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Effect of Maturity & Storage on Distribution of Phosphorus Among Starch & Other Components of Potato Tuber[1]

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Of the minor constituents of the potato starch granule, only phosphorus in the form of orthophosphate esterified with the C-6-hydroxyl of about 1 in every 150 glucosyl residues of the amylopectin moiety of the starch has been shown to be chemically bound to the starch (5). The amount of phosphorus bound to the starch appears to be correlated with the total phosphorus content of the potato tuber (10) and also with the viscosity of gels prepared from the starch (11, 12). Although the starch-bound phosphorus represents only a very small percentage of the starch, it may constitute as much as one-third of the total tuber phosphorus, thus suggesting that it constitutes a reservoir of phosphorus (9).

Although some information has been accumulated regarding the level of starch as affected by maturity of the tuber and by post-harvest storage conditions, nothing is known about the concomitant fate of starch-bound phosphorus. This is the subject of this paper. The relationship between levels of starch-bound phosphorus and those of other forms of phosphorus is also presented.

Materials & Methods

The cultural and post-harvest history of the Kennebec and White Rose varieties used in the present investigation has been detailed elsewhere (6). The potatoes were harvested 60, 80, and 102 days after planting. They were stored for six or seven weeks at 0 C and for five or six weeks at 25 C. The scheme for preparation of the phosphorus components of the tubers into four main fractions is outlined in figure 1. These four phosphorus fractions are as follows:

► I. Starch phosphorus, expressed either as P_{ss}, the mg of starch-bound phosphorus per 100 g of isolated starch granules (4), or as P_{st}, the mg of starch-

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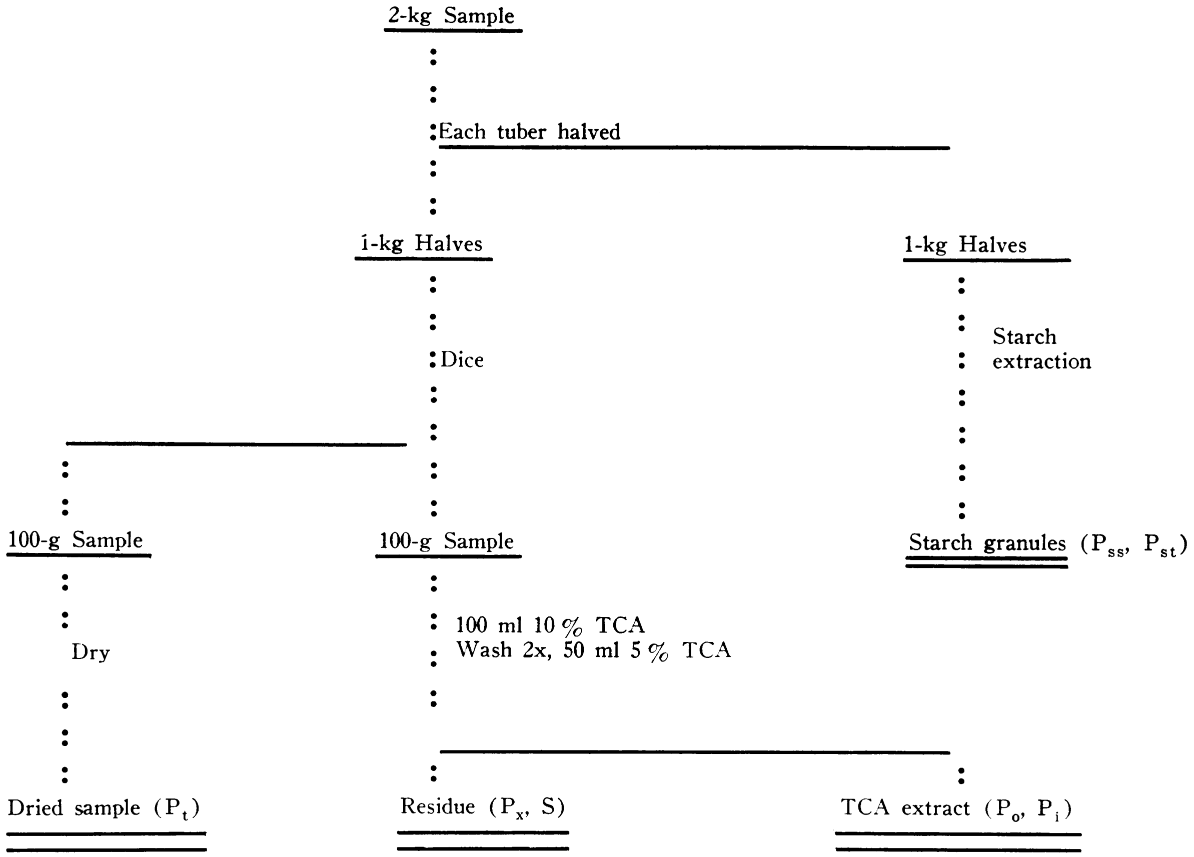

