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Starch Gelatinization as Affected by Lipid

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To the Graduate Council:

I am submitting herewith a thesis written by Nina Sue Berry entitled "Starch Gelatinization as Affected by Lipid." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Food Science and Technology.

Ada Marie Campbell, Major Professor

We have read this thesis and recommend its acceptance:

Bernadine Meyer, Mary Rose Gram

Accepted for the Council:
Dixie L. Thompson

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

December 15, 1971

To the Graduate Council:

I am submitting herewith a thesis written by Nina Sue Berry entitled "Starch Gelatinization as Affected by Lipid." I recommend that it be accepted for nine hours of credit in partial fulfillment of requirements for the degree of Master of Science, with a major in Food Science.

Ada Marie Campbell
Major Professor

We have read this thesis and recommend its acceptance:

Bernadine Meyer

Mary Rose Gram

Accepted for the Council:

Hilton A. Smith
Vice Chancellor for
Graduate Studies and Research

STARCH GELATINIZATION AS AFFECTED BY LIPID

A Thesis

Presented to

the Graduate Council of

The University of Tennessee

In Partial Fulfillment

of the Requirements for the Degree

Master of Science

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by

Nina Sue Berry

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ABSTRACT

Gelatinization of untreated and defatted corn starch as affected by added elaidinized and non-elaidinized olive oil was investigated. The experimental plan was a 2 x 3 factorial, which included no added lipid as well as elaidinized and non-elaidinized olive oil. The added lipids were used at the level of 6 mg per gram of starch in pastes containing 8 g of starch per 100 ml of liquid. Seven replications were completed. Suspensions were heated in the Brabender Amylograph from 25°C to 92.5°C (45 min) and held at 92.5°C for 15 min. Data taken from each amylogram included: the transition temperature, the temperature of maximum viscosity, viscosity after 45 min of heating and terminal viscosity. Photomicrographs were made of samples of each paste taken before heating and at several stages during heating. Pastes were poured while hot into custard cups and held at room temperature for 24 hr. Penetrability measurements were made on the gels. Viscosity and penetrability data, as well as transition temperature, were subjected to analysis of variance.

Defatting the corn starch resulted in reduced transition temperature ($P < 0.01$), reduced maximum viscosity ($P < 0.01$), essentially unaffected terminal viscosity and increased gel strength ($P < 0.01$). The photomicrographs indicate that possibly the granules of defatted starch swelled more freely and rapidly and showed more implosion than the granules of untreated starch. The greater implosion could explain both lower maximum viscosity and higher gel strength of samples containing defatted

starch. The effect of added lipid was limited to increased gel strength and only in the case of untreated starch. The photomicrographs show a possible protective effect of lipid on the granules so that in the presence of lipid, granules were permitted to implode sufficiently but not too extensively and fragmentation did not occur during the holding period. The interaction between starch treatment and lipid was significant ($P < 0.01$). No clear-cut differences were found between elaidinized and non-elaidinized lipid. Possibly future work should involve the addition of higher concentrations of lipid than used in this study.

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CHAPTER I

INTRODUCTION

Corn starch is important for both home and industrial use as a thickening agent because of its ability to swell to a paste of moderate viscosity when heated in the presence of water. It is of particular importance in the formulation of pie fillings and sauces.

Upon cooling, a corn starch paste may form an opaque and moderately firm gel. This gelling property contributes to the firmness and structure of various products having corn starch in their formulas. Since textural quality is an important aspect of starchy foods, the effects of various treatments and added ingredients on viscosity and gel strength have been studied extensively.

Review of the literature reveals apparently conflicting information on the effects of lipids on the gelatinization of starch, possibly because of the variety of approaches and conditions among the investigations. Studies have been reported on starches from different sources and on starches that have undergone various treatments such as defatting to remove naturally bound lipids. Work also has involved the reimpregnation of defatted cereal starches with lipids, addition of lipids to non-defatted cereal starches and addition of lipids to root or tuber starches that are relatively lipid-free. Some researchers have separated the extracted lipids from starch into polar and nonpolar fractions and investigated the effects of the fractions on the gelatinization properties of starch.

Some investigators have attempted to explain their results on the basis of actual penetration of lipid molecules into starch granules. Lipid treatments that change molecular conformation thus might be expected to provide information as to whether the effect of lipid is a surface effect or whether it involves an interaction within the granule. Elaidinization is such a treatment; whereas an unsaturated fatty acid chain with the cis configuration is folded back on itself, the same chain with the trans configuration is extended.

The present study was undertaken, therefore, to investigate the effect of elaidinized lipid on the gelatinization of corn starch. Olive oil was chosen as the lipid to be used because it contains 65-85% oleic acid (Swern, 1964), and the structural configuration of mono-unsaturated fatty acids readily lends itself to rearrangement from the cis to the trans configuration, possibly permitting more ready access to granule interiors and also leaving more of the fatty acid chain available for complexing with linear starch chains. Some of the corn starch was defatted in order to determine whether the effect of added lipid was dependent on the presence of naturally occurring lipids in the starch.

