EFFECT OF COMBINED WAXY MAIZE AND REGULAR CORN STARCH ON VISCOSITY AND COLD PASTE FLOW OF SIMPLE PUDDINGS

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EFFECT OF COMBINED WAXY MAIZE AND REGULAR CORN STARCH ON VISCOSITY AND COLD PASTE FLOW OF SIMPLE PUDDINGS

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Betty Jo Sullivan

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INTRODUCTION

Developing and maintaining desirable consistency in cream puddings and pie fillings are often problems in quantity food preparation. Ordinary cornstarch is the thickening agent most frequently employed in making these products. At normal starch concentrations, cornstarch puddings are fluid when hot but undergo the process of gelation when allowed to cool. The freshly cooled product has a delicate, gel-like character with a slightly firm body and creamy consistency. These characteristics are very desirable in cream puddings and pie fillings.

The longer holding periods often required in institution food service, however, frequently result in excessive stiffness, cracking, and some liquid separation in these products. The use of cornstarch in combination with a non-gelling type of thickening agent has been suggested as a possible way to eliminate these undesirable characteristics and still retain the fairly firm body which is desirable in cream puddings and pie fillings. Tapioca, which does not retrograde on cooling, has been used to some extent in this role.

The war period saw the development of the commercial production of waxy cereal starches which make pastes possessing the non-gelling properties of tapioca to an even greater degree. The starch from waxy maize has been processed in the largest quantities. Industry has developed methods for chemical treatment to modify the raw waxy maize starch; and, as a result, some of its less desirable properties have been overcome. Several of these modified starches are now available for use in institutions.

The purpose of this study was to investigate the effects produced upon hot and cold paste characteristics by modified waxy maize starches used in combination with ordinary corn starch in preparation of cream-type puddings. Two waxy maize starches, representing different levels of modification, were used in this investigation. It is hoped that the results of this study may reveal some basic information concerning the behavior of these modified, waxy starches when they are used as part of the total starch concentration in cream fillings and puddings. Such data could point the way to future exploration of possibilities for the use of these waxy starches in similar products in large quantity food production.

REVIEW OF LITERATURE

Brautlecht (14) described starch as that material formed in all green plants which is subsequently stored as microscopic granules to be used as a future food supply for the germinating seed. Starch is commercially obtainable from cereal grains, tubers, roots, and the pith of certain palms. The Egyptians, prior to 3000 B.C., obtained the first starch from wheat and utilized it for purposes of food and for binding fibers to make papyrus. Whistler and Smart (59) reported that since that time starches have been made in increasing quantities. During the fourteenth century the industrial preparation of starches first became prevalent in Europe. Today the manufacture of starch is a world-wide industry of great importance. Schoch (51), in a review of starch research, stated that only since the late 1930's has real progress been made in explaining the basic structure, composition, and behavior of starch. This advancement has paralleled the development of modern colloid chemistry.

Starch Fractions

According to Frankel (26), starch belongs to that group of organic substances which, besides carbon, contain hydrogen and oxygen in the same proportions found in water. Among other substances belonging to this classification are the celluloses, dextrins, and sugars. Schoch (51) stated that starch is a polymer of glucose units which, on complete hydrolysis with acid, yields 100 per cent of this hexose sugar.

As early as 1834 the behavior of a cooked starch suspension was interpreted as evidence that starch contained two or more carbohydrate substances (51). In 1924 Alsberg and Rask (2) reported that starches of certain varieties of cereals gave a red color with iodine and those of other varieties showed a blue color. Pastes made from the starches giving the red color with iodine were more viscous than those that colored blue.

In a discussion of the physical properties of starch, French (27) stated that with the perfection of fractionating procedures two extremes of starch types are recognized. These fractions are thought to be homogeneous with regard to chemical type but heterogeneous with regard to molecular size and the degree and order of branching. Current definitions are made on the basis of chemical structure, although earlier definitions were based on such properties as solubility, enzyme digestibility, and iodine color. Whistler and Smart (59) refer to the linear molecule as amylose and to the branched structure as amylopectin. Some investigators prefer to call these the A-fraction and the B-fraction, respectively.

Schoch and Elder (52) described the linear fraction as being made up of a long chain of glucose units. The introduction of other glucose units along these linear chains results in a branched structure and, ultimately, in a tree-like molecule. Ordinary corn, wheat, potato, and tapioca starches contain both the linear and branched molecules. The ratio of these components is fairly constant for any given plant species. The amount of linear material ranges from 17 per cent in tapioca starch to 28 per cent in ordinary corn starch. Starches designated as waxy starches contain only the branched fraction. On the other hand, starches of wrinkled-seeded garden peas and certain varieties of sweet corn contain a larger proportion of the linear fraction. With regard to molecular size, Kerr (40) stated that there is considerable variation among the molecules of each structural type, even in one variety of starch. This investigator reported that Beckmann and Landis estimate the average molecular size of the amylose fraction as 300 to 400 glucose units and the amylopectin fraction as 1000 times larger.

Radley (49) reported that, according to several investigators, the presence of phosphoric acid in the amylopectin molecule and its resistance to enzyme action distinguish this fraction from the amylose fraction. Schoch (51) discussed some of the differences between the A and B fractions. Five to ten per cent solutions of the linear A-fraction show exaggerated tendencies to retrograde and to set up to an irreversible gel on cooling. This behavior is attributed to the strong associative forces between the long, linear molecules. The bush-like structure of the B-fraction prevents any such orderly parallel alignment of molecules. Only in instances where gel formation is a desirable characteristic is the

A-fraction alone technologically useful. The B-fraction is the component of starch which makes it useful as a thickening agent, protective colloid, or as a sizing material for paper and textiles. Although the presence of the A-fraction makes a starch unsuitable for certain purposes, the undesirable characteristics can be reduced to a minimum by chemical modification.

Many investigators have studied the nature of the iodine reaction with starch. Bates and co-workers (6) used a potentiometric method for quantitative determination of amylose components of starch. His preliminary results showed that affinity for iodine varied inversely with the degree of branching of the starch chains but directly with the length of the starch chain.

Structure of Starch Granules

Whistler and Smart (59) stated that starches typically occur in nature as discrete granules. The appearance and size of starch granules are characteristic of the plant type from which they originate. Starches from various sources can be differentiated by careful physical examination of the granules under a microscope. According to Schoch and Elder (52), granules of potato starch are relatively large, ranging from 15 to 100 microns in diameter. The smallest of the common starch granules are those from rice with a diameter of 5 to 6 microns. Corn starch granules are similar in appearance to rice starch granules but are considerably larger.

Brautlecht (14) described the starch granule as a minute structure built of layers of molecules arranged concentrically. According to his investigations, shapes ranged from small polygons to large spherical granules with a dark spot, the hilum, eccentrically located in each. In addition to this concentric organization, Schoch and Elder (52) observed the presence of a radial structure which resulted in the typical radial direction of cleavage. Sjostrom (55) supported this latter view.

Radley (49) concluded that the inner portion of the starch granule consisted of soluble amylose and the outer layer was composed of amylopectin which gave the pasting characteristics to a cooked starch suspension. Alsberg (1) and Katz (39) supported this theory. In 1955 Badenhuizen (5) found no such decrease in content of the linear fraction from center to periphery. This investigator concluded that the linear molecules are distributed uniformly throughout the layers of the starch granules in most starches.

Swelling of Starch Granules

Starch granules are insoluble in cold water. In 1924 Alsberg and Rask (2) observed that when a suspension of starch granules in water was heated, the granules first swelled, then burst, and finally lost their anistropy. The resultant viscous product they termed a starch paste. These investigators reported that this swelling was not a sharp transition point, as previously postulated, but a phenomenon occurring over a range of temperatures specific for each of the various starches. Using a viscometric technique, they determined that increases in viscosity were gradual and extended over a range of 25° to 30° C. They defined the temperature of gelatinization as the point at which the initial stage in the process begins. Whistler and Smart (59) reported that the gelatinization ranges may be used as an aid in distinguishing starches from various sources. During the process of swelling, the starch granules absorb water slowly at first and the viscosity of the suspension is not perceptably altered. At the critical temperature the granules undergo sudden rapid swelling to several hundred times their original size, and the viscosity of the suspension is greatly increased. Crossland and Favor (22) reported that some starches exhibit more than one stage of gelatinization.

In 1926 Alsberg (1) made the observation that swollen starch granules did not burst even after many hours of boiling. He stated that boiled starch suspensions were not true solutions unless the cooking period had been unduly prolonged or other treatment had been applied to disintegrate the suspended particles. This investigator interpreted gelatinization to be dependent upon the softening of the rigid structure of the granules by moist heat. From this he concluded that the amylopectin fraction, located in the outer layer, preserves the suspensoid character of the boiled starch. Katz and co-workers (39) reported that the swollen starch granules were surrounded by vesicle walls which enveloped the soluble starch material. Whistler and Smart (59), however, stated that starch granules had no definite membranes and that the apparent sacs were artifacts produced in the process of swelling.

Bechtel and Fischer (10) reported that starch granules from the potato and those from highly modified starches were easily ruptured. Granules of native or unmodified corn starch they found to be strongly resistant to rupture even at high temperatures and with vigorous agitation.

Radley (49) described a starch paste as a mixture of granules at various stages of swelling, some soluble material, and debris from the outer portion of the burst granules. According to this investigator, the larger granules appeared to swell at a lower temperature than did the smaller granules. He pointed out that this difference in swelling behavior of large and small granules may be due to a difference in the ratio of the amylose and amylopectin fractions.

French (27) reported that swelling of starch granules could be induced at room temperature by many alkalies and metallic salts.

Viscosity

Radley (49) stated that starch granules occupied a much larger volume in the system after swelling and gelatinizing than before and that viscosity altered more or less with the swelling. Kerr (40) stated that starch pastes possessed an anomalous viscosity instead of viscosity in the same sense as that observed in the more nearly perfect fluid bodies. The effect measured appeared to this investigator to be due to a combination of properties. Bechtel and Fischer (10) referred to this phenomenon in starch pastes as apparent viscosity and attributed it to the presence of swollen granules, granule fragments, and colloidal particles. Anker and Geddes (4) stated that apparent viscosity depended on the extent of aggregation of the granules, of swelling, and of granule disintegration.

Schoch (51) attributed viscosity to be the result of the mechanical jostling of the swollen starch granules. He reported that these swollen masses could be disintegrated to produce a paste of greatly reduced viscosity by autoclaving. Katz and associates (39) stated that viscosity was due to the friction of the swollen starch granules against one another and to the inhibition of the flow of water by the suspension of starch vesicles.

Whistler and Smart (59) attributed the great difference in viscosities of various starch pastes to the degree of swelling and the ease with which granules were ruptured.

Gel Formation

According to Brimhall and Hixon (16), viscosity measurements should be made only on hot pastes. When a starch paste is cooled, portions of the dispersed material tend to revert to a more insoluble state by a process called retrogradation. The workers believed that the setting-up of starch gels was caused by the interlacing of crystalline starch fragments between and within the aggregated starch granules. Therefore, they explained the rigidity of cooked starch pastes as the result of crystallization as well as an increase in the degree of structural viscosity.

Kerr (40) attributed retrogradation of cooked starch pastes to the amylose molecules with the straight chains. Schoch and Elder (52) stated that the branched starch fraction had less tendency to retrograde and also had a moderating influence on retrogradation of the linear fraction. They found that only extremely high concentrations of the branched fraction would harden to a gel on standing at room temperature. Retrograded linear fraction could not be reversed by autoclaving, whereas associated branched fractions returned to their original state upon heating to a temperature of 50° to 60° C.

Anker and Geddes (4) observed from their studies that starch pastes had gel properties when quiescent, became more fluid on the application of shearing force, and again formed gels after the disturbing force had been removed. Brimhall and Hixon (15) studied the rigidity of starch pastes and observed that viscosity and gel strength measured two different properties in starch. Woodruff and MacMasters (60) studied corn and wheat starches from various sources and concluded that viscosity differences in the starches studied were very small, whereas differences in gel strength were more pronounced. Knowles and Harris (42) conducted a similar study and found no correlation between viscosity and gel strength.

Schoch (50) stated that the speed of retrogradation was dependent on the starch concentration and varied directly with it. He concluded that the associative force between the starch molecules themselves was more powerful than that between the starch and water. Kerr (40) pointed out that retrogradation could be hastened by freezing.

Factors Affecting Behavior of Cooked Starch Pastes

Some of the factors which have been reported to affect properties of starch pastes are inherent starch characteristics, treatment of starch during manufacture, starch concentration, presence of electrolytes and non-electrolytes, mechanical agitation, and the time and temperature of cooking.

Source: inherent characteristics

Whistler and Smart (59) stated that, although starches may be almost identical in chemical composition, those from the various sources produce pastes of very different character. This difference in behavior they attributed to the complexity of the colloidal properties of the starch pastes.

Beckford and Sandstedt (11) studied gelatinization of two types of wheat starch by means of a light transmission device. These investigators observed that large and small granule wheat starch preparations gave similar swelling curves and concluded that these two types of wheat starch granules were similar in gelatinization characteristics. Morgan (46) employed a similar photoelectric method to follow changes in tuber and grain starch pastes during heating. The tuber type of starch showed steeper pasting curves than did grain starches. Waxy corn starch pasted completely over a narrow temperature range below 80° C. This was also characteristic of the behavior of sweet potato and tapioca starches.

Tanner and Englis (57) studied starches from different varieties of corn and found distinct differences between hard and soft corn starches. Granules of hard starches appeared to be smaller and less rounded than soft granules which contained more non-carbohydrate material. Hard starches formed more viscous pastes than did the soft starches of approximately the same granule size.

Mangels and Bailey (44) compared the viscosities of four types of wheat starches treated with cold gelatinizing reagents. These different wheat starches showed great variations in swelling capacity; the extent of swelling appeared to be determined by the type of gelatinizing agent employed. These investigators concluded that variations in properties of starches were due in part to morphological differences in the starch granules as well as to certain complex chemical differences.

Harris and Jesperson (33) made a study of the effects of various factors on the swelling of a variety of cereal starches. These investigators noted that all the starches studied varied among themselves in swelling capacity at all temperatures; barley starch showed the lowest and corn starch the highest values. Woodruff and Nicoli (61) observed the behavior of cooked starch pastes made from various cereal and root starches. The gelatinization temperatures varied with each individual type of starch and ranged from 69° C for potato starch to 87° C for wheat starch.

Hughes and co-workers (37) compared temperature and time periods for gelatinization of starches and cereals of wheat and corn. These investigators observed that the starches were more rapidly and completely gelatinized at any given temperature or time period of heating than the cereals containing those starches.

