



A study of the consistency of starch gels prepared at a higher altitude  
by Jean T Chase

A THESIS Submitted to the Graduate Committee in partial fulfillment of the requirements for the  
degree of Master of Science in Home Economics  
Montana State University  
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Abstract:

Starch gels made with corn starch or all-purpose flour tad using as liquid distilled water, tap water and milk, respectively, were prepared under high altitude conditions for the purpose of studying their relative consistencies. Their qualities and breaking strengths (measured on the Delaware jelly strength tester) were compared with those of a standard gel.

It was found that at an altitude of 4700 feet above sea level where the boiling point of water is about 95.5°C., more complete gelatinization and better gels could be obtained when the starch paste was cooked over direct heat and allowed to boil only five minutes. This method was preferred to that of cooking in a boiling water bath where the temperature of the starch paste was too low to insure complete gelatinization.

There was a definite indication that the presence of ash or salts in tap water, milk and flour had a depressing effect on the thickening property of the starch and lowered the breaking strength of the gels. When 20 per cent of sugar was added to the pastes, the gel strength was slightly increased. When a larger amount of sugar (60 per cent) was added to the pastes, the resulting gels were decidedly weaker than the standard. To obtain complete starch gelatinization under the latter conditions, it was necessary to withhold one-half of the sugar until the end of the cooking period. If fruit acid was also added to the gel at the end of the cooking period, it had no apparent effect on the gel strength.

A STUDY OF THE CONSISTENCY OF STARCH GELS  
PREPARED AT A HIGHER ALTITUDE

by

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Submitted to the Graduate Committee

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ABSTRACT

Starch gels made with corn starch or all-purpose flour and using as liquid, distilled water, tap water and milk, respectively, were prepared under high altitude conditions for the purpose of studying their relative consistencies. Their qualities and breaking strengths (measured on the Delaware jelly strength tester) were compared with those of a standard gel. It was found that at an altitude of 4700 feet above sea level where the boiling point of water is about 95.5°C., more complete gelatinization and better gels could be obtained when the starch paste was cooked over direct heat and allowed to boil only five minutes. This method was preferred to that of cooking in a boiling water bath where the temperature of the starch paste was too low to insure complete gelatinization.

There was a definite indication that the presence of ash or salts in tap water, milk and flour had a depressing effect on the thickening property of the starch and lowered the breaking strength of the gels. When 20 per cent of sugar was added to the pastes, the gel strength was slightly increased. When a larger amount of sugar (60 per cent) was added to the pastes, the resulting gels were decidedly weaker than the standard. To obtain complete starch gelatinization under the latter conditions, it was necessary to withhold one-half of the sugar until the end of the cooking period. If fruit acid was also added to the gel at the end of the cooking period, it had no apparent effect on the gel strength.

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INTRODUCTION

Starch is an important granular material produced only by plants and constitutes one of the forms in which plants store their carbohydrate. One of the characteristics of starch that is responsible for its extensive use in commercial and home processes, is its thickening or gel-forming property. When starch granules are added to water they swell slightly and form a paste, which upon heating to a certain temperature, thickens or gelatinizes. By controlling the proportions of starch and water and heating the paste to a definite temperature, there results a cooked product that gelatinizes when cooled and forms a standard gel. It is understood that a standard gel holds its shape when removed from a mold, shows no syneresis or weeping, quivers when gently moved, and has a jelly-like texture exhibiting a smooth continuous surface when sheared.

In cookery, starch gels are frequently used for such products as puddings and pie-fillings. For this purpose the starch is usually obtained from either corn starch or flour. The former contains little besides starch, but flour is a composite substance, having various amounts of protein and ash in addition to the starch, and all of the ingredients must be considered. An examination of so-called reliable recipes for starch gels show that they do not agree in the relative amounts of starch used. It is apparent that little comparative study has been made of the thickening or gel-forming power of corn starch and flour, and that little is known about the specific requirement of either corn starch or flour for making a standard gel.

Studies in recent years have shown that starches obtained from corn

and wheat are not always of a uniform quality. There are vague references in the literature to "thin-boiling" and "thick-boiling" starches, indicating that some inherent characteristic of the starch must affect its gelatinization.

Another factor that seems to affect starch gelatinization is the elevation above sea level at which starch is cooked. With elevation comes a lowering of the boiling point of water so that the cooking temperature may fall below the gelatinization point of some starches. Whether failure of starch to gel is due to the lowered cooking temperature, faulty proportions of ingredients or poor quality of starch is still a problem. At times, this difficulty of obtaining gelatinization in starch cookery is reported by homes and institutions at higher altitudes.

In preparation of starch gels for food, other materials such as sugars, salt, fruit acids, milk and chocolate, are often added to increase palatability. It is desirable to determine how these added ingredients will affect the final consistency of starch gels.

While some limited observations on starch cookery problems have previously been made under conditions at sea level, this study proposes to further investigate starch gelatinization at a higher altitude by determining the effect of a lowered cooking temperature with varied proportions of ingredients.

## HISTORY

Before attempting to study starch gel formation and its uses in cookery, it is necessary to thoroughly understand the physical and chemical nature of starch, its basic qualities and its variations.

Starch, the form in which plants store their reserve carbohydrate, makes up a large part of such foods as the cereal grains (wheat, corn, and oats) and potatoes. Raw starch granules taken from different plants and examined under the microscope vary greatly in size and shape, those from wheat and corn ranging from 3 to 35 microns in diameter. The granules may be round or oval and may occur singly or in aggregates of 2 to 25 or more.

Ordinarily starch is not used in its natural raw state but is subjected to a refining process consisting of a series of washings with water, acid and salt solutions, bleaches, alcohol and ether, that remove undesirable ingredients and increase the thickening property (14). The composition of commercial corn starch, called a pure starch after refining, is 87 per cent carbohydrate and 12 per cent water, while flour, a wheat starch, contains about 75 per cent carbohydrate, 12 per cent water, and about 11 per cent protein (11). In addition, both starches contain small amounts of fat and ash. This difference in composition partly accounts for the variation in thickening capacity of corn starch and wheat flour.

Some workers have regarded starch as a homogeneous colloidal substance and thought that variations in its characteristics were due to different colloidal conditions. However, Samec (27) and others believe that starch is a heterogeneous system built up from polysaccharides together with organic or inorganic substances. Changes in the non-starch components would then modify the properties of the starch.

From a chemical viewpoint, the starch particle is made up of two fractions, a less soluble portion called alpha-amylase or amylpectin, which forms a viscous opalescent paste on heating in water; and a more soluble portion known as beta-amylase or amylase, which upon heating forms a clear liquid

"solution"(32). Starch is not always reported as containing the same proportions of amylopectin and amylose owing to different methods of separating the fractions. Also different proportions may be due to a process called "retrogradation" that takes place in the starch molecule, in which the amylose changes to the insoluble form, amylopectin, and thus increases the gel-forming quality of the starch. A possible explanation for this change is given by Richardson and coworkers (25) who believe that starch molecules contain glucose units that are linked into continuous chains varying from 460 to 1470 units. The longer chains make up the amylopectin and are insoluble, while the shorter chains constitute the soluble amylose. These shorter chains may aggregate to form the longer chains.

If starch granules have been injured in milling or grinding, the starch chains are broken into shorter, more soluble units which make the heated solution less stiff as they increase (18).

Closely associated with the amylopectin and amylose in the starch is phosphoric acid. Samac (28) states that in the starch of some species of plants, both fractions are combined with phosphoric acid, while Alsberg (2) claims that in wheat starch phosphoric acid is combined only with the amylopectin. Samac (28) found that an increase in phosphoric acid caused an increase in paste formation of starches with the exception of wheat starch, in which, he believes, the phosphoric acid may be combined with proteins.

Still another distinction between the two starch fractions is made by Taylor and associates (37-42) who state that the insoluble fraction, amylopectin, which is responsible for thickening, carries certain high molecular-weight fatty acids combined with its carbohydrate. The percentage

of fatty acids ranges from none in potato starch to relatively high percentages in cereal starch. However, their bearing upon starch gelatinization is not known.