CHAPTER II

REVIEW OF LITERATURE

Corn starch is constituted of linear and branched molecules, arranged in the granule in such a manner that crystalline regions occur as a result of hydrogen bonding between parallel chains. Both the linear and branched molecules are polymers of glucose. In the linear fraction, amylose, the glucose units are bonded through α1-4 glycosidic linkages. In the branched fraction, amylopectin, α1-6 linkages provide the branching points of chains having α1-4 glycosidic bonds. The degree of polymerization is much greater in amylopectin than in amylose. Amylopectin also is more abundant than amylose, making up as much as 75% of the corn starch granule (Schoch, 1962; Leach et al., 1959).

In addition to the crystalline, or "micellar," regions, all cereal starches contain small amounts of fatty materials. Corn starch contains 0.6-0.7% lipid, whereas wheat starch contains about 0.5%. The fatty material in starches appears to be complexed with the linear fraction in native starch, and its presence significantly affects such properties as granule swelling, enzyme conversion and iodine affinity (Schoch, 1945, 1964). Schoch recommended pretreatment of starch to remove fat before use in fundamental investigation.

Defatted corn starch, according to Schoch (1964), was more readily dispersed, gave a clearer paste and possessed more pronounced gelling qualities than did the original raw starches. Schoch (1962) reported also that defatting corn starch raised the pH slightly.

Composition of lipid extracted from starch varies with the extracting solvent. Glycerides predominated in extracts obtained from corn starch with carbon tetrachloride (Rogols et al., 1969), but cereal starches contain lipid materials that cannot be removed with nonpolar fat solvents such as ether and carbon tetrachloride (Schoch, 1945). Schoch (1964) recommended the use of relatively polar fat solvents such as methyl Cellosolve for defatting starch. Medcalf et al. (1968) extracted both polar and nonpolar lipids from corn starch but did not report either the relative proportions of the fractions or their specific composition.

Gelatinization

Gelatinization comprises all of the changes that occur when starch is heated in water. When heat is applied to an aqueous starch suspension, the amorphous starch between the crystalline, or "micellar," regions within the granule is readily hydrated, permitting each granule to swell. The micellar regions hold the granule together because their tight structures resist disruption; therefore, dispersion of individual starch molecules does not occur to an appreciable extent until late in the gelatinization process. Swelling of the granules results in increased viscosity of the suspension, primarily because of the greatly increased surface area of the granules. With continued swelling, the crystallinity disappears and the granule structure becomes sufficiently "open" to permit loss of some linear molecules into the dispersion medium (Schoch, 1969). A treatment that causes early loss of crystallinity may result in granule fragmentation if heating time is not reduced and if mechanical stress is considerable.

The extent of granule swelling, as indicated by the change in viscosity of the starch suspension, can be measured with the amylograph (Anker and Geddes, 1944). An appropriate amount of starch is slurried in distilled water, transferred into the amylograph bowl and heated at a rate of 1.5°C per min to 92-95°C with continuous stirring at a constant rate. Increasing resistance to stirring, representing increasing viscosity, is recorded as a curve that begins on the base-line of the chart. The first point of interest on the curve ("amylogram") is that at which the curve leaves the base-line; this point is referred to as the stage of initial viscosity and the temperature at which it occurs, as the transition temperature. The curve rises gradually as the heating is continued and the granules swell to the point of peak or maximum viscosity of the suspension. This stage of maximum viscosity is the one through which most pastes must be cooked in order to be usable (Mazurs et al., 1957).

After the specified heating period, usually 45 min, the paste is held for 15 min without further temperature change but with continued stirring for determining the stability of the starch suspension. The "terminal viscosity," represented by the curve height after the holding period, is an indication of stability. Often the lowering of viscosity during the holding period in the amylograph can be attributed to granule disintegration resulting from the mechanical action of stirring (Crossland and Favor, 1948).

Unmodified corn starch has a peculiar 2-stage swelling, indicating the presence of two sets of bonding forces within the granule (Schoch, 1962; Kite et al., 1957; Leach et al., 1959). This 2-stage swelling is detected only if the amylograph testing is made very sensitive to early viscosity change. Addition of carboxymethyl cellulose, which increases initial viscosity and is not affected by heat, provides one means of increasing sensitivity.

Kite et al. (1957) found corn starch pastes to have a low maximum viscosity and high cooking stability as compared with non-cereal starches. Mazurs et al. (1957) reported that swollen corn starch granules evidenced greater resistance to mechanical disintegration than did potato starch granules. The decreased viscosity that did occur in a corn starch paste held at 95°C for 1 hr occurred during the first 15 min of holding.

