DEHYDRATED FOODS

Changes in Physical Properties of Starch in Potato Granules During Processing

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During tempering in the production of potato granules, the physical properties of the cooked potatoes undergo an important change. It appeared that this change might be the result of a change in certain physical characteristics of the starch in the potatoes. The solubility and swelling power of the starch of cooked potatoes and potato starch gels were measured under various conditions of temperature and moisture. The rate of change of these physical characteristics of the starch increased as the moisture content was decreased to 30% and as the temperature was lowered from 50° to 5° C. (122° to 41° F.). These changes paralleled the increase in degree of granulation and improved product quality of potato granules. It is concluded that starch plays an important role in determining the effectiveness of the tempering period in potato granule production.

Potato granules are dehydrated precooked potatoes in granular form. The product consists largely of separated, whole-tissue cells which are reconstituted easily by the addition of hot water to form a product that closely resembles freshly prepared mashed potatoes in color, flavor, and texture. High-quality granules contain only a small percentage of damaged potato-tissue cells.

Current production methods utilize the so-called "add-back" process. Potatoes are cooked in steam, mashed, and mixed thoroughly with sufficient previously dried granules to give a mixture with a moisture content of approximately 40%. This moist mix is dried in a pneumatic dryer with or without an intermediate holding (tempering) period. Olson and Harrington (*4*) have summarized the information available on this method and others for manufacture of potato granules. Recently Olson, Harrington, Neel, Cole, and Mullins (*5*) have studied the effect of process variables including moisture level, tempering period, and temperature of drying on quality of potato granules.

During the tempering period, the physical properties of the moist mix change considerably. Reduced moisture content, reduced temperature, and increased time of holding before drying generally improve the friability or degree of granulation of the moist mix. These changes are probably due to equilibration of the moisture between the freshly cooked potatoes (about 76% moisture) and the previously dried granules (about 10% moisture), followed by changes in the constituents of the potato tissue. Because starch is the major solid component, changes may be attributed for the most part to changes in the physical properties of the starch. The purpose of the work reported here was to investigate these changes as they occur during the tempering of the moist mix.

Investigations by Katz (*2*) and Schoch and French (*6*) on the staling of bread have shown that the solubility and swelling power of starch decrease as bread stales and, also, that the rate of these changes is faster at lower temperatures and moisture levels. By analogy, these studies suggest that the changes occurring in the moist mix during the tempering period may be due to changes in the physical properties of starch in the potato cells. To study this possibility, the solubility of starch in moist mixes of varying moisture content and in starch gels stored over a range of temperatures was measured, as was the swelling power of the starch.

Experimental

Preparation of Moist Mix Peeled, halved Idaho Russet Burbank potatoes were cooked in steam for 35 minutes, mashed, and thoroughly mixed in a planetary mixer with previously dried potato granules. Different ratios of freshly cooked potatoes to potato granules were used to give the selected moisture content. It was more expedient to prepare the samples of the lower moisture levels by drying a moist mix of approximately 40% moisture to the desired moisture content in a laboratory pneumatic dryer (*5*) operated at 90° to 100° C. The moist mix was transferred to a jar, which was then stored in a constant-temperature water bath. The material was stirred every 10 minutes until it reached the storage temperature, 5°, 25°, or 50° C.—usually 40 to 50 minutes. Zero storage time was set at 10 minutes after the material had reached the bath temperature. In all instances, the moisture content of the mix was determined by the toluene distillation method.

Preparation of Starch Gels Gels were prepared with potato and wheat starches. The potato starch was isolated from Idaho Russet Burbank potatoes. The potatoes were blended in a Waring Blendor at high speed with water and the mixture was mashed and screened through a fine nylon cloth to remove the fiber, which was again mixed with water and pressed on the nylon cloth. The starch settled from the filtrates on standing for 2 hours. The supernatant liquid was decanted and the starch purified by four additional settlings from water. The wheat starch was prepared at the Northern Regional Research Laboratory from wheat flour in a pilot plant operation using the batter process (*7*).