When starch granules are added to cold water, they swell and form a milky, non-viscid suspension (18). If the suspension is allowed to stand, the starch granules sink to the bottom of the container, leaving the supernatant liquid clear. During the swelling no change in structure is noted in the polarizing microscope.

Upon heating starch granules in water, they swell, undergo hydration, and form an opaque or transparent paste, depending upon the kind of starch used. Corn starch produces a transparent paste while flour yields an opaque paste due to the combination of starch with phosphorus and protein (28). When the starch pastes have been heated to a certain temperature, then cooled, they take on jell-like qualities and gelatinization is said to have taken place.

Several attempts have been made to describe the processes that take place in starch gelatinization. An early theory and the one usually found in older text books was developed by Pringsheim (1). He believed that starch was insoluble in cold water but that, when heated, starch paste was formed through the swelling and final bursting of the granules. However, Alsberg (1) maintains that this view is incorrect and believes that when starch granules are heated in water, they swell but do not ordinarily disintegrate. Instead, the starch granules absorb a maximum amount of water and the cell walls become so thin and elastic that they readily adhere and mold into a continuous jelly-like mass. Similar views have been held since 1848 by

workers in the textile industry such as Harrison, Bergerinok, and Nivling.

Gelatinization seems to depend upon (1) the kind of starch, (2) the size of the starch granule, and (3) the temperature to which the starch paste is heated. As a rule, gelatinization begins at a lower heating point and continues over a wide range of temperature. Alsberg and Rask (4) report that corn and wheat starch gelatinize over a range of 25 to 30 degrees, beginning at about 65°C. and continuing to 95°C. Woodruff and Nicoli (45) heated five per cent suspensions of various starches in a water bath and noted a sudden increase in translucency in the corn starch suspension at 86 to 87°C. and in the flour suspension at 87 to 88°C. However, they found that maximum gelatinization occurred only after the paste had been heated to 90°C. or above. On the other hand, Richardson and Waite (26) found that under certain conditions corn starch gelatinizes slowly in water at temperatures up to 100°C. and that the granules are not completely dispersed in the solution even after heating for 30 minutes. Caesar and Moore (9) state that there is no such thing as a definitely fixed and specific gelatinization temperature for all of the granules of a starch.

Alsberg (1) suggests that three factors are involved "in determining the degree to which heat will cause a granule to swell, (1) its rigidity or the ease with which its anatomical structure is softened by moist heat, (2) the inherent swelling power of the granule substance, and (3) the relation of mass of swelling substance to surface area of the granule". It is easy to understand how the first two points would affect the swelling. The third point is significant for "as the diameter is increased, the volume of a sphere or its mass increases much faster than its surface area". Thus, a larger

granule would swell more readily than a small one because of its greater internal pressure (1).

Variation in the swelling of starch granules seem to cause variation in the stiffness of the resulting gel. In order to investigate the characteristics of starches, many methods have been devised for testing the stiffness of starch gels. The earliest method used was a test of viscosity, which according to Rask and Alsberg (24) is "the resistance due to internal friction which viscous substances offer to deforming forces". The reliability of this test was questioned by Buchanan and Naudain (7) who suggested that the difficulty of securing reproducible results whether a rotating, torsional or capillary type of viscosimeter is used might be due to difference in size of starch granule. Because starch is a suspensoid, it may be difficult to secure reproducible viscometric readings (1). Recent studies have been made by Woodruff and McMasters (44) to show the relation of gel strength and viscosity. They gelatinized five per cent starch suspensions and allowed them to mold. These molds were tested for gel strength on a Tarr and Baker jelly tester (5, 36). Viscosity readings on two per cent corn starch suspensions were also made with a Stormer viscometer. Results showed that viscosity differences were very small compared with differences in gel strength and that frequently the two properties did not vary in the same direction. The writers give this as evidence that "viscosity and gel strength seem to measure two different sets of properties in the starch" (44). Brimhall and Hixson (6) quote Schwedoff as stating that the viscosity of a liquid is not necessarily an index of its rigidity. The lack of correlation between viscosity and gel strength of starch pastes

is recognized in industry, although not often encountered in the literature (6).

Seck and Fischer (31) observed no relation between viscosity and degree of gel formation but found that there is a relationship between viscosity and degree of swelling. Tanner and Englis (35) in a study on corn starch found no correlation between swelling power and relative viscosity but suggest the possibility that as viscosity decreases, swelling power may increase. Many workers found no correlation apparent between pH of the starch solutions and viscosity (22, 24, 35).

Several instruments have been devised to measure gel strength of starch molds. The Delaware jelly strength tester measures the centimeters of hydrostatic pressure required to force a plunger through the surface of a gel (5, 36). This instrument proved satisfactory when used by Woodruff and McMasters (44) for testing five per cent starch gels. A gelometer, replacing an earlier tester called a "rigidometer", has been devised by Hixson and Brimhall (13) for use with six and one-half to eight and one-half per cent starch pastes. "Suction is used to deform the gel, the volume of deformation being measured by hydrostatic means". For starch pastes of higher concentrations, Caesar and Moore (9) have worked on a consistometer which measures the whole paste history of twenty per cent starch concentrations from cooking to cooling. To record physical differences of the gels, Woodruff and McMasters (44) have made photographs of starch gels, in which outstanding characteristics of gel strength can easily be seen.

When starch gels are used in food preparation, other ingredients are often added and it is desirable to know what effect they may have upon the

starch. A few studies have been made to determine in what way some of these materials influence gelatinization of starch. Nevenzel (22) states that the more sugar present in starch gels, the greater must be the amount of starch in order to maintain a desirable consistency of the product, for the tendency to gel decreases as the proportion of sugar to starch is increased. Both Nevenzel (22) and Woodruff and Nicoli (45) found that more than 50 grams of sucrose prevented the molding of starch paste containing 5 grams of starch in 100 cubic centimeters of water.

Samuel (29) studied the effect of metallic salts on starch pastes and found that some salts lowered the gelatinization temperature. He found the addition of calcium chloride effective in inhibiting the molding of gels. At times, acids have been added to starch pastes with the result that the starch undergoes hydrolysis and loses some of its thickening power. This action is more rapid as the temperature increases.

It will be noted that throughout this discussion, considerable work has been reported on theoretical aspects of starch chemistry and on testing starch gels for use in the textile industry. Apparently, much less has been done in studying the preparation and properties of starch gels used in cookery. The few studies that have been made were carried on under sea level conditions. It therefore seems desirable to enlarge on present information by further investigating the relative thickening capacity of flour and corn starch and by determining the consistency of their gels when prepared at a higher altitude.

### EXPERIMENTAL PROCEDURE

For this study two types of starch, corn starch and flour, were chosen as those most frequently used in home cookery. Two representative standard brands were selected for testing, Staley's corn starch and Gold Medal Kitchen-Tested flour. Amounts large enough to supply starch for the entire testing period were purchased at one time from the same lots. Both the flour and corn starch were blended thoroughly and stored in paraffin-sealed tin cans at temperatures ranging from 52° to 62°F.

Tests to determine the percentage of moisture, ash, and protein at the time of storage were run by the Montana Grain Inspection Laboratory with the following results:

| <u>Sample</u> | <u>Moisture</u> | <u>Protein</u> | <u>Ash</u> |
|---------------|-----------------|----------------|------------|
| G. M. flour   | 13.8%           | 12.00%         | 0.36%      |
| S. starch     | 11.3%           | 0.60%          | 0.011%     |

An examination of the starches under the microscope showed the corn starch particles to be rounded and smooth-edged, while the flour particles had rough, jagged edges and were larger in size.

