Dynamics of phosphorus compounds in ripening and germinating cereal grains

Part II. Changes in phosphorus compounds content during germination of wheat, barley and rye grains

J. TLUCZKIEWICZ AND W. BERENDT

Institute of Plant Biology, Agricultural-Technical Academy, Olsztyn

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Abstract

The dynamics of phosphorus compounds was investigated in the embryos and endosperm of wheat (Grana), barley (Kosmos) and rye (Pancerne) grain after 2, 4 and 6 days of germination. In germinating grain the phosphorus compounds transformations ran along the way of synthesis in the embryo and of breakdown in the endosperm. The level of phosphorus: inorganic, nucleotides, saccharides esters and their metabolites, lipid, RNA, DNA, phytin free and phytin bound with proteins and proteins rapidly increased in germinating seed embryos. The content of phosphorus free phytin and that bound with proteins, lipids, RNA and DNA in the endosperm rapidly decreased during germination. On the other hand, the saccharides phosphorus and that of their metabolites did not change, and inorganic, nucleotides and proteins-P slightly increased. Germinating rye grains showed a higher rate of synthesis in the embryos and of breakdown in the endosperm of the investigated phosphorus compounds than wheat and barley grains.

INTRODUCTION

The metabolism of germinating seeds is closely bound with that of phosphorus compounds.

During germination of seeds of various plant species the total phosphorus content consistently decreases in the endosperm and cotyledones, whereas it rapidly increase in the embryo (Cherry and Hageman, 1961; Ergle and Guin, 1959; Hall and Hodges, 1966; Jakovlev and Ovchinnikova, 1974; Siedencko, 1975).

During germination the amount of acid-soluble phosphorus also increases in the embryos (Ergle and Guin, 1959; Hall and Hodges, 1966; Siedenko, 1975), and decreases in the endosperm (Hall and Hodges, 1966; Jakovlev and Ovchinnikova, 1974) and cotyledons (Ergle and Guin, 1959).

From the beginning of germination breakdown of phytin systematically occurs in the seeds with liberation of inorganic phosphorus (Ching, 1972; Jakovlev and Ovchinnikova 1974; Mayer, 1973; Sartirana and Blanchetti, 1967; Srivastava, 1963). Phytin hydrolysis starts in imbibitions crested wheatgrass seeds as early as after 12 h. (Wilson and Harris, 1966). Phytin degradation occurs as the result of gradual decomposition of the phytin phosphorus groups to penta-, tetra-, tri- and so on phosphate inositol derivatives (Sobolev, 1966; Wilson and Harris, 1966).

With phytin breakdown the inorganic phosphorus concentration increases in germinating seeds (Ching, 1972; Hall and Hodges, 1966; Srivastava, 1963; Sobolev, 1966; Walker, 1974). The inorganic-P level increased in the embryos and does not undergo major changes in the endosperm and cotyledones (Ergle and Guin, 1959; Hall and Hodges, 1966).

The level of other compounds of the acid-soluble fraction — nucleotides and phosphate esters of saccharides — rapidly rises in germinating seeds. Wilson and Harris (1966) found in crested wheatgrass seeds an increase in ATP, UDPG and UTP contents as early as after 6 h of imbibition. The concentration of the remaining nucleotides consistently increases during germination (Beever and Guernsey, 1966; Ching, 1973; Durzan et al., 1972; Jakovlev and Ovchinnikova, 1974; Srivastava, 1963; Tłuczkievicz, 1974b).

Synthesis of phosphate esters of saccharides starts at early stages of germination (Wilson and Harris, 1966), and the content of these compounds increases during the first few days of germination (Ergle and Guin, 1959; Sartirana and Blanchetti, 1967).

In the course of germination total phospholipids content rises in the seeds and grain (Ching, 1972; Srivastava, 1963). The transformations of phospholipids in germinating cereal seeds are of breakdown character in the endosperm and of synthesis character in the embryos (Hall and Hodges, 1966; Jakovlev and Ovchinnikova, 1974; Siedenko, 1975).

Nucleic acids content in the seeds as a whole may not undergo changes during germination (Hall and Hodges, 1966), mostly, however, it increases (Beever and Guernsey, 1966; Grzesiuk, 1967; Srivastava, 1963). The rise in nucleic acids level occurs mainly in the developing embryos (Beever and Guernsey, 1966; Kulka and Mierzwińska, 1971).