Harris and Jesperson (34) found that swelling power decreased as wheat matured, irrespective of variety and environmental factors. At the same time, gel strength and viscosity tended to increase with degree of ripeness. These changes with maturity were associated with changes in other factors such as moisture content and density. Little difference in viscosities was noted between wheat, rice, and barley starches. Potato starch, however, exhibited a much higher viscosity and swell than did the cereal starches.

Woodruff and MacMasters (60) studied gelatinization and retrogradation changes in corn and wheat starches. These investigators noted that gel strength fluctuated widely with the variety of corn and with the growing conditions under which it was produced. Knowles and Harris (42) made observations on the behavior of starch gels from different classes and varieties of wheat. Environmental and climatic conditions under which wheats were grown showed definite effects on gel strength. Differences were noted between the same varieties grown in two different years. Tests also revealed an increase in gel strength with increasing maturity of the wheat.

Bechtel (9) stated that certain native starches, such as tapioca, potato, and waxy maize, showed less tendency to form firm gels than did the ordinary cereal starches such as corn and wheat.

Effect of treatment during manufacture

Tanner and Englis (57) studied effects of grinding hard and soft corn starches. Grinding corn 624 hours was sufficient to disintegrate hard starches but did not completely disrupt soft corn starches. French (27) stated that the application of physical stress to the starch granule disarranged the molecules rather than merely breaking the crystals apart. He concluded that bonding between crystals was stronger than the forces between the polysaccharide chains within the crystals. According to Radley (49), starch granules injured by grinding formed pastes of lower viscosity than those formed with uninjured granules.

Kerr (40) stated that after the native starch has been prepared, it is frequently modified to make it more suitable for specific uses. These various treatments during manufacture may produce very minor to very significant changes in the physical and, in some cases, the chemical structure of the starch granule. Treatments have been developed to produce starches of very high viscosities at specific temperatures, starches of reduced viscosities or thin-boiling starches, and starches which produce a paste with cold water.

Schoch and Elder (52) described some of the types of modifications used in commercial starch manufacture. The simplest type of manufactured starch is the thin-boiling starch, which is prepared by suspending ungelatinized starch in warm, dilute acid. The acid hydrolyzes a few of the glucosidic bonds and weakens the intermicellar structure within the granule without altering the outward appearance. Such starches produce pastes of relatively low viscosity. Enzymes can be applied in a similar way to weaken the intermicellar structure. Thick-cooking products are prepared by chemically cross-bonding these intermicellar areas with such agents as formaldehyde. These granules swell more slowly and show an increased resistance to mechanical disintegration, producing a paste of high and stable viscosity. Heating dry starch with traces of acid brings about partial hydrolysis to produce dextrins. Ordinary starches can be oxidized to reduce the influence of the linear fraction so that it no longer associates or retrogrades.

Harris and Jesperson (33) found the swelling curve to be greatly altered in pastes made from starches pretreated with sodium hydroxide. These divergences in pasting characteristics increased with rising temperature.

According to Sjostrom (55), granules of thin-boiling starches increased in volume less than granules from ordinary starch when heated in water. The room occupied by these swollen granules was less in relation to total volume and the pastes were correspondingly thinner.

Morgan (46) found that tapioca starch, with increasing degrees of oxidative treatment, produced pastes at a lower temperature and with greater clarity. Other modified starches showed similar properties.

Bisno (13) stated that the neutral and alkali starches tended to show greater resistance to acid, somewhat greater clarity, but had weaker gels than did pastes made from chlorinated starches. Felton and Schopmeyer (24) described a method of producing starches with granules that were tough and resistant to disintegration when they were heated with water. These starches were prepared by treatment with an acid chloride in the presence of large amounts of water at a pH of 8 to 12. When a suspension of this modified starch is cooked, swelling occurs at a much slower rate than it does in a similar suspension of the raw starch. Viscosity also tends to increase over longer periods of cooking.

Bechtel (9) studied properties of gels made from regular commercial grades of unmodified and modified corn starches. This investigator found the effect of cooking temperature on the properties of starch gels varied with the degree of modification. With increasing modification of the starch, the viscosity of the hot pastes decreased and the breaking strength of their gels decreased to a lesser degree.

Radley (49) stated that the drying treatment to which starch is subjected during manufacture may affect the viscosity of starch pastes. A starch dried slowly at very low temperatures shows greater viscosity when made into a paste than one dried quickly at higher temperatures.

Effect of electrolytes

French (27) stated that starch granules which have been hydrolyzed by the action of acids no longer swell in hot water but disintegrate and pass into solution. The acid breaks down starch to smaller molecules which are incapable of forming the giant networks characteristic of swollen starch granules.

Bechtel (8) discussed the effect of differences in pH on the viscosity of starch pastes. This investigator stated that differences in pH altered the temperature of initial viscosity rise and maximum viscosity and also changed the maximum viscosity values and the rate of paste breakdown.

Harris and Banasik (32) studied the effect of the electrolytes on swell of corn and wheat starch pastes. Treatment with 0.125 N sodium hydroxide during preparation in the laboratory increased the pH and greatly increased the swell. Preparations treated with 0.123 N sulfuric acid lowered the pH and increased swell only slightly. Starch pastes cooked in the presence of hydrochloric acid and sodium hydroxide also showed an increased swell. These investigators suggested that H^+ and OH^- ions were more effective in increasing swell than other ions studied. Sodium chloride and magnesium sulfate decreased swelling to some extent. Cooking starches, previously prepared with sodium hydroxide, showed marked decreases in swell in the presence of acid. These writers concluded that their results emphasized the complexities involved in the problem of the effect of electrolytes on the swelling power of starch.

Anker and Geddes (4) reported from gelatinization studies on commercial wheat starch suspensions that maximum paste viscosity decreased in linear fashion with an increase in pH from 5.2 to 6.8. Schoch (50) stated that retrogradation of starch pastes is favored by a low pH.

Hains (29) reported the effect of 0.1 N citric acid at levels of 40, 44.5, 49.5 per cent of the water content of the formula on the viscosity of sweetened and unsweetened starch pastes. Acid decreased viscosity of pastes made with no sugar and with 20 per cent sugar but had no appreciable effect on the pastes containing 40 and 60 per cent sugar. The gel strength of the starch pastes at all sugar levels increased when they were cooked with citric acid.

Morse and co-workers (47) added sodium chloride to pastes made with flour, water, and nonfat dry milk solids. Sodium chloride increased the viscosity to some degree in the thin pastes but had no effect on gel strength of the thick pastes tested. Alteration of the pH from 6.9 to 6.0 in the thick pastes resulted in a decrease in gel strength; a rise in pH from 6.9 to 7.7 showed no consistent effect. Thin pastes were curdled by lowering the pH from 6.9 to 6.0 and at a pH of 8.0 there was a slight but inconsistent rise in viscosity above that observed at 6.9 pH.

Radley (49) asserted that certain salts and alkalies lowered specific gel points of starch. He found that the presence of the very small amount of electrolytes in tap water resulted in lowering of the viscosity of starch pastes. Bisno (13) stated that the solids present in tap water were sufficient to affect significantly the consistencies of starch pastes. Differences in flow rate were noted when distilled water and tap water were compared as liquid medium for starch pastes. The effect of pH variation upon viscosity did not appear to be the same for starches from different sources. However, Bisno pointed out that much of the data from various investigators was not comparable because of differences in methods of study. Ferree (25) found that sweetened and unsweetened cornstarch pastes made with tap water were more unstable on continued cooking after maximum viscosity was reached than pastes made with distilled water.

Effect of starch concentration

Bechtel and Fischer (10) observed that the initial viscosity rise occurred at successively lower temperatures as starch concentration was increased. The rate of rise of the curve was more rapid, the maximum viscosity occurred at a lower temperature, and the decrease in apparent viscosity on continued cooking was more rapid. Anker and Geddes (4) supported these findings. Bisno (12) stated that with increase in dry starch concentration a relatively greater viscosity drop is observed with continued heating and agitation. This investigator attributed this phenomenon to the increased internal stress developed from the numerous contacts among the granules.

Katz and associates (39) reported that there was no proportionality between viscosity of pastes and concentration of starch. According to Harris and Jesperson (33) the lowest starch concentrations, on a dry basis, gave the highest swelling power.

Crossland and Favor (22) studied starch gelatinization in a viscous, water-binding, dispersion medium of low solids content. These investigators observed that the temperature of initial swelling was more sharply defined as the level of starch was increased. The temperature of initial swelling remained fairly constant at all starch levels in contrast to results obtained when water alone was used as the dispersion medium. Varied levels of starch produced a greater influence on the contours of the curves than did variations in concentration of the medium.

Schoch (50) reported speed of retrogradation to be dependent on the concentration of the starch in the paste or solution. An autoclaved 1 per cent starch solution remained fairly clear for several days, whereas a 2 per cent solution flocculated overnight. French (27) stated that dilute starch pastes, thinned by mechanical treatment or boiling, showed less tendency to set rapidly to strong gels than did thick starch pastes similarly treated.

Trempel (58) concluded that types and proportions of other ingredients included in a formula may influence the concentration of starch required to thicken a given amount of liquid to produce a pie filling of desired consistency.

Effect of time and temperature

Alsberg (1) concluded from his studies on starch that there was no such physical constant as gelatinization temperature. Results of his work indicated that there was only a range of temperatures over which initial swelling of starch granules occurred. This investigator stated that most starches remained swollen but intact even after boiling for an hour. Alsberg and Rask (2) observed that the viscosity of a suspension of wheat starch in water increased gradually over a range of 25° to 30° C during gelatinization. These workers stated that there was probably no definite temperature of gelatinization. If the temperature of gelatinization is defined as that point where anisotropy disappears, then it must be regarded as the temperature of the beginning of the gelatinization process. Gelatinization temperature, they concluded, could not be viewed as a sharp transition point, specific for the various starches as the melting point is for crystalline substances.

Schoch and Elder (52) stated that little change occurred until a certain critical temperature was reached during the heating of a starch suspension. Gelatinization began suddenly and, because some granules swelled more slowly than others, continued over a range of several degrees. After initial rapid swelling, the individual granule continued to expand more slowly with a continued rise in temperature. Unless stirred vigorously, swollen granules were not disrupted but behaved as individual gelled bodies, coherent and elastic. Autoclaving a starch paste at 18 to 20 pounds steam pressure for an hour or two was required for solution of the starch granules.

Hughes and co-workers (37) studied the effect of various temperatures and time periods on the gelatinization of cereals and starches from wheat and corn. Complete gelatinization of corn and wheat starch was obtained at 100° C after the solutions were boiled two minutes. A shorter period of heating was required when a higher temperature was used. Granular cereals were not completely gelatinized when subjected to similar heating treatment.

Beckford and Sandstedt (11) studied starch gelatinization with a spectrophotometer. The rate of heating was controlled by a variable transformer. These investigators found that rates of heating, ranging from 2.5° to 0.15° C per minute, produced identical pasting with no significant changes in gelatinization temperatures of wheat and corn starches. Harris and Jesperson (33) stated that the viscosity of any particular starch was influenced by the pasting temperature and the duration of heating. These investigators, finding very significant differences between the swelling power at the different temperatures, reported that the swelling power increased greatly with the gelatinization temperature.

Anker and Geddes (4) studied gelatinization of wheat starches with the amylograph. In this instrument the thermoregulator allowed the temperature to rise at a constant rate of approximately 1.5° C per minute. Wheat starch suspensions, gelatinized from initial temperatures above 45° C, gave markedly higher peak viscosities than did corresponding suspensions gelatinized from lower initial temperatures. Bechtel (8) investigated paste characteristics of various starches with the Corn Industries viscometer. Viscosity curves for a starch slurry prepared at 25° C with the water bath preheated to 92° C were compared with those of a similar starch slurry prepared at 25° C with a bath of the same 25° C initial temperature. Viscosity curves on unmodified cornstarch indicated that rapid heating lowered the temperature of initial viscosity rise and decreased the time required to attain maximum viscosity after the paste reached 90° C. With rapid heating, 2 minutes were required to reach maximum viscosity after the paste temperature had reached 90° C. With slow heating, 7 minutes were required for maximum viscosity to be reached after the paste temperature was 90° C. Rapid heating increased the maximum viscosity value and resulted in a correspondingly higher curve for the remainder of the test. In all unmodified corn and wheat starches and in the modified corn starches tested, higher temperatures favored more rapid paste breakdown; small temperature differences also resulted in very different viscosity characteristics.

Effect of fatty acids

Whistler and Smart (59) reported that cereal starches usually contained 0.5 to 1.0 per cent fatty acids. According to these workers, these acids are not combined directly with the carbohydrate but adsorbed on the carbohydrate and may be completely removed by extraction with aqueous methanol. Waxy corn starch contains only 0.06 per cent fatty material.

Bechtel (8) found that defatted corn starch differed markedly from normal corn starch throughout its viscosity curve. Pastes made from defatted corn starch were found to show initial viscosity rise and maximum viscosity at lower temperatures than pastes made with normal corn starch. These pastes made with defatted corn starch also had lower maximum viscosity values than pastes made with ordinary corn starch. The rate of breakdown of pastes made from defatted corn starch was usually greater than that of pastes from the corresponding commercial starch.

Bisno (13) stated that vegetable shortenings were frequently added to pie fillings to increase tenderness and to retard quick-drying of the starch-thickened mixture. He reported that addition of monoglycerol stearate and polyoxyethylene stearate tended to delay retrogradation. According to Schoch and Elder (52), the linear fraction of starch forms insoluble complexes with these polar organic substances. They found that the monoglycerides or the higher fatty acids precipitated the linear fraction from a cooked starch paste and thus produced a paste of increased opacity, which showed short, thick consistency and almost a complete loss of gel strength. Starch pastes cooked with polar fatty adjuncts had a higher pasting temperature, retarded swelling, and no breakdown or dissolution of the granule. Commercial corn starch ordinarily contains about 0.65 per cent free fatty acids bound by the linear fraction. If corn starch is defatted by alcohol extraction, the resulting starch gives a paste curve with lower temperature of gelatinization and much lower viscosity. The curve can be restored by introducing lipid material into the defatted starch.

Jordan and co-workers (38) studied the effect of homogenized milk upon the viscosity of cornstarch puddings. The Brookfield viscosimeter was used for measurement of pasting characteristics. When a cornstarch concentration of three grams or more per 100 grams of milk was used, the puddings made with homogenized milk were more viscous when hot and firmer when cold than similar puddings made with non-homogenized milk. The degree of difference was dependent upon the level of cornstarch. These investigators attributed these differences in consistency to the differences in the surface area of the fat globules in the two kinds of milk tested.

