PHYSIOLOGICAL AND MORPHOLOGICAL STUDIES ON POTATO PLANTS

Part 9. Studies on nitrogen metabolism in potato tubers during the storage period

By

TAKASHI TAGAWA and YOZO OKAZAWA

Introduction

The present investigation is one of a series of experiments carried out under the title of physiological and morphological studies on potato plants. In a previous paper[7], the authors have reported some information on the variation of the nitrogen compounds in the mother tubers at the sprouting stage and on the translocation and the accumulation of nitrogen fractions in the young tubers during an entire growing season of the potato plants.

Although the potato is one of the most valuable of all the vegetable crops in Hokkaido and large quantities of potatoes are held in storage every year, little attention has been paid to the physiological behaviour and the chemical constituents of the tubers during the storage period. According to APPLEMAN[1], it has been shown that the contents of nitrogen compounds in the potato tubers during the dormant period did not vary significantly, and that their contents in the basal parts of the tuber were much greater than in any other parts of the tubers. The data at hand, however, do not answer the question as to the distribution and the translocation of the nitrogen fractions in the potato tubers during their storage period.

In the present investigation, in extending the work on nitrogen metabolism of potato plants, particular attention was paid to the variation and distribution of the nitrogen compounds in the tubers during the storage period and to the rôle of the nitrogen compounds from the physiological and nutritional points of view.

The expenses incurred in the present study were met in part

by a grant from the Scientific Research Fund of the Department of Education. The writers express their gratitude to the Department of Education.

Materials and Methods

A variety of potato "Irish Cobbler" obtained from the Central Foundation Seed Potato Farm, Hiroshima in Hokkaido was used throughout the present experiment as materials. The experimental materials were stored in a wooden box of about 50×30×30 cm volume at room temperature in our laboratory. Samplings were made at intervals of about 10 days ranging from mid-October, 1949 to late February, 1950. The nitrogen fractions determined were total, protein, soluble, ammonia, nitrate, amide, and amino nitrogen, and at the same time the starch content was also determined. Their amounts were expressed in mg per 1 gram fresh weight. The analytical methods are similar to those used in the previous work[7], so full descriptions are omitted here.

Results and Discussion

Judging from the results obtained in the present investigation, the storage period of the potato tubers may be divided into three stages, namely, rest, rest-end, and sprouting stage, and accordingly, for convenience of explanation, the feature of nitrogen metabolism in the tubers at each stage may be stated separately.

(1) The nitrogen metabolism of the potato tubers during the rest stage:

As to the variation of the nitrogen fractions in the tubers during the rest stage, as has already been reported by APPLEMAN[1], no remarkable changes were recognized. The duration of this stage may be assumed to range from early October to the middle of December, and during about these two months, as shown in figure 1 (a–e), the physiological activities in the tubers were the lowest in contrast to the activity during the other two stages. In a previous paper[5], the authors have ascertained the fact that the contents of the reserved carbohydrates, the respiration rate and the water contents of the tubers showed no striking variations during the rest period. In the present investigation (fig. 1, A–F), on the other hand, it was also ascertained that the nitrogen frac-