Pathways of nucleic acids in the embryos run in various directions and at various rates. Decomposition of nucleic acids was noted in the scutellum (Cherry and Hageman, 1961), whereas in the sprouts and roots their sustained production was observed (Hall and Hodges, 1966). Changes in the content of the known kinds of RNA occur in the embryos. The amount of r-RNA systematically and rapidly increases in germinating seeds (Ching, 1972; Durzan et al., 1972). t-RNA concentration in wheat embryos at first decreases, but as the growth processes start, a rapid increase of transfer RNA occurs (Kulka and Mierzwińska, 1971; Vold and Sypherd, 1968). m-RNA content remains at the beginning of germination at a constant level, then its amount slowly increases (Ching 1972, 1973). In growing embryos the DNA content rises proportionally to the increase in the number and dimensions of cells (Beever and Guernsey, 1966; Ching, 1973; Vold and Sypherd, 1968).

The amount of nucleic acids in germinating seeds decreases in the cotyledones and endosperm (Beever and Guernsey, 1966; Grzesiuk, 1967; Hall and Hodges, 1966; Jakovlev and Ovchinnikova, 1974; Siedenko, 1975). In the storage organs of germinating seeds RNA shows a higher breakdown rate than does DNA (Beever and Guernsey, 1966; Kulka and Mierzwińska, 1971).

Phosphorus bound with proteins appearing in seeds during germination decreases in the endosperm and cotyledones (Ching 1972; Hall and Hodges, 1966) and increases in the embryos Ergle and Guin, 1959; Hall and Hodges, 1966).

The present study was undertaken to:

1. examine the quantitative relations of phosphorus compounds in the embryos and endosperm of germinating wheat, barley and rye grain;
2. to compare the dynamics of phosphorus compounds in the above named cereal species during the process of germination.

MATERIAL AND METHODS

1. Material

The investigations were performed separately on the embryos and endosperm of germinating seeds of wheat (Grana), barley (Kosmos) and rye (Pancerne). The outset phosphorus compounds level in the embryos and endosperm was determined after soaking of the seeds in water for 12 h at 1-2°C. This treatment was introduced for easier separation

of the embryos from the endosperm. Grain for further analyses was germinated for 2, 4 and 6 days on filter paper imbibed with water in a thermostat set at constant temperature of 25°C.

2. Methods

For establishing the phosphorus compounds content in the embryos and endosperm of germinating seeds analogous methods were applied as those described in the case of ripening seeds (Tłuczkiewicz and Berendt, 1977).

RESULTS

The total phosphorus content increases rapidly during germination in the embryos and decreases in the endosperm in all the examined cereal species (Fig. 1). The phosphorus level after 6 days of germination diminished 3-4 times in the endosperm and increased 5-6 times in the embryos. Phosphorus concentration in relation to dry weight decreased both in the embryos and endosperm (Fig. 1). After 6 days of germination 81 per cent of total grain phosphorus was found in rye embryos, 71 per cent in barley and 65 in wheat embryos. The level of phosphorus fell quicker in rye endosperm than in the remaining species.

Changes in acid soluble-P content in the embryos and endosperm of germinating grain were of a similar character as the above described quantitative proportions of total-P (Fig. 2). In spite of the general increase in acid-soluble phosphorus, its contribution to the total-P pool diminished with progress of germination from 70-64 to 53-50 per cent.

In the examined period of germination mineral-P content in the embryos increased on the average 10-12-fold (Fig. 3). Over the entire period of germination the amount of inorganic-P in the endosperm increased only slightly. The inorganic-P level in relation to the weight of the growing embryos first increased and then fell (Fig. 3). The relative inorganic-P level in the endosperm increased during germination.

The free phytin-P level in germinating grain rapidly fell both in the embryos and the endosperm (Fig. 4). In the germination period analysed phytin contained in the embryos was almost completely degraded. The fall of the phytin-P level in relation to the weight of the germinating tissues occurred rapidly in the embryos, but much slower in the endosperm. Phytin content in the endosperm in relation to its initial level decreased in rye 50, in barley 10 and in wheat 5 times.