Fig. 1. Scheme for the preparation of phosphorus fractions from potato tubers. Symbols in parentheses are defined in the text.

bound phosphorus per 100 g of tuber. P_{st} was obtained by multiplying P_{ss} by S, g of starch per 100 g of fresh potato (10), and dividing by 100.

► II. P_i, inorganic phosphorus, determined in the trichloroacetic acid (TCA) extract before digestion with sulfuric acid.

► III. P_o, TCA-soluble, organically bound phosphorus, obtained by subtracting P_i from the total phosphorus of the TCA extract. P_o consists mainly of phytic acid phosphorus and, to a smaller extent, of enzyme nucleotides and sugar phosphates (4, 8).

► IV. P_x, non-starch, TCA-insoluble phosphorus, obtained by subtracting P_{st} from the total phosphorus content of the TCA-insoluble residue. This fraction probably comprises phosphorus from proteins, nucleic acid, and phospholipids.

These four forms of phosphorus account, within experimental error, for the total phosphorus (P_t) of the tuber as determined by direct analysis of tuber solids and expressed as mg of phosphorus per 100 g of potato tuber (corrected for loss of weight during storage). The mean difference between P_t determined directly and P_t calculated by summing up the four fractions amounted to −0.1 mg phosphorus per 100 g of tubers for the 17 samples. The standard deviation of the differences was 1.2.

The phosphorus content of these fractions was determined by the method of Müller (*2*) before and after digestion with concentrated sulfuric acid and H_2O_2.

Results

► Level and Distribution of Phosphorus in Freshly Harvested Potatoes: The results for White Rose tubers are shown in figure 2 and for Kennebec tubers in figure 3. P_t increased with increasing maturity, most of the increase occurring between the second and third harvests for both varieties of tubers. Phosphorus attached to starch also increased whether calculated as P_{st} or P_{ss}. In contrast to changes in P_t, the rise of P_{st} was fairly uniform with respect to time. There was a slight but steady increase in P_i and no increase in P_x. P_o increased significantly only between the second and third harvest for both varieties of potatoes. Indeed, most of the rise of P_t in the White Rose variety during this period could be accounted for as a rise in P_o.

► Effect of Post-Harvest Storage at 25 C: The only marked changes were an increase in P_i and a decrease in P_x in potatoes of both varieties from the first and second harvest.

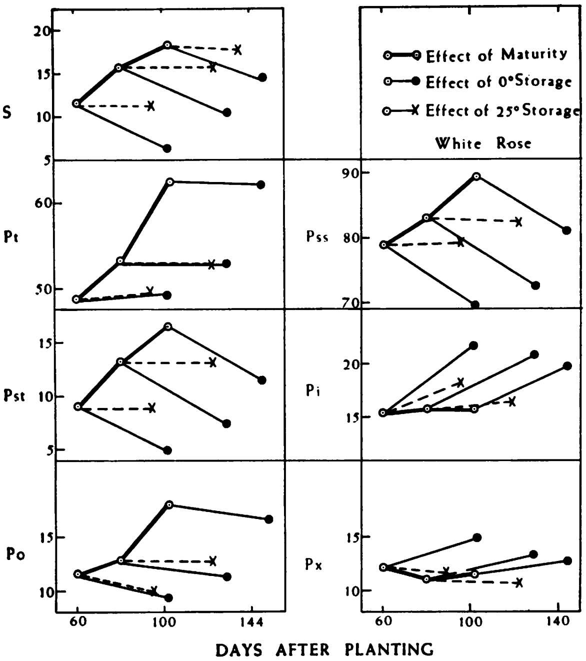

Fig. 2. Effect of maturity and storage on the levels of starch and phosphorus components of White Rose potatoes.