Before starting the tests, numerous reports on starch cookery were consulted to find the amounts of corn starch and flour commonly used in making starch gels. Recipes were collected from reliable sources for making corn starch pudding (table I), and cream and lemon pie filling (table II). Wide variations were noted in these recipes; for example, the amount of corn starch varied from 3.3 grams to 13.5 grams per 100 cubic centimeters of liquid used and the sugar, from 5.1 grams to 87.6 grams per 100 cubic centimeters of liquid. The larger amounts of corn starch and sugar were found in lemon pie fillings, where a high percentage of acid had been added. This increase in sugar and

Table I.--Relation of corn starch and sugar to liquid in corn starch pudding recipes

| Corn starch pudding source <sup>1</sup> | Liquid cc. | Corn starch gm. | Sugar gm. |
|-----------------------------------------|------------|-----------------|-----------|
| 1                                       | 100        | 3.3             | 5.1       |
| 2                                       | 100        | 4.1             | 10.2      |
| 3                                       | 100        | 4.1             | 10.2      |
| 4                                       | 100        | 4.9             | 20.5      |
| 5                                       | 100        | 6.6             | 10.2      |
| 6                                       | 100        | 6.6             | 10.2      |
| 7                                       | 100        | 6.6             | 10.2      |
| 8                                       | 100        | 6.6             | 15.4      |

1/ Sources:

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Table II.--Relation of corn starch, flour and sugar to liquid in cream and lemon pie filling.

| Recipe                   | Source <sup>1</sup> | Liquid<br>cc. | Corn starch<br>gm. | Flour<br>gm. | Sugar<br>gm. | Comment         |
|--------------------------|---------------------|---------------|--------------------|--------------|--------------|-----------------|
| Cream Pie<br>Corn starch | 3                   | 100           | 3.3                |              | 20.5         | Soft gel        |
|                          | 6                   | 100           | 6.6                |              | 20.5         | Stiff gel       |
|                          | 10                  | 100           | 6.6                |              | 20.5         |                 |
|                          | 12                  | 100           | 8.7                |              | 19.4         |                 |
| Cream Pie<br>Flour       | 5                   | 100           |                    | 4.2          | 20.5         | Soft gel        |
|                          | 9                   | 100           |                    | 5.7          | 20.5         |                 |
|                          | 11                  | 100           |                    | 7.4          | 30.7         | Stiff gel       |
|                          | 7                   | 100           |                    | 7.5          | 30.7         |                 |
| Lemon Pie<br>Corn starch | 7                   | 100           | 7.0                |              | 65.7         | Soft gel        |
|                          | 9                   | 100           | 10.1               |              | 63.4         | Standard<br>gel |
|                          | 10                  | 100           | 10.5               |              | 67.6         |                 |
|                          | 2                   | 100           | 13.5               |              | 64.6         | Soft gel        |

<sup>1/</sup> Sources same as for table I.

starch was apparently needed to produce a gel that would mold. Sometimes, the recipes suggested that flour could be substituted for corn starch, using twice as much flour as corn starch. When this recommendation was tried in preliminary tests, the resulting gels were not comparable in quality. Therefore it was necessary to first investigate the relationship in thickening capacity of corn starch and flour by trial and error, finally obtaining simple gels made with distilled water having similar strengths.

Preliminary tests were made to determine the optimum amounts of starch pastes to be cooked, the cooking period, and the most satisfactory molds for use with the Delaware jelly tester. Testing was begun using five grams of starch weighed to one decimal place, made up to 100 cubic centimeters with distilled water. This amount was not sufficient to fill two molds and was increased, in the same proportion, using 12.5 grams of starch made up to 250 cubic centimeters which required approximately 240 grams of water. Starch pastes of this concentration were cooked for varying lengths of time over an electric burner with thermostat control, to determine the preferred cooking period. Preheating periods of five and ten minutes, in which the temperature of the paste was brought to  $94^{\circ}\text{C}.$ , and boiling periods of five, ten, and fifteen minutes with the pastes at  $94^{\circ}\text{C}.$ , were tried. The pastes were then poured into molds. After cooling five minutes, the gels were covered with petri dishes that had been fitted with filter papers to absorb condensed moisture. The gels were stored in the refrigerator at a temperature of  $5^{\circ}\text{C}.$  for 24 hours. Then they were taken out and tested on the Delaware jelly tester to determine their breaking strength. They were also examined for their ability to hold the shape of the mold; for delicate, jelly-like, smooth qualities

when sheared with a knife; and for absence of syneresis or weeping. It was decided that pastes brought to the boiling point in ten minutes and boiled for five minutes, gave the best product. This view is substantiated by Hughes and coworkers (14) who state that "when five per cent concentrations of corn and wheat starch were cooked at a temperature of 95°C., five minutes was required, after the temperature reached 95°C., to obtain 95 per cent gelatination".

The 5 per cent corn starch gel was a standard product and tests were made with flour to arrive at a gel strength comparable to that of the corn starch molds. Recipes, as a rule, substitute flour for corn starch in a two to one ratio. However, a 10 per cent flour gel made too stiff a product and the flour was reduced to 9 per cent. After tests had been made on simple gels containing 5 per cent of corn starch or 9 per cent of flour in distilled water, tap water, or milk, the percentages of the thickening agents were varied to make standard gels when other ingredients were added.

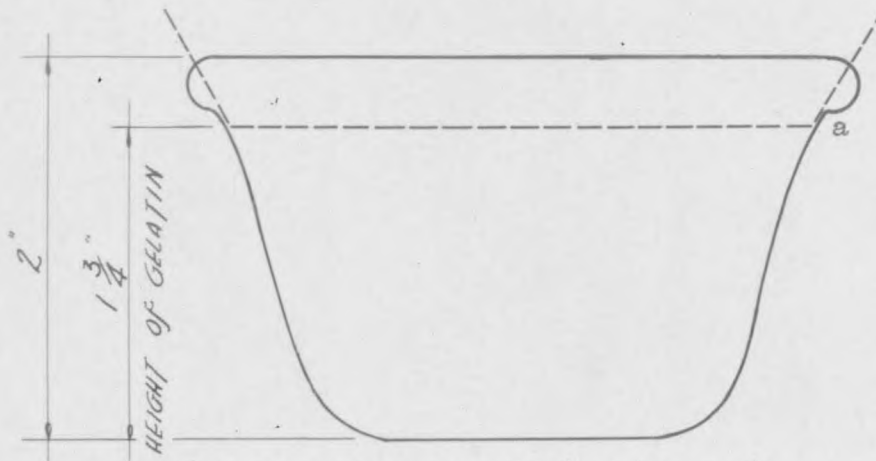
At the same time, a series of tests was run to determine the kind of container for gels that would give the most uniform results on the Delaware jelly tester. Small glasses, crucibles, plastic cups, "tin" molds, and pyrex custard cups were used as containers for the gels. The glasses, crucibles, and tin molds were discarded because of too small a diameter in proportion to the size of the plunger on the tester. The gels adhered to the plastic molds, making them difficult to remove. The pyrex custard cups gave more satisfactory results, because, with a larger diameter, the effect of the container wall on breaking strength was lessened. Also, after testing, the molded gel could be removed easily from the container for further examination. It was decided

that the pyrex custard cup was the best mold for the purpose (fig. 1), and it was used throughout the study.