Gelation

Gelation occurs during cooling of the gelatinized starch suspension, or "paste," if conditions permit. Schoch (1962) stated that starch granules do not collapse or burst during gelatinization as is implied by many writers, but tend to implode after swelling sufficiently to lose amylose. The presence of amylose in the dispersion medium facilitates gelation because the linear molecules align themselves in an orderly arrangement, possibly including amylopectin chains protruding from granules. Hydrogen bonding between linear chains results in formation of a gel.

Upon storage and aging of the gel, increasing association of the starch molecules results in retrogradation. This phenomenon involves development of crystallinity and decreased water-holding capacity. Listed among the conditions that favor retrogradation are low temperature and high concentrations of dispersed amylose (Pelshenke and Hampel, 1962).

Effects of Lipids on Starch

The small amount of naturally occurring lipid present in corn starch tends to restrict granule swelling because of the helical complex existing with the linear starch fraction (Schoch, 1969). Leach et al. (1959) found that defatted corn starch tended to swell more freely and uniformly than untreated starch. Collison (1968) indicated that the extent of swelling is increased by removal of lipid.

Properties of defatted starch can be modified greatly by addition of lipids. Schoch (1969) stated that the helical complex that is formed between lipid and linear starch chains restricts granule swelling but he did not indicate whether the complexing occurs at the surface. Earlier (Schoch, 1945) he referred to the "water-proofing" effect of adsorbed lipid. Medcalf et al. (1968) added lipids to defatted starch in order to determine whether polar and nonpolar lipids exert different effects on the pasting characteristics of the starch. When defatted starch was impregnated with lipids, maximum paste viscosity was lowered by polar lipid and increased by nonpolar lipid. They theorized that polar lipids retard the penetration of water into the granule in the early stage of gelatinization by preferentially complexing with the linear chains in the amorphous region; the effect is a decreased extent of granule swelling. According to their theory, nonpolar lipid not only does not have this retarding effect on granule swelling, but it has a protective effect on the granule structure after swelling has occurred; they attribute the protective effect to a decreased disruption of the micellar regions, which are largely responsible for maintenance of granule integrity.

Additions to undefatted starch have been reported to affect rate and extent of gelatinization. Osman and Dix (1960) reported that adding oil to untreated corn starch slightly lowered the transition temperature and markedly lowered the temperature of maximum viscosity. If a surfactant, rather than oil, were added, gelatinization was greatly retarded; maximum viscosity could not be reached even at 95°C. Tenney et al. (1968) reported that the addition of the surfactant stearoyl-2-lactylate to cereal starches increased the transition temperature. Longley and Miller (1971) found monoglycerides to reduce the extent of gelatinization. They suggested that the effect might be either through a reaction occurring within the swelling granule or through a reduced rate of water absorption. The effect increased with length of the fatty acid chain.

Little information was found in the literature concerning the effect of lipid on gelation of starch pastes. Schoch (1969) stated that a paste of defatted cereal starch forms a gel of unusually high strength and that addition of lipid to the defatted starch may inhibit gelation.

Elaidinized Lipid

During the process of hydrogenation, some elaidinization may occur along with hydrogenation of unsaturated fatty acid chains. Hydrogenation is not complete during the attainment of desirable shortening consistency; therefore, positional and geometric isomers also may be formed. Geometric isomerization involves replacement of the naturally occurring cis arrangement by the trans configuration. As a result of this side reaction, shortenings and margarines may contain as much as 23-42% concentration of trans isomers (Mabrouk and Brown, 1956; Allen and Kiess, 1955).

The study of elaidinization is of interest for several reasons. Elaidinization enhances the keeping quality of fats as compared to ordinary or hydrogenated fats, possibly because selenium from the elaidinization process inhibits autoxidation or possibly because the elaido configuration of the unsaturated acids is more resistant to oxidation than is the oleic configuration (Bertram, 1949). Trans mono-unsaturated acids have high melting points and contribute to the plastic properties of margarines containing them (Mabrouk and Brown, 1956). Most pertinent to this study is the effect of elaidinization on the molecular configuration of the lipid. When the cis configuration is replaced by the trans, the fatty acid chain is more extended. It seems possible that interaction with the linear starch chains thus might be greater than is possible in the case of lipid molecules having the cis configuration.

CHAPTER III

PROCEDURE

The experimental plan was a 2 x 3 factorial with 7 replications. Both defatted and non-defatted corn starch were gelatinized with no added lipid, with untreated olive oil and with olive oil that had been elaidinized according to the procedure of Litchfield et al. (1965). Added lipid was used at the level of 6 mg per gram of starch in pastes containing 8 g of starch per 100 ml of liquid.

Defatting Corn Starch

Unmodified corn starch, obtained from a commercial source, was extracted 10 times with 3 volumes of ethylene glycol monoethyl ether according to the method described by Schoch (1964). The extraction procedure consisted of stirring the suspension at room temperature 24 hours each time. The starch was filtered out of the suspension after each extraction. After the final extraction, the starch was spread on paper towels on trays and air-dried under the hood. A total of 1250 g of starch was extracted in 3 lots. The 3 lots of defatted starch were combined and mixed thoroughly prior to sampling.