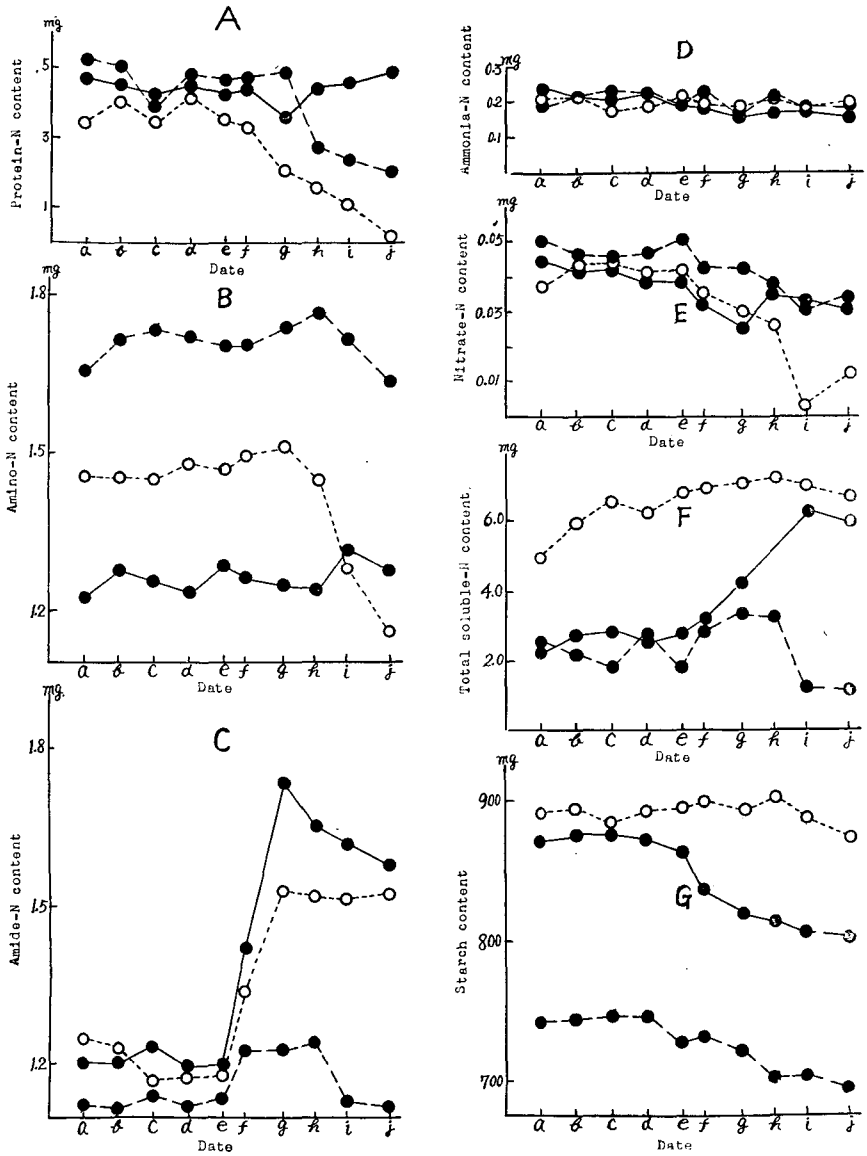

Fig. 1. The variations of various forms of nitrogen contents and starch in the potato tubers during the storage period.

●——● Terminal bud. a. Oct. 15, 1949. f. Dec. 27, 1949.
●----● Pith. b. Nov. 1st, " g. Jan. 13, 1950.
○·····○ Cortex. c. Nov. 15, " h. Jan. 25, "
d. Dec. 1st, " i. Feb. 10, "
e. Dec. 15, " j. Feb. 29, "

tions in the tubers, viz., protein-N and soluble-N, especially in the forms of amino-N, amide-N, ammonia-N and nitrate-N showed no remarkable variations. As to the protein-N, as similarly as shown by APPLEMAN[1], DENNY[2], and PAPLAWSKI[3], a slightly higher content of protein-N was ascertained in the vicinity of terminal bud than in any other parts of the tubers (fig. 1, A) while, an abundant accumulation of soluble-N (fig. 1, F), especially in the from of amino-N (fig. 1, B), was recognized in the pith of tubers.

Judging from these just-stated results and from those reported in the previous paper[7], it seems quite reasonable to assume that the amino acid translocated from the tops to the pith of the tubers according to the tuber maturity may be stored mainly in the pith of the tuber during the rest stage, which in turn substantiates the fact reported by SCHULZE[4], whose opinion was that the amino-N may be the main storage nitrogen compound of the potato tubers. The contents of amide-, ammonia- and nitrate-N showed little variations during rest stage. In detail, however, the content of nitrate-N in the vicinity of the terminal bud and that of amide-N in the cortex were a little richer than the others during the rest stage. In contrast to the variations of various nitrogen contents, the starch content as the main reserve carbohydrate of the potato tubers, as might be expected, showed almost constant value, but, in detail, a little higher content was recognized in the cortex region of the tuber (fig. 1, G). When bearing in mind the facts reported in a previous paper[5] that the amylase activity in the tubers is very low during the rest stage, it seems very reasonable that one should see such little variation of starch content in the tuber during the same stage.

(2) The nitrogen metabolism of the potato tubers during the rest-end stage:

The duration of this stage may be assumed to range from middle December to the late of January. Characteristic of this stage, the renewal of the physiological activities of the tubers may be pointed out with the termination of the rest stage. Accordingly this stage may be assumed as the preparatory stage for sprouting. In a previous paper[5], the writers have reported the fact that the content of reducing-sugar in the tuber increased steeply at the later part of the dormant condition, which may be assumed as the indicator of the termination of the rest stage.