Table I. Influence of Solids Content on Swelling Volume

Sample	Total Solids, G.	Ml. Swollen Material per Gram Solids	
		As determined	Calcd. to 4 g. solids
Potato granules (6% moisture)	1.88	5.3	4.7
	3.76	4.7	4.7
	5.64	4.1	4.5
	7.52	3.9	4.6
Moist mix (40% moisture)	1.5	4.5	4.0
	3.0	4.0	3.8
	4.5	3.9	4.0

Table II. Effect of Moisture Content on Swelling Power of Moist Mix During Storage

Time of Storage, Hours	Ml. Swollen Material per Gram Solids				
	73% H_2O	43% H_2O	36% H_2O	28% H_2O	20% H_2O
0	4.6	4.7	4.4	4.2	4.1
1	4.6	4.2 (2 hr.)	3.7	3.9	4.1
3	4.6	4.1	3.4	3.6	4.0
5	4.5	3.8	3.1	3.3	4.1
24	4.5	3.6	3.0	3.2	4.1
48	4.5	3.5	3.0	3.0	4.1
96	4.5	3.3	2.8 (72 hr.)	3.0	4.1

The starches were defatted by four successive 3-hour extractions in boiling 85% methanol and then air-dried at room temperature. An amount of starch equivalent to 2, 3, or 4 grams on the dry-starch basis was mixed with distilled water, giving a total weight of 10 grams in a 16 × 110 mm. test tube. The tube was placed in a water bath at 59° C. and stirred with a small stainless steel spatula. Usually a series of tubes at each concentration of starch was prepared and in order to keep the concentration of the starch constant only one spatula was used to mix the contents of all the tubes which were in a water bath at 59° C. The first tube stirred was discarded. The tubes were loosely stoppered and the water bath was heated slowly to 65° C. on an electric hot plate. The bath was further heated to 85° C. in 20 minutes and then the heat was increased in such a manner that the temperature reached 96° C. in an additional 10 minutes. The heat was then lowered and the tubes were allowed to remain in the bath for 30 minutes, while the temperature dropped to 90° C. The tubes were then tightly stoppered and cooled for 15 minutes in a water bath at the storage temperature. Zero storage time was taken at the end of this cooling period.

Determination of Soluble Starch Schoch and French (*6*) stirred bread crumb–water mixtures with a propeller-type stirrer to separate intact starch granules from the crumb; in this way they were able to study the change in amount of starch extracted from swollen starch granules. However, in order to study the changes in the solubility of the starch in cooked potatoes it is necessary first to break the cell walls. Several methods for doing this were considered. Every method used to determine the soluble starch of freshly prepared mashed potatoes destroyed the starch granule structure while the potato cells were being fractured. Most of the starch in freshly mashed potatoes was dissolved regardless of the procedure used. Use of the Waring Blendor was found to yield reproducible extractions of the starch from moist mixes, provided time, temperature, and rate of stirring were carefully controlled. Potato granules were blended in water for 1, 2, 4, 8, and 16 minutes. An amount of starch corresponding to 0.052, 0.087, 0.106, 0.128, and 0.143 gram per gram of total solids was dissolved. Microscopic examination of the mixture after blending for 1 minute showed a considerable number of unbroken potato cells. While a similar examination after 2 minutes of blending revealed only a few unbroken potato cells, blending for periods longer than 2 minutes disintegrated the starch gels within the cells into smaller fragments. Thus in the first 2 minutes the most rapid increase in rate of solution of starch occurred. A 2-minute blending time was therefore used for determining the amount of soluble starch in potato cells in the following experiments. It was desirable to have comparable data from pure starch gels to show that the physical changes in pure starch gels were similar to those measured in the moist mixes of potato cells. The extraction procedure was carried out as follows:

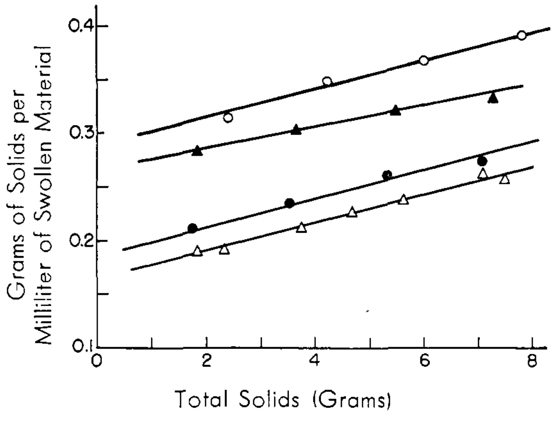
At various intervals, 1-gram samples of the moist mix or a starch gel were blended in a Waring Blendor at high speed for 2 minutes with 250 ml. of water containing 25 to 30 grams of ice. The ice was added to compensate for the heat generated during blending. The mixture was transferred to a 500-ml. volumetric flask, diluted to volume, and placed in a water bath at 25° C. for 30 minutes, while it was shaken occasionally. Approximately 200 ml. of the mixture in a 250-ml. centrifuge bottle was centrifuged for 10 minutes (1800 r.p.m. with a head of 14.5-cm. radius). Soluble starch was determined in an aliquot of the supernatant fluid by the anthrone–sulfuric acid reaction (*3*). Because extracts of the moist mix contained (in addition to starch) other materials which would react with the anthrone (sugars, etc.), portions of these extracts were mixed with 100 mg. of potassium acetate and 5 volumes of 95% ethyl alcohol and refrigerated overnight at 3° C. The precipitated starch was centrifuged from the supernatant liquid, dissolved in hot water, cooled, and then determined by the anthrone–sulfuric acid reaction.

Swelling Power Five- to 10-gram samples of the moist mix were placed in a 40-ml. graduated centrifuge tube and mixed with sufficient water to give a final volume of 40 ml. The tube was placed in a constant-temperature bath at 25° C. for 1.5 hours and centrifuged for 15 minutes (1800 r.p.m., radius of the head, 13.5 cm.). The supernatant liquid was decanted immediately, 10 ml. of water was pipetted into the tube, and the total volume was determined. The volume of the swollen material, designated as the swelling power, is equal to the total volume minus 10.

The volume per gram of solids depends on the total solids present during the determination of the volume of swollen material. Within the range of solids from 1.5 to 7.8 grams, a straight-line relationship was found between the reciprocal of the volume of swollen material per gram of solids and the total weight of solids used as shown in Figure 1. From the slope of the lines, which seems to be

Figure 1. Effect of total amount of solids on swelling volume of potato granules

○ Russet Burbank moist mix, 52 hours at 5° C., 40% moisture
▲ White Rose granules, 8.8% moisture
● Russet Burbank granules, 11.6% moisture
△ Russet Burbank granules, 6.0% moisture



similar for different swelling powers, the volume per gram of solids may be calculated for any particular amount of total solids. All data are expressed on the basis of 4 grams of total solids. The equation for this is:

$$\frac{1}{A} = \frac{1}{B} + 0.012\ (4 - C)$$

where A is volume of swollen material per gram of solids (total solids = 4.0 grams), B is volume of swollen material per gram of solids as determined, and C is total solids during the determination. With this calculation, the results from experiments on different amounts of material can be compared and any possible misunderstanding of the data will be avoided by giving values corrected to a comparative level. Table I presents data obtained on swelling power before and after correction to the solid basis of 4 grams and shows the necessity for correction to a common total solids basis. That the above relationship may also vary with the variety of potatoes used and the locale in which they are grown was indicated when the swelling powers of potato granules prepared from White Rose and Idaho Russet Burbank potatoes were determined. The slope of the line was not so great with the former as with the latter. This difference in behavior of the two varieties is due probably to the fact that the White Rose potato is considered nonmealy as compared to the Idaho Russet Burbank, a mealy type. A nonmealy potato produces a pastier mashed potato. As a consequence, in the determination of swelling power, the insoluble residue forms a more dense pack in the centrifuge tube. This would be more pronounced if a small amount of solids is used. Therefore, the slope of the line would be less if it were determined using nonmealy potatoes.