The acid hydrolysis procedure, as outlined by Schoch (1964), was used for determining fat content. The procedure involves hydrolysis of the starch in a weighed sample, followed by solvent extraction of the lipid. After evaporation of the solvent, the lipid is weighed and its concentration in the starch is calculated on the dry weight basis. The value obtained for the defatted starch was 0.02% lipid, as compared with 0.50% for the untreated.

Preparation of Starch and Lipid Samples

Moisture content of the defatted and untreated starch was determined in triplicate by the AACC method (1962). The samples were dried in an air oven 2 hrs at 110°C.

Starch samples for individual pastes were pre-weighed and stored in covered jars until needed. The weight of starch for each sample was based on 8 g, dry weight basis, per 100 ml liquid for a total of 400 ml liquid.

Lipid samples of 192 mg per paste (6 mg/g starch) were pre-weighed and stored at -20°C in 30-ml beakers tightly covered with foil. At the time of use, the lipid was dissolved in 5 ml chloroform-methanol, 1:1 (v/v).

Viscosity Measurement

The starch was slurried in a 1000-ml Erlenmeyer flask with 385 ml water, and chloroform-methanol solution was added in amounts of 5 ml used as solvent for the added lipid and 10 ml used for rinsing the lipid solution into the slurry. For pastes containing no added lipid, 15 ml of the chloroform-methanol solution were added to the slurry. Each starch slurry was heated in the Brabender Amylograph from 25°C to 92.5°C (45 min) and held at 92.5°C for 15 min. Data taken from the amylogram included: the transition temperature, the temperature of maximum viscosity, maximum viscosity, viscosity after 45 min of heating (if not maximum) and terminal viscosity.

Photomicrographs

Samples of each paste were taken before heating and at 3 stages during heating: 1) after the 45 min heating period, 2) at the stage of maximum viscosity and 3) at the end of the 15 min holding period. For one replication a sample was taken also when the curve began to leave the base-line. A metal knitting needle, bent at a 90° angle 10 cm from the tip, was inserted through the cooling coil opening for transferring a drop of paste from the amylograph bowl to a slide. The starch was stained lightly with iodine (in potassium iodide) and glycerol was added before the coverslip was applied. Photomicrographs were made of the slides on a Bausch and Lomb Dynazoom research microscope. Total magnification of 450x resulted from use of the 10x objective, a zoom factor of 1.5 and a camera magnification of 3x. Panatomic FX 135 film was exposed 1/10 sec.

Gel Measurements

At the end of the 15 min holding period, 3 samples of each paste were poured into custard cups to be used for gel measurements. The cups were covered tightly with aluminum foil and stored at room temperature for 24 hr before measurement. Penetrability was measured on a Universal Penetrometer, with the 12.73 g cone attachment and no added weight. The plunger was allowed to descend for 30 sec before the reading was taken.

Statistical Analysis

Viscosity and penetrability data, as well as transition temperature, were subjected to analysis of variance for a 2-factor experiment.

(Snedecor and Cochran, 1967). The effect of interaction between starch treatment and lipid was tested, in addition to main treatment effects.

CHAPTER IV

RESULTS AND DISCUSSION

The data will be presented in the body of the thesis in the form of 2-way tables of means. Complete data are included in tables in the Appendix.

Transition Temperature

The transition temperature, the point of initial rise in viscosity for the heated starch slurry, was lower ($P < 0.01$) for the pastes of the defatted corn starch than for those of the untreated samples (Table 1). Comparable data were not found in the literature, though the statement of Leach et al. (1959) that defatted corn starch swells more freely than untreated starch suggests that a lower transition temperature would be associated with defatted starch. Addition of lipid, either elaidinized or non-elaidinized, had no effect on the transition temperature. This finding is in disagreement with the lowered transition temperature observed by Osman and Dix (1960) when soybean oil was added to corn starch suspension.

Maximum Viscosity

The maximum or peak viscosity of pastes containing the defatted corn starch was lower ($P < 0.01$) than that of pastes containing the untreated corn starch (Table 2). Medcalf et al. (1968) reported a higher maximum viscosity for pastes of defatted starch than for those of untreated starch. The addition of lipids had no effect on maximum

Table 1. Transition Temperature of Pastes of Untreated and Defatted Corn Starch, without and with Added Lipid[a]

	Lipid			
Starch[b]	None °C	Elaidinized °C	Non-elaidinized °C	Mean °C
Untreated	70.6	70.3	70.7	70.5
Defatted	68.4	68.4	68.0	68.3
Mean	69.5	69.4	69.4	- -

[a]Values are averages for 7 replications.

[b]Effect of starch treatment was significant at the level $P < 0.01$.