Morse and associates (47) studied the effect of nonfat dry milk solids on viscosity of thin pastes and gel strength of thick pastes made from flour and water or fluid milk. The Stormer viscosimeter was used to measure viscosity of thin pastes and the Bloom gelometer to measure gel strength of heavier pastes. The nonfat dry milk solids increased the viscosity of the thin pastes and gel strength of the thick pastes in proportion to the amount of dry milk used. The addition of fat to the same pastes decreased the gel strength in the heavier pastes but did not affect the viscosity of the thin pastes.

Effect of sucrose

In 1931 Woodruff and Nicoli (61) studied gels of 5 per cent cereal and root starch pastes. Sucrose was added at levels of 0, 10, 30, 50, and 60 grams per 100 grams of starch paste. Differences in gel characteristics were described and photographs served to record differences in physical appearance and outline of the gel. In all starches studied, each increment in sugar concentration up to 50 per cent produced a gel of more tender and transparent character. No gel was formed with the addition of 60 per cent sucrose.

Hains (29) reported viscosity measurements of 12 per cent cornstarch puddings with sucrose added at levels of 0, 20, 40, and 60 per cent by weight of the liquid. A sucrose concentration of 20 per cent produced a pudding with a higher viscosity than noted in the control without sucrose. Puddings containing this level of sucrose required only a slightly longer cooking time than did the control. Additions of 40 and 60 per cent sucrose, however, produced pastes of progressively decreasing maximum viscosity values which required higher temperatures and much longer cooking periods.

Ferree (25) studied the effect of the proportion of sucrose on the viscosity of corn starch pastes using different liquid mediums. Sucrose concentrations of 0, 15, 21, and 27 per cent were used in this study. The liquid mediums were distilled water, tap water, nonfat dry milk solids reconstituted in distilled water, and whole dry milk solids reconstituted in distilled water. Starch slurries containing 27 per cent sucrose made with all liquid mediums required longer cooking times and higher temperatures to reach maximum viscosity than did the control pastes made without addition of sucrose. Lower sucrose concentrations did not consistently alter the cooking time or the temperature required by the control to reach maximum viscosity. All sucrose concentrations appeared to decrease the rate of breakdown of the starch paste with increase in cooking time. From a comparison of the maximum viscosity values of sweetened and unsweetened pastes, viscosity appeared to depend more on the particular liquid medium than on the sucrose concentration. In general, the results did not show a consistent decrease in viscosity with an increase in sucrose concentration.

Trempel (58) stated that the addition of certain solids, such as sugar, raised the pasting point of starch. He found that, under normal cooking conditions, a pie filling containing more than 3½ times as much sugar as starch (by weight) produced a thin gel on cooling which had a raw cereal taste. This characteristic he attributed to incomplete cooking of the starch. In preparing fillings with relatively high sugar concentrations, Bisno (13) suggested that 2/3 of the sugar be added after the starch paste became transparent and thick. This writer stated that sugar competes with starch for water; at high levels of sugar concentration the amount of available water is reduced to the point at which complete gelatinization of the starch cannot occur.

Effect of mechanical agitation

Bechtel and Fischer (10) concluded from their experiments that the rate of pasting was affected by differences in agitation. The rate of pasting in the double boiler was found to be approximately double that in the Corn Industries viscometer. Differences in agitation, however, apparently did not alter the nature of the pasting process. Corn, wheat, and unmodified starches exhibited a somewhat smaller change than did potato and acid-modified corn starches in apparent viscosity with variations in the rate of shear.

Schoch and Elder (52) stated that when starch paste was subjected to violent shear, as in the Waring Blendor or by high-pressure homogenization, the opposing stresses might actually break glucosidic bonds rather than destroy the individual micelle.

French (27) stated that dilute starch pastes may be thinned by boiling or by other mechanical treatment such as passing them through a homogenizer. Pastes which have been treated in this manner have less tendency to set rapidly into strong gels. At higher concentration, however, gels are readily formed even from thoroughly dispersed starch pastes.

The Waxy Starches

A relatively new kind of starch extracted from waxy and glutinous varieties of certain cereals is being manufactured in increasing quantities in the United States. These starches possess many unique characteristics and are gaining acceptance for specific uses in food preparation.

In 1909 Collins (19) reported on a new type of Indian corn from China. He stated that in March, 1908, the office of Foreign Seed and Plant Introduction received a small sample of shelled corn from a missionary in Shanghai, China. Plants were grown from this seed the following season and proved to be quite unlike any of the cultivated varieties known in the United States or Tropical America. This new type of corn plant showed a resistance to drying out of the silks by dry, hot winds. The endosperm of the grain was completely opaque as opposed to the translucent appearance of the common varieties known in the United States. The texture of the endosperm suggested that of hardest wax, and from this resemblance the term cereous or waxy endosperm was suggested. Because this waxy endosperm was completely recessive to the horny and starchy endosperm of our common varieties of corn, its appearance in all kernels of the original seed indicated that the seed was grown in a section of China where varieties of corn with a horny endosperm were completely absent.

In 1913 Collins and Kempton (20) stated that maize varieties were based on the character of the seed. The varieties with horny, soft, and sweet endosperm represented the only forms known to exist until the discovery of the waxy endosperm in a variety of maize introduced from China in 1908. Brink (17) explained the difference in the character of reserve starch in waxy maize from the endosperm and pollen of non-waxy maize. He concluded that both kinds of starch are composed of sugar units but that the intermediate compounds between the polysaccharides and the sugars differed in molecular structure or in degree of association of their elementary molecule. He also pointed out that waxy starch contained only about one-twelfth as much combined organic phosphorus as did common maize starch.

In 1943 Sprague and associates (56) presented evidence that the waxy gene in corn was not completely recessive in its influences as had been previously believed. These investigators asserted that starches of intermediate characteristics between waxy and starchy endosperm could be produced.

Schoch (51) stated that plant geneticists have discovered waxy strains of sorghum, rye, barley, and rice. No waxy variety of wheat has yet been found. It is believed that the waxy strain represents a primitive variety which has been completely bred out of wheat during its long history of cultivation. Waxy strains of the root and tuber starches have not been reported.

Hixon and Sprague (35) stated that starches from waxy maize and other waxy cereals stain red-brown rather than blue with iodine. Corn exhibiting these characteristics was termed "waxy"; rice, millet, and sorghum with similar properties were termed "glutinous". These starches possess many other unique properties. Granules from waxy and ordinary corn starch appear alike with respect to size and shape, crystalline x-ray patterns, and digestion with B-amylase. The essential differences in the properties of waxy corn starch and ordinary corn starch appear to lie in the molecular structure. It is thought that these structural differences may be responsible for differences in behavior of pastes prepared from these starches and pastes prepared from common corn starch. Gelatinization of ordinary corn starch begins at about 64° C and continues over a range of 30°. Pastes of waxy starches show initial rise in viscosity at about 70° C and progress uniformly and completely within a narrow range of 8°. The shape of the latter gelatinization curve resembles that of tapioca rather than corn starch. The hot viscosity of dilute waxy corn starch pastes was reported to be greater than that of tapioca from 75° to 90° C but less resistant to breakdown on continued cooking (35). Morgan (46) reported similar findings concerning the pasting curves of waxy corn starch pastes.

Schoomeyer and associates (54) stated that waxy corn starches are almost completely lacking in the linear fraction, whereas potato, tapioca, and the common corn starches have been shown to contain up to 22 per cent of the straight-chained glucose polymer. They explained that the absence of this gel-forming constituent contributed to the fluid character of pastes made from both unmodified and modified waxy corn starch. According to Whistler and Smart (59), starches from waxy varieties of corn, sorghum, rice, barley, and millet may contain only amylopectin or, in certain varieties, up to 6 per cent amylose.

Schoomeyer and co-workers (54) stated that the yield of the original Chinese waxy corn was too low to be considered a commercial source of waxy corn starch. Through a cooperative breeding program carried out by the Iowa Agricultural Experiment Station and the United States Department of Agriculture an improved variety of waxy corn was developed in 1941. Part of this seed was planted in Iowa and part in Indiana. Another quantity of open-pollinated waxy corn obtained from the University of Nebraska was planted in Nebraska for the National Starch Products Company. The crop harvested from all these lots was combined and processed by American Maize-Products Company. The starch thus obtained represented the first commercial production of waxy maize starch in the United States.

Schoomeyer (53) stated that the production of amioca (a generic term adopted by all members of the starch industry for waxy corn starch) has developed at a rapid rate since its beginning in 1943. Chemical analysis shows that waxy corn has a consistently higher content of oil and of water soluble material than does common corn. The amioca granule is composed entirely of amylopectin, and its properties are very similar to those of amylopectin fractionated from common starch. Although unswollen amioca granules appear very much like those of common corn starch, the two can be differentiated readily by their color reaction with iodine. Schoonmeyer carried out a study of the effect of various agents on the viscosity of amioca to determine the usefulness of the starch. At low concentrations, the hot viscosity of unmodified amioca was much higher than that of tapioca and similar to that of potato starch. With an increase in concentration of the starch and length of cooking time, the viscosity of amioca was only slightly higher than that of tapioca and lower than that of potato starch. Mixtures of amioca with common starch showed a higher viscosity than either amioca or common corn starch alone in the same concentration. Amioca, tapioca, and corn starch pastes, adjusted to varying pH values with citric acid and allowed to stand overnight, were compared for viscosity changes. Both amioca and tapioca showed a marked decrease in viscosity at pH values of 5.5 or higher and were comparatively stable in the range of 3.5 to 5.0. Both thinned out at pH values below 3.5. Ordinary corn starch did not show sensitivity to pH changes. Liquifying enzymes were found to breakdown amioca and tapioca at about the same rate. Common corn starch proved more resistant to the action of these enzymes. The addition of amioca greatly retarded the gelling of common starch, even at high concentrations of the latter. Although concentrated pastes of acid-modified amioca remained soft and fluid on cooling, ordinary corn starch with similar modification formed a brittle gel when cooled.

Schoch and Elder (52) stated that tapioca and waxy maize starches produced pastes of "long", cohesive stringiness. They found that these starches required less cooking and yielded clearer pastes than corn starch but gave very high peak viscosities and thinned out quickly on continued cooking. The internal cross-bonding within the waxy starch granules by treatment with small amounts of acid chloride or other agents eliminated the stringy paste character and stabilized the viscosity. Schoonmeyer and associates (54) pointed out that modification of waxy starches by treatment with acid or oxidizing agents improved the product for specific uses. These starches are characterized by remarkable clarity, high fluidity, and lack of gel formation on cooling.

Bisno (12) reported that waxy corn starch has gradually begun to replace tapioca for use in conjunction with corn starch in the preparation of fruit pie fillings to produce desirable transparency and flow characteristics. If used alone in pie fillings, starches with the amylopectin characteristics cause excessive flow. For this reason, thickeners of the tapioca or waxy maize type are usually blended with a gel-forming starch.

According to Schoch and Elder (52), a 5 per cent paste of waxy maize starch remained clear and fluid for long periods of time; however, a 30 per cent paste hardened to a gel on standing. In a 5 per cent waxy starch paste, which was frozen and thawed, the branched material was converted to an insoluble state and x-ray diffraction patterns indicated crystalline association of linear chains.

Noznick and co-workers (48) studied the effect of waxy maize starch on the staling of bread in which it was an ingredient. Results showed that the waxy maize starch had a very detrimental effect on dough and bread quality and was of no value in decreasing the rate of staling. These results suggest that bread staling may be associated with the amylopectin component of the starch molecule and cannot be completely attributed to the retrogradation tendencies of the amylose fraction of wheat starch.

Hanson and co-workers (30) made extensive studies to determine possible factors contributing to liquid separation in sauces and gravies subjected to freezing temperatures. When waxy starches and flours were used as thickening agents for these frozen sauces and gravies, liquid separation upon thawing was almost completely eliminated even after several months of frozen storage. Waxy rice flour was found to be the best thickening agent, but the other waxy flours and starches were markedly superior to ordinary flour. These investigators pointed out that all waxy starches are not the same. The degree of branching of waxy rice starch lies between that of ordinary amylopectin and glycogen. The results of these studies may reflect a greater amount of

branching in molecules of waxy cereals than in molecules of common cereals. The results further suggest variation in the extent of branching and molecular size of the amylopectin present in the different waxy cereal starches. The instability of the thawed sauces appeared to be associated with the amylose fraction of the starch molecule and, to a lesser extent, with the molecular size and degree of branching of the amylopectin fraction.

Hanson and associates (31) reported the effect on the stability of frozen puddings of substituting waxy rice flour for corn starch and for part of the egg in frozen custards of both soft and baked varieties. A definite improvement was observed in the stability of the thawed puddings and soft custards containing waxy rice flour as all or part of the thickening agent. Those puddings and custards containing waxy rice flour stored at -10° F showed greater stability after long storage periods than did puddings and custards stored at 0° F. Liquid separation in baked custards subjected to freezing was not prevented by using waxy rice flour as part of the thickening agent.

Davis and co-workers (23) prepared pastes and thickened carrot soups with ordinary and waxy cereal starches and flours as thickening agents. These products were canned, autoclaved, and stored at room temperature. The waxy starches and flours appeared to prevent retrogradation and liquid separation in these canned food products. The results of these investigators

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suggests that the use of starches from waxy cereals may find increasing application in food preparation.

Objective Tests for Cooked Starch Pastes

Various objective tests are applied in industry for evaluation of starches for specific uses. These tests involve the measurement of colloidal paste properties such as viscosity, plasticity, and gel strength.

Viscosity measurements

Industry has developed several methods for measurement of viscosity in both hot and cold starch pastes. Several of these procedures are described on the following pages.

Scott test for hot paste viscosity (40). This test is extensively used to determine hot paste viscosity of starch pastes. A quantity of starch at known pH is stirred to a slurry with 280 cubic centimeters of distilled water in a German-silver beaker. The starch is gelatinized by placing the beaker and contents in a boiling water bath. The paste is stirred mechanically and heated for 15 minutes. At some definite period of time prior to 15 minutes, 200 cubic centimeters of the paste are transferred to a Scott viscosity cup, also in the boiling water bath. At the end of the total heating time of 15 minutes, the plunger valve which closes the orifice on the bottom of the cup is raised and the time, in seconds, is noted for a given volume of paste to fall into a graduated cylinder. The specific Scott test viscosity of the starch under consideration is measured in terms of the time required for a specified amount of paste to flow from the test cup.

The measurement is one of relative viscosity in the sense that standard starches are used to set up permissible limits of variation of the starches to be tested.

Stormer viscosimeter (40). This test may be used to good advantage in evaluating cold paste body. The starch is gelatinized by heating for 15 minutes in a water bath. The paste is then placed in a constant temperature water bath, preferably 25° C, in a closed container. At the end of a definite aging period, any surface skin is carefully removed and discarded. The remaining paste is very gently stirred with a spatula for several seconds and then transferred to the cup of the Stormer viscosimeter. The Stormer viscosimeter is comprised of a cylinder immersed in the test paste which is contained in a metal cup surrounded by a water bath. The immersed cylinder is rotated by a free-falling weight acting through a gear-and-pulley system. The time, in seconds, necessary for a given weight to produce a certain number of revolutions is taken as a measure of cold paste body. The revolution counter is a part of the instrument.