Table III. Changes During Storage at 25° C. in Ability of Potato Starch Gels to Absorb Water

Storage, Hours	Grams Swollen Material per Gram Starch: 20% starch gel	40% starch gel
0	9.3	8.3
1	9.0	7.6
3	8.8	6.4
5	8.3	6.1
24	8.5	5.3
48	8.1	4.8
75	8.0	4.7
140	8.0	4.7

The swelling power of the starch gels was determined by blending a starch gel with 100 ml. of water and 25 to 30 grams of ice for 2 minutes. The mixture was transferred to a tared 250-ml. centrifuged bottle, diluted to about 200 ml., and allowed to stand for 1 hour at 25° C. The insoluble residue was separated from the supernatant liquid by centrifuging at 1800 r.p.m. for 15 minutes. The quantity of swollen material was determined by weighing. Swelling power is defined as weight of swollen material divided by grams of starch in original gel.

Results

Changes in Starch Solubility The rate of decrease of the starch dissolved from gelatinized starch during storage depends on concentration of the starch originally present. In Figure 2, the starch dissolved from cooked potatoes with different moisture contents is shown at various time intervals of storage at 25° C. As moisture content decreases, rate of retrogradation increases until there is about 30% water. Below this point the rate begins to decrease, until at 15% water there is no measurable change in solubility of the starch. Figure 3 shows that by increasing concentration of starch in starch gels, rate of retrogradation is increased. Gels containing more than 40% starch were not studied because it was very difficult to prepare a uniform gel of potato starch at the higher concentrations.

Figures 4 and 5 illustrate the effect of storage temperature on rate of retrogradation of starch in cooked potatoes (45% moisture) and in 40% potato starch gels. The rate at which solubility of starch decreases is increased by reducing the holding temperature.

In Figure 3 data obtained from 40% wheat starch gels stored at 25° C. are included because results from wheat starch gels in connection with the bread staling problem have previously been published (*2*, *6*). The results of this investigation indicate that potato starch is more completely solubilized by the methods used in the present work and that retrogradation in potato starch gels is faster.

Changes in Swelling Power The data summarized in Table II show that swelling power of the moist mix at high moisture content (73%) and low moisture (20%) does not change appreciably during storage. But at the other moisture levels studied (28 to 43%), there was a de-

Figure 2. Effect of moisture content of moist mix on retrogradation of starch at 25° C.