Table 2. Maximum Viscosity of Pastes of Untreated and Defatted Corn Starch, without and with Added Lipid[a]

	Lipid			
Starch[b]	None B.U.	Elaidinized B.U.	Non-elaidinized B.U.	Mean B.U.
Untreated	612	607	609	609
Defatted	578	572	579	576
Mean	595	590	594	- -

[a]Values, expressed as Brabender Units, are averages for 7 replications.

[b]Effect of starch treatment was significant at the level $P < 0.01$.

viscosity for either defatted or untreated starch in the present study. Medcalf et al. reported an increase in maximum viscosity when nonpolar lipid was added to defatted starch.

Viscosity at End of 45 Minutes

The viscosity at the end of the 45 min heating period in most cases was the same as the maximum viscosity. Thus the results indicated in Table 3 are the same as those stated for maximum viscosity.

Terminal Viscosity

Defatting alone did not affect terminal viscosity, as indicated by the mean terminal viscosities of 550 and 548 B.U. for pastes of untreated and defatted starch respectively (Table 4). The means suggest that elaidinized and non-elaidinized lipids affected terminal viscosity of pastes of untreated corn starch differently but terminal viscosity varied among replications and the addition of lipid actually had no significant effect. The terminal viscosity means for untreated and defatted starch, which are essentially alike for pastes having no added lipid and also are alike for those having elaidinized lipid apparently are different for pastes with non-elaidinized lipid. This suggests an interaction between starch treatment and lipid. Again, variability among replications ruled out identification of a significant effect.

Decrease in Viscosity

The percent decrease in viscosity observed with holding at 92.5°C

Table 3. Viscosity of Pastes of Untreated and Defatted Corn Starch, without and with Added Lipid, after 45 Minutes of Heating[a]

	Lipid			
Starch[b]	None B.U.	Elaidinized B.U.	Non-elaidinized B.U.	Mean B.U.
Untreated	608	600	605	604
Defatted	575	572	578	575
Mean	592	586	592	- -

[a]Values, expressed as Brabender Units, are averages for 7 replications.

[b]Effect of starch treatment was significant at the level $P < 0.01$.

Table 4. Terminal Viscosity of Pastes of Untreated and Defatted Corn Starch, without and with Added Lipid[a]

	Lipid			
Starch	None B.U.	Elaidinized B.U.	Non-Elaidinized B.U.	Mean B.U.
Untreated	550	540	563	551
Defatted	548	539	542	543
Mean	549	540	552	- -

[a]Values, expressed as Brabender Units, are averages for 7 replications.

for 15 min (Table 5) reflects the maximum and terminal viscosities. There was a greater ($P < 0.01$) percent decrease in viscosity from the maximum to the terminal stages for the untreated starch pastes than for the defatted corn starch samples, reflecting the relatively high maximum viscosity of the pastes of the untreated starch. The enhanced stability apparently achieved for pastes of untreated corn starch through the addition of non-elaidinized lipid reflects the relatively high terminal viscosity of those pastes. This effect was not observed with defatted corn starch; the starch-lipid interaction was significant ($P < 0.01$).

Gel Measurements

The defatted corn starch gels were more resistant to penetration, i.e., were stronger ($P < 0.01$), than were those of untreated starch (Table 6). This is in agreement with Schoch's (1969) observation that defatted cereal starches form gels of unusually high strength. With respect to added lipid, a slightly enhancing effect on gel strength is seen in the case of untreated starch but not in the case of defatted starch. The interaction between starch treatment and lipid is significant ($P < 0.01$).

Photomicrographs

Changes in granule size during gelatinization are shown in Figure 1. In Figure 2, granules at maximum and terminal paste viscosity are shown for untreated and defatted starch. The granules from pastes of defatted starch have relatively rough, poorly defined surfaces, i.e.

Table 5. Decrease in Viscosity of Pastes of Untreated and Defatted Corn Starch, without and with Added Lipid[a]

Starch[b,c]	Lipid[c] None %	Lipid[c] Elaidinized %	Lipid[c] Non-elaidinized %	Mean %
Untreated	10.1	11.0	7.5	9.5
Defatted	5.2	5.8	6.3	5.8
Mean	7.6	8.4	6.9	- -

[a]Values, expressed as percent change from maximum to terminal viscosity, are averages for 7 replications.

[b]Effect of starch treatment was significant at the level $P < 0.01$.

[c]The starch-lipid interaction was significant at the level $P < 0.01$.

