CHANGES IN COMPOSITION OF POTATOES IN STORAGE[1] 2247

W. L. PORTER[2] AND P. H. HEINZE[3]

Harvested potatoes are living tissues and are responsive to the environmental conditions to which they are subjected. Metabolic activity in the tubers continues during storage and with this activity, changes in composition occur. Some of these changes may be advantageous, others may be detrimental. A judicious selection of conditions for storage could well lead to a raw material much better adapted to a particular product than the usual product available. However, to select such conditions, we must know more about the composition of potatoes and, in addition, more about the changes which occur during the dormant storage under a variety of conditions.

Considerable work has been reported over the years on the composition of potatoes. However, much of this work was limited in its value due to lack of analytical methods of sufficient specificity and accuracy to study individual compounds in detail. Much of the data is on broad groups of compounds such as reducing sugars; amino nitrogen, soluble nitrogen, protein nitrogen by difference, total acidity, etc. Data on composition directly related to storage was limited in the older literature. However, during the past ten years, availability of new and refined procedures and equipment has made it possible to investigate the relationship of storage and composition on a more detailed basis.

In this review only specific examples from many references are chosen to serve as sources of information for those who may be interested in further details of the subjects covered.

CARBOHYDRATES

Years ago it was noted that potatoes became sweet in taste after being subjected to storage at temperatures slightly above the freezing points of the tissues. Muller-Thurgau in 1882 (25) was one of the first to consider the quantitative accumulation of sugars in potatoes stored at low temperatures and study some of the relationships between sugar content and respiration. Since then, and especially with the advent of the potato processing industry in recent years, the starch-sugar transformation has become a major concern. Many publications are available on the effects of various factors, particularly storage temperature and variety, upon the sugar content. A number of these reports were reviewed by Kroner and Volksen (19), Burton (4), and Talburt and Smith (43).

In 1936, Wright (46) reported on some changes in carbohydrate content of four varieties at storage temperatures ranging from 32 to 60 F. One of the most significant findings was the close similarity of the sugar, starch, and soluble and insoluble solids content of potatoes after storage at temperatures of 50 and 60 F with the content of these constituents in the same lots of potatoes when first put into storage. Those stored at lower temperatures showed a marked increase in sugar content in all varieties as the storage temperature was

---

[1]Prepared as a report of the Potato Storage and Transportation Committee of the Potato Association of America, 1964, P. H. Heinze, Chairman, W. C. Sparks, W. Redit, and J. Hunter.

[2]Chemist, Eastern Utilization Research and Development Division, Agricultural Research Service, U. S. Department of Agriculture, Philadelphia, Pa. 19118.

[3]Plant Physiologist, Market Quality Research Division, Agricultural Research Service, U. S. Department of Agriculture, Beltsville, Md. 20705.

lowered. Other work by Burton (4), Scheffer and Rotzold (35) and Schwimmer, et al. (37) has shown that at lower temperatures sucrose predominated in the early storage period and approached 70% of the total sugar after the first 14 days but dropped to about 30% of the total after 28 days of storage. As the storage temperature is changed from lower to higher levels, sucrose may represent only 10% of the total sugars present. These results were obtained with fairly mature potatoes harvested late in the season.

With less mature potatoes, harvested in the summer months, fructose is found to predominate after storage for six weeks at 32 F, as shown by Samotus and Schwimmer (33), although the freshly harvested, immature potatoes contain mainly sucrose, Samotus and Schwimmer (33) and Clegg and Chapman (5). Potatoes harvested in the summer months, according to Wright and Whiteman (47), lose starch and accumulate sugars at much higher storage temperatures than those harvested in the fall.

Sucrose, fructose and glucose comprise the major sugars in the potato and vary in concentration within the tuber with different storage conditions. A number of other sugars have been isolated in trace amounts, Talburt and Smith (43), but little or no data on the quantitative changes in storage are available.

