The enlargement of the starch granules was, however, not strictly dependent on photosynthesis. Our results show a notable increase in granule diameter after senescence of the foliage (Fig. 1), at a time when the starch content of the tubers was decreasing slightly (Table 1). This indicates that starch is rearranged inside the tuber after leaf senescence and as tubers mature, as suggested by Putz & Tegge (1980).

Table 1. Parameters of starch quality in potato tubers during growth.

Days after planting	69	83	97	111	125	139	153	167	$LSD_{0.95}$
Starch (%)	n.d.	12.1	15.0	16.1	17.8	17.8	17.4	16.7	0.4
Granule diameter (μm)[1]	33.6	38.8	40.5	43.8	43.7	44.7	46.1	47.9	2.6
Glc-6-P (nmol/mg starch)	n.d.	16.8	n.d.	21.8	n.d.	24.7	n.d.	24.2	2.9
Amylose (%)	n.d.	29	n.d.	29	n.d.	28	n.d.	28	n.s.

[1] Mean values of distributions.
n.d.: Not determined.
n.s.: Not significant.

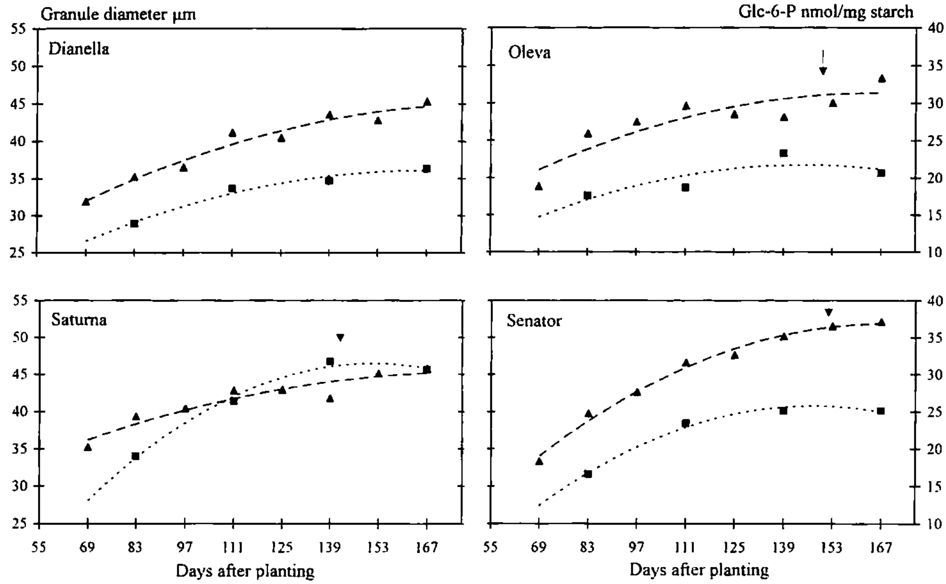

Fig. 1. Changes in granule size and Glc-6-P content of starch from four potato cultivars during growth.
▲: Granule diameter, mean values of distributions.
■: Glc-6-P content.
Leaf senescence indicated with an arrow.

In this study the phosphorus content of the starch is presented as Glc-6-P because a good correlation between total and Glc-6 bound phosphorus has been found (Muhrbeck & Tellier, 1991; Bay-Smidt et al., 1994). The Glc-6-P content increased by an average of 47% during growth to a maximum at 139 DAP (Table 1, Fig. 1), and was approximately constant during the rest of the growing period. The change from increasing Glc-6-P content to a constant level occurred at leaf senescence. Our results are in accordance with those of Samotus & Schwimmer (1962), who observed an increase in starch bound phosphorus in two cultivars during growth, but contradict the conclusions of Nielsen et al. (1994), who found that the concentration of Glc-6-P was constant during tuber development.

The amylose concentration in the four cultivars was independent of the harvesting date (Table 1) and tuber size. These observations are supported by the findings of Halsall et al. (1948) and Haase (1993). Our results, however, contradict the conclusions of Geddes et al. (1965) who found an increasing amylose concentration during tuber development (i.e. as tuber size increased), but this might be due to the fact that their investigation included smaller tubers from earlier stages of development.

Tuber size is important to the granule size of starch (Görlitz, 1963; Geddes et al., 1965; Putz & Tegge, 1980; Haase, 1993). From Fig. 2 it is clear that granule size