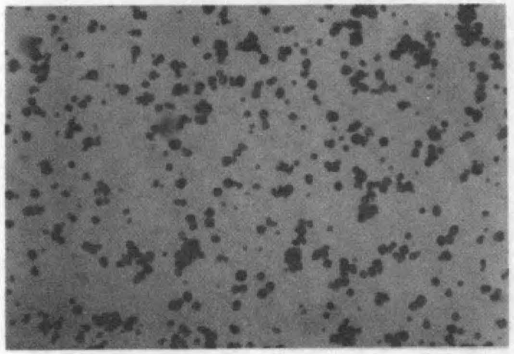
Table 6. Penetrability of Gels of Untreated and Defatted Corn Starch, without and with Added Lipid[a]

Starch[b,c]	Lipid[c] None mm	Lipid[c] Elaidinized mm	Lipid[c] Non-elaidinized mm	Mean mm
Untreated	9.6	8.8	9.1	9.2
Defatted	8.1	8.0	8.0	8.0
Mean	8.8	8.4	8.6	- -

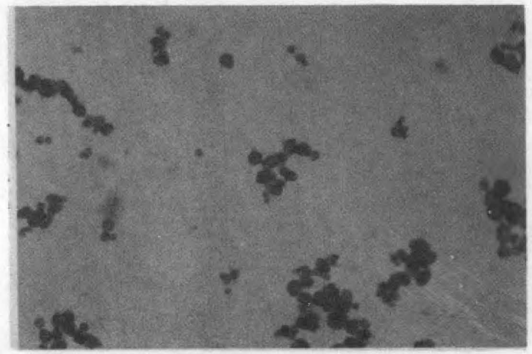
[a]Values are averages of 7 replications, 3 readings/replication.

[b]Effect of starch treatment was significant at the level $P < 0.01$.

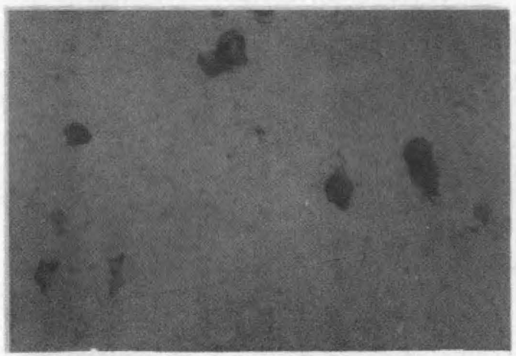
[c]The starch-lipid interaction was significant at the level $P < 0.01$.



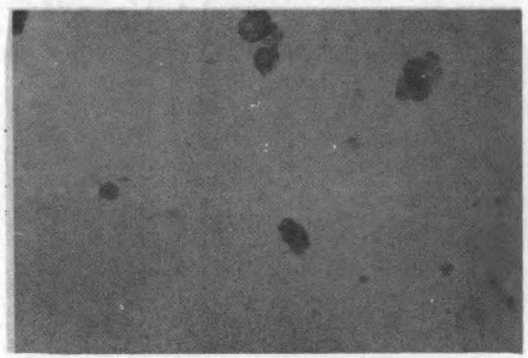
(a) Unheated Corn Starch Granules



(b) Granules at Transition Temperature of Paste



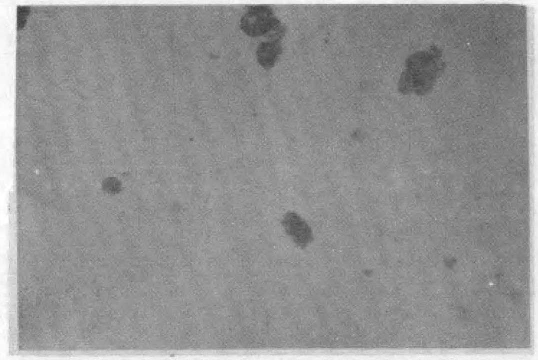
(c) Granules at Maximum Paste Viscosity



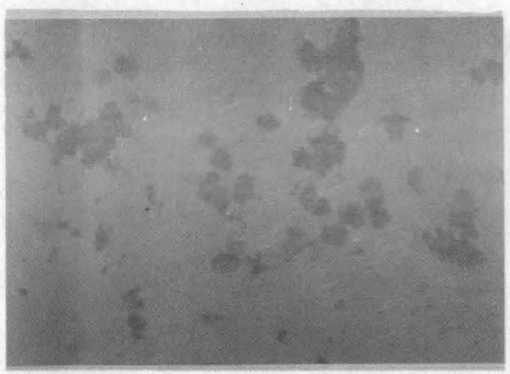
(d) Granules at Terminal Paste Viscosity

Figure 1. Photomicrographs of Untreated Corn Starch at Different Stages of Gelatinization (with Added Olive Oil).