MacMichael viscosimeter (40). This instrument may be used for measurement of cold paste body. The apparatus consists of a cylindrical cup, in which the starch paste is placed, surrounded by a bath with an electric heating device to regulate the bath temperature. The cup and bath rotate at constant speed. A second cylinder is suspended in the paste by means of a torsion wire. The twist that develops in the torsion wire is read by noting the position of a fixed pointer in relation to a moving scale mounted on the torsion wire. The instrument is supplied with several interchangeable torsion wires to permit measurement of a wide range of viscosities.

Hoeppler viscosimeter (40). This instrument involves the use of a principle different from that of the Stormer and the MacMichael viscosimeters. Measurements are made of the time required for a given weight to fall, in vertical motion, through a measured column of paste. The column is surrounded by a constant-temperature bath so that, with only slight modification, the instrument can be adapted to the measurement of hot paste viscosity as well as cold paste body.

Caesar consistometer (40). This apparatus records a continuous history of pasting characteristics of the starch over the entire period from the time gelatinization starts until the paste is cooled to a given temperature. The essentials of the method described by Caesar are to suspend a standard paddle, connected by a shaft to an electric motor, in a beaker containing the starch slurry. The latter is surrounded by a heating bath, and the temperature of the bath is raised at a regular rate. The paddle and the motor move at constant speeds. Changes in the viscosity or paste body are indicated by the differences in the electrical input to the motor necessary to maintain a constant speed of agitation. After the starch is cooked, cold water may be introduced into the bath to cool the paste.

Caesar and Moore (18) reported that this apparatus is only sensitive to starch concentrations of 20 per cent or greater. The degree of degeneration of a starch is revealed by the form of the curve, on which paste temperature is plotted against the net power in watts required to maintain a constant stirring speed.

Brabender amylograph (4). This instrument is a torsion viscosimeter which automatically records the resistance to shear offered by a flour or starch suspension as the temperature of the suspension is increased at a constant rate. The cylindrical, tinned-brass bowl in which the suspension is placed contains eight fixed, vertical pins and is rotated at a constant rate in an electrically heated air bath by means of a synchronous motor. This motor also operates the kymograph and the device for controlling rate of temperature increase. The measuring device consists of a circular, metal disc to which are attached seven metal pins. The frictional resistance exerted as the bowl rotates around the disc causes the free-moving pins to rotate on their central axis. The torque is transmitted through the central shaft and coiled wire spring to the recording torsion balance.

Corn Industries viscometer (41, 7). This instrument was used by Pechtel in testing various corn starches for the corn industry. It provides for a continuous record of viscosity changes during cooking of starch pastes. The starch slurry to be tested is placed in a stainless steel beaker immersed in a thermostatically controlled liquid bath. A synchronous electric motor drives the stirring mechanism at a constant speed. The stirrer is constructed with scrapers to remove pasted starch from the walls of the container. This mechanism keeps the paste smooth and of uniform temperature throughout. A propeller is separately mounted within the hollow shaft of the scraper. The resistance which the propeller meets as it turns in the paste is the basis for noting viscosity changes and is independent of any internal friction encountered by the scraper blades coming in contact with the walls of the cooking vessel. The force thus encountered is transmitted through the gear differential to the drum and the dynamometer and recorder. A pen attached to the dynamometer traces the record of viscosity changes on a strip-type recorder. The recording paper moves at a speed of one-half inch per minute, giving a continuous record during the cooking period. The weight arm of the dynamometer alone has a torque at full scale of 225 gram centimeters above that of water. Additional weights are provided to extend the range of torque values which can be measured. A thermometer is inserted through the condenser cover into the paste to obtain temperature readings.

Line-spread tests

Two investigators have described procedures for the determination of flow properties of hot and cold starch pastes. These tests involve the measurement of spread of a given amount of material when released from a mold to flow on a flat surface.

Gravemeyer and Pfund test (28). For this test a flat glass plate is placed on a level surface; beneath the plate is a diagram of concentric circles spaced 1/8 inch apart and numbered in order of size. The smallest circle with a diameter of two inches is not numbered. A hollow cylinder, the exact diameter of the smallest circle, is placed on the glass plate directly above this innermost circle. The cylinder is filled with the material to be tested and leveled with a spatula. The cylinder is then carefully lifted and material allowed to spread for exactly two minutes. At the end of this period, readings are taken at four widely separated points that mark the limits reached by the substance. The average of the four readings is recorded as the line-spread of the sample.

Miller test for cold paste flow (45). This technique was developed for objective measurement of flow of a cut sample of pie filling. For this test a glass plate 12x12x.25 inches, from which a circle 9.375 inches in diameter had been removed, was superimposed upon a second glass plate of similar dimensions but without the circle removed. The two plates were bound together by four rubber bands. A metal mold, nine inches in diameter, was devised from a standard baking pan with a circle seven inches in diameter removed from the bottom. The pan was inverted and placed within the cut-out area of the upper glass plate. A sample cutter was constructed with a diameter of 3.125 inches and a height of 1 inch. An outer band of metal .375 inches wide and .0625 inches thick was welded one-fourth inch from the top edge of the cutter to form a base for the expansion band. A round, stainless steel expansion band, constructed with a diameter of 3.25 inches and a height of .75 inch, was mounted in place so that it rested on the thickness of the outer band of the sample cutter,

Three pints of hot filling were poured into the large metal mold adjusted on the double glass plates. The opening was covered with a double layer of absorbent paper and an outer layer of Saran Wrap. The poured molds were allowed to cool at room temperature for a specified time period. At the end of the cooling period, the rubber bands were severed and the coverings removed. The cutting edge of the sample cutter was lubricated with salad oil, and one sample was cut from the center of the mold of filling. The upper glass plate and the metal mold were then removed. With the cutter still in position, the excess filling was removed from around the edges and the glass plate wiped clean. The expansion band was then removed from the cutter and the sample leveled to a constant depth of 1 inch, the height of the cutter without the expansion band. The cutter was then removed and the sample released to flow. Each sample was permitted to flow 90 minutes before measurements were taken.

The image of the sample was recorded by exposing the sample on the glass plate, placed over a sheet of light-sensitive paper, to a photoflood lamp placed in position 12 inches above the sample. Images were then developed on the paper with ammonia fumes, and their areas were determined by measurement with the compensating polar planimeter. The amount of flow was determined by subtracting the area of the cutter from the area of flow of the cut sample.

Gel strength tests

Kerr (40) stated that gel strength of starch pastes has been measured by a variety of instruments based on different principles and involving measurement of different characteristics in a gel. Some of the instruments employed in practice are the rigidometer, penetrometer, and Tarr-Baker jelly tester. These instruments may measure rigidity, elasticity, resistance to cutting action, or a combination of these characteristics.

Tarr-Baker jelly tester (40). The principle of this test for gel strength is the gradual application of pressure to a plunger, of known area, resting upon the surface of the gel. The sample to be tested is cooked in a boiling water bath for 30 minutes. The paste is cooled quickly and sufficient water is added to compensate for moisture evaporation. The paste is poured into aluminum moisture dishes, covered with a light film of mineral oil, and placed in a water bath at 20° C for 1 hour. At the end of this aging period, the oil is drained off and the dish is placed under the plunger of the tester. With 500 cubic centimeters of water in the Tarr-Baker jelly testing jar at the start, the flow of water is adjusted so that the manometer column rises 60 centimeters per minute. The manometer is read the instant the starch jelly breaks. Tests are made in triplicate and averaged. The gel strength is reported as the height, in centimeters, reached by the liquid in the manometer at the breaking point of the gel.

Exchange Ridgelimeter (21). For this test, paste batches are made using identical formulas and cooking periods. Jelly glasses are provided with paper-strip extensions acting as sideboards. Containers are filled to capacity, covered, and set aside for 18 to 24 hours. At the end of the aging period, the paper strips are removed and the exposed gel is sliced level with the rims of the glasses with a tightly stretched wire. The gel in the glass is then unmolded in an inverted position on a circular glass plate. The plate is placed on the base of the tester and the gel centered under the point of the micrometer. The point is made to touch the gel surface by carefully turning the micrometer head and watching for the first sign of contact. At this point, the sag is read to the nearest 0.1 per cent. This test measures rigidity of the gel in terms of percentage of sag.

Saare disc method (40). This test was among the first proposed for the evaluation of a cold paste. Kerr described a modification of this method which he has used in research. The starch paste is cooked in a manner similar to that described for the Scott test. The paste is poured into a glass vessel to a definite level. A circular metal disc of known diameter is suspended in the paste by means of a metal rod connected to the center of the upper surface of the disc. The metal rod, which is crooked at the top, is hung over a bar which rests on the top edge of the vessel holding the paste. The length of the rod permits immersion of the disc in the paste to a depth of three centimeters. A thin film of light oil is placed on top of the paste and the vessel and contents placed in a constant temperature bath of 25° C and held for 24 hours. At the end of this time the vessel is removed and placed on a bridge over one pan of a large but sensitive beam balance. A hook suspended from the beam of the balance engages the crook of the rod. Small size shot are added at a fixed rate to the other pan, and the weight of shot is noted at the time the disc fractures the gel. The weight of the shot measured, less the weight of disc and all connections to the beam balance, divided by the exact area of the lower surface of the disc is taken as gel strength. The result is expressed in grams per square centimeter for a given concentration of starch.

Fuchs penetrometer (40). According to Kerr, most of the various penetrometers which have been proposed for use in measuring gel properties are not sufficiently sensitive to distinguish between the various grades of acid-modified industrial starches. This writer states, however, that the instrument constructed by F.W. Fuchs is sensitive and accurate. For this test, the paste is cooked as in the Scott test and placed immediately in a closed, wide-mouth container for storage in a constant temperature bath. At the end of the aging period a ¼-inch layer of the gel is cut off and discarded. The plunger, which consists of a sharpened, highly polished, metal tube, is adjusted to rest on the surface of the prepared gel. A weight is imposed on the plunger in a receptacle on top of the rod attached to the top of the plunger. The plunger is released and the time, in seconds, required for the plunger to cut into the gel up to certain depth is noted.

Recording gel tester. Hjermstad (36) described a gel tester designed to utilize the embedded disk method proposed by Saare and Martens for measurement of gel strength. The system is composed of a device which lowers, at a constant rate, a gel containing an embedded disk which is attached by a cord directly to a dynamometer capable of registering the desired range of force. As the gel is slowly lowered, the dynamometer reacts upward with a continuously increasing force on the disk until the yield point of the gel is reached. The motion of the dynamometer is transmitted to a chart-recorder mechanism to produce a continuous curve defining the applied force, the deformation of the gel, and yield-point of the gel.

PROCEDURE

Selection of Formula

A formula which contained the ingredients commonly found in simple, pudding-type desserts was selected for this study. The proportions of ingredients were defined after a preliminary examination of standard recipes for cornstarch type puddings and pie fillings. Proportions of the individual ingredients were based on standard formulas but adjusted to yield a finished product which had hot paste viscosities within the range of sensitivity of the cooking and recording instrument used.

Many of the recipes reviewed included eggs as an important ingredient. In addition to contributing to flavor and nutritive value of a product, egg proteins produce a definite thickening effect when coagulated by heat. Because the thickening effect of the combination of starches was the major factor under consideration in this investigation, eggs were omitted from the formula used in this study. A blanc mange type of pudding, very satisfactory in consistency was obtained without them.

Starch concentration

Several different starch concentrations were used in preliminary cooking trials. The proportion of starch in simple blanc mange was found to very from 5 to 11 per cent of the weight of the liquid. Lower proportions of starch were used in most pudding recipes which included eggs.

During the preliminary period a 5 per cent starch concentration was tested in the cooking instrument. These 5 per cent starch pastes were somewhat thinner than desirable for pudding mixtures and registered in the lowest limits of the range detectable by the recording apparatus. Starch concentrations were increased until a desirable consistency was obtained. A total starch concentration of 6.7 per cent was finally selected for this study.

Sucrose concentration

The concentration of sugar in the pudding and pie filling recipes varied from 4 to 27 per cent of the weight of the liquid. A sucrose concentration of 10 per cent was arbitrarily selected for this study. This amount was lower than found in many previous studies but appeared to be sufficient to yield a simple pudding of acceptable sweetness.

Liquid medium

Most pudding recipes require some form of milk as the liquid ingredient. At the present time dry milk solids are recommended as an economical and practical replacement for fluid milk. The slight variations in the composition of fresh fluid milk, even when obtained from the same source of supply, could introduce uncontrolled variables during the course of an extended study. Dry milk solids of known composition, obtained from the same processing run, can be stored for use throughout the study. Whole dry milk solids were selected for use in the formula for this study. These solids were reconstituted in distilled water in the proportion of 12.01 per cent of the weight of the water in the formula. This percentage was consistent with the composition of solids in whole fluid milk. Distilled water was used because of the variation in the mineral content of tap water. The presence of electrolytes in tap water has been shown to have a definite effect on the gelatinization of starch pastes.

Salt concentration

The proportion of salt used was based on a preliminary check of formulas, and the level was arbitrarily set at 0.217 per cent of the weight of the liquid.

Basic Formula

The percentages of all dry ingredients in this study were based on the weight of the distilled water. Weights of all ingredients in the formula, based on predetermined percentage relationships, were calculated to yield batches of approximately one liter, the capacity of the beaker in the cooking instrument. The weights and percentages of all ingredients, except the starches, remained the same in the preparation of all starch slurries. The total percentage of starches remained constant in all slurries. However, the proportion of the starches constituting this total varied in progressive steps. The kind and proportion of starch or starches used to make up the total amount were the sources of variation in the study.

The basic formula was as follows:

Ingredients	Weight (grams)	Per cent of liquid
Distilled water	870.0	100.00
Whole dry milk solids	104.5	12.01
Sugar	87.0	10.00
Salt	1.9	.217
Total starch	58.29	6.70

Variations

The purpose of this study was to determine the effect of using a combination of cornstarch and a modified waxy maize starch on the hot paste viscosity and cold paste flow of pudding-type desserts. The thickening agents used included ordinary cornstarch and two waxy maize starches representing different degrees of modification. The modified waxy maize starches were designated by the trade names W-13 and Amaizo "400". Both of the modified starches undergo a certain degree of treatment during processing from the original raw waxy maize starch (43). During manufacture the raw waxy maize starch is treated with an acid chloride with which it is very reactive in the presence of water. This treatment reduces the long pastiness character of the raw starch. The W-13 starch undergoes slightly less treatment than the Amaizo "400".