With respect to the variation of the various forms of nitrogen in the tuber during the rest-end stage, a significant increase of amide-N content was recognized (fig. 1, C–e–f–g), in striking contrast to a falling off of the amount of protein-N in the tubers (fig. 1, A–e–f–g). It would appear that, in this way, an insoluble form of nitrogen may be transformed into a soluble and mobile form of nitrogen and then may be utilized as material for the formation of new sprout.

As for the variation of protein-N content in the tubers, the decrease of it was recognized at first in the pith and then in the cortex. On the contrary, the increase of protein-N content was ascertained in the vicinity of the terminal bud of the tuber. In this respect, the view expressed by DENNY[2] and PAPLAWSKI[3] was that the physiological activities of the tuber piece of potato with a bud on it, are greater than that of the tuber piece without a bud. The evidence at hand makes it seem highly probable that the temporary accumulation of nitrogen fraction in the vicinity of bud at this stage may be due to the translocation of the nitrogen from the other parts of the tuber to the terminal bud where it may be utilized as a material for the formation of new sprout. With regard to the variation of the total soluble-N in connection with the fact described above, the contents of soluble-N in both the vicinity of terminal bud and in the pith during the rest stage were less than that in the cortex, while attainment to the subsequent rest-end stage, the soluble-N contents, especially in the terminal bud, increased significantly and the nitrogen content in the terminal bud at the time just prior to the sprouting was almost as much as that in the cortex (fig. 1, F–f–g–h).

Such increase of the soluble-N content in the vicinity of the terminal bud keeping pace with that of the protein-N, seems to offer the most reasonable explanation for the translocation of various forms of nitrogen compounds from the different parts of the tuber to the terminal bud, due to the apical dominance after the termination of the rest stage. The results of the present investigaton indicate that such remarkable increases of the soluble-N contents in the terminal bud and in the cortex may be attributed to the significant accumulation of amide-N in these tissues (fig. 1, C–f–g). On the other hand, the content of amino-N which may be assumed as a main storage nitrogen compound of the potato tuber,

showed remarkable decline, especially in the cortex (fig. 1, B–g–h) and similarly the content of nitrate-N decreased equally throughout all the tissues of the tuber at this stage (fig. 1, E–f–g–h).

Taking into account the results described above, the period lasting for about 30 days after late December (f, g, h, in fig. 1), following close on the rest stage, may probably be assumed as a preparatory stage for sprouting. During this stage a translocation and a temporary accumulation of various forms of nitrogen in the vicinity of terminal bud were recognized. A part of the nitrogen fractions accumulated in the vicinity of the terminal bud is synthesized to the protein and stored there temporarily. At the same-time a significant increase of amide-N content is found in the same region which may be utilized afterward as the nitrogen source by the formation of new sprout. On the other hand, decreases of nitrate- and ammonia-N contents in the tuber may be pointed out as the characteristic physiological feature at this stage.

In a previous paper[4], we have reported the facts that the reducing and non-reducing sugar contents increased rapidly at this stage throughout all parts of the tuber. The experimental results of the present investigation which was conducted in contrast to the previous one indicate a gradual decline of the starch content in the tuber at the same stage (fig. 1, G–f–g–h). Accordingly, the assumption seems probable that the sugars derived from the starch decomposition in the tuber at this stage may be utilized for the synthesis of nitrogen compounds in the sprout.

(3) The nitrogen metabolism of potato tubers during the sprouting stage:

The duration of this stage is a period ranging from late January to the beginning of March; upon ageing in storage, the eyes on the tubers were noticed to have begun swelling.

With respect to the distribution of nitrogen fractions in the tuber at this stage, the protein-N content increased merely in the vicinity of the terminal bud similarly as in the preceding stage, while in the other parts of the tuber it likewise decreased (fig. 1, A–h–i–j).

As to the soluble-N contents a general increase of them was observed in the vicinity of terminal bud (fig. 1, F–h–i). Continuing decreases of amino-N contents in the pith and in the cortex of the tuber were also ascertained during this sprouting stage as in the

preceding stage, and especially their falling off in the cortex was very pronounced (fig. 1, B–h–i–j).