Hyde and Morrison (17) recently suggested that the greater phosphorylase activity in potatoes stored at lower temperatures may be due to the lower pH value of the juice from these potatoes. The increased phosphorylase activity may influence the sugar accumulation.

Potatoes that have been stored at low temperatures are frequently held at higher temperatures for short periods of time before processing to decrease the sugar concentrations and improve the quality of the processed product (17, 43).

The pectic substances have been investigated but, according to Potter and McComb (30) and Talburt and Smith (43), most of the evidence indicates little relationship between the quantity of various fractions and variations in quality. However, Sharma et al. (39) found that "hard" cooking potatoes contained more insoluble pectins than those cooking "soft" and that storage reduced the amount of insoluble pectins.

NITROGENOUS COMPOUNDS

The relationship of the nitrogenous constituents of potatoes to storage is intricately involved with the total solids of the samples and must be studied with this in mind. Heinze (14) in a 1961 review reported that, generally, those potatoes with higher nitrogen content are of lower quality for baking, mashing, boiling, etc. Fitzpatrick et al. (11) and Heinze et al. (16) showed that, on a dry basis, potatoes of low specific gravity tend to have a high nitrogen content. Low specific gravity potatoes also produce low quality baking potatoes. However, they have also shown that on a fresh basis, for any one sample, the potato tends to lay down the same amount of nitrogen regardless of the specific gravity of the potato. This is assumed to be caused by the high specific gravity potatoes containing a higher content of non-nitrogen containing materials such as starch. Thus the relationship of high nitrogen to cooking quality may really be a relationship to low specific gravity.

Total nitrogen and soluble nitrogen vary little with storage time, Talley et al. (42). However, insoluble nitrogen tends to decrease during the first few months of storage with a partial recovery as storage is continued. This confirms work by Stuart and Appleman (40) reported in 1935 and is consistent with the data of Levitt (21), who showed a steady decrease in protein content of tubers stored at 79F but at 37 this initial decrease was followed by a return to the original level in a relatively short time.

Emilsson (10) studying the whole tuber found no significant changes in nitrogen. However, Cotrufo and Levitt (6), studying only parenchyma tissue, showed that nitrogen changes do occur during the rest period.

Sirenko (39) reported in 1957 on four varieties stored cold for eight months, and showed a loss in proteins at the end of the period and indicated that most of the loss could be accounted for by an increase in non-protein nitrogen. It is not clear from abstracts whether protein was determined as such or as measured by total nitrogen. Sirenko also indicated that with these compounds, changes in storage conditions (light, moisture, temperature, aeration), affect early ripening potatoes much more than the late-ripening ones. This is explained by the higher activities of the proteolytic enzymes in the tubers of the former. At lower temperatures less non-protein nitrogen and more protein were found at the end of the storage period.

Talley, Fitzpatrick and Porter (41) found that, in general, an inverse relationship exists between total solids and the individual free amino acids, when calculated on a moisture-free basis. Little difference was found on a fresh weight basis. The proline content appeared to increase during storage but changes in the other amino acids were quite indefinite. The greatest changes in the proline and to a lesser extent in other amino acids occurred when the tubers sprouted. In fact, the proline content of the sprouts was tremendously increased with respect to the content of other amino acids. Bailova-Yankulova (1) reported the content of free amino acids, except asparagine, was less in the spring than in the fall. Heilinger and Breyhan (13) showed qualitative and quantitative differences in the amounts of free amino acids in the course of storage and showed that changes in the proline content were notable. In the latter two investigations samples were taken at the beginning and the end of storage which covered only dormant and vegetatively active tubers. As shown by Fitzpatrick et al. (11) these changes only occurred after a long period of storage and after sprouting had begun. Therefore, loss or gain of amino compounds was probably not due to storage but can be attributed to the induction of vegetative activity.