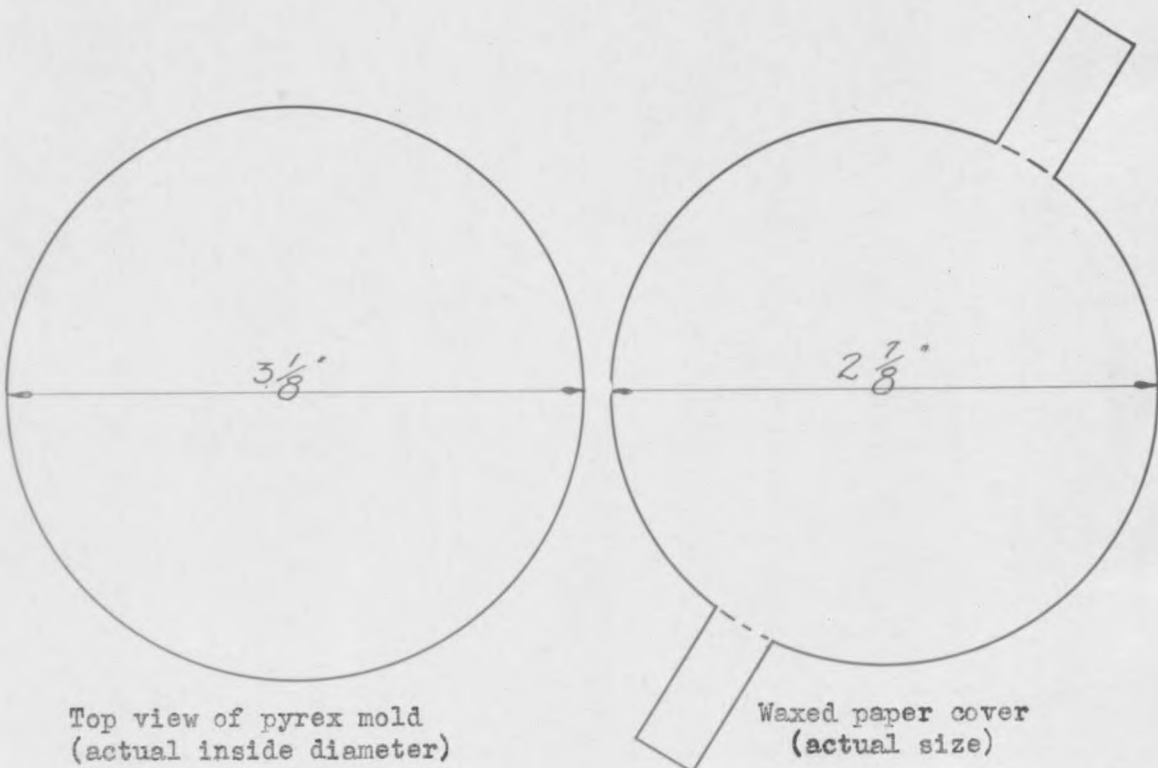
When first testing the gels for strength, it was found that a skin or thickened layer had formed on top of the gel which made testing less reliable so it was necessary to devise a method to eliminate skin effect. A round piece of waxed paper with tabs on two sides for lifting (fig. 1), was cut to fit the pyrex mold when it was partially filled with starch paste. The starch paste was poured into the mold, the waxed paper was laid on and then a thin layer of the starch paste was poured on top and the mold was covered with a petri dish lined with filter paper as before. When the mold had cooled, the waxed paper was lifted, leaving a delicate, skinless surface for testing.

The jelly tester, used for determining breaking strength of gels, was developed by Tarr and Baker at the Delaware Agricultural Experiment Station (5, 36) and has proved sufficiently accurate so that it has been used in a number of prominent laboratories (23, 44). The principle of the apparatus is simply that water flowing into a bottle creates an air pressure which forces a plunger into the gel and records the pressure of the system on a manometer, graduated in centimeters. Details for the construction of the tester will be found in fig. 2.

In preparing the gels for testing, three general methods were used. In the first, where corn starch was combined with distilled water or tap water, 12.5 grams of corn starch were weighed out and placed in a beaker of 600 cubic centimeter volume. With continuous stirring, water was added until the total volume was 250 cubic centimeters. The mixture was then heated over an electric burner so controlled that it reached the boiling point in ten minutes. After



Side view of pyrex mold (actual size)  
a. Wax paper cover



Top view of pyrex mold  
(actual inside diameter)

Waxed paper cover  
(actual size)

Fig. 1--Equipment used in making starch molds.

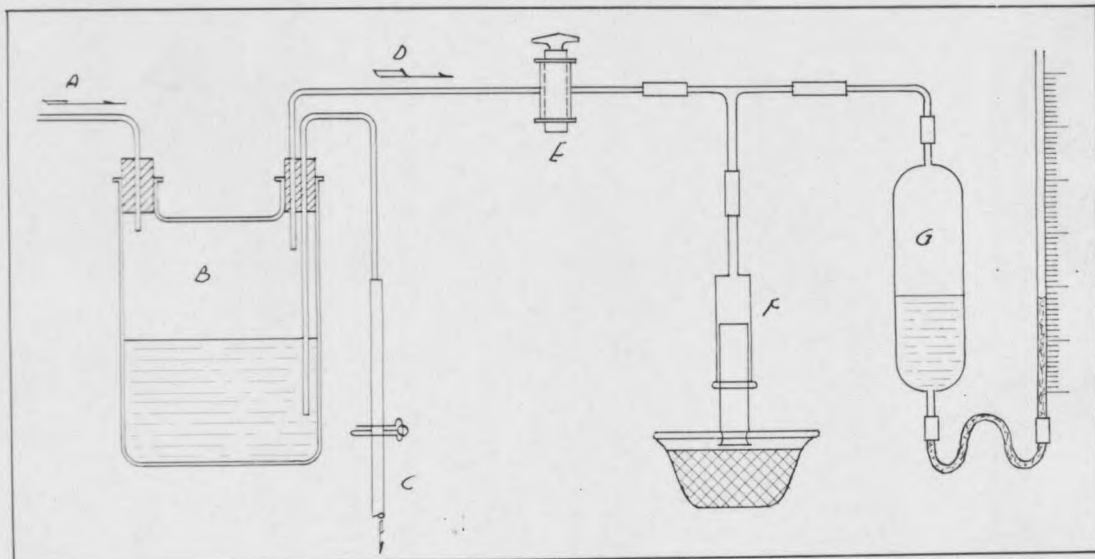


FIG 2 DIAGRAM OF JELLY STRENGTH TESTER

- A. Water inlet
- B. Woulff bottle of two liter capacity
- C. Siphon for water outlet
- D. Outlet tube for air
- E. Three way stopcock
- F. Luer syringe of 10 cubic centimeter capacity
- G. Manometer

this it was boiled for five minutes, removed from the burner, weighed and poured into the pyrex molds, covered with waxed paper and paste, cooled five minutes, then covered with a petri dish, fitted with filter paper to absorb excess moisture. When cool, the gels were placed in the refrigerator to stand 24 hours.

When the flour and water pastes were mixed it was necessary to use another method to prevent a lumpy product. A sample of 22.5 grams of flour was weighed out and mixed with 70 cubic centimeters of water to form a paste. The remaining amount of water (170 cubic centimeters) was heated to the boiling point and the flour-water paste stirred into it. The mixture was brought back to the boiling point and boiled for five minutes. The final weight was recorded and the paste treated as in the preceding description.

When milk was substituted for water as the liquid for both the corn starch and flour samples, the procedure was the same as described in the preceding paragraph except that milk was heated to the scalding point, between 80° and 85°C., and then the paste was added.

With the addition of 20 per cent of sugar (20 grams of sugar in 100 cubic centimeters of water), another change in method was necessary. The entire amount of liquid was weighed and heated to the boiling or scalding point. The starch and sugar were weighed, thoroughly mixed, and added to the hot liquid, stirring until the thickening process began. The paste was cooked for five minutes with occasional stirring to prevent burning, then treated as before. In the final series of tests where 60 per cent of sugar was added to the pastes, only one-half of the total weight of sugar was mixed with the thickening agent and added to the boiling water. The pastes were cooked as

before and the remaining 30 per cent of sugar added at the end of the cooking period. When 25 per cent of lemon juice was added to the pastes, the same procedure was followed, with the lemon juice being added after the final addition of sugar. The acid was not added during the cooking period as doubtless it would have caused some inversion of the sugar, resulting in a strong, bitter flavor. There is a possibility that the acid present throughout the cooking might have hydrolyzed the starch and thus lessened its thickening power.

The methods for the preparation of starch gels, which have been outlined in the preceding discussion are considered to be those which result in standard gels.

## RESULTS

The results obtained from the experimental tests, which were designed to determine the optimum proportions and conditions for the preparation of starch gels, are presented in tables III to IX. Preliminary tests were made using various amounts of corn starch in distilled water, to determine the percentage of starch that would yield a smooth, tender quivery gel which would be considered a standard. A 5 per cent corn starch paste (5 grams of corn starch in 100 cubic centimeters of water) made such a gel and the breaking strength of one hundred of these gels was determined on the jelly strength tester (table III, column a) (figure 3,a). Following this group of tests, it was desirable to find the percentage of flour cooked in distilled water which would produce gels having similar strengths. It was found that a 9 per cent flour gel had a mean breaking strength similar to that of the corn starch gel adopted as a standard (table III, column b) (figure 3,d).