The amide-N content in the cortex which showed significant increase in the preceding stage, remained the same during this stage as during the preceding stage, while, the content in the terminal bud and in the pith decreased during this stage (fig. 1, C–h–i–j).

As to the ammonia-N content in the tuber there is no significant difference between the amounts observed during the preceding and present stages (fig. 1, D). With regard to the nitrate-N content a gradual decrease was recognized according to the ageing of the tuber (fig. 1, E–h–i–j). Upon ageing of the tuber during this stage, the gradual decline of the starch content, especially in the terminal bud, became significant, while contrariwise the contents of reducing and non-reducing sugars became richer. At the same time a rapid falling off in the water content, especially in the cortex, was recognized during this stage, resulting in a pronounced shrinkage of the tuber in appearance.

In short, as a physiological characteristic at this stage an awakening of bud sprouting may be pointed out. In the vicinity of the terminal bud, the accumulations of soluble- and insoluble-N were pronounced during this stage. And also from the temporary accumulation of amide-N in the terminal bud, the assumption seems very probable that various forms of nitrogen were translocated into the vicinity of terminal bud during this stage and there accumulated to be utilized for the actual growth of the new sprout. The evidence that amino acid declined rapidly concomitant with the growth of new bud makes it highly probable that the insoluble-N may be converted at first to the mobile form of soluble-N, and then it may be utilized for the formation of new bud. Similarly, amide-N which had been accumulated temporarily in the terminal bud may also be converted into a more simple form of nitrogen before being utilized for the bud growth, which topic was discussed in detail in a previous paper[7]. At the same time the protein-N contents in the cortex and in the pith of the tuber decreased markedly, and then concomitant with this change, the accumulation of soluble-N resulted. Data obtained in the present investigation with regard to the nitrogen metabolism in the potato tubers indicate that the various nitrogen compounds may be converted into

more simple and more mobile forms of nitrogen at the termination of the rest stage and then translocated to the terminal bud to be utilized for the new growth of the bud.

Summary

In the present investigation, particular attention was given to the distribution of the various nitrogen fractions in potato tubers during the storage period using the variety "Irish Cobbler" as material. The nitrogen fractions determined were the protein, total, soluble, amino, amide, ammonia and nitrate nitrogen. At the same time the starch and moisture contents were also determined.

Judging from the results obtained, the storage period of the potato tubers may be divided into three stages, namely, rest, rest-end and sprouting stage and the feature of nitrogen metabolism in the potato tubers at each stage may be summarized as follows:

1. During the rest stage the facts that the moisture, various forms of nitrogen fraction and carbohydrate contents showed no marked variation respectively, may be pointed out as the characteristic feature of this stage. The terminal bud and the cortex are rich in protein-N, but poor in soluble-N, while the pith is poor in protein-N but rich in soluble-N, mainly in the form of amino-N.

2. With the termination of rest stage a marked increase of soluble-N content, especially in the form of amide-N, in the terminal bud and in the cortex was recognized, showing a striking contrast to the decrease of protein-N content in the pith.

Accordingly the rest-end stage may be characterized by the transferrence of storage insoluble-N into mobile, soluble-N and its translocation to the terminal bud to be utilized for renewal of sprout growth.

3. During the sprouting stage increases of protein- and soluble-N, especially in the form of amide-N, were ascertained in the vicinity of the terminal bud, contrary to the decrease of protein-N in the other parts of the tuber. At the later part of this stage moisture content in the tuber, especially in the cortex, begins to show signs of decrease, which causes the commencement of the tuber shrinkage.

Botanical Institute, Faculty of Agriculture,
Hokkaido University,
Sapporo, Japan

Literature Cited

1) APPLEMAN, C. O., Bot. Gaz., 61 (1916), 265-294.
2) DENNY, F. E., Amer. Jour. Bot., 16 (1929), 326-337.
3) PAPLAWSKI, S., Biol. Abst., 6 (1932), 24599.
4) SCHULZE and BARBIERI., Landw. Versuchsstat, 24 (1884), 167.
5) TAGAWA, T., Y. OKAZAWA and R. SAKAI., Agr. Sci. North Region, 2 (1948), 39-55, (In Japanese).
6) TAGAWA, T. and Y. OKAZAWA., Bull. Hokkaido Seed Potato Grower's Association, No.. 5 (1949), 1-13, (In Japanese).
7) ————, ————, Trans. Sapporo Nat. Hist. Soc., 19 (1950), 16-23, (In Japanese).