Figs. 1—2. Changes in total-P and acid soluble-P content in embryos and endosperms of germinating wheat, barley and rye grain (data of 2—3 experiments)

Triangles — rye; squares — wheat; circles barley

Upper curves: P content per dry weight; lower curves: P content per grain

Figs. 3—4. Changes in inorganic-P and free phytin-P content in embryos endosperm of germinating wheat, barley and rye grain (explanations as in Fig. 1) (data of 2—3 experiments)

Protein-bound phytin-P increased in the embryos and diminished in the endosperm (Fig. 5). The rise in protein-bound phytin content in the embryos was much slower than that of the other compounds of phosphorus. Protein-bound phytin content when converted to dry weight decreased rapidly in the embryos and slower in the endosperm (Fig. 5). Germinating barley embryos as compared with wheat and rye ones produced less protein-phytin complexes.

In the germination period analysed an 11-12-fold and 2-fold increase of nucleotides-P content occurred in the embryos and endosperms, respectively (Fig. 6). In developing embryos the nucleotides level first increased in relation to their dry weight and then fell, whereas in the endosperm the nucleotides level rose in relation to their decreasing weight. Rye embryos and barley endosperm showed a markedly higher dynamics of nucleotides-P as compared with the parts of other analysed cereal grains.

During the whole period of germination the saccharides-P amount in the embryos of all 3 cereal species increased 10-14 times (Fig. 7). At the same time, in the endosperm phosphorus of these compounds increased only slightly. Changes in the content of phosphorylated saccharides and their metabolites in relation to the weight of the embryos showed a rising tendency only in the early stage of germination (Fig. 7). The quantity of ester combinations of phosphorus with saccharides in the endosperm showed a sustained increase in relation to their weight. Rye embryos and barley endosperm as compared to other embryos and endosperms were characterized by a higher dynamics of phosphorus of saccharide and phosphorus of their derivatives.

Phospholipids content in the period of germination increased rapidly in the embryos and diminished in the endosperm (Fig. 8). The outset level of lipids-P during germination rose in growing embryos 8-9 times and decreased in the endosperm 3-5-fold (Fig. 8). Lipids-P content in relation to dry weight of the examined grain diminished during germination both in the embryos and endosperm (Fig. 8). Phospholipids synthesis in germinating embryos occurred more rapidly in rye and slower in wheat and barley. Phospholipids degradation in rye endosperm was more dynamic than in wheat and barley.

Nucleic acids-P level during germination rapidly increased in the embryos and distinctly fell in the endosperm (Fig. 9). The course of RNA-P (Fig. 10) and DNA-P content (Fig. 11) was similar in both parts of the grain. RNA-P in the embryo increased 8-10-fold and DNA-P 5-7-fold. The RNA and DNA levels of phosphorus in the endosperm fell 3-5-fold. After 6 days of germination the ratio of RNA-P to DNA-P increased in the embryos from 2.0-2.3 to 3.2-3.5. Nucleic acid-P (Fig. 9) as well as DNA-P (Fig. 11) and RNA-P content diminished after 48 h of germination (Fig. 10) in relation to the weight of the growing

Figs. 5—6. Changes in bound phytins-P and nucleotides-P content in embryos and endosperm of germinating wheat, barley and rye grains (explanations as in Fig. 1) (data of 2-3 experiments)

Figs 7—8. Changes in phosphorus of saccharides and their metabolites and lipids-P content in embryos and endosperm of germinating wheat, barley and rye grains (explanations as in Fig. 1) (data of 2-3 experiments)

Figs. 9—10. Changes in nucleic acids-P (jointly) and in RNA-P content in embryos and endosperm of germinating wheat, barley and rye grains (explanations as in Fig. 1) (data of 2—3 experiments)

Figs 11—12. Changes in DNA-P and protein-P content in embryos and endosperm of germinating wheat, barley and rye grains (explanations as in Fig. 1) (data of 2—3 experiments)

embryos. During germination the quantity of RNA-P and DNA-P also diminished in the endosperm when converted to dry weight. From among the studied cereal species the highest dynamics of changes in RNA and DNA were noted in the embryos and endosperm of rye. The other grain species did not differ in the rate of RNA and DNA metabolism.

A 5-fold increase in the amount of phosphoproteids was observed in the embryos of germinating cereal seeds and an only slight increase in the endosperm (Fig. 12). The studied grain species did not exhibit major differences in phosphoprotein concentration during germination.