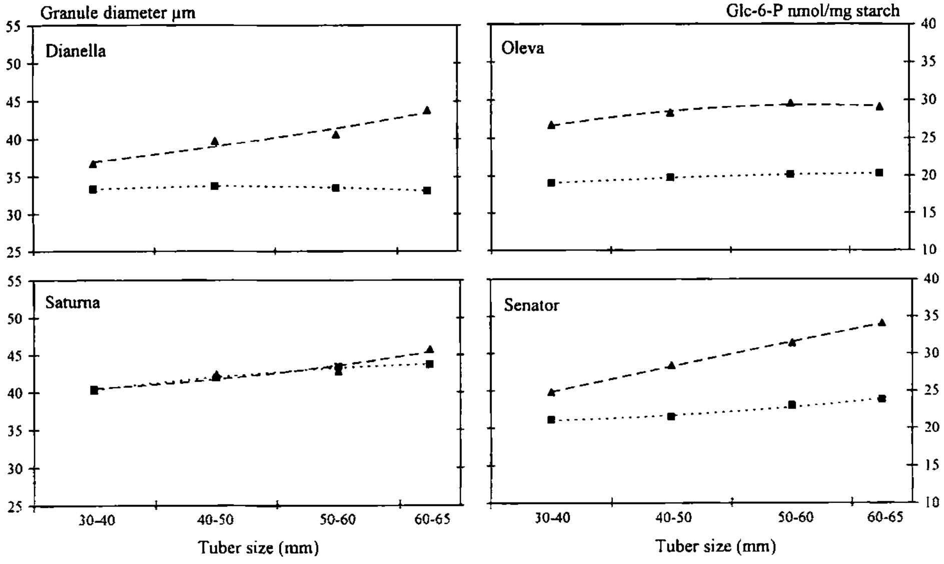

Fig. 2. Effect of tuber size on granule diameter and Glc-6-P (means of seven and four harvesting dates (according to Table 1), respectively. Only results from tuber size grades present at all harvesting dates are included).
▲; Granule diameter, mean values of distributions.
■; Glc-6-P content.

increased with tuber size. Furthermore, an interaction between cultivar and tuber size was observed (Fig. 2), implying that the magnitude of starch granule enlargement due to tuber size depends on the cultivar. In this study the rate of granule growth was: cv. Oleva < cv. Dianella = cv. Saturna < cv. Senator (Fig. 2).
Tuber size was of minor importance to the Glc-6-P (Fig. 2) and total P-content of starch (results not shown), but we found a low positive correlation, unlike Putz & Tegge (1976) and Nielsen et al. (1994). The Glc-6-P of cv. Dianella was constant, while the other cultivars showed increasing values with increasing tuber size (Fig. 2).

The enlargement of starch granules during growth was not equal in all tuber sizes (Fig. 3). The size of the granules from tubers of 20–40 mm was similar from 125 DAP onwards, while the granules of the larger tuber size grades increased. Likewise, the incorporation of phosphorus into the starch after 111 DAP was negligible in small compared to larger tubers (Fig. 3). The rather constant granule size and phosphorus content of the small tubers are likely to be due to inactive small tubers being outgrown by the larger ones. Tuber yield in the 20–40 mm size grade was generally constant after 111 DAP, and these tubers had a slowly decreasing starch content (results not shown), which supports the idea of inactive tubers. The largest tubers at harvest are likely to be those which were initiated first (Hide & Welham, 1992), but tuber size is often misleadingly interpreted as tuber age, meaning that larger tubers at

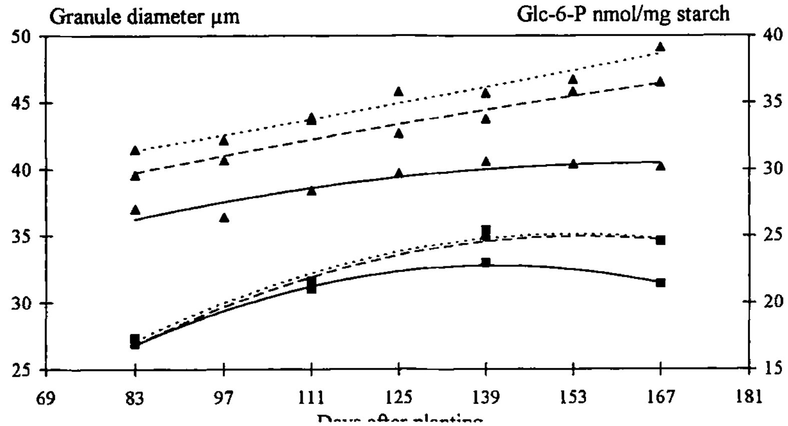

Fig. 3. Changes in granule diameter and Glc-6-P content of potato starch from three tuber size grades during growth (means of four cultivars).
▲; Granule diameter, mean values of distributions.
■; Glc-6-P content.
———— ; Tuber size 20–40 mm.
- - - - - - - ; Tuber size 40–60 mm.
--------- ; Tuber size 60–75 mm.

a certain time are older or more mature than smaller tubers. It is clear from Fig. 3 that when the composition of starch is analyzed, the different quality parameters (including amylose concentration) show different correlations with tuber age (represented by DAP) and tuber size. Our results demonstrate that the resulting granule size is a combined effect of harvesting date and tuber size. Therefore, tuber size or granule size alone cannot be used as a criterion of maturity, as Geddes et al. (1965) concluded.

It is notable that the different starch characteristics (granule size, Glc-6-P and amylose) changed more or less independently during development. The amylose concentration did not change at all, while the content of amylopectin bound phosphorus increased significantly. Takeda & Hizukuri (1982) showed that there were more binding sites for phosphorus when the amylopectin chains where long rather than short. A change towards longer chains during growth could explain the rise in Glc-6-P content. Another explanation might be an increased absorption rate of phosphorus from the soil during growth, thereby producing more phosphorus for incorporation into starch. The relationship between changes in granule size and Glc-6-P content during growth depends on the cultivar (Fig. 1). Dianella and Senator showed a good correlation (r=0.99 and 0.97 respectively) while in the other cultivars the correlation was weaker due to the period of constant granule diameter. Even though the phosphorylation process constitutes an integrated part of starch biosynthesis in potato (Nielsen et al., 1994), our results demonstrate that changes in the rate of phosphorylation are independent of the level of starch biosynthesis.

Further studies are needed to provide precise information on the biochemical changes (e.g. molecular size and chain length) of starch during granule growth. An understanding of starch biosynthesis and the influence of environmental factors on starch quality will offer the possibility of producing native potato starches for specific applications.

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