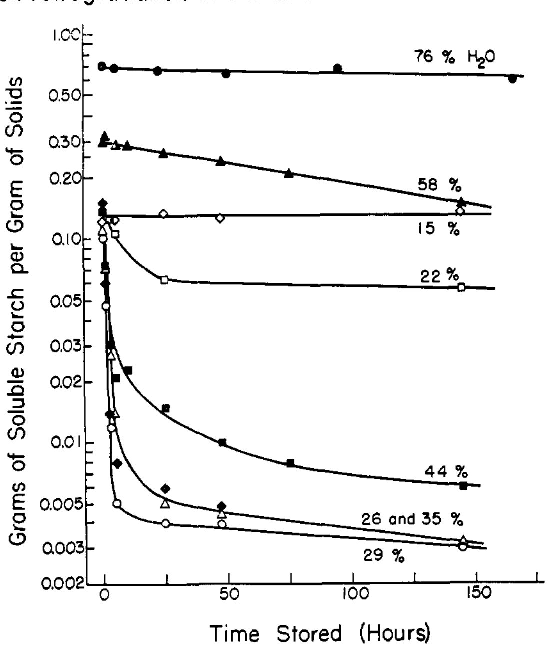
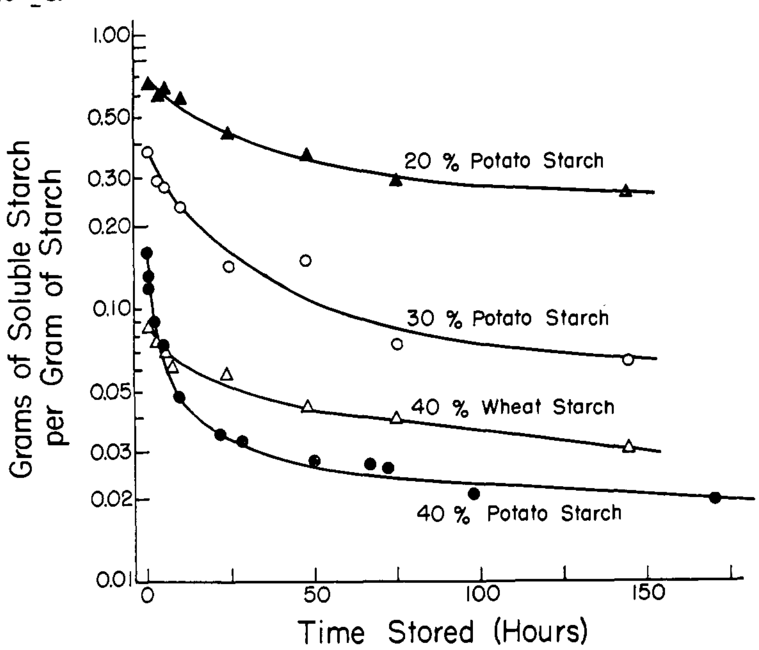


Figure 3. Effect of starch content on retrogradation of starch gels at 25° C.



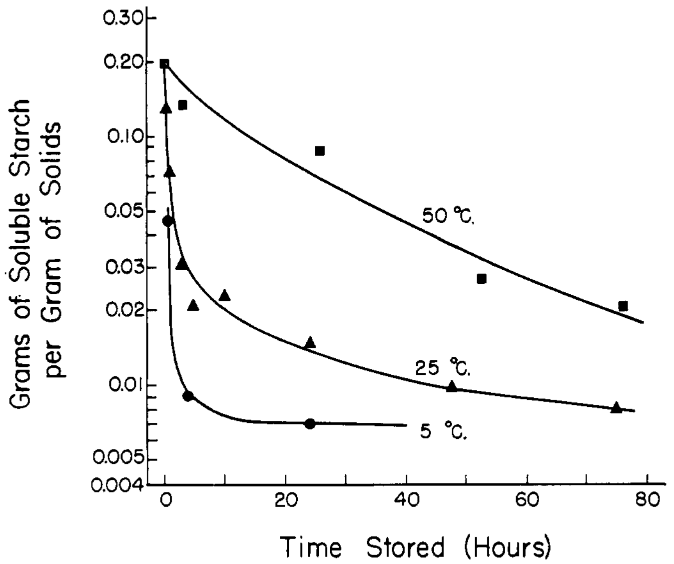


Figure 4. Effect of storage temperature on retrogradation of starch in a moist mix, 45% moisture