Further tests were carried on using the same percentages of the two starches, 5 per cent corn starch and 9 per cent flour, but varying the kind of liquid by substituting tap water or milk for distilled water. This was done to determine in what way a change in liquid would affect the breaking strength of simple starch gels. When tap water was used as the liquid, the strength of the resulting corn starch gel was less than that of the standard gel while the flour gel strengths remained unchanged (table IV). When milk was used as the liquid (table V), the variation in breaking strength was marked. The strength of the corn starch gel was even less than when made with tap water. The flour gel showed an increase in stiffness and a much higher breaking strength.

Table III.--Breaking strength of starch gels prepared from pastes containing (a) five per cent of corn starch, (b) nine per cent of flour in distilled water.

| (a)                                      |           | (b)                                |           |
|------------------------------------------|-----------|------------------------------------|-----------|
| Breaking strength<br>of corn starch gels | Frequency | Breaking strength<br>of flour gels | Frequency |
| cm.                                      |           | cm.                                |           |
| 14.0                                     | 1         | 16.0                               | 1         |
| 16.0                                     | 1         | 16.5                               | 1         |
| 17.5                                     | 2         | 18.0                               | 3         |
| 18.0                                     | 2         | 18.5                               | 7         |
| 18.5                                     | 3         | 19.0                               | 3         |
| 19.0                                     | 2         | 19.5                               | 6         |
| 19.5                                     | 1         | 20.0                               | 10        |
| 20.0                                     | 5         | 20.5                               | 8         |
| 20.5                                     | 5         | 21.0                               | 7         |
| 21.0                                     | 4         | 21.5                               | 6         |
| 21.5                                     | 9         | 22.0                               | 11        |
| 22.0                                     | 4         | 22.5                               | 9         |
| 22.5                                     | 9         | 23.0                               | 5         |
| 23.0                                     | 6         | 23.5                               | 8         |
| 23.5                                     | 7         | 24.0                               | 2         |
| 24.0                                     | 17        | 24.5                               | 4         |
| 24.5                                     | 1         | 25.0                               | 2         |
| 25.0                                     | 5         | 25.5                               | 4         |
| 25.5                                     | 4         | 26.0                               | 1         |
| 26.0                                     | 1         | 26.5                               | 1         |
| 26.5                                     | 3         | 27.0                               | 1         |
| 27.0                                     | 4         |                                    |           |
| 27.5                                     | 2         |                                    |           |
| 28.5                                     | 1         |                                    |           |
| 30.5                                     | 1         |                                    |           |
|                                          | 100       |                                    | 100       |

Mean breaking strength =  
22.7  $\pm$  2.8  
Probable error = 1.9

Mean breaking strength =  
21.6  $\pm$  2.2  
Probable error = 1.5

Table IV.--Breaking strength of starch gels prepared from pastes containing (a) five per cent of corn starch (b) nine per cent of flour in tap water.

| (a)                                      |           | (b)                                |           |
|------------------------------------------|-----------|------------------------------------|-----------|
| Breaking strength<br>of corn starch gels | Frequency | Breaking strength<br>of flour gels | Frequency |
| cm.                                      |           | cm.                                |           |
| 10.0                                     | 4         | 18.0                               | 1         |
| 10.5                                     | 1         | 18.5                               | 1         |
| 11.5                                     | 6         | 19.0                               | 2         |
| 12.0                                     | 7         | 19.5                               | 3         |
| 12.5                                     | 10        | 20.0                               | 3         |
| 13.0                                     | 5         | 20.5                               | 4         |
| 13.5                                     | 7         | 21.0                               | 5         |
| 14.0                                     | 18        | 21.5                               | 8         |
| 14.5                                     | 9         | 22.0                               | 12        |
| 15.0                                     | 4         | 22.5                               | 12        |
| 15.5                                     | 6         | 23.0                               | 12        |
| 16.0                                     | 4         | 23.5                               | 5         |
| 16.5                                     | 3         | 24.0                               | 11        |
| 17.0                                     | 3         | 24.5                               | 5         |
| 17.5                                     | 2         | 25.0                               | 6         |
| 18.0                                     | 3         | 25.5                               | 6         |
| 18.5                                     | 1         | 26.0                               | 2         |
| 19.0                                     | 2         | 26.5                               | 1         |
| 19.5                                     | 3         | 27.5                               | 1         |
| 20.0                                     | 2         |                                    |           |
|                                          | 100       |                                    | 100       |

Mean breaking strength =  
 $14.3 \pm 2.4$   
 Probable error = 1.6

Mean breaking strength =  
 $22.8 \pm 1.9$   
 Probable error = 1.3

Table V.—Breaking strength of starch gels prepared from pastes containing (a) five per cent of corn starch (b) nine per cent of flour in milk.

| (a)                                      |            | (b)                                |            |
|------------------------------------------|------------|------------------------------------|------------|
| Breaking strength<br>of corn starch gels | Frequency  | Breaking strength<br>of flour gels | Frequency  |
| cm.                                      |            | cm.                                |            |
| 9.0                                      | 1          | 33.5                               | 2          |
| 9.5                                      | 1          | 34.0                               | 1          |
| 10.0                                     | 5          | 35.0                               | 3          |
| 10.5                                     | 3          | 35.5                               | 1          |
| 11.0                                     | 3          | 36.0                               | 6          |
| 11.5                                     | 8          | 36.5                               | 6          |
| 12.0                                     | 9          | 37.0                               | 8          |
| 12.5                                     | 5          | 37.5                               | 5          |
| 13.0                                     | 10         | 38.0                               | 9          |
| 13.5                                     | 7          | 38.5                               | 7          |
| 14.0                                     | 7          | 39.0                               | 9          |
| 14.5                                     | 9          | 39.5                               | 4          |
| 15.0                                     | 4          | 40.0                               | 11         |
| 15.5                                     | 5          | 40.5                               | 4          |
| 16.0                                     | 3          | 41.0                               | 5          |
| 16.5                                     | 5          | 41.5                               | 2          |
| 17.0                                     | 2          | 42.0                               | 9          |
| 17.5                                     | 4          | 42.5                               | 2          |
| 18.0                                     | 3          | 43.0                               | 4          |
| 18.5                                     | 4          | 44.0                               | 2          |
| 19.5                                     | 1          |                                    |            |
| 21.0                                     | 1          |                                    |            |
|                                          | <u>100</u> |                                    | <u>100</u> |

Mean breaking strength =  
13.9 ± 2.5  
Probable error = 1.7

Mean breaking strength =  
38.9 ± 2.4  
Probable error = 1.6

Table VI.--Breaking strength of starch gels prepared from pastes containing (a) five per cent of corn starch (b) seven and one-half per cent of flour in tap water, with twenty per cent of sugar added in both cases.

| (a)                                        |            | (b)                                        |            |
|--------------------------------------------|------------|--------------------------------------------|------------|
| Breaking strength<br>of corn starch gels   | Frequency  | Breaking strength<br>of flour gels         | Frequency  |
| cm.                                        |            | cm.                                        |            |
| 12.5                                       | 1          | 15.0                                       | 3          |
| 13.0                                       | 1          | 15.5                                       | 3          |
| 13.5                                       | 3          | 16.0                                       | 8          |
| 14.0                                       | 1          | 16.5                                       | 3          |
| 14.5                                       | 5          | 17.0                                       | 15         |
| 15.0                                       | 3          | 17.5                                       | 14         |
| 15.5                                       | 5          | 18.0                                       | 9          |
| 16.0                                       | 8          | 18.5                                       | 20         |
| 16.5                                       | 6          | 19.0                                       | 9          |
| 17.0                                       | 4          | 19.5                                       | 4          |
| 17.5                                       | 7          | 20.0                                       | 4          |
| 18.0                                       | 5          | 20.5                                       | 3          |
| 18.5                                       | 7          | 21.0                                       | 1          |
| 19.0                                       | 6          | 21.5                                       | 1          |
| 19.5                                       | 7          | 22.0                                       | 3          |
| 20.0                                       | 7          |                                            |            |
| 20.5                                       | 9          |                                            |            |
| 21.0                                       | 7          |                                            |            |
| 21.5                                       | 3          |                                            |            |
| 22.0                                       | 3          |                                            |            |
| 22.5                                       | 1          |                                            |            |
| 23.0                                       | 1          |                                            |            |
|                                            | <u>100</u> |                                            | <u>100</u> |
| Mean breaking strength =<br>18.1 $\pm$ 2.5 |            | Mean breaking strength =<br>18.0 $\pm$ 1.5 |            |
| Probable error = 1.7                       |            | Probable error = 1.0                       |            |