DISCUSSION

Phosphorus compounds metabolism was very intensive in germinating cereal seeds. During germination the phosphorus level rapidly increases in growing embryos and declined proportionally in the degraded endosperm. The decrease in phosphorus compounds content in the endosperm is due to their breakdown and translocation in mineral or organic form to the developing embryos (Ching, 1972; Grzesiuk, 1967; Mayer, 1973). Similar tendencies of phosphorus metabolism during germination have been noted in various seeds (Ergle and Guin, 1959; Hall and Hodges, 1966; Jakovlev and Ovchinnikova, 1974; Siedenko, 1975).

In germinating seeds, similarly as in ripening ones (Tłuczkiewicz and Berendt, 1976) quantitatively largest was the acid soluble fraction. However, with absolute increase in the amount of acid soluble-P, its contribution to the total-P pool diminished. On the other hand, in the endosperm, in spite of the rapid fall of the acid soluble-P level, its percentual content did not change in relation total-P. These relations prove that the increase in the acid soluble fraction content in the embryos occurs slower than synthesis of other phosphorus compounds, whereas the decrease in the endosperm of all phosphorus compounds runs a similar course.

The dynamics of changes in the components of the acid soluble fraction in the embryos and endosperm showed different directions and intensity. In both parts of germinating grain free phytin was intensively degraded. This degradation during germination has been observed in various seeds (Mayer, 1973; Siedenko, 1975; Sobolev, 1966; Srivastava, 1963; Walker, 1974). It has been demonstrated that phytin-P begins to be released already during inhibition (Wilson and Harris, 1966) and its total degradation occurs after 6-8 days of germination (Ergle and Guin, 1959; Hall and Hodges, 1966). From among the phytin forms present in grain, only the complexes

with proteins were not decomposed in the embryos during germination. Moreover, the rise of the phosphorus content in these complexes is evidence of formation in the embryos of phytin-protein combinations. The site at which phytin combines with proteins is supposedly the scutellum. The proteins bound with phytin can take part in releasing phosphate groups from it (Sobolev, 1966).

Phosphorus from phytin hydrolysis, and in some smaller degree from other phosphorus compounds in the endosperm is the source of inorganic-P in germinating seeds (Ching, 1972; Ergle and Guin, 1959; Sobolev, 1966). Phytin breakdown occurs under the influence of phytase and other phosphatases (Jakovlev and Ovchinnikova, 1974; Siedenko, 1975; Srivastava, 1963; Walker, 1974). Phytase activity in germinating grains is regulated by inorganic phosphate concentration (Sartirana and Blachetti, 1967). Thus, the almost stable inorganic phosphorus level in the endosperm could have been conditioned by the controlled phytin degradation. The increase in inorganic-P concentration in the embryos did not show any strict relation with the level of phosphorus released from phytin, as had been suggested by Hall and Hodges (1966). The increment of inorganic-P in the embryos during germination was many times lower than the amount of phosphorus released from both forms of phytin, free and bound.

The phosphorus content in nucleotides and saccharides esters and their metabolites points to an enhanced production of these compounds in germinating embryos. Numerous authors (Beevers and Guernsey, 1966; Cherry and Hageman, 1961; Ching, 1972; Jakovlev and Ovchinnikova, 1974; Srivastava, 1963) stress the low nucleotide level in dry seeds and an intensification of their synthesis in the initial stages of germination. Synthesis of nucleotides and phosphate esters of saccharides starts in the period of imbibition of the grain (Wilson and Harris, 1966). As germination advances the level of nucleoside di- and triphosphates rises (Cherry and Hageman, 1961; Durzan et al., 1972; Tłuczkiewicz, 1974b) and so does the level of saccharides phosphates (Ching, 1972; Mayer, 1973) and of their phosphates derivatives formed in the process of respiration (Kulka and Mierzwińska, 1971; Tłuczkiewicz, 1974a).

With synthesis continuing in the germinating embryos, a slight rise of the nucleotides level and saccharides phosphates occurred in the endosperm. The nucleotides concentration in the endosperm depends on nucleic acids hydrolysis by nucleases (Ching, 1972; Grzesiuk, 1967). On the other hand, a rise in the saccharides level is connected with starch phosphorolysis (Kulka and Mierzwińska, 1971) and decomposition of other polysaccharides (Mayer, 1973).