(a) Granules of Untreated Starch at Maximum Paste Viscosity



(b) Granules of Untreated Starch at Terminal Paste Viscosity



(c) Granules of Defatted Starch at Maximum Paste Viscosity

(d) Granules of Defatted Starch at Terminal Paste Viscosity

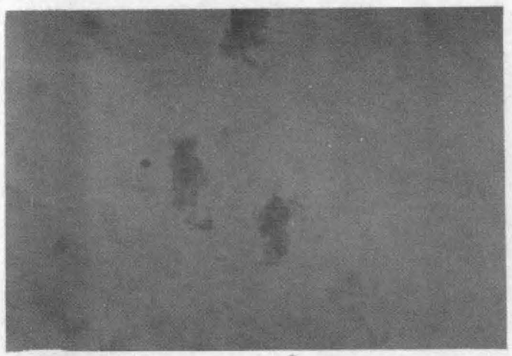
Figure 2. Photomicrographs of Defatted and Untreated Corn Starch Heated to Maximum and Terminal Paste Viscosity (with Added Olive Oil).

they appear more imploded and less compact than those from pastes of untreated starch. Photomicrographs of granules of untreated starch, gelatinized with and without olive oil (Figure 3), show a protective effect of the lipid on granule integrity.

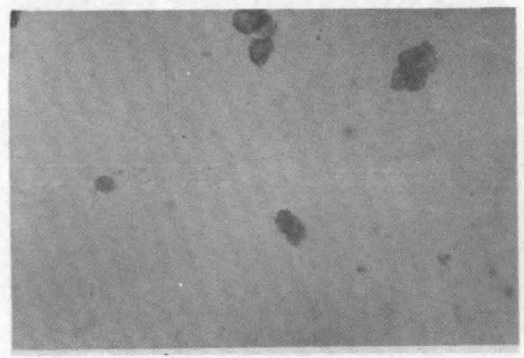
Discussion

The effects of defatting the starch may be summarized as follows: reduced transition temperature, reduced maximum viscosity, essentially unaffected terminal viscosity and increased gel strength. The reduced transition temperature theoretically could result from defatted corn starch swelling more freely than untreated starch (Leach et al., 1959). However, if the granules really were swelling more freely as a result of defatting, it is not clear why maximum viscosity was relatively low. A possible explanation for the apparent inconsistency is the following: Although the defatted granules were swelling more freely and at a more rapid rate than the untreated starch granules, they also were imploding at an earlier stage and amylose was being leached out into the aqueous medium to a greater extent. The resulting decrease in surface area then could have resulted in a lower maximum viscosity for the pastes containing defatted starch than for those containing the untreated starch.

The stronger gels obtained from pastes of defatted starch than from pastes of untreated starch could be the result of the larger amount of amylose from the imploded granules. As indicated previously (Figure 2), the granules in pastes of defatted starch did appear to be more imploded than those in pastes of untreated starch.



(a) Starch Granules from Paste without Added Lipid



(b) Starch Granules from Paste with Added Olive Oil

Figure 3. Photomicrographs of Untreated Corn Starch Heated without and with Added Olive Oil (at Terminal Viscosity).

The effect of added lipid was limited to increased gel strength, only in the case of untreated starch. No clear-cut differences were found between elaidinized and non-elaidinized lipid.

The lack of an effect on the maximum viscosity when lipid was added to either the defatted or the untreated corn starch pastes may have been related to the small amounts of lipid added. Whereas the added lipid in this study was roughly equivalent to the amount removed in the defatting process, Medcalf et al. (1968) and Osman and Dix (1960) added larger amounts of lipid.

The slight enhancing effect of lipid on the gel strength of the untreated corn starch pastes suggests that the lipids may have had a protective effect on the granules, permitting sufficient but not too extensive implosion to occur and keeping the granules from fragmenting during the holding period. As indicated previously, the granules of untreated starch with added lipid appear less disrupted than those heated with no added fat (Figure 3).

Possibly further work should involve the use of larger concentrations of added lipid. Although it seemed reasonable to use a concentration comparable to that of undefatted starch, failure to show more than a limited effect of added lipid made it impossible to relate effects to molecular configuration. An effect of elaidinization has not been shown.

CHAPTER V

SUMMARY

Gelatinization of untreated and defatted corn starch as affected by added elaidinized and non-elaidinized olive oil was investigated. The experimental plan was a 2 x 3 factorial, which included no added lipid as well as elaidinized and non-elaidinized olive oil. Seven replications were completed. Suspensions were heated in the Brabender Amylograph from 25°C to 92.5°C (45 min) and held at 92.5°C for 15 min. Data taken from each amylogram included: the transition temperature, the temperature of maximum viscosity, viscosity after 45 min of heating and terminal viscosity. Photomicrographs were made of samples of each paste taken before heating and at several stages during heating. Pastes were poured while hot into custard cups and held at room temperature for 24 hr. Penetrability measurements were made on the gels. Viscosity and penetrability data, as well as transition temperature, were subjected to analysis of variance.