Table VII.—Breaking strength of starch gels prepared from pastes containing (a) five and three-tenths per cent corn starch (b) six and three-tenths per cent flour in milk, with twenty per cent of sugar added in both cases.

| (a)                                      |           | (b)                                |           |
|------------------------------------------|-----------|------------------------------------|-----------|
| Breaking strength<br>of corn starch gels | Frequency | Breaking strength<br>of flour gels | Frequency |
| cm.                                      |           | cm.                                |           |
| 13.5                                     | 1         | 14.0                               | 2         |
| 14.0                                     | 3         | 14.5                               | 1         |
| 14.5                                     | 1         | 15.0                               | 3         |
| 15.0                                     | 3         | 15.5                               | 2         |
| 15.5                                     | 3         | 17.0                               | 1         |
| 16.0                                     | 4         | 17.5                               | 4         |
| 16.5                                     | 7         | 18.0                               | 3         |
| 17.0                                     | 1         | 18.5                               | 2         |
| 17.5                                     | 2         | 19.0                               | 4         |
|                                          |           | 19.5                               | 3         |
|                                          | <u>25</u> |                                    | <u>25</u> |

Mean breaking strength =  
15.7 ± 1.1  
Probable error = 0.8

Mean breaking strength =  
17.2 ± 1.9  
Probable error = 1.3

Table VIII.--Breaking strength of starch gels prepared from pastes containing (a) seven per cent of corn starch (b) nine per cent of flour in tap water with sixty per cent of sugar added in both cases.

| (a)                                      |           | (b)                                |           |
|------------------------------------------|-----------|------------------------------------|-----------|
| Breaking strength<br>of corn starch gels | Frequency | Breaking strength<br>of flour gels | Frequency |
| cm.                                      |           | cm.                                |           |
| 14.5                                     | 1         | 17.0                               | 1         |
| 15.0                                     | 1         | 17.5                               | 2         |
| 15.5                                     | 2         | 18.0                               | 2         |
| 16.0                                     | 3         | 18.5                               | 4         |
| 16.5                                     | 8         | 19.0                               | 2         |
| 17.0                                     | 4         | 19.5                               | 5         |
| 17.5                                     | 1         | 20.0                               | 2         |
| 18.0                                     | 1         | 20.5                               | 1         |
| 18.5                                     | 1         | 21.0                               | 3         |
| 19.0                                     | 2         | 21.5                               | 1         |
| 20.0                                     | 1         | 22.5                               | 1         |
|                                          |           | 23.0                               | 1         |
|                                          | <u>25</u> |                                    | <u>25</u> |

Mean breaking strength =  
 $16.8 \pm 1.2$   
 Probable error = 0.9

Mean breaking strength =  
 $19.5 \pm 1.5$   
 Probable error = 1.0

Table IX.--Breaking strength of starch gels prepared from pastes containing (a) eight and one-half per cent of corn starch (b) eleven and one-half per cent of flour in tap water, with sixty per cent of sugar and twenty-five per cent of lemon juice added in both cases.

| (a)                                      |           | (b)                                |           |
|------------------------------------------|-----------|------------------------------------|-----------|
| Breaking strength<br>of corn starch gels | Frequency | Breaking strength<br>of flour gels | Frequency |
| cm.                                      |           | cm.                                |           |
| 14.5                                     | 1         | 18.0                               | 1         |
| 15.0                                     | 2         | 18.5                               | 1         |
| 16.0                                     | 3         | 19.0                               | 3         |
| 16.5                                     | 1         | 19.5                               | 4         |
| 17.0                                     | 1         | 20.0                               | 4         |
| 17.5                                     | 4         | 20.5                               | 3         |
| 18.0                                     | 2         | 21.0                               | 2         |
| 18.5                                     | 2         | 21.5                               | 2         |
| 19.0                                     | 1         | 22.0                               | 2         |
| 19.5                                     | 1         | 22.5                               | 1         |
| 20.0                                     | 1         | 23.0                               | 2         |
| 20.5                                     | 2         |                                    |           |
| 21.0                                     | 1         |                                    |           |
| 22.0                                     | 1         |                                    |           |
| 22.5                                     | 1         |                                    |           |
| 23.0                                     | 1         |                                    |           |
|                                          | <u>25</u> |                                    | <u>25</u> |

Mean breaking strength =  
18.2  $\pm$  2.4  
Probable error = 1.6

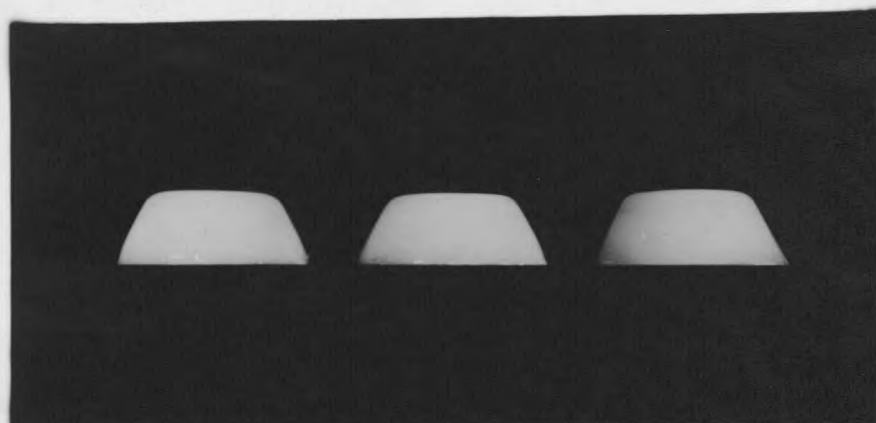
Mean breaking strength =  
20.4  $\pm$  1.4  
Probable error = 0.9

After the series of simple gels had been completed, tests on gels more closely approximating those found in puddings and pie fillings, were made. In studying the collected recipes (tables I and II), it was noted that three proportions of sugar were commonly used; 10 grams per 100 grams of liquid for puddings, 20 grams per 100 grams of liquid in cream pie fillings, and 60 grams per 100 grams of liquid in lemon pie fillings.

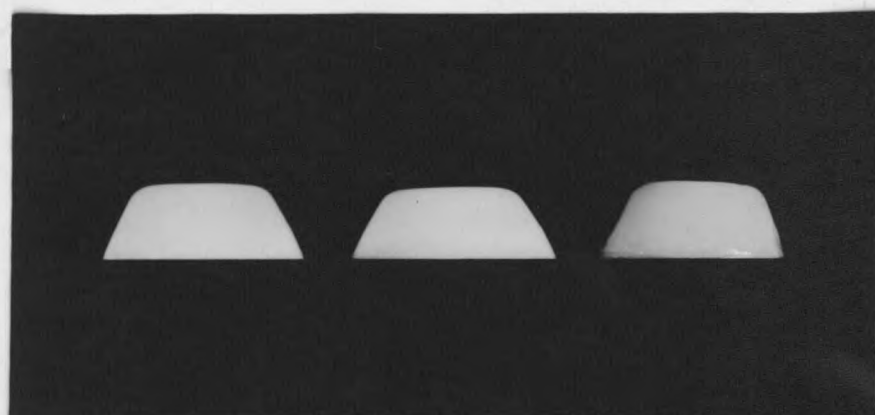
By comparing the strengths of gels made with corn starch or flour in tap water, both before and after the addition of 20 per cent of sugar (tables IV and VI), it can be seen that the sugar increased the gel strength. This was desirable in the case of the corn starch (figure 3,b), as it will be noted in table IV, that, without sugar, its strength was less than that of the standard gel. In the flour gels, the added sugar gave too stiff a product and it was necessary to decrease the amount of flour to 7.5 per cent to obtain a standard gel, with a breaking strength similar to that of the corn starch gels (table VI) (figure 3,e).