The changes in phospholipids metabolism which took place in the

growing and storage organs of germinating cereal seeds have also been reported by other investigators (Ching, 1972; Hall and Hodges, 1966; Jakovlev and Ovchinnikova, 1974; Siedenko, 1975). Analysis of lipids-P content in germinating grains demonstrated that phospholipids production occurs more intensively in the embryos than their degradation in the endosperm. After 6 days of germination the lipid-P level in the embryos exceeded even its level in the whole dry grains. These regularities suggest that other phosphorus substances beside lipid-P, are translocated to the embryos for phospholipid synthesis.

Nucleic acids metabolism in germinating grains was of synthesis character in the embryos and hydrolysis character in the endosperm. Analogous regularities were observed in the seeds of various plant species (Beever and Guernsey, 1966; Ching 1975; Ergle and Guin, 1959; Hall and Hodges, 1966; Siedenko, 1975). An increase in RNA-P content in germinating embryos occurs mainly in the r-RNA fraction (Durzan et al., 1972) and t-RNA (Vold and Sypherd, 1968). The rise of the DNA level in the embryos is proportional to the number of cells (Ching 1972; Kulka and Mierzwińska, 1971). The synthesis of new DNA molecules start at the moment of initiation of growth processes by the embryo (Vold and Sypherd, 1968).

Some authors (Ergle and Guin, 1959; Hall and Hodges, 1966; Kulka and Mierzwińska, 1971) believe that nucleic acids of the storage tissues are the source of nucleotides for synthesis of new RNA and DNA in the growing embryo. In the present investigations a distinct relation in the quantitative exchange between the nucleic acids of the endosperm and embryos could not be established. The DNA-P decrease in the endosperm was more than twice lower than its increase in the embryos. On the other hand, after 6 days of germination RNA-P content in the embryos exceeded 5 times the amount of phosphorus released from RNA in the endosperm. These observations are evidence of close connections between nucleic acids metabolism and the remaining phosphorus compounds in germinating grain.

The rise of protein-P content in embryos has also been noted in cotton seeds (Ergle and Guin, 1959) and in oats (Hall and Hodges, 1966).

The results of the present study indicate that during germination there occurs in endosperm a continuous breakdown of storage and structural phosphorus substances and their translocation in simpler form to the growing embryos. These compounds are utilized there for synthesis of new phosphorus compounds of the embryonal cells. In the early stages of germination endosperm phytin is the main source of phosphorus for the growing embryo.

REFERENCES

- Beevers L., Guernsey F. S., 1966. Changes in some nitrogenous components during the germination of pea seeds. *Plant Physiol.* 41: 1455—1458.
- Cherry J. H., Hageman R. H., 1961. Nucleotide, ribonucleic acid metabolism of corn seedlings. *Plant Physiol.* 36: 163—168.
- Ching T. M., 1972. Metabolism of seeds germination. [In:] *Seed Biology* Ed. Kozłowski T. T., Acad. Press New York, London, v. II: 103—219.
- Ching T. M., 1973. Biochemical aspects of seed vigour. *Seed Sci. Technol.* 1: 73—88.
- Durzan D. J., Pitel J., Ramaiah P. K., 1972. Acid soluble nucleotides and ribonucleic acids from germinating jack pine seeds. *Can. J. Forest Res.* 2: 206—216.
- Ergle D. R., Guin G., 1959. Phosphorus compounds of cotton embryos and their changes during germination. *Plant Physiol.* 36: 476—481.
- Grzesiuk S., 1967. *Fizjologia nasion*. PWRiL, Warszawa.
- Hall J. R., Hodges T. K., 1966. Phosphorus metabolism of germinating oat seeds. *Plant Physiol.* 41: 1459—1464.
- Jakovlev A. P., Ovchinnikova M. F., 1974. Izucheniye fosfornogo obmena w prorstaiukhchykh siemienakh gibridnoi i inbrednoi kukuruzy. *Fizjolog. Rast.* 21: 87—92.
- Kulka K., Mierzwińska T., 1971. Przemiany biochemiczne podczas pęcznienia i kiełkowania nasion. *Zesz. Probl. Post. Nauk Rol.* 113: 111—132.
- Mayer A. M., 1973. The control of the initial stages of germination: some biochemical investigations. *Seed Sci. Technol.* 1: 51—72.
- Sartirana M. L., Blanchetti R., 1967. The effect of phosphate on the development of phytase in the wheat embryo. *Physiol. Plant.* 20: 1066—1075.
- Siedenko D. M., 1975. Fosfornyye soedineniya i fitaznaya aktivnost u siemyan kukuruzy khronivchysya s raznoy iskhodnoy vlaznostyu. *Fizjolog. Rast.* 22: 236—240.
- Sobolev A. M., 1966. O sostoyaniy fityna w aleironovykh ziernakh zrelykh i prorstaiukhchykh siemyan. *Fizjolog. Rast.* 13: 193—200.
- Srivastava B. J. H., 1963. Effect of gibberellic acid on phosphorus metabolism of germinating barley seeds. *Plant. Physiol.* 38 Suppl. 43.
- Tłuczkiewicz J., 1974a. Influence of Simazin 50 and Dicuran on oxidative phosphorylation in the mitochondria of spring barley (Damazy) embryos. *Acta Agrobot.* 27: 61—69.
- Tłuczkiewicz J., 1974b. Effect of some herbicides on metabolism of free nucleotides in germinating seeds of brewing barley. *Bull. Acad. Pol. Sci. ser. biol.* 22: 421—424.
- Tłuczkiewicz J., Berendt W., 1977. Dynamics of phosphorus compounds in ripening and germinating cereal grains. P. I. Changes in phosphorus compounds content during ripening of wheat, barley and rye grains. *Acta Soc. Bot. Pol.* 46 (1): 3—14.
- Vold B. S., Sypherd P. S., 1968. Changes in soluble RNA and ribonuclease activity during germination of wheat. *Plant. Physiol.* 43: 1221—1226.