ORGANIC ACID CONSTITUENTS

Again relatively few studies have been reported on the relationship of organic acid content to storage. This may be due to the fact that up to the last three or four years it was difficult to analyze for individual acids.

Thunberg (44) reported on the citric acid content of several varieties of potatoes over a storage period up to six months. Minina (22) investigated the concentrations of both citric and malic acids during seven months' storage. He concluded that there was an initial decrease in citric acid content followed by an increase, a decrease in malic acid toward the end of the storage period, and a preponderance of citric over malic acid at all stages. Schwartz, Greenspun and Porter (36) showed an increase in citric acid between the second and eighth months of storage and this increase is equal to the initial decrease, and to the decrease in malic acid occurring at the same time. This shows a possible conversion of malic to citric acid: such conversions have been reported by Krotkev and Barker (20) and Pucher et al. (31). Schwartz et al. (36) also showed that the final two months of storage at higher temperatures produced no significant changes but upon sprouting the tubers exhibited a strikingly different pattern of acid concentrations.

POLYPHENOLIC COMPOUNDS

Craft, Siegelman and Butler (8) showed that in Russet Rural and Kennebec potatoes the total phenolic content did not change significantly during five months' storage at 55 and 40 F. or three months at 32. Both varieties showed evidence of low temperature injury after four months at 32 F and the total phenolic and o-dihydroxyphenolic content showed small but significant increases which were attributed to the injury rather than to the storage temperature.

Mondy, Klein and Smith (23) reported that cytochrome oxidase and the concentrations of phenolic substances increased in tubers from harvest time up to three months of storage at 40 F. Polyphenol oxidase activity decreased markedly during the first two weeks of storage and then remained relatively low thereafter. Discoloration of potatoes increased with storage duration and was accompanied by an increase in phenolic content and cytochrome oxidase. Polyphenol oxidase appeared to be inversely related to potato discoloration.

VITAMINS

Many of the vitamins necessary for balanced nutrition are found in potatoes. Potatoes are a long recognized source of vitamin C (ascorbic acid) and in some instances supply a critically needed level of this vitamin in the diet. Many factors affect the variation of vitamin C content (32, 43). It is generally recognized that losses of vitamin C occur during storage and that the losses increase as lower storage temperatures are used. Minimum losses appear to occur in potatoes stored at 50 to 60 F. A number of investigators have found that the greatest losses occur during the early portion of the storage period. In a few instances the decrease in vitamin C content has been rather steady from harvest to spring, Werner and Leverton (45). Barker and Mapson (2), working with immature potatoes found that after a period of storage, transfer of the potatoes to either a higher or lower temperature resulted in an increase in vitamin C content. However, the increases at the lower temperature are temporary and are followed by decreases which ultimately result in lower values than those preceding transfer.

Page and Hanning (28) found that niacin remained approximately constant in Wisconsin Irish Cobbler and Bliss Triumph potatoes stored at 40 F for six months. However, vitamin B_6 increased about 2½ fold during the same period.

LIPID COMPOUNDS

Although some work has been reported on the lipid components of potatoes, only a few reports have applied to the effect of storage. Mondy, Mattick and Owens (24) reported that the amount of total lipid did not change significantly during storage. Potato varieties appear to differ not only in their initial lipid content but also in changes in their fatty acid content during storage. Pontiac showed a marked decrease in linoleic acid and an increase in palmitic acid, whereas Ontario showed a decrease in both linoleic and palmitic acids. Fatty acids containing more than eighteen carbon atoms were present in both varieties in significant quantities and these increased in quantity during storage.

Cotrufo and Lunsetter (7) reported a significant increase in fatty acids during storage, especially from November to January, and noted that at this time the break in the rest period of the potato tubers often occurs. Since the interactions were not significant, it could not be determined if a particular variety or fatty acid was involved. They suggested that the approach of Levitt (21) and Cotrufo and Levitt (6) be employed to study possible changes in fatty acids due to a break in the rest period. This approach of studying only the parenchyma tissue of the tubers stored at 37 and 79 F showed that nitrogen changes do occur during changes in the rest period. This was in contrast to the work of Emilsson (10) who examined the entire tissue and found no significant changes in nitrogen.