When milk was substituted for tap water in the series containing 20 per cent of sugar (table VII) it seemed to decrease the stiffness of the corn starch gels and increase the strength of the flour gels to such an extent that it was desirable to raise the percentage of the former to 5.5 and to lower the latter to 6.5 per cent. The resulting gels were very tender and smooth and could be considered a desirable standard for cream pie fillings (figure 4,a,b).

In the preparation of gels containing 60 per cent of sugar (60 grams of sugar in 100 cubic centimeters of liquid), some difficulties were encountered, as the product was cloudy and sticky regardless of the amount of

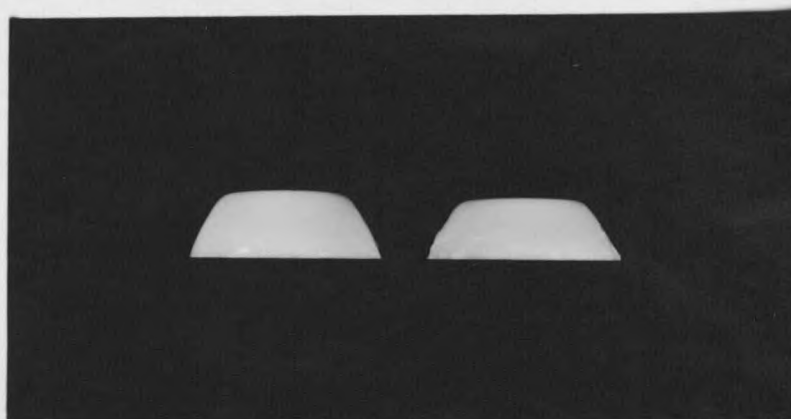


|                   |                |                |
|-------------------|----------------|----------------|
| (a)               | (b)            | (c)            |
| 5% Corn starch    | 5% Corn starch | 7% Corn starch |
| No sugar          | 20% Sugar      | 60% Sugar      |
| 100% Dist'd water | 100% Tap water | 100% Tap water |



|                   |                |                |
|-------------------|----------------|----------------|
| (d)               | (e)            | (f)            |
| 9% Flour          | 7.5% Flour     | 9% Flour       |
| No sugar          | 20% Sugar      | 60% Sugar      |
| 100% Dist'd water | 100% Tap water | 100% Tap water |

Fig.3--Standard starch gels containing various percentages of starch and sugar in one hundred per cent of distilled or tap water.



(a)  
5.3% Corn starch  
20% Sugar  
100% Milk

(b)  
6.3% Flour  
20% Sugar  
100% Milk



(c)  
8.5% Corn starch  
60% Sugar  
25% Lemon juice  
100% Tap water

(d)  
11.5% Flour  
60% Sugar  
25% Lemon juice  
100% Tap water

Fig. 4--Standard starch gels containing various percentages of starch and sugar in one hundred per cent of liquid, the gels shown in the lower plate containing added fruit acid.

starch used. Several methods for combining ingredients were tried. Finally it was found that by withholding half of the sugar and adding it at the completion of the cooking period, the difficulty was overcome. This method seemed to allow the starch granules to swell more easily and take up more water, resulting in a tender, quivery gel. The first group of tests where a high percentage of sugar was used (table VIII), indicated that sugar appeared to have a greater depressing effect upon the thickening property of corn starch than of flour. In order to obtain standard gels, the corn starch had to be increased to 7 per cent while the flour remained at 9 per cent (figure 3,c,f). This work was preliminary to the preparation of gels similar to lemon pie fillings in which 25 per cent of lemon juice (25 grams lemon juice per 100 cubic centimeters of liquid) was also added to the pastes containing 60 per cent of sugar in tap water. With the addition of the fruit acid to the pastes, the amount of corn starch required was 8.5 per cent and flour, 11.5 per cent to produce standard gels (table IX) (figure 4,c,d). However, these increases in starch were necessitated by the dilution of the paste when the fruit acid was added. Otherwise, the acid appeared to have no effect upon the thickening property of corn starch or flour.

All of the gels prepared for the tests were cooked by direct heat at a temperature of  $94^{\circ}\text{C}$ . A higher temperature could not be attained because this work was carried on in a laboratory where the altitude was 4700 feet above sea level and the boiling point of water was about  $95.5^{\circ}\text{C}$ . Some preliminary work was done in cooking starch pastes in double boilers similar to the method frequently used in home cooking. However, the highest temperature that could be reached in the paste while cooking in the double

boiler was 88.5°C. and this did not seem adequate for the complete gelatinization of the starch granules.

The question of the temperature necessary to bring about complete starch gelatinization during cooking led to some further tests. Five per cent corn starch pastes made with tap water were cooked over direct heat to various temperatures. Beginning at 50°C., a 16 milliliter sample was withdrawn from one of the cooking pastes, placed in a centrifuge tube and centrifuged for three minutes. This was repeated with the various pastes at five degree intervals until a temperature of 90°C. was reached. By examining the centrifuged paste samples, it was possible to determine at what temperature complete gelatinization occurred. When incomplete, there was a definite line of demarcation between the swollen starch granules and the liquid. The results shown in figure 5, indicate that complete gelatinization did not take place until a temperature of about 90°C. had been reached. It is therefore obvious that cookery of starch pastes in double boilers, where a temperature of only 88.5°C. was reached, could not be employed successfully and that at higher altitudes, cookery over direct heat is essential.

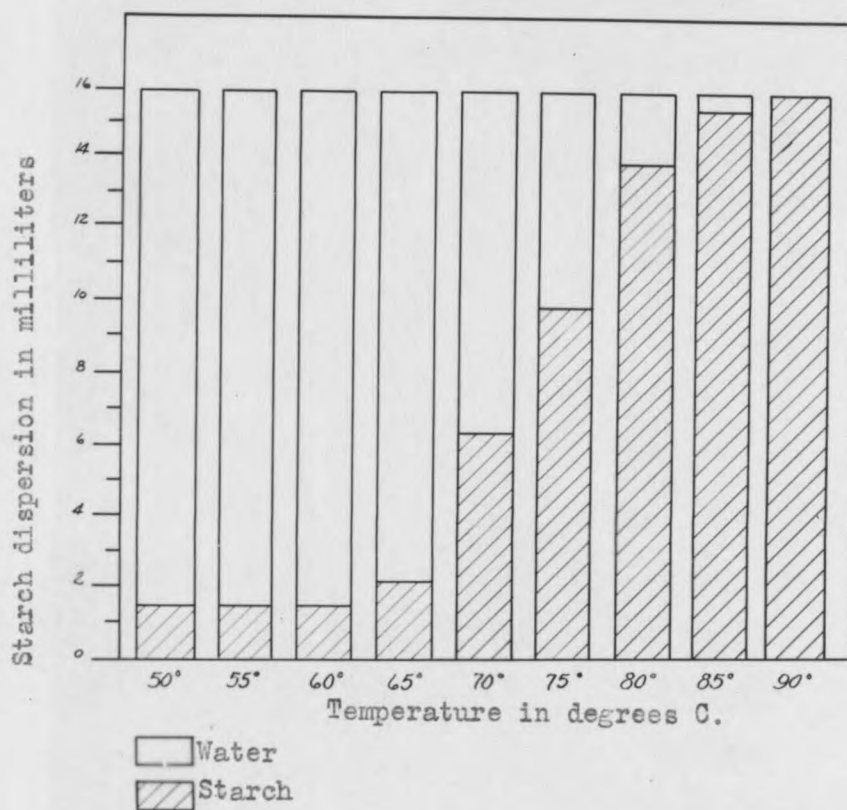


Fig.5--Dispersion of identical amounts of corn starch in identical volumes of water heated to various temperatures and centrifuged.