Each of these modified waxy maize starches was used in combination with cornstarch at specified percentages of the total starch concentration. Series A consisted of varying percentages of cornstarch and W-13 and Series B consisted of similar variations of cornstarch and Amaizo "400". One variation using cornstarch alone was prepared as a control. The amounts and percentages of the starches making up the combinations in the two series are shown in the following tables.

Table 1. Starch composition for Series A.

	Cornstarch		W-13	
Variation	Gm.	% of total starch	Gm.	% of total starch
1	58.29	100	0	0
2	55.38	95	2.91	5
3	52.46	90	5.93	10
4	49.55	85	8.74	15
5	46.63	80	11.66	20
6	43.72	75	14.57	25
7	40.80	70	17.49	30

Table 2. Starch composition for Series B.

	Cornstarch		Amaizo "400"	
Variation	Gm.	% of total starch	Gm.	% of total starch
1	58.29	100	0	0
2	55.38	95	2.91	5
3	52.46	90	5.93	10
4	49.55	85	8.74	15
5	46.63	80	11.66	20
6	43.72	75	14.57	25
7	40.80	70	17.49	30

Preparation of Formula

Ingredients

The cornstarch was obtained from a single 100-pound bag from the University Food Stores. It was stored in a covered container at room temperature. The waxy maize starches, designated by the trade names W-13 and Amaizo "400", were supplied by the American Maize Products Company and were stored at room temperature in the lined bags in which they were shipped. These bags were placed in covered containers. All remaining dry ingredients were obtained from the Food Stores. The granulated sugar was placed in a covered container and kept at room temperature. One box of iodized salt was designated for use in this study and kept at room temperature. Whole dry milk solids*, manufactured by the spray drying process by the Borden Milk Company, were obtained in five-pound sealed cans. The composition of the whole dry milk solids was as follows:

Butterfat ---	28.0%
Milk sugar --	37.7%
Protein -----	26.5%
Minerals ----	5.8%
Moisture ----	2.0%

Freshly distilled water was used as the liquid medium for reconstituting the milk solids in all replications. The distilled water was kept in a stoppered glass jug and stored at room temperature.

All dry ingredients were weighed out in advance. A triple-beam balance, accurate to 0.01 gram, was used for

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*Parlac

weighing both the cornstarch and the waxy maize starches. The starches were weighed on squares of stiff white paper from which they were easily removed to the storage containers. All other dry ingredients were weighed on a Torsion balance on squares of wax paper. A rubber scraper was used to aid in complete removal of all material from the wax paper. Sugar, salt, and starches for the individual variations were combined and placed in plastic, moisture proof storage containers and covered with tightly fitting lids. Individual weighings of whole dry milk solids were stored separately in similar storage containers and the lids were sealed on with freezer tape. Distilled water was weighed out in a 1-liter glass beaker on a Harvard Trip single-beam balance at the time of each experiment.

Mixing procedure

Care was taken throughout the experiment to standardize all procedures. From preliminary trials the required time for combining and pouring slurries was determined. A time schedule for these procedures was outlined and followed throughout the study. Three replications were prepared of each variation.

The distilled water was drawn and 870 grams weighed into a 1-liter beaker. This beaker was then immersed in a bath of warm tap water where it remained until the temperature of the distilled water reached 41° C. When this temperature was attained, approximately 1/3 of the distilled water was poured into a 250 cc glass beaker. The whole dry milk solids were sprinkled on the surface of the remaining 2/3 of distilled water which had been removed from the warm water bath. The mixture was stirred with a narrow rubber scraper to remove lumps and allowed to stand for 15 minutes, stirring occasionally, to dissolve the milk solids completely.

During this period the mixture of starches, sugar, and salt was transferred to a 1-liter graduated glass beaker. After the milk solids were dissolved the final step in combining ingredients was begun. Only enough of the reconstituted milk solids were added to moisten the dry ingredients. The mixture was stirred vigorously with a narrow rubber scraper to produce a smooth paste. When the slurry was free from lumps the remaining milk was added and the mixture blended well. Half of the distilled water set aside was then used to rinse the beaker from which the reconstituted solids were poured. The temperature of the mixture at this point was $33.5^{\circ} \pm 1^{\circ}$ C. This temperature was achieved by the previous adjustment of the temperature of the distilled water and the maintenance of a time schedule for combining ingredients.

The motor of the stirring mechanism in the viscometer was then turned on, and the slurry was immediately poured into the preheated cooking container in the Corn Industries viscometer. The beaker was rinsed with the remaining distilled water and these rinsings added to the mixture in the cooking beaker.

The entire mixing and pouring process required a period of four minutes. The condenser cover was then replaced and the motor of the recording device switched on.

Cooking procedure

The Corn Industries viscometer, described in the review of literature, was used for cooking the starch puddings and for recording viscosity measurements. Figure 1 shows a cross section diagram of the viscometer.

Bechtel (6) recommended that standard speed of the stirring mechanism be used during the gelatinization of starch. Standard stirring speed was used throughout this investigation. His recommendation for a chart speed of one-half inch per minute was also followed.

During the preliminary trials in this study it was found necessary to extend the range of the weight arm on the dynamometer by adding the specified weight to increase the torque range to 900 gram-centimeters. This additional weight was required for the entire series. The recording chart used in this study was scaled up to 225 gram-centimeters making it possible to read torque values directly. The additional weight used in this study required that the torque readings be multiplied by four to obtain the correct values.

A temperature endpoint of 95° C was selected arbitrarily for the pastes in this study. This assured attaining a record of the maximum viscosity of the paste. To achieve this paste temperature, a bath temperature of 100° ± 1° C was necessary.

Figure 1. Sectional drawing of the Corn Industries viscometer (7).

1. Recorder and dynamometer (Dynamometer not shown)

2. Cable from viscometer to recorder

3. Cable drum

4, 5, 6, 7. Gears of sun and planet differential

8. Worm, turned by synchronous motor (not shown)

9. Worm gear

10. Spring pins for holding center shaft

11. Coupling to attach stirrer

12. Condenser cover

13. Liquid bath

14. Overflow

15. Drain cock

16. Starch beaker

17. Electric heater, thermostatically controlled

18. Scraper blades

19. Propeller

20. Thermometer in paste

21. Thermometer in bath

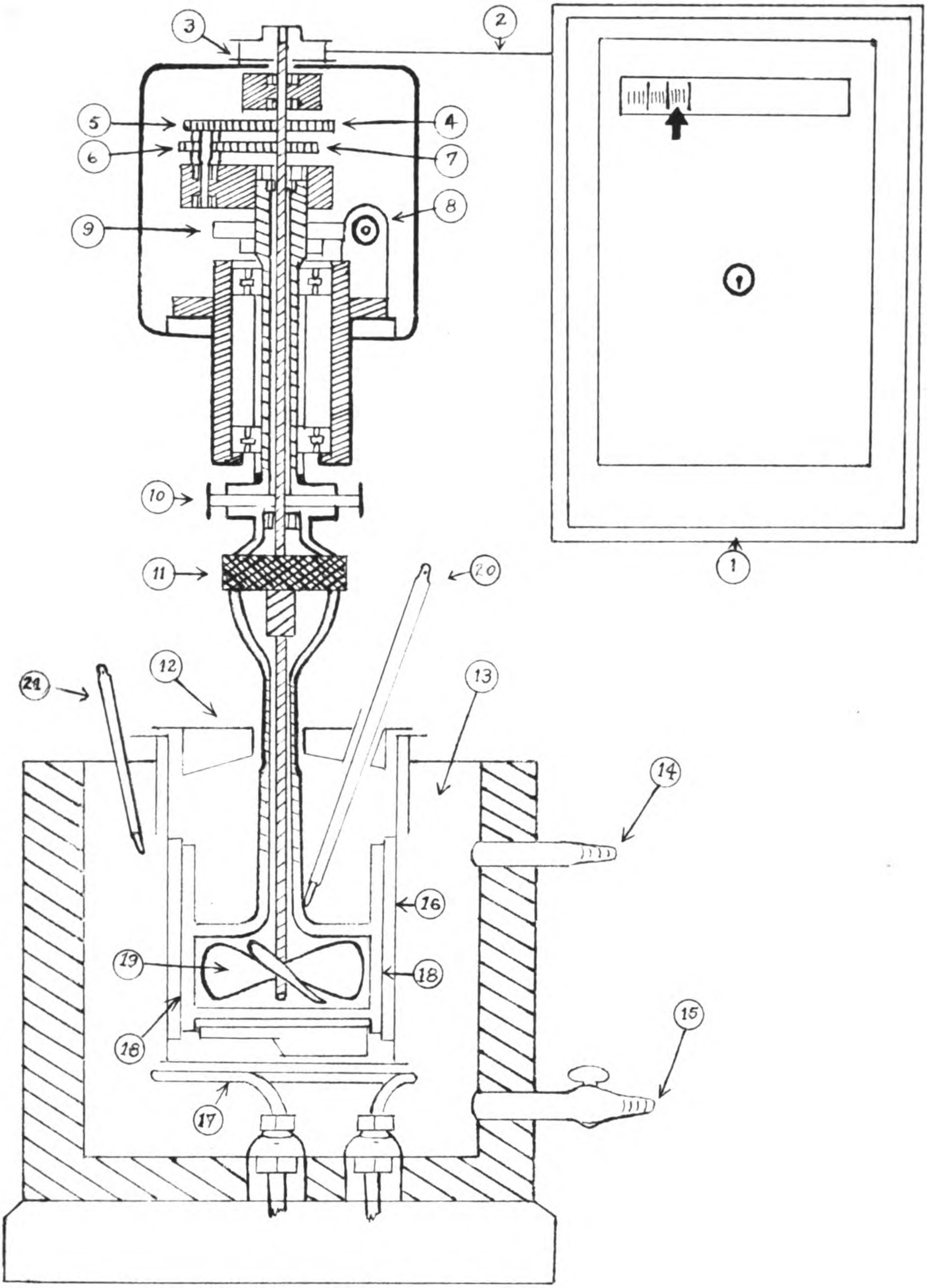

Figure 1. Sectional Drawing of the Corn Industries Viscometer.

Because a bath of distilled water alone evaporates excessively at this temperature, a glycerol-type of permanent antifreeze was combined with an equal amount of water for the bath. The thermostat was adjusted to maintain a constant temperature of the bath. With this type of bath some evaporation still occurs, and it was necessary at intervals during the investigation to add more glycerol-water mixture to the bath. These components were combined using specific gravity determinations to obtain the desired concentration of each.

Previous to each cooking period, the stainless steel beaker, stirrer and condenser cover were placed in position. The viscometer was then plugged in to begin heating. A temperature of 70° C inside the cooking container and a bath temperature of 100° C were reached before the slurry was poured and cooking was begun.

The temperature of the pudding was recorded at 1-minute intervals throughout the cooking period from the thermometer inserted into the paste through a rubber stopper in the condenser cover. As soon as the temperature of the cooked paste reached 95° C, the mechanical stirrer and recording mechanism were turned off and the beaker containing the cooked pudding was removed at once. Four samples were poured immediately into the specially designed metal molds adjusted on double glass plates. These molds, which hold approximately 7/8 cup each,were filled about level with the top. A period of 1½ minutes was required to remove the beaker from the bath and pour the four samples. The pudding samples were covered with a circle of absorbent paper in addition to an overall covering of Saran wrap which was placed over the top of the absorbent paper and the edges were pressed firmly to the upper glass plate. The glass plates were numbered with a red wax pencil in the order in which the molds were poured.

Testing Equipment

The testing equipment used for measurement of cold paste flow was a modification of the method used by Miller (45). A glass plate 12" x 12" x ¼" from which a circle of 3.5" in diameter had been removed was superimposed upon a second glass plate of the same dimensions without the circle removed. These two plates were held together by the means of four rubber bands stretched over each of the four edges. The mold was a circular metal band of stainless steel, 3.5" in diameter and 1¼" deep, with one edge rolled. This mold was placed with the rolled edge up within the cut-out area of the upper glass plate. A round metal sample cutter was constructed with a diameter of 3 1/8" and a height of 1". An outer band of metal 3/8" wide and 1/16" thick was welded ¼" from the top edge of the cutter to form a base for the expansion band. A round metal expansion band was constructed with a diameter of 3¼" and a height of 3/4". When mounted in place, the expansion band rested upon the 1/16" ridge formed by the thickness of the outer band of the sample cutter.

Testing Procedure

After cooling at room temperature for a period of one hour for the first 2 samples and three hours for the last 2 samples from each batch, the samples were cut and line spread measurements made. The samples were handled consecutively in the order in which they were poured initially. The investigator prepared the first sample and released it to flow; during the period of flow for the first sample, the second sample was prepared for release. Each complete testing procedure required eleven minutes; but with the overlap of time in handling the samples, the two tests were completed within a fifteen-minute period. The second sample was ready for flow measurements exactly four minutes after the first sample.

To prepare the samples for testing, the paper coverings were removed gently from the top of the mold. Care was taken to prevent any moisture condensed between the two layers from dropping back on the sample. The cutting edge of the sample cutter was lubricated with salad oil and wiped free of excess. This procedure was necessary to prevent material from sticking to the sides of the cutter. The cutter was then pressed firmly down into the center of the molded pudding. The cutter was held firmly in place and the mold was removed. The rubber bands were snipped with scissors, and the upper glass plate gently withdrawn. Excess material was removed from around the edge of the cutter and the lower glass plate was wiped clean.

The upper expansion band was then detached and the sample was leveled with a straight-edge knife. The glass plate was again wiped clean. The cutter was then lifted and the sample was allowed to flow freely for five minutes.

A photoflood lamp with a No. 2 bulb was mounted on a ringstand 12 inches above the upper surface of the glass plate holding the sample. After the 5-minute flow period, a sheet of Tecnifax Diazo blue line paper, which is light-sensitive, was placed directly under the glass plate and the light switched on. The area around the sample was exposed to the light and the image of the sample was recorded as the unexposed area on the Tecnifax Diazo blue line paper. The exposure time for all samples was arbitrarily set for 2 minutes. The exposed paper was immediately placed in a dark colored box.

After testing was concluded the images of all four samples were developed with ammonia fumes. About a cupful of household ammonia was placed in a stainless steel bowl mounted on a ringstand over a lighted Bunsen burner. When the ammonia was sufficiently heated to volatilize, the exposed paper was removed from the storage box and held over the ammonia fumes. The unexposed area on the paper developed to a sharply defined blue outline in a few seconds.

The areas of the prints were measured with the compensating polar planimeter. The area of flow for each sample was determined by subtracting the area of the cutter, which was the size of the original sample, from the area of the image taken after the sample was allowed to flow. As the cutters varied slightly in size, all cutters were coded and their individual areas determined.