Due to the important influence of lipids on the keeping quality of some processed products, made from stored potatoes, it is essential that more information be obtained on the changes in lipid constituents during storage. These data may aid in explaining some of the quality problems encountered in processed products.

SPECIFIC GRAVITY

Specific gravity is influenced by many factors such an environment, culture, variety, etc. The influence of storage, however, is subject to much conjecture. Heinze and Craft (15) showed that the specific gravity tends to increase with storage time if the relative humidity was less than about 85%. Varietal differences were also shown. Murphy and Goven (26) reported on several years work at the Maine Station which indicated that shrinkage due to respiration at storage temperatures of 40 to 45 F. is small compared with the shrinkage due to loss of water during the entire storage period. They assumed from their data that any changes in specific gravity were due primarily to moisture loss at varying temperatures and periods of storage. In general, it was concluded that specific gravity increased as a result of transpiration losses which increased as length and temperature of storage increased. In addition, they showed that increased relative humidity prevented some of the specific gravity increases. Talley, Fitzpatrick, Porter, and Murphy (42) reported that, with Katahdin potatoes, there was little or no increase in specific gravity at 38 F and relatively high humidity. Any shrinkage was due to loss of water and solids in the ratio of their content in the freshly harvested material.

Studies on specific gravity, however, should be accompanied by total solids data due to the inherent inconsistencies of the relationship of solids to specific gravity. Porter, Fitzpatrick, and Talley (29) have shown by examining the data of Glynne and Jackson (12), Von Scheele et al. (34), and Behrand et al. (3), that, although a high correlation value is obtainable between specific gravity and dry matter content, the range of their individual determinations was as high as ± 2.0% of the values calculated with the regression equation. Using the results of thirty samples of five varieties grown in six different areas of the United States in 1962 and 1963, they demonstrated a confidence limit of ± 1.5% on total solids calculated from the specific gravity values and that the regression curve for American potatoes does not necessarily coincide with Von Scheele's curve although the latter is within the confidence limits with these samples.

Davis (9), Nissen (27), Iritani et al. (18), Porter et al. (29) and others have pointed out the possible influence of tissue air space on the specific gravity of individual samples. Porter et al (29) were able to calculate that a variability of ± 1.5% total solids would require a variation of approximately ± 0.008 specific gravity units. Such variations could well be produced by individual variations of samples as well as by storage changes.

LITERATURE CITED

1. Bailova-Yankulova, M. 1961. The free amino acids in the tubers of potatoes of the varieties Early Rose and Aquila infected by virus. Comp. Rend. Acad. Bulgare Sci. 14: 515-518.
2. Barker, J. and L. W. Mapson. 1950. The ascorbic acid content of potato tubers. II. The influence of the temperature of storage. New Phytologist 49: 283-303.
3. Behrend, P., M. Maercker and A. Morgen. 1880. Uber den zusammenhang des spezifischen Gewichts mit dem Starkemehl-und Trockensubstanzegehalt der Kar-

toffeln, sowie uber die Methode der Starkebestimmung in den Kartoffeln. Landw. Vers. Sta. 25: 107-165.

4. Burton, W. G. 1948. The potato. Chapman and Hall, London.

5. Clegg, M. D. and H. W. Chapman. 1962. Sucrose content of tubers and discoloration of chips from Early Summer potatoes. Am. Potato J. 39: 212-216.

6. Cotrufo, C. and J. Levitt. 1958. Cytoplasmic particulates and proteins of potato tubers. VI. Nitrogen changes associated with emergence of potato tubers from the rest period. Physiol. Plant. 11: 240-248.