Defatting the corn starch resulted in reduced transition temperature ($P < 0.01$), reduced maximum viscosity ($P < 0.01$), essentially unaffected terminal viscosity and increased gel strength ($P < 0.01$). The photomicrographs indicate that possibly the granules of defatted starch swelled more freely and rapidly and showed more implosion than the granules of untreated starch. The greater implosion could explain both lower maximum viscosity and higher gel strength of samples containing defatted starch. The effect of added lipid was limited to increased gel strength and only in the case of untreated starch. The photomicrographs show a possible protective effect of lipid on the granules so that in the presence of lipid, granules were permitted to implode sufficiently but not too extensively and fragmentation did not occur during the holding period. The interaction between starch treatment and lipid was significant ($P < 0.01$). No clear cut differences were found between elaidinized and non-elaidinized lipid. Possibly future work should involve the addition of higher concentrations of lipid than used in this study.

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APPENDIX

Table 7. Transition Temperature (°C) of Pastes of Untreated and Defatted Corn Starch, without and with Added Lipid

Reps	Untreated			Defatted		
	No Lipid	Elaidinized	Non-elaidinized	No Lipid	Elaidinized	Non-elaidinized
1	71.5	68.5	71.5	68.5	68.5	68.5
2	70.5	70.0	71.0	68.0	68.5	69.0
3	70.0	70.0	70.0	68.0	68.0	67.0
4	70.0	70.0	69.0	68.0	68.0	68.0
5	70.0	71.0	71.0	69.0	68.0	67.8
6	71.5	73.0	71.5	69.0	69.5	68.5
7	70.7	69.6	70.7	68.5	68.2	67.0
Mean	70.6	70.3	70.7	68.4	68.4	68.0

Table 8. Maximum Viscosity of Pastes of Untreated and Defatted Corn Starch, without and with Added Lipid[a]

Reps	Untreated			Defatted		
	No Lipid	Elaidinized	Non-elaidinized	No Lipid	Elaidinized	Non-elaidinized
1	606	614	600	570	586	585
2	620	602	613	580	569	573
3	611	610	615	579	570	578
4	614	613	599	583	573	580
5	615	609	605	565	574	580
6	608	606	607	585	573	576
7	608	598	621	585	562	580
Mean	612	607	609	578	572	579

[a]Values are expressed in Brabender Units.

Table 9. Terminal Viscosity of Pastes of Untreated and Defatted Corn Starch, without and with Added Lipid[a]

Reps	Untreated			Defatted		
	No Lipid	Elaidinized	Non-elaidinized	No Lipid	Elaidinized	Non-elaidinized
1	559	572	564	552	548	553
2	560	548	580	550	545	550
3	504	545	560	545	530	534
4	570	553	540	540	540	546
5	500	528	535	524	540	530
6	570	552	559	567	540	548
7	586	485	603	558	530	536
Mean	550	540	563	548	539	542

[a]Values are expressed in Brabender Units.

Table 10. Decrease in Viscosity of Pastes of Untreated and Defatted Corn Starch, without and with Added Lipids[a]

	Untreated			Defatted		
Reps	No Lipid	Elaidinized	Non-elaidinized	No Lipid	Elaidinized	Non-elaidinized
1	7.8	6.8	6.0	3.2	6.5	5.5
2	9.7	9.0	5.4	5.2	4.2	4.0
3	17.5	10.7	8.9	5.9	7.0	7.6
4	7.2	9.8	9.8	7.4	5.8	5.9
5	18.7	13.3	11.6	7.3	5.9	8.6
6	6.3	8.9	7.9	3.1	5.8	4.9
7	3.6	18.5	2.9	4.6	5.7	7.6
Mean	10.1	11.0	7.5	5.2	5.8	6.3

[a]Values are expressed as percent change from maximum to terminal viscosity.

Table 11. Penetrability of Gels of Untreated and Defatted Corn Starch, without and with Added Lipid[a]

Reps	Untreated			Defatted		
	No Lipid	Elaidinized	Non-elaidinized	No Lipid	Elaidinized	Non-elaidinized
1	9.8	8.6	9.3	7.8	7.9	8.0
2	9.4	9.1	8.9	8.1	7.9	7.9
3	10.0	9.0	9.1	8.2	8.0	8.0
4	9.3	8.7	9.2	8.4	7.8	7.9
5	9.9	8.7	9.1	8.0	8.2	8.0
6	9.4	8.9	9.2	8.0	8.1	8.1
7	9.8	8.8	9.1	8.1	7.8	7.8
Mean	9.6	8.8	9.1	8.1	8.0	8.0

[a]Values, expressed as mm, are averages of 3 readings/replication.

VITA

The author, Nina Sue Berry, was born in Corinth, Mississippi, on April 13, 1948. She received the Associate of Arts degree in Home Economics from Freed Hardeman College in August, 1967, and the Bachelor of Science degree from the University of Tennessee at Martin in June, 1969. Miss Berry was initiated into Phi Theta Kappa at Freed-Hardeman College and into Phi Beta Alpha and Pi Sigma Phi at the University of Tennessee at Martin. She was a member of the American Home Economics Association and a student member of the Institute of Food Technologists. In June, 1970, she accepted a teaching assistantship at The University of Tennessee and began working toward the Master of Science degree in Food Science.