► Effect of Post-Harvest Storage at 0 C: In contrast to storage at 25 C, storage of potatoes at 0 C induced changes in the phosphorus content of all four fractions. P_{st} and P_o decreased, whereas P_i and P_x increased. The magnitude of these changes was, on the whole, independent of the maturity of the tubers. In figure 4 is shown a very close linear relationship which is independent of variety, between percentage loss of starch and percentage loss of starch-bound phosphorus (P_{st}) upon storage at 0 C. The percentage losses decreased with increasing maturity.

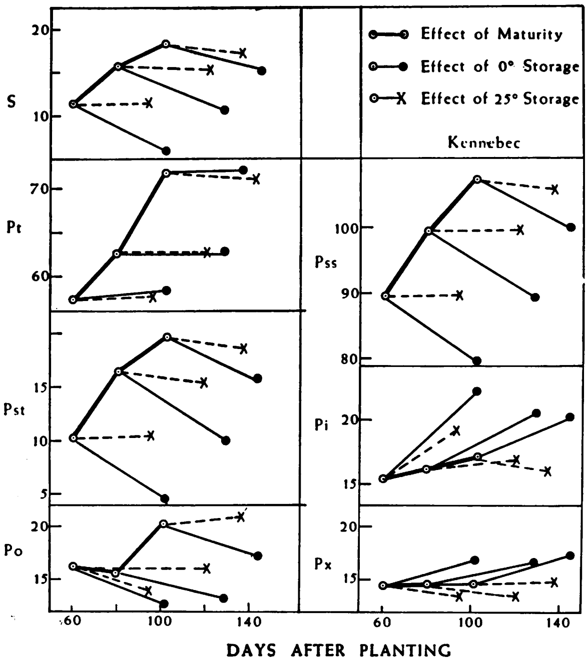

Fig. 3. Effect of maturity and storage on the levels of starch and phosphorus components of the Kennebec potatoes.

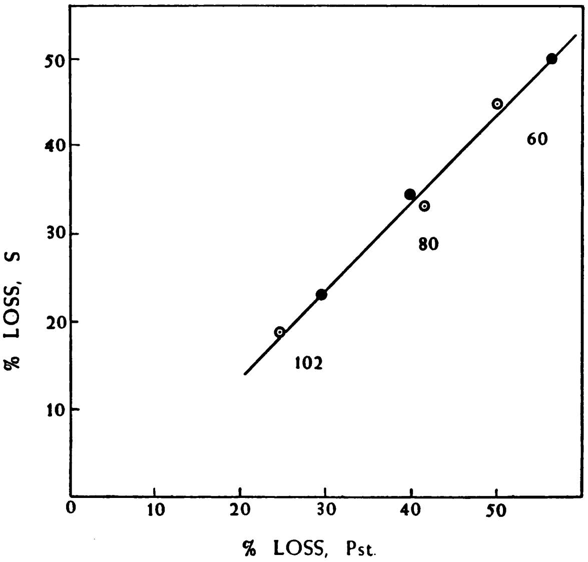

Fig. 4. Relationship between percentage loss of starch (S) and percentage loss of starch-bound phosphorus (P_{st}) upon storage at 0 C. *Open circles,* White Rose variety; *closed circles,* Kennebec variety. The numbers 60, 80, and 102, refer to days after planting.