7. Cotrufo, C. and P. Lunsetter. 1964. The fatty acids of potato tubers (*Solanum tuberosum*). Am. Potato J. 41: 18-22.

8. Craft, C. C., H. W. Siegelman, and W. L. Butler. 1958. Study of the phenolic compounds in potato tubers during storage. Am. Potato J. 35: 651-661.

9. Davis, R. M., Jr. 1962. Tissue air space in the potato; Its estimation and relation to dry matter and specific gravity. Am. Potato J. 39: 298-305.

10. Emilsson, B. 1949. The rest period and dormant period in the potato tuber. Acta Agric. Suecana 3, No. 3: 189-282.

11. Fitzpatrick, T. J., E. A. Talley, W. L. Porter and H. J. Murphy. 1964. Chemical composition of potatoes. III. Relationships between specific gravity and the nitrogenous constituents. Am. Potato J. 41: 75-81.

12. Glynne, M. D. and V. G. Jackson. 1919. The distribution of dry matter and nitrogen in the potato tuber. Variety, King Edward. J. Agr. Sci. 9: 237-258.

13. Heilinger, F. and T. Breyhan. 1959. Amino acids in potatoes. Landbauforsch. Volkenrode 9: 17-18.

14. Heinze, P. H. 1961. Effect of storage on potato quality. Potato Handbook VI: 32-36.

15. Heinze, P. H., C. C. Craft, B. M. Mountjoy and M. E. Kirkpatrick. 1952. Variations in specific gravity of potatoes. Am. Potato J. 29: 31-37.

16. Heinze, P. H., M. E. Kirkpatrick and E. F. Dochterman. 1955. Cooking quality and compositional factors of potatoes of different varieties from several commercial locations. U. S. Dept. Agr., Technical Bull. No. 1106.

17. Hyde, R. B. and J. W. Morrison. 1964. The effect of storage temperature on reducing sugars, pH, and phosphorylase enzyme activity in potato tubers. Am. Potato J. 41: 163-168.

18. Iritani, W. M., W. C. Sparks and W. M. Weinheimer. 1964. Factors affecting the accuracy of specific gravity determinations. Presented 48th Annual Meeting of the Potato Association of America, Idaho Falls, Ida. July 15-17.

19. Kroner, W. and W. Volksen. 1950. Die Kartoffel, Second Ed. Johann Ambrosius Barth, Leipzig.

20. Krotkov, G. and H. A. Barker. 1948. Utilization of acetate by tobacco leaves, as determined with C^{14}. Am. J. Botany 35: 12-15.

21. Levitt, J. 1952. Two methods of fractionating potato-tuber proteins and some preliminary results with dormant and active tubers. Physiol. Plant. 5: 470-484.

22. Minima, A. K. 1953. Changes in organic acid content of potato leaves and tubers. Biokhimiya 18: 718-724.

23. Mondy, N. I., B. P. Klein and L. I. Smith. 1960. The effect of maturity and storage on phenolic content, enzymatic activity and discoloration of potatoes. Food Res. 25: 693-705.

24. Mondy, N. I., L. R. Mattick and E. Owens. 1963. The effect of storage on the total lipides and the fatty acid composition of potatoes. J. Agr. and Food Chem. 11: 328-329.

25. Muller-Thurgau, H. 1882. Uber Zuckeranhaufung in Pflanzentheilen in Folge niederer temperatur. Landw. Jahrb. 11: 751-828.

26. Murphy, H. J. and M. J. Goven. 1959. Factors affecting the specific gravity of the white potato in Maine. Maine Agr. Expt. Sta. Bull. No. 583.

27. Nissen, M. 1955. The weight of potatoes in water. Am. Potato J. 32: 332-339.

28. Page, E. and F. M. Hanning. 1963. Vitamin B_6 and niacin in potatoes. J. Am. Dietet. Assoc. 42: 42-45.

29. Porter, W. L., T. J. Fitzpatrick and E. A. Talley. 1964. Studies of the relaitonship of specific gravity to total solids of potatoes. Am. Potato J. 41: 329-336.