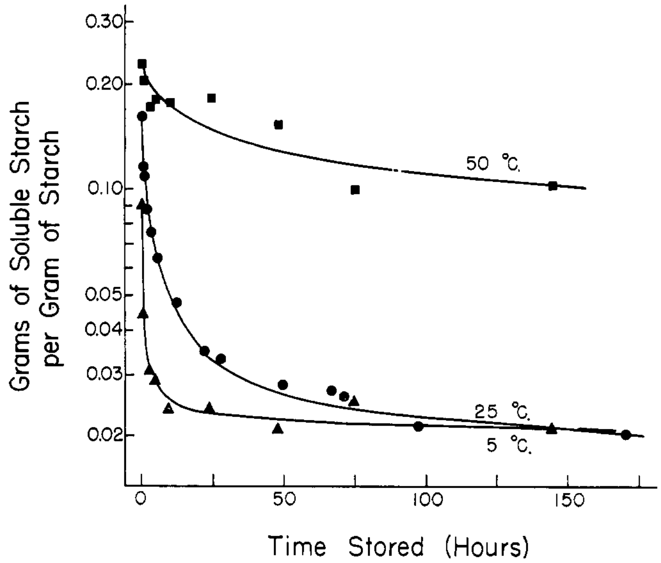


Figure 5. Effect of storage temperature on retrogradation of 40% potato starch gels

crease in swelling power of the moist mix, and the rate of change was approximately the same at each of these concentrations.

The swelling power of 20 and 40% potato starch gels, given in Table III, decreases during storage at 25° C., a more rapid decline being shown in the 40% gel.

As storage temperature is decreased the rate of change in swelling power of moist mixes increases. This is indicated by data in Table IV obtained from moist mixes of 40% moisture stored at 5°, 25°, and 50° C.

Discussion and Conclusion

Heating a suspension of potato starch granules to 90° C. gelatinizes the starch. The swollen material consists of granule sacks with dissolved starch in the interiors. Some of the starch will after a time diffuse from the gelatinized granules, but the sack membrane must be broken in order to liberate the starch *en masse* from the granule. Continued heating while the suspension is stirred will destroy the swollen granular structure and liberate a large percentage of the starch. If the paste is allowed to cool and age before the sack membranes are broken by stirring or other means, the free starch as well as the starch within the swollen granules becomes associated and less starch will pass into solution. This occurs in the case of pastes with lower moisture contents after being stored at temperatures approximately 25° C. or below.

Potato starch granules are larger and easier to gelatinize than those from most cereals. Therefore, the granule sacks of gelatinized potato starch are easier to rupture than the swollen granules of cereal starches. Figure 3 shows that the amount of starch dissolved from freshly prepared potato starch gels is about twice that dissolved from similar wheat starch gels by the technique used here. The amount of starch dissolved from potato starch gels aged for 3 hours is the same as that dissolved from wheat starch gels aged an equal time. When gels are stored longer than 3 hours, the amount of starch dissolved from potato starch gels is less than that from wheat starch gels stored for the same period. It is not possible to determine whether the different rates of retrogradation are a function of the size of the granules or more directly concerned with the molecular constitution of a particular starch.

Table IV. Effect of Storage Temperature on Swelling Power of Moist Mix, 40% Water

Storage, Hours	*Ml. Swollen Material per Gram Solids of Moist Mix Stored at* 5° C.	25° C.	50° C.
0	3.80	3.80	3.80
1	3.30	3.45	3.80
3	3.05	3.35	3.60
5	3.05	3.10	3.40
24	3.05	2.75	2.85
48	3.00	2.80	2.85
96	2.90	. . .	2.80

If the tempering period in the production of potato granules is increased from 0 to 3 hours and if the moisture content of the moist mix is reduced from 45 to 35%, the degree of granulation and quality of granules are improved (*5*). Lowering the temperature of the moist mix to room temperature during the tempering period also improves the quality of the granules (*4*). The results of this investigation show that during a tempering period, the conditions which cause the fastest change in physical properties of starch in potato cells of moist mix are similar to those conditions that improve quality of the granules. Therefore, it is concluded that changes in physical properties of starch play an important role during the tempering period in the production of potato granules. Furthermore, the change in friability of the moist mix during the holding or tempering period cannot be accounted for simply by the equilibration of moisture from the freshly mashed potatoes to the dry granules that are added.

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