RESULTS AND DISCUSSION

Viscosity Tests

Maximum viscosity values

The range and average torque values at maximum viscosity of the three replications of each variation in Series A and B is shown in Table 3.

Table 3. Range and average maximum viscosity values in three replications of Series A and B.

Level of waxy starch, in terms of percentage of total starch	Series A, W-13 starch		Series B, Amaizo "400" starch	
	Range	Average	Range	Average
0 (control*)	408-428	418	408-428	418
5	412-452	435	412-432	421
10	436-460	449	432-436	435
15	456-468	463	444-448	447
20	480-488	484	436-448	441
25	500-512	505	448-492	471
30	508-564	540	476-496	489

*Regular cornstarch comprised entire starch content.

Proportion of starch

The effect of the percentage of waxy maize starch W-13 on the viscosity of cornstarch puddings is shown in Figure 2. Analysis of variance for the puddings made with varying levels of waxy maize starch W-13, Table 4, showed highly significant differences in the average maximum viscosity values within the series.

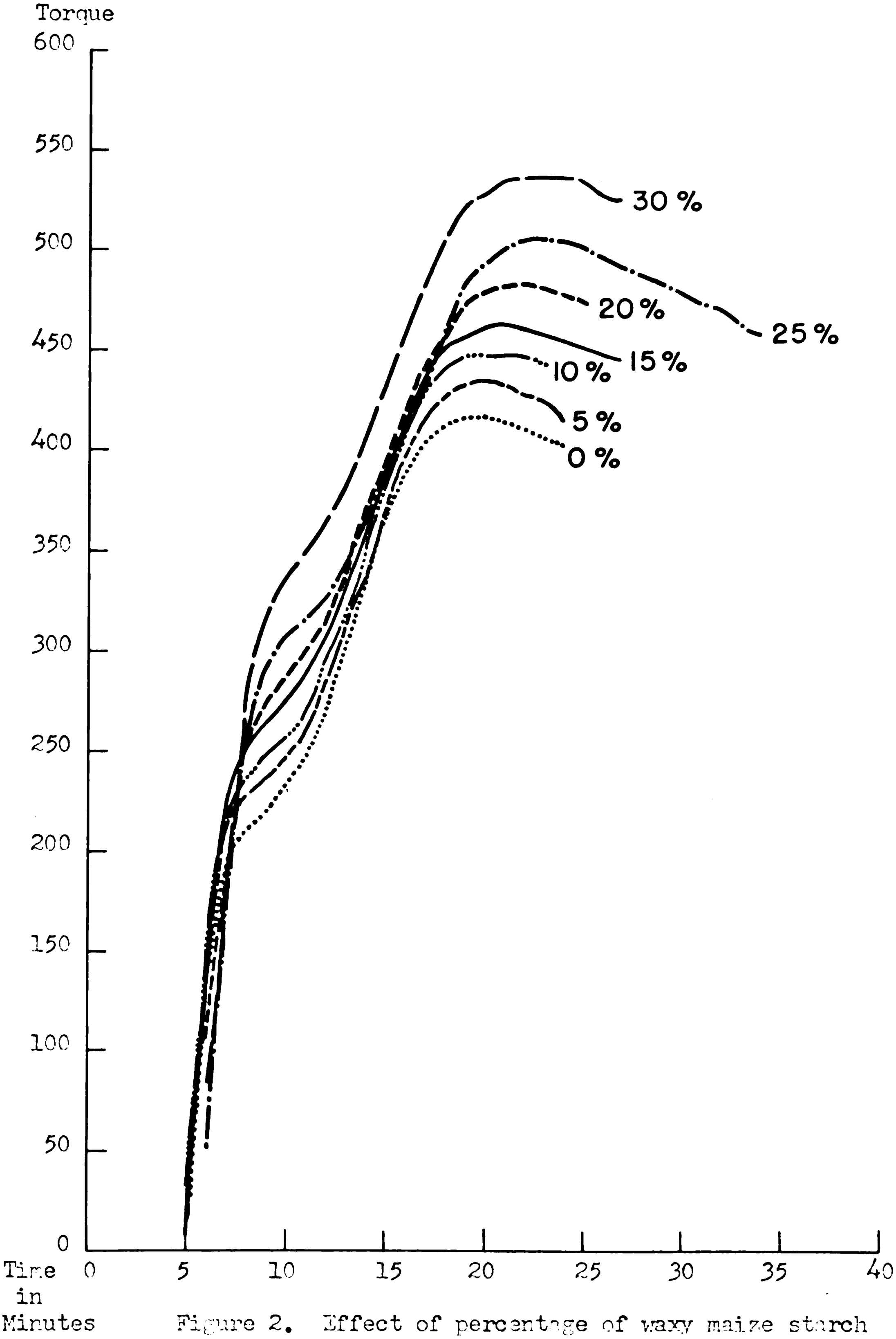

Figure 2. Effect of percentage of waxy maize starch W-13 on the initial viscosity rise, maximum viscosity, and final viscosity of puddings in series A.

Table 4. Analysis of variance of maximum viscosity values for Series A.

Source of variance	D. F.	M. S.	F.
Total	20		
Between treatment averages	6	5423	23.78**
Within treatments	14	228	

**Significant at 1% level of probability

Maximum viscosity values showed progressive increases with increase in percentage of waxy maize starch W-13. Differences between averages were tested by Studentized ranges. At the 5 per cent level of probability the following significant differences were noted in Series A.

30 per cent differed from all lower levels.
25 per cent differed from 15 per cent and all lower levels.
20 per cent differed from 10 per cent and all lower levels.
15 per cent differed from the control.
10 per cent differed from the control.

The effect of the percentage of waxy maize starch Amaizo "400" on the viscosity of cornstarch puddings is shown in Figure 3. Analysis of variance for the puddings made with varying levels of waxy maize starch Amaizo "400", Table 5, showed highly significant differences in average maximum viscosity values within the series.

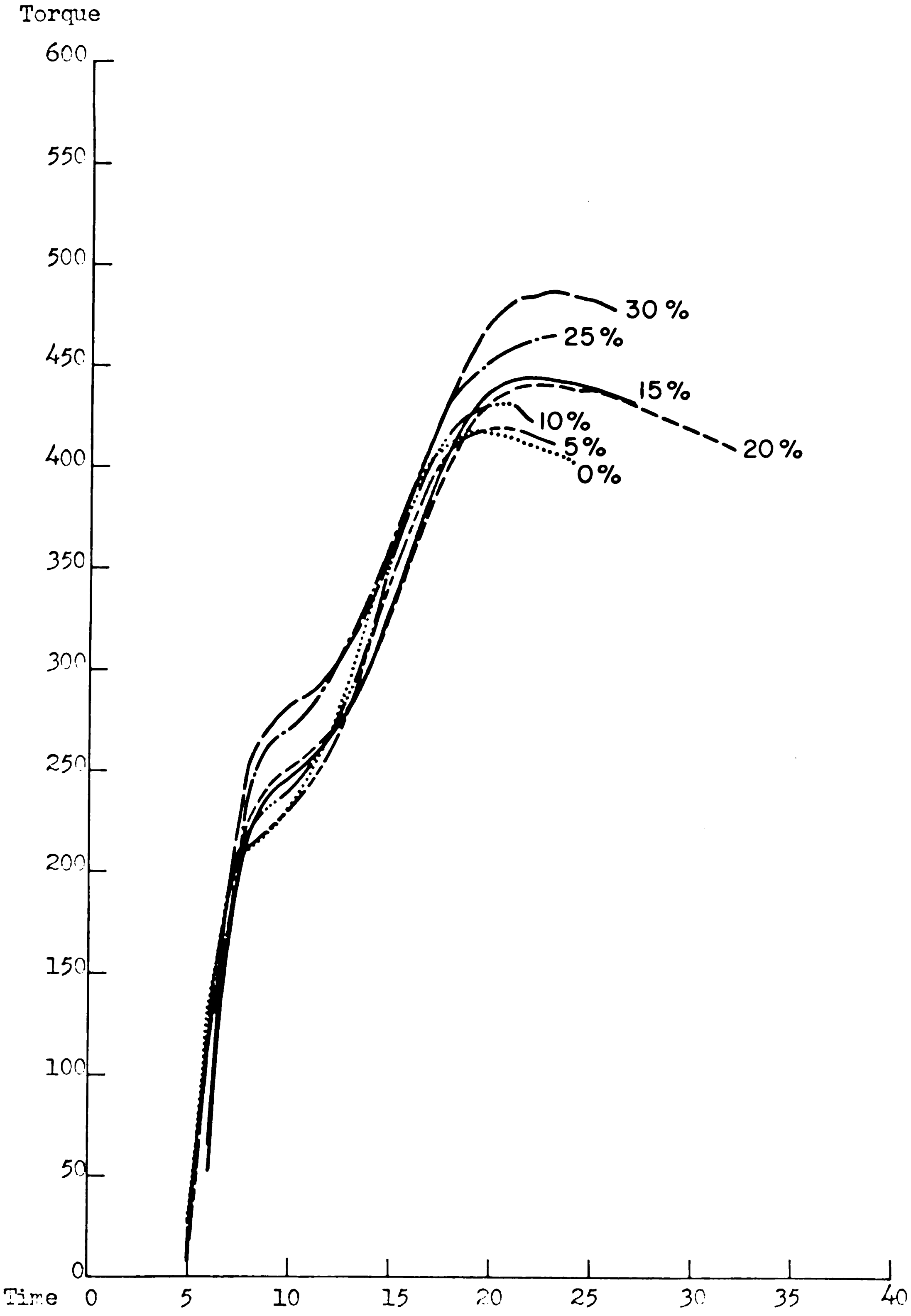

Figure 3. Effect of percentage of waxy maize starch Amaizo "400" on the initial viscosity rise, maximum viscosity, and final viscosity of puddings in series B.

Table 5. Analysis of variance of maximum viscosity values for Series B.

Source of variance	D. F.	M. S.	F.
Total	20		
Between treatment averages	6	2033	16.395**
Within treatments	14	124	

**Significant at 1% level of probability

Maximum viscosity values showed progressive increases with increase in percentage of waxy maize starch Amaizo "400" with the exception of the 20 per cent level which fell slightly below the 15 per cent level. Differences between averages were tested by Studentized ranges. At the 5 per cent level of probability the following significant differences were noted in Series B.

30 per cent differed from 20 per cent and all lower levels.
25 per cent differed from 20 per cent and all lower levels.
20 per cent differed from the control.
15 per cent differed from 5 per cent and the control.

Cooking time

Temperatures of initial viscosity rise ranged from 77° to 78° C in Series A and from 77.25° to 78° C in Series B. No progressive changes in temperatures of initial viscosity rise occurred with an increase in the level of waxy maize starch in either Series A or B. Five to seven minutes were required in both Series A and B to reach the point of initial viscosity rise. The time required for initial rise in viscosity was not related to the level of waxy maize starch in either Series A or B.

In this study all puddings were cooked to an endpoint of 95° C. The length of time required to reach this temperature varied from 23 to 38 minutes in Series A and from 22 to 40 minutes in Series B. The time required to reach maximum viscosity varied from 18 to 24 minutes in both Series A and B. The temperature at maximum viscosity ranged from 92° to 94° C in both Series A and B. Tables 6 and 7 show data on time and temperatures required to reach maximum viscosity and temperatures of initial viscosity drop in Series A and B.

These differences in cooking time did not appear to be associated directly with the level of waxy maize starch but appeared to be more related to a variation in the rate of heating. No logical explanation could be given for this behavior as the temperature of the cooking bath was apparently well controlled. The differences in rate of heating were not sufficient to overcome the influence on maximum viscosity exerted by the level of waxy maize starch when the three replications were averaged.

Table 6. Cooking times and temperatures to reach maximum viscosity, and temperatures of initial viscosity drop in all replications of Series A.

Percentage of W-13	Maximum viscosity value (torque)	Cooking time to reach maximum viscosity (minutes)	Temperature upon reaching maximum viscosity (° Centigrade)	Temperature of initial viscosity drop (° Centigrade)
0	428	18	92.5	94.0
0	408	18	93.0	94.0
0	416	19	93.0	94.25
5	452	19	93.25	94.0
5	440	19	93.25	94.5
5	412	20	93.5	94.25
10	452	19	93.25	94.5
10	460	19	93.5	94.0
10	436	21	94.0	94.25
15	456	18	92.5	94.0
15	464	19	93.25	94.25
15	468	21	93.25	94.25
20	484	20	93.5	94.25
20	480	19	93.25	94.5
20	488	22	92.0	93.0
25	512	22	92.5	93.0
25	500	22	92.5	93.25
25	504	22	92.25	93.5
30	548	19	93.0	94.75
30	564	21	93.25	94.0
30	508	24	92.25	93.25

Table 6. Cooking times and temperatures to reach maximum viscosity, and temperatures of initial viscosity drop in all replications of Series A.

Percentage of W-13	Maximum viscosity value (torque)	Cooking time to reach maximum viscosity (minutes)	Temperature upon reaching maximum viscosity (° Centigrade)	Temperature of initial viscosity drop (° Centigrade)
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5	440	19	93.25	94.5
5	412	20	93.5	94.25
10	452	19	93.25	94.5
10	460	19	93.5	94.0
10	436	21	94.0	94.25
15	456	18	92.5	94.0
15	464	19	93.25	94.25
15	468	21	93.25	94.25
20	484	20	93.5	94.25
20	480	19	93.25	94.5
20	488	22	92.0	93.0
25	512	22	92.5	93.0
25	500	22	92.5	93.25
25	504	22	92.25	93.5
30	548	19	93.0	94.75
30	564	21	93.25	94.0
30	508	24	92.25	93.25

Table 6. Cooking times and temperatures to reach maximum viscosity, and temperatures of initial viscosity drop in all replications of Series A.

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0	408	18	93.0	94.0
0	416	19	93.0	94.25
5	452	19	93.25	94.0
5	440	19	93.25	94.5
5	412	20	93.5	94.25
10	452	19	93.25	94.5
10	460	19	93.5	94.0
10	436	21	94.0	94.25
15	456	18	92.5	94.0
15	464	19	93.25	94.25
15	468	21	93.25	94.25
20	484	20	93.5	94.25
20	480	19	93.25	94.5
20	488	22	92.0	93.0
25	512	22	92.5	93.0
25	500	22	92.5	93.25
25	504	22	92.25	93.5
30	548	19	93.0	94.75
30	564	21	93.25	94.0
30	508	24	92.25	93.25

Table 7. Cooking times and temperatures to reach maximum viscosity, and temperatures of initial viscosity drop in all replications of Series B.