30. Potter, A. L. and E. A. McComb. 1957. Carbohydrate composition of potatoes. Pectin Content. Am. Potato J. 34: 342-346.

31. Pucher, G. W., H. B. Vickery, W. D. Ginter, L. S. Nolan and C. S. Leavenworth. 1949. The metabolism of the organic acids of tobacco leaves. I. Effect of culture of excised leaves in solutions of organic acid salts. J. Biol. Chem. 178:557-575.

32. Rose, D. H. and H. T. Cook. 1949. Handling, storage, transportation, and utilization of potatoes. U.S.D.A. Bibliog. Bull. No. 11.

33. Samotus, B. and S. Schwimmer. 1962. Predominance of fructose accumulation in cold-stored immature potato tubers. J. Food Sci. 27: 1-4.

34. von Scheele, C., G. Svensson and J. Rasmusson. 1936. Die Bestimmung des Starkegehalts und der Trockensubstanz der Kartoffel mit Hilfe des spezifischen Gewichts. Landw. Vers.-Sta. 127: 67-96.

35. Scheffer, F. and H. Rotzoll. 1961. Einfluss der Lagerungsledingungen auf die loslichen Zucker in der Kartoffelknolle. Z. Pflanzenernahr. Dueng. Bodenk. 94: 125-133.

36. Schwartz, J. H., R. B. Greenspun and W. L. Porter. 1961. Chemical composition of potatoes. II. Relationship of organic acid concentrations to specific gravity and storage time. Food Technol. XV: 364-366.

37. Schwimmer, S., A. Bevenue, W. J. Weston and A. L. Potter. 1954. Potato composition. Survey of major and minor sugar and starch components of the white potato. J. Agr. Food Chem. 2: 1284-1290.

38. Sharma, M. K., D. R. Isleib and S. T. Dexter. 1959. The influence of specific gravity and chemical composition on hardness of potato tubers after cooking. Am. Potato J. 36: 105-112.

39. Sirenko, L. A. 1957. The influence of the storage conditions upon the material contained in potato tubers. Nauk. Zapiski, Kiiv. Derzhav. Univ. im T. G. Shevchenka 16, No. No. 1, Pratsi Botan. Sadu im. O. V. Fomina No. 25: 141-164.

40. Stuart, N. W. and C. O. Appleman. 1935. Nitrogenous metabolism in Irish potatoes during storage. Maryland Agr. Expt. Sta. Bull. No. 372.

41. Talley, E. A., T. J. Fitzpatrick and W. L. Porter. 1964. Chemical composition of potatoes. IV. Relationship of the free amino acid concentrations to specific gravity and storage time. Am. Potato J. 41: 357-366.

42. Talley, E. A., T. J. Fitzpatrick, W. L. Porter and H. J. Murphy. 1961. Chemical composition of potatoes. I. Preliminary studies on the relationships between specific gravity and the nitrogenous constituents. J. Food Sci. 26: 351-355.

43. Talburt, W. F. and Ora Smith. 1959. Potato processing. Avi Pub. Co.

44. Thunberg, T. 1945. The citrate content of the potato. Kgl. Fysiograf. Sallskap. Lund. Forh. 15: 58-62.

45. Werner, H. O. and R. M. Leverton. 1946. The ascorbic acid content of Nebraska-grown potatoes as influenced by variety, environment, maturity, and storage. Am. Potato J. 23: 265-267.

46. Wright, R. C., W. M. Peacock, T. M. Whiteman and E. F. Whiteman. 1936. The cooking quality, palatability, and carbohydrate composition of potatoes as influenced by storage temperature. U. S. Dept. Agr. Tech. Bull. No. 507.

47. Wright, R. C. and T. M. Whiteman. 1951. Chips from Early Crop Potatoes. Potato Chipper 10, No. 6: 28-32.