## DISCUSSION OF RESULTS

In beginning this study, it seemed desirable to develop a standard for starch gels to be used as a basis for comparison in further work. It was found that by cooking a starch paste containing 5 per cent of a given corn starch in distilled water at a temperature of  $94^{\circ}\text{C}$ . for five minutes, such a gel could be produced. This gel would hold its shape when removed from a mold, did not undergo syneresis or "weeping", was smooth in texture, and would quiver when gently shaken. The mean breaking strength of one hundred of these gels, thus prepared, was  $22.7 \pm 2.8$  when using the Delaware jelly strength tester. This agrees very well with the work reported by Woodruff and McMasters (14) who also found that a 5 per cent corn starch paste, when brought to a temperature of  $95^{\circ}\text{C}$ . by immersing in a boiling water bath, would set to a standard gel upon cooling. It will be noted that they used a boiling water bath comparable to a double boiler but they were working at an altitude slightly above sea level. In the present study it was necessary to use direct heating on account of the higher altitude (about 4700 feet above sea level) where the boiling point of water is around  $95.5^{\circ}\text{C}$ . This practice has been recommended by Hughes et al (14) who state that cooking starch pastes over direct heat for 5 minutes at  $95^{\circ}\text{C}$ . produces 95 per cent gelatinization of the starch.

When an all-purpose flour was used as the source of starch, a 9 per cent flour paste in distilled water was required to produce a gel having standard qualities and a similar breaking strength. It is an interesting fact that 9 grams of flour seemed to have thickening properties equivalent to 5 grams of corn starch (table III). The corn starch contained 87 per cent

or 4.4 grams of actual starch, while the flour contained 75.9 per cent or 6.8 grams of actual starch. It is therefore apparent that some factor depresses the thickening property of the starch in the flour. The only points of difference in the composition of the flour and corn starch were the presence of more protein and more ash in the flour.

When tap water was substituted for distilled water in making gels, the strength of the corn starch gel was less than with distilled water, while the strength of the flour gel was the same as that with distilled water (table IV). Since the only variable factor was the impurities in the water, it would appear that the salts present in the tap water were responsible for the results obtained. A possible explanation for the variations in gel strength may lie in the fact that the corn starch contained a very small amount of ash (0.011 per cent) while the flour contained 0.36 per cent of ash. Samuel (29) has shown that ash has a depressing effect upon starch gelatinization. When he added calcium salts to starch pastes, they inhibited the molding of the starch gels.

In the present study, corn starch pastes made with distilled water contain practically no salts. However, in flour pastes made with distilled water considerable ash is found. This may be the reason that the starch in the flour does not exhibit the same thickening power as that in the corn starch, which has been previously noted. When the corn starch paste is made with tap water, the decreased strength of its gel may be due to the presence of ash in the water, but no change is seen in the gel strength of the flour paste in tap water for ash was also present when distilled water was used.

When milk was substituted for distilled water, the strength of the

corn starch gel was again lower but very similar to that made with tap water (table V). However, the strength of the flour gel was much higher than the standard gel made with distilled or tap water. Again, the presence of ash in the milk may be responsible for the lower strength of the corn starch gel. The greater strength of the flour gel made with milk is more difficult to explain. Possibly the presence of solids in the milk combined with the flour solids may account for the increase in gel strength.

With the addition of 20 per cent of sugar to the corn starch and flour pastes made with tap water, an increase in gel strength was noted in both cases. But when milk was used as the liquid, the corn starch gel was again lower in strength.

If the added sugar was increased to 60 per cent in pastes made with tap water, the resulting gels were decidedly weaker. These pastes were somewhat similar in proportion to those used by Nevenzel (22) and she attributed their weakness to a depressing effect of high sugar concentration on starch gelatinization. She believed that the starch granules were unable to swell to their full extent when large amounts of sugar were present and found it necessary to double her percentages of corn starch and flour in order to produce standard gels. Here, such increases in starch and flour did not seem necessary. In fact, raising the percentage of corn starch from 5 to 7 per cent resulted in a standard product, while no increase was made in the percentage of flour. This might be explained by noting that Nevenzel used cooking periods of forty to forty-five minutes, while the present work found a short cooking period of five minutes more desirable. Also a different method of combining ingredients seemed to improve gel formation when large

amounts of sugar were used. If half of the sugar was withheld from the paste during the cooking process and added at the end of the cooking period<sup>1</sup>, the depressing effect was not as great as if all the sugar had been added at the beginning. As a result, smaller amounts of starch could be used for it could swell more readily, absorb greater amounts of water and produce gels that were transparent and tender.

With addition of fruit acid (lemon juice) to starch pastes containing 60 per cent of sugar, there was no apparent effect on the breaking strength of the gels. Although in table IX, corn starch and flour were used at 8.5 and 11.5 per cent respectively, these increases in starch were made only to take care of the dilution of the paste caused by the liquid in the acid.

The proportions finally adopted as producing a standard gel for cream pie fillings were 5.3 grams of corn starch or 6.3 grams of flour in 100 cubic centimeters of milk, with 20 grams of sugar added at the beginning of the cooking period. For a lemon pie filling, 8.5 grams of corn starch or 11.5 grams of flour in 100 cubic centimeters of water were used, with 30 grams of sugar added at the beginning of the cooking period and 30 grams of sugar and 25 cubic centimeters of lemon juice added at the end of the cooking period. When these figures are converted into proportions commonly used in cookery, the amounts are as follows:

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<sup>1</sup>/This suggestion was found in a pamphlet sent out by the National Starch Products, Inc., 820 Greenwich St., New York. 1940.

Basis for cream pie filling: Use  $1\frac{1}{2}$  tablespoons corn starch or 2 tablespoons plus 1 teaspoon flour in 1 cup of milk with  $\frac{1}{4}$  cup of sugar added.

Basis for lemon pie filling: Use  $2\frac{1}{2}$  tablespoons corn starch or 4 tablespoons flour with 1 cup of water, adding  $\frac{3}{8}$  cup sugar during the cooking period and  $\frac{3}{8}$  cup sugar plus  $\frac{1}{4}$  cup lemon juice at the end of cooking period.

From this study, it would appear that in cooking starch pastes at higher altitudes, it is imperative to use direct heat instead of a boiling water bath so that a higher cooking temperature may be reached and more complete starch gelatinization may be obtained. Whenever higher concentrations of sugar are used with the starch pastes, it is advisable to include only half of the sugar during the cooking process and thus prevent the depressing or weakening effect of sugar on the strength of the resulting gel. If these recommendations are followed, starch cookery at a higher altitude does not demand increased percentages of starch.

#### SUMMARY AND CONCLUSIONS

1. A series of fourteen types of starch gels, varying in composition, were prepared under high altitude conditions for the purpose of studying their relative consistencies.
2. The qualities of a starch gel that indicate desirable consistency were established. Such a gel holds its shape when removed from a mold, does not show syneresis, is smooth in texture, and quivers when gently shaken. The measurement of gel strength using the Delaware jelly strength tester was adopted as a definite indication of consistency.
3. It was found that a starch paste containing 5 per cent of a given corn starch in distilled water, cooked over direct heat at a temperature of  $94^{\circ}\text{C}$ . for five minutes would produce a gel having these desired qualities and a breaking strength of  $22.7 \pm 2.8$  centimeters of hydrastatic pressure. This was adopted as the standard gel.
4. A 9 per cent flour paste in distilled water, cooked under the above conditions, produced a gel similar to the standard gel.
5. When tap water was substituted for distilled water in making starch gels, the strength of the corn starch gel was lower than that of the standard, while the flour gel strength remained the same as the standard.
6. When milk was substituted for distilled water, the strength of the corn starch gel was as low as when made with tap water, but the strength of the flour gel was greater than that made with tap water.
7. There is an indication that the presence of ash or salts in tap water, milk, and also in flour may have a depressing effect on the thickening

property of starch.

8. An increase in gel strength was noted with the addition of 20 per cent of sugar to the corn starch and flour pastes made with tap water.
9. When the sugar was increased to 60 per cent in starch pastes made with tap water, the resulting gels were decidedly weaker than a standard gel.
10. The addition of fruit acid to corn starch and flour pastes containing 60 per cent of sugar had no apparent effect on the strength of the gels.
11. From this study, it would appear that, in cooking starch pastes at higher altitudes, direct heat instead of a boiling water bath must be used to secure complete starch gelatinization.
12. When higher concentrations of sugar are used in making starch gels, a standard product is obtained if only half of the sugar is included during the cooking process, with the remainder added at the end of the period. This seems to insure better starch gelatinization.

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A study of the consistency  
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