Walker K. A., 1974. Changes in phytic acid and phytase during early development of *Phaseolus vulgaris*. *Planta*, 116: 91—98.

Wilson A. M., Harris G. A., 1966. Hexose-inositol- and nucleosides phosphate esters in germinating seeds of crested wheatgrass. *Plant. Physiol.* 41: 1416—1419.

Author's address:

J. Tłuczkiewicz and W. Berendt
Institute of Plant Biology
Agricultural-Technical Academy
10-957 Olsztyn-Kortowo, Poland

Dynamika związków fosforowych w dojrzewających i kielkujących ziarnach zbóż

Cz. II. Zmiany zawartości związków fosforowych podczas kielkowania ziarna pszenicy, jęczmienia i żyta

Streszczenie

W pracy badano dynamikę związków fosforowych w zarodkach i bielmach kielkujących 2, 4 i 6 dni ziarnach pszenicy (Grana), jęczmienia (Kosmos) i żyta (Pancerne). Po 6 dobach kielkowania zawartość fosforu ogólnego zwiększyła się 5—6 razy w zarodkach i zmniejszyła się 3—4 razy w bielmach. Z całości fosforu ziarna występowało w zarodkach żyta 81%, jęczmienia 71% i pszenicy 65%. Zawartość fosforu kwasorozpuszczalnego w podobnym stopniu (3—5 razy) wzrastała w zarodkach i obniżała się w bielmach. W analizowanym okresie następował znaczny rozpad fityny wolnej w bielmach i prawie całkowita jej degradacja w zarodkach. Hydrolizie fityny wolnej towarzyszyła synteza w zarodkach i rozpad w bielmach kompleksów fityny z białkami. Fosfor nieorganiczny uwalniany z fityny i innych organicznych połączeń w bielmach przemieszczał się szybko do zarodków. W zarodkach zachodziła wzmożona synteza nukleotydów oraz estrów fosforanowych cukrowców i ich metabolitów. W bielmach poziom tych związków miał niewielkie tendencje zwyżkowe. Podczas kielkowania w zarodkach szybko wytwarzane były fosfolipidy i znacznie wolniej fosfoproteidy. W bielmach następował rozpad fosfolipidów, lecz poziom fosfoproteidów nieznacznie wzrastał. Przez cały okres kielkowania przebiegała w zarodkach intensywna synteza RNA i DNA. Przy czym bardziej dynamicznie wzrastał poziom RNA. W bielmach hydroliza RNA zachodziła z podobnym nasileniem jak DNA. Wyższą dynamiką syntezy w zarodkach i rozpadu w bielmach związków fosforowych podczas kielkowania charakteryzowało się ziarno żyta w porównaniu z ziarnami pszenicy i jęczmienia.