Percentage of Amaizo (400"	Maximum viscosity value (torque).	Cooking time to reach maximum viscosity (minutes)	Temperature upon reaching maximum viscosity (° Centigrade)	Temperature of initial viscosity drop (° Centigrade)
0	428	18	92.5	94.0
0	408	18	93.0	94.0
0	416	19	93.0	94.25
5	432	19	93.5	94.0
5	420	19	93.25	94.0
5	412	21	93.0	94.25
10	436	20	93.75	94.0
10	436	19	93.25	94.25
10	432	22	93.75	94.0
15	448	20	93.5	94.5
15	448	23	93.5	94.0
15	444	22	93.75	94.0
20	440	21	93.0	93.5
20	436	22	93.75	94.5
20	448	22	93.0	94.25
25	472	20	94.0	95.0
25	492	20	93.75	94.5
25	448	24	92.0	92.5
30	496	21	93.5	94.0
30	496	21	93.5	94.25
30	476	23	93.25	94.25

Because of these differences in cooking time an attempt was made to find a relationship between cooking time to reach maximum viscosity and the maximum viscosity value of the individual replications. These factors did not show any straight correlation when the entire series was considered because the level of waxy maize starch appeared to have much greater influence on maximum viscosity than cooking time. A partial correlation, holding the level of starch constant, however, showed a negative correlation between maximum viscosity and cooking time which was highly significant at the 1 per cent level of probability in Series B. However, a significant correlation could not be shown between cooking time and maximum viscosity in Series A. These results indicate that the longer cooking time to reach maximum viscosity may have reduced the maximum viscosity value in Series B.

These findings are not in agreement with Harris and Jesperson (33) who reported that swelling power was not significantly affected by rate of heating. Bechtel (8), however, found that an increase in rate of heating increased the maximum viscosity to a marked degree and that the difference in viscosity was evident throughout the remainder of the cooking period.

Kind of starch

The height of the pasting curves and the maximum viscosity values were greater in puddings made with all levels of both waxy maize starches in combination with ordinary corn starch than in those puddings made with only ordinary corn starch as the thickening agent. Chemists for American Maize-Products Company (3) have found that the raw waxy maize starch (amioca) gives much higher viscosity values than does ordinary corn starch at similar concentration in a paste.

A straight line was fitted to the maximum viscosity values in both Series A and B. The slopes of the lines were tested statistically and results showed the two starches to be different at the 1 per cent level of probability. Figure 4 shows graphically the average viscosity values at each level of waxy maize starch and the regression lines fitted to these values of both Series A and B. The rate of increase in maximum viscosity of puddings with each increment of waxy maize starch W-13 was significantly greater than the rate of increase in viscosity observed in those made with corresponding levels of waxy maize starch Amaizo "400". Figure 5 shows a series of graphs comparing viscosity curves in Series A and B at each level of waxy maize starch. With each increment in the level of waxy maize starch the difference between the heights of the viscosity curves of Series A and B became greater.

These findings are in agreement with the statements of the manufacturers of these two modified waxy maize starches. They assert that with increased treatment the waxy maize starch exhibits characteristics approaching more nearly those of the ordinary common corn starch (43). Waxy maize starch Amaizo "400" had undergone more chemical treatment than had waxy maize starch W-13.

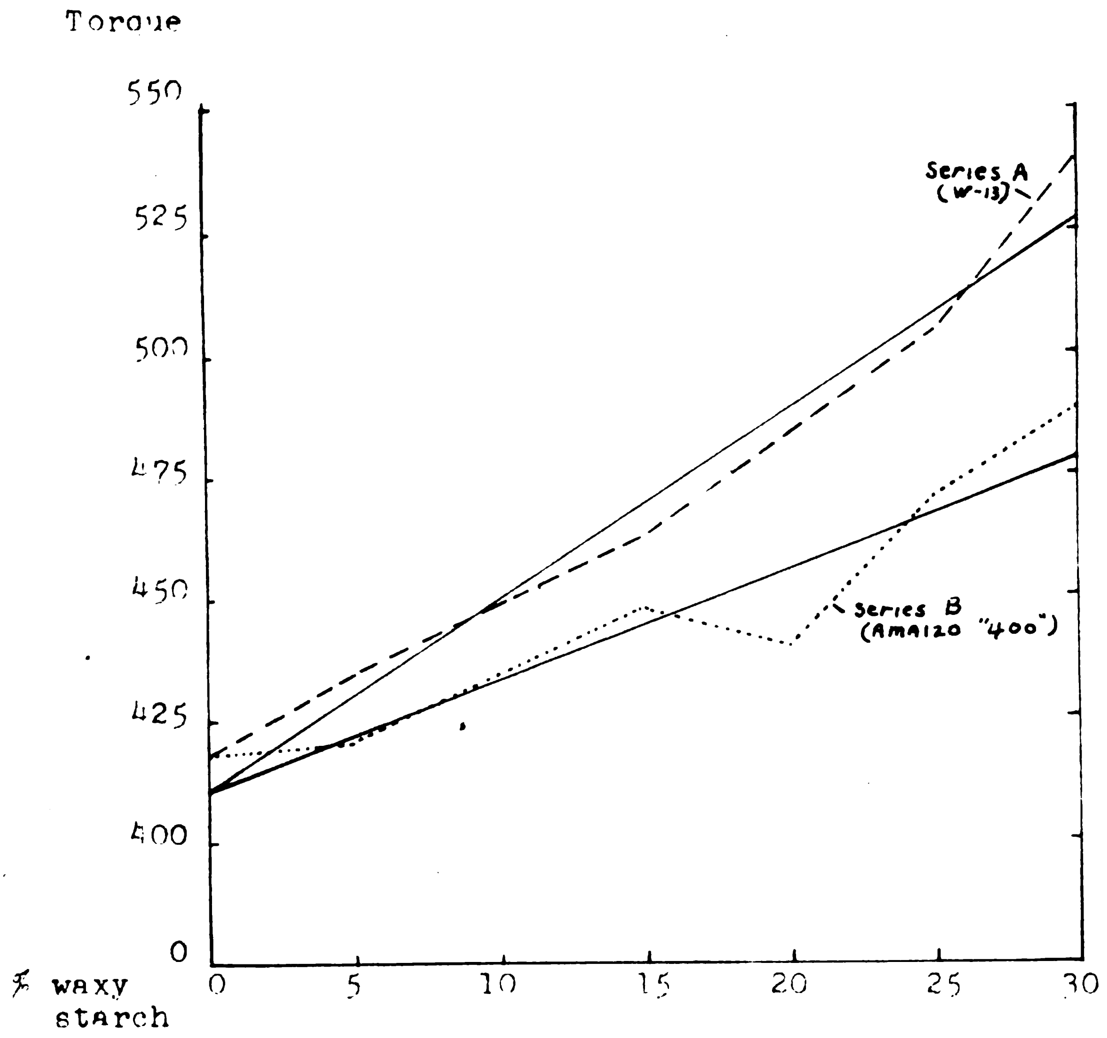
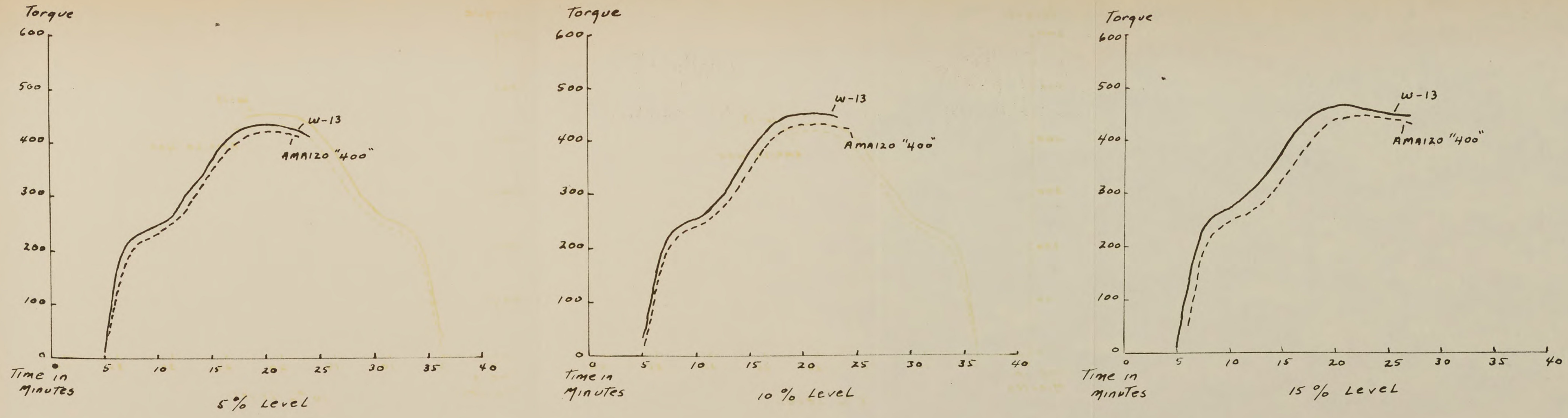


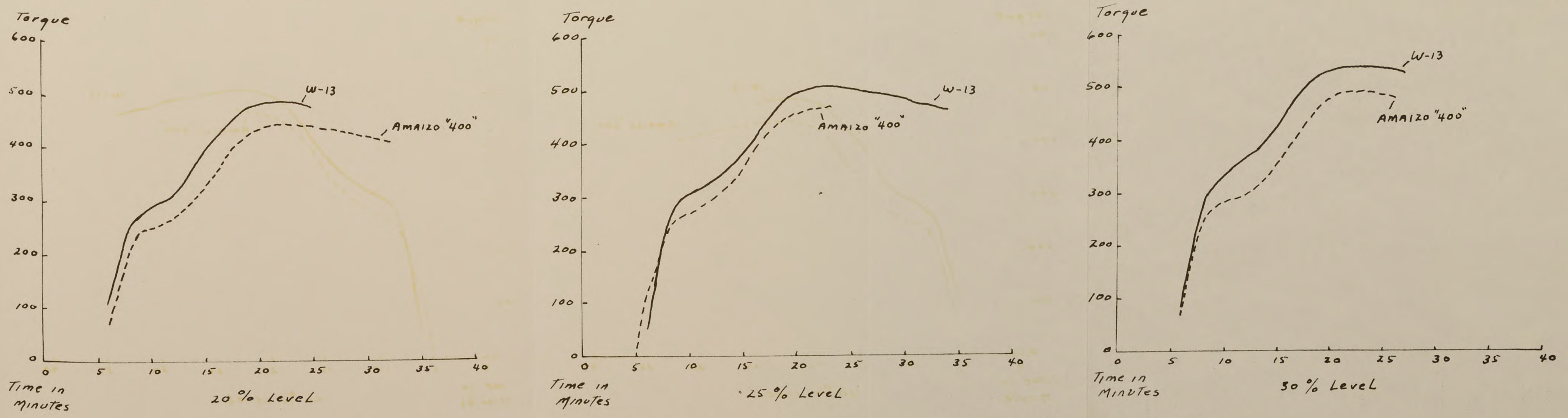
Figure 4. Effect of percentage of waxy maize starch on average maximum viscosity values for series A and B as shown by lines of regression.



5 % Level

10 % Level

15 % Level



20 % Level

25 % Level

30 % Level

FIGURE 5. EFFECT OF KIND OF WAXY MAIZE STARCH AT CORRESPONDING LEVELS OF TOTAL STARCH CONCENTRATION ON VISCOSITY CURVES OF PUDDINGS

Cold Paste Flow

Proportion of waxy maize starch

The samples of pudding used for flow tests were held at room temperature. The first tests were made on 2 samples after a 1-hour holding period, and the tests on the remaining 2 samples were made after a 3-hour holding period. The measurement of flow for samples, expressed in square centimeters, were determined by measuring the prints of the samples with the compensating polar planimeter. The flow readings for the two samples tested at each holding period were averaged. The range of the average values for the three replications for each holding period are shown in Table 8 for both Series A and B.

Table 8. Range in flow values of three replications of each series.

Series	Type of waxy starch	Holding time	Waxy starch level in terms of percentage of total starch. 0	5	10	15	20	25	30
A	W-13	1 hr.	31.6-33.5	31.0-33.7	31.4-34.8	31.6-32.6	32.4-37.5	36.3-36.9	33.1-38.1
B	Amaizo "400"	1 hr.	31.6-33.5	29.9-34.2	31.1-33.9	32.8-33.9	35.0-40.2	29.6-40.0	32.2-35.1
A	W-13	3 hrs.	22.6-22.9	22.2-24.0	21.8-24.1	20.7-22.1	23.2-24.5	23.2-25.3	23.3-24.5
B	Amaizo "400"	3 hrs.	22.6-22.9	21.2-23.4	21.6-24.1	21.7-23.4	23.4-24.0	21.8-26.0	21.6-22.9

The average readings for the three replications for each holding period for both Series A and B are shown in Table 9.

Table 9. Summary of average flow readings of three replications for each series at 1-hour and 3-hour holding periods.

Series	Type of waxy starch	Holding time	Waxy starch level in terms of percentage of total starch.						
			0	5	10	15	20	25	30
A	W-13	1 hr.	32.3	32.4	32.8	31.9	34.3	36.7	34.9
B	Amaizo "400"	1 hr.	32.3	32.0	32.2	33.3	38.0	33.4	33.8
A	W-13	3 hrs.	22.7	23.3	23.1	21.3	24.0	24.4	23.8
B	Amaizo "400"	3 hrs.	22.7	22.6	23.0	22.3	23.8	23.3	22.3

Analysis of variance of flow readings showed no significant difference between the mean squares of between replications within treatments and within replications within treatments. Therefore, a common error term was found by combining the sums of squares for these two sources of variance.

Analysis of variance of flow readings in Series A, Table 10, showed highly significant differences between levels of waxy maize starch W-13 within each holding period.

Table 10. Analysis of variance of flow readings in Series A.

Source of variance	D. F.	After 1-hour holding period M. S.	F.	After 3-hour holding period M. S.	F.
Total	41				
Treatments	6	18.4	4.00**	5.96	4.89**
Between replications within treatments	14	6.2	1.82	1.40	1.15
Within replications within treatments	21	3.4		1.10	
Common error	35	4.6		1.22	

**Significant at 1% level of probability

Analysis of variance of flow readings in Series B, Table 11, showed highly significant differences between levels of waxy maize starch Amaizo "400" for the 1-hour holding period but no significant differences for the 3-hour holding period.

Table 11. Analysis of variance of flow readings in Series B.

Source of variance	D. F.	After 1-hour holding period M. S.	F.	After 3-hour holding period M. S.	F.
Total	41				
Treatments	6	25.58	3.47**	1.86	.93
Between replications within treatments	14	14.29	1.94	2.83	1.42
Within replications within treatments	21	2.77		1.44	
Common error	35	7.38		2.0	

**Significant at 1% level of probability

These differences in flow readings did not appear to be related to the level of waxy maize starch. There was no progression in flow values within each series with increase in the level of waxy maize starch. At the concentrations used in this study, the waxy maize starches had no apparent effect on gel-forming tendencies of cooled cornstarch puddings. These findings are not in agreement with Schopmeyer (53) who stated that the addition of amioca greatly retarded the gelling tendency of common starch, even when common corn starch constituted the major proportion of the total starch.