Discussion

Inspection of figures 2 and 3 reveals certain trends which appear to be, in general, independent of variety. The four phosphorus fractions (P_{st}, P_i, P_o, & P_x) comprising the total phosphorus (P_t) fall into pairs. Starch phosphorus (P_{st}) and TCA-soluble, organically-bound phosphorus (P_o) tend to increase in value with increasing maturity and decrease upon storage of the tubers at 0 C. On the other hand, the levels of inorganic phosphorus (P_i) and non-starch, TCA-insoluble phosphorus (P_x) do not change during maturity but do decrease upon storage at 0 C. The increase in phosphorus upon maturation appears chiefly as starch-bound phosphorus during early stages of development and predominantly as phytic acid phosphorus in tubers approaching maturity. [More than 2/3 of the P_o fraction is present as phytic acid (7)]. Working with potato plants grown in nutrient solution, Houghland (3) showed that phosphorus absorbed by the plant during development tended to concentrate in the tubers with increasing maturity. An arithmetical balance of changes in the forms of phosphorus occurring at 0 C storage shows that the disappearance of starch phosphorus (P_{st}) can largely be accounted for as a gain in P_i and that corresponding loss of phytic acid phosphorus (P_o) can be accounted for as a gain in P_x. The P_x fraction, as mentioned before, most probably consists of phosphoprotein, nucleic acids, and phospholipids. In view of the widespread occurrence of inositol phosphatides, the role of phytic acid as a precursor to inositol and phosphorus of these phospholipids is suggested. The possibility of interchanges among all four forms of phosphorus is, of course, not ruled out. Thus Mori et al. (4) report an enhanced incorporation of labelled inorganic phosphorus into nucleotides and sugar phosphates at low temperature.

Table I

Periodicity of Occurrence of Phosphorus in Amylopectin Moiety of Starch

Source of starch	Variety					
	White Rose			Kennebec		
	Days after planting					
	60	80	102	60	80	102
	Periodicity*					
Freshly harvested	180	172	160	160	144	133
Stored at 0 C	200	196	173	180	155	143
Lost during storage at 0 C	163	143	128	146	128	102
Formed during development	154**	114***		117**	115***	

* Number of glucosyl residues of amylopectin moiety of starch per atom of bound phosphorus.
** Periodicity of phosphorus of amylopectin moiety of starch formed between 60 and 80 days after planting.
*** Periodicity of phosphorus of amylopectin moiety of starch formed between 80 and 102 days after planting.

The increase in starch phosphorus (calculated as P_{st}) during the development of the tuber is to be expected, in view of the increasing starch content. However, the finding that the amount of phosphorus per unit weight of starch also increases indicates that much of the excess of phosphorus absorbed by the tuber finds its way to the starch. It is of interest to calculate the periodicity (reciprocal of frequency) of occurrence of the phosphorus in the amylopectin moiety of the starch. In table I is shown the periodicity expressed as the number of amylopectin glucosyl residues per atom of bound phosphorus. Note that the periodicity decreases with increasing maturity and increases upon storage at 0 C. However, the average number of glucosyl residues between P atoms of the amylopectin of the starch formed during development or lost upon storage at 0 C is decidedly less than the corresponding phosphorus periodicity calculated for the actual samples. If one assumes that the number of plastids per unit volume or weight does not change during maturation of the tuber and that the starch is deposited in the plastids by apposition (1), then decrease in periodicity implies that there is more phosphorus near the exterior of the starch granule than in the interior. Therefore, one would predict that upon decomposition of the granules, as occurs during storage of potato, the starch remaining would, as was found, have less phosphorus per unit weight, providing the decomposition takes place via a peeling off of successive layers.

Summary

The effect of maturity and post-harvest storage of potato tubers on the content of starch-bound phosphorus and other phosphorus fractions of the potato has been investigated. The increase in phosphorus upon maturation appears chiefly as starch-bound phosphorus in very young tubers and mostly as trichloroacetic acid-soluble organic phosphorus (i.e. phytic acid) in older tubers. During cold storage of the tubers, the phosphorus split off from the starch appears as inorganic phosphate, whereas phytic acid phosphorus appears mainly in the trichloroacetic acid-insoluble, non-starch fraction of the tubers, consisting of nucleic acids, phosphoproteins, and phospholipids. From the observations that the starch granules increase in phosphorus content during development and decrease during post-harvest storage at 0 C, it seems probable that phosphorus is distributed heterogeneously within the starch granules, the outer layers containing more phosphorus than the inner layers.

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