Cooking time

Since the significant differences in flow measurements between treatments could not be attributed to the level of waxy maize starch, this variable was disregarded and an attempt made to find another cause for the differences in flow measurements within each series. As cooking time appeared to be a factor influencing maximum viscosity values, it appeared that this factor might also logically affect end viscosity and perhaps in some way affect flow of the cooled sample. Analyses were made to correlate cooking time with end viscosity as well as cooking time and flow measurements of the cut samples.

A partial correlation carried out between cooking time and end viscosity, holding the level of waxy starch constant, showed a negative correlation significant at the 1 per cent level of probability in both Series A and B. These results indicate that as cooking time was increased, the end viscosity values were correspondingly decreased when the influence of the level of waxy maize starch was eliminated. It is generally agreed that continued cooking of a starch paste after maximum viscosity is reached will result in paste breakdown. After maximum viscosity has been reached the extent of decrease in viscosity of a given paste depends on the length of the cooking period.

There was no straight correlation between end viscosity and the flow of cut samples in either series. A partial correlation carried out between end viscosity and the flow of cut samples of puddings in Series A, with the level of waxy maize starch held constant, showed a negative correlation at the 1-hour holding period, significant at the 1 per cent level of probability. The partial correlation between end viscosity and the flow of the cut samples at the 3-hour holding period was not significant in Series A. A similar correlation was found to be highly significant at the 1 per cent level of probability for both 1-hour and 3-hour holding periods in Series B. In both series the correlation between end viscosity and the flow of cut samples was greater at the 1-hour holding period than at the 3-hour holding period. These results indicate that as end viscosity decreased, the flow of the cut samples increased when adjustments were made to eliminate the influence of the level of waxy maize starch. The correlation appeared to diminish gradually with increased holding time.

As the level of waxy maize starch did not appear to influence flow of the cut samples, a straight correlation was carried out between flow measurements and cooking time. A positive correlation between cooking time and flow of the 1-hour samples in Series A was found to be highly significant at the 1 per cent level of probability. A similar correlation was found between cooking time and flow of the cut samples at the 3-hour holding period significant at the 5 per cent level of probability. The correlation between cooking time and flow of cut samples of puddings in Series B for both 1-hour and 3-hour holding periods was significant at the 1 per cent level of probability.

The correlation was greater, however, after the shorter holding period in both series. Figure 6 shows values for flow plotted against cooking time for both 1-hour and 3-hour holding periods in both series.

These results indicate that as cooking time was increased and end viscosity decreased, the flow of the cooled sample of pudding was increased. The fact that the correlation is less pronounced for the samples held 3 hours would indicate that the end viscosity value had less influence on consistency of these samples than on samples held only 1 hour.

Many investigators have found no relationship between hot paste viscosity and cold paste characteristics. In this study it appeared that within the limits of a 3-hour holding period complete gelation had not yet occurred. Therefore, it seemed that the effect of hot paste viscosity, as related to extent of paste breakdown, had not entirely disappeared.

Holding time

An easily discernable difference was observed between the flow of the cut samples of pudding after the 1-hour holding period and after the 3-hour holding period. Increase in holding time decreased the flow of the cut samples in both Series A and B.

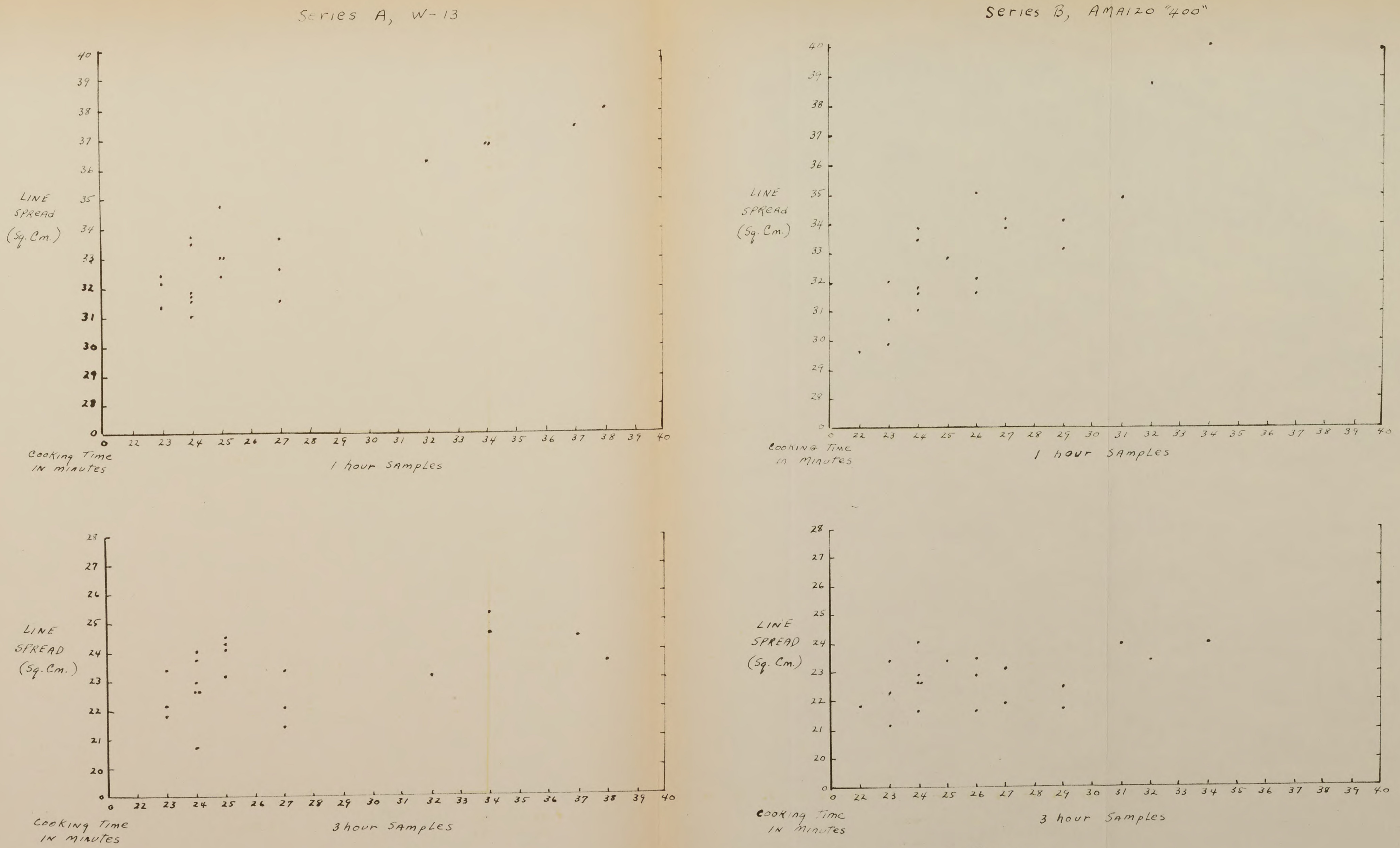


FIGURE 6. Effect of Cooking Time on Line Spread Readings For both 1 hr. and 3 hr. Samples in Series A and B

Kind of starch

No significant differences could be found between the flow measurements of cut samples of puddings in Series A and B at corresponding levels of waxy maize starch concentrations and at corresponding holding periods. If any differences were present, they were completely concealed by the more obvious effects produced by variations in cooking time.

SUMMARY

The maximum viscosities of puddings made with waxy maize starch W-13 at levels of 0, 5, 10, 15, 20, 25, and 30 per cent of the total starch concentration showed highly significant differences. Maximum viscosity values showed progressive increases with increase in the level of waxy maize starch W-13. Puddings made with waxy maize starch Amaizo "400" at similar levels of the total starch concentration showed highly significant differences in maximum viscosity values. A progressive increase in maximum viscosities with increase in the level of waxy maize starch Amaizo "400" was observed with the exception of the 20 per cent level which fell slightly below the viscosity of the 15 per cent level of this waxy starch.

Initial viscosity rise occured within a very narrow range of time and temperature for puddings in both Series A and B, and slight variations did not appear to be related to the level or kind of waxy maize starch.

The cooking time required to reach maximum viscosity as well as to reach the endpoint of 95° C showed a wide variation for puddings in both Series A and B. These differences in cooking time did not appear to be related to the level or kind of waxy maize starch but to an unexplainable variation in the rate of heating.

A highly significant correlation was found in Series B between time required to reach maximum viscosity and the maximum viscosity value when the level of waxy maize starch Amaizo "400" was held constant. As cooking time necessary to reach maximum viscosity increased, the maximum viscosity value was correspondingly decreased. A similar correlation was not found to be significant in Series A.

Puddings made with all levels of both waxy maize starches gave higher viscosity readings than the control in which ordinary corn starch constituted the entire starch concentration.

Maximum viscosity values of puddings at all levels of waxy maize starch W-13 were higher than maximum viscosity values of puddings at corresponding levels of Amaizo "400". The rate of increase in maximum viscosities of puddings with each increment in the level of waxy maize starch W-13, Series A,, was significantly greater than that made with corresponding increases in the level of waxy maize starch Amaizo "400", Series B.

Flow readings for cut samples of puddings in Series A showed significant differences between treatments for both the 1-hour and 3-hour holding periods. Significant differences were found between flow readings of puddings after the 1-hour holding period in Series B but differences after the 3-hour holding period were not significant. The differences in flow readings for puddings in both Series A and B did not appear to be related to the level of waxy maize starch.

There was no progression in values for flow measurements within each series with increase in the level of waxy maize starch.

The correlation between time required for the paste to reach 95° C and the end viscosity of puddings, with the level of waxy starch held constant, was found to be highly significant in both series. As the cooking time required for the paste to reach the temperature endpoint of 95° C increased, the viscosity decreased.

The correlation between end viscosity and the flow of cut samples of puddings, with the level of waxy maize starch held constant, was highly significant after the 1-hour holding period in both Series A and B and after the 3-hour holding period in Series B. Flow of cut samples of pudding increased with a decrease in the end viscosity. In both Series A and B this correlation was less with an increase in holding time.

A significant correlation was found between cooking time and the flow readings for puddings after both 1-hour and 3-hour holding periods in both Series A and B. As cooking time was increased, the flow of the cooled pudding sample was also increased. This correlation was greater at the 1-hour holding period than at the 3-hour holding period in both Series A and B.

A pronounced difference was observed in the flow of cut samples of puddings in both Series A and B after the 1-hour holding period and after the 3-hour holding period. Increase in holding time decreased the flow of the cooled samples of pudding.

No significant differences were found in flow measurements of puddings made with the two waxy maize starches at any of the corresponding levels of the total starch concentration.

CONCLUSIONS

Waxy maize starch used in combination with common cornstarch had significant effects on the hot paste viscosities of simple cornstarch puddings. Each increment in the level of waxy maize starch produced puddings with progressively higher maximum viscosity values and correspondingly higher pasting curves than did the control in which ordinary cornstarch made up the total starch concentration. The waxy maize starch which had undergone less chemical treatment increased hot paste viscosities to a greater degree than did the waxy maize starch which had received more treatment.

From this limited study it appears that concentrations of waxy maize starch up to 30 per cent of the total starch do not alter appreciably the gelling tendencies of ordinary cornstarch in simple puddings.

In spite of the wide variation in hot paste viscosities attributable to the kind and the level of waxy maize starch, no differences were observed between the flow measurements of the cut pudding samples which could be related to these same factors.

Differences in cooking time as related to the rate of heating and the extent of paste breakdown appeared to affect the flow of the cooled samples of pudding. An increase in cooking time produced an increase in flow. This relationship seemed to diminish with the length of holding time. It appeared from this study that cold paste flow cannot be predicted directly from hot paste viscosity, although it did seem to be somewhat related to the extent of paste breakdown and cooking time.

As this study was confined to the production of puddings in small quantity, no definite conclusions can be reached concerning the behavior of puddings made from similar formulas cooked in large quantity. However, when waxy maize starches are used as part of the total starch concentration, it seems feasible to expect an increase in hot paste viscosity above that obtained with ordinary cornstarch.

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EFFECT OF COMBINED WAXY MAIZE AND REGULAR CORN STARCH ON VISCOSITY AND COLD PASTE FLOW OF SIMPLE PUDDINGS

By

Betty Jo Sullivan

AN ABSTRACT

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ABSTRACT

The primary objective of this study was to determine the effect of combined waxy maize and regular corn starch on the viscosity and cold paste flow of simple puddings.

The formula consisted of constant proportions of sugar, distilled water, whole dry milk solids, and salt. The total starch concentration of 6.7 per cent, based on the weight of the liquid, remained at a constant level throughout the study. The proportions of waxy maize starch and ordinary corn starch making up the total starch were varied in progressive steps. Two waxy maize starches representing different levels of modification were used separately in combination with regular corn starch. The waxy maize starches constituted 0, 5, 10, 15, 20, 25, and 30 per cent of the total starch concentration.

The Corn Industries viscometer was used for cooking the puddings and for measuring the viscosity of the hot pastes. The beginning temperature of the uncooked puddings was 33.5° C. All puddings were cooked to a temperature endpoint of 95° C in a liquid bath thermostatically controlled at 100° C ± 1° C.

At the end of the cooking period 4 samples of the hot pudding were poured immediately into specially designed metal molds adjusted on double glass plates. These samples were covered and held at room temperature for 1-hour and 3-hour periods. Flow measurements were made on 2 samples at the end of each of these holding periods.

Results of viscosity tests showed that maximum viscosity values and the height of the pasting curves were progressively increased with an increase in the level of waxy maize starch. The waxy maize starch which had undergone less chemical modification had a greater effect on increasing viscosity than did the more highly modified waxy maize starch.

Despite the wide variation in hot paste viscosities attributable to the kind and the level of waxy maize starch, no differences were observed between the flow measurements of the cut pudding samples which could be related to these same factors.

From this limited study it appears that concentrations of waxy maize starch up to 30 per cent of the total starch do not alter appreciably the gelling tendencies of ordinary corn starch in simple puddings.

Differences in cooking time required to reach 95° C were not related to the kind or level of waxy maize starch but appeared to be associated with some unexplainable differences in the rate of heating in the cooking instrument. Differences in flow of the cooled samples were shown to be related to the length of cooking time and the degree of paste breakdown. An increase in cooking time produced an increase in flow of the cooled sample. The significance of this relationship appeared to diminish with an increase in the length of the holding period.