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THE USE OF TROPICAL ROOT STARCHES IN BREAD MAKING

by

© Erastus Lamenya Keya

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH

IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE

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ABSTRACT

The physico-chemical properties of tropical root starches from arrowroot, cassava, sweet potato, taro, and yam were studied in order to clarify their possible incorporation and role in a bread making formulation. These properties were then compared with those of starches from a Canadian western red spring wheat (CWRSW) (cv. Neepawa) of good baking, and a soft white spring wheat (SWSW) (cv. Fielder) of inferior baking quality. A flour composite formula of 85% starch and 15% vital gluten was adopted for all starches. Bread from pure wheat flours obtained from Neepawa and Fielder were used as the standard and internal references. Based on the influences in bread making of starch granule size distribution and morphology, percent amylose and mineral contents, water binding capacities, swelling power and solubilities, gelatinization properties and enthalpies of fusion, gel viscosity, retrogradation in gels, affinity for gluten, interaction with monoglycerides, dough rheological properties, bread qualities in the presence and absence of monoglyceride, and sensory evaluation, it was concluded that wheat starches made better composite breads than root starches with the same grade of vital gluten. Of the root starches, cassava produced the best composite bread next in quality to those of the wheat starches, followed respectively by yam, sweet potato, taro and lastly by arrowroot starch. Subtle differences between starch composite breads and the standard wheat flour

breadindicated the need for the establishment of proper formulations and baking conditions for the compositebreads. The study, however, demonstrated that root starches possess varying potentials of being used in composite bread making with gluten or strong wheat flours. The study, in addition, has provided fundamental results which could be useful in further baking investigations involving root tuber flours, since such flours are predominantly composed of starch.

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1. INTRODUCTION

Wheat bread products are staple foods in many countries (Pomeranz and Shellenberger, 1971). Consumption patterns vary widely from one region to another, but they are generally higher and on the increase in developing countries. In recent years high population increase rates and urban migration of people in search of better occupations and standards of living are more responsible for this occurrence than any other factors.

In contrast, wheat cultivation on a large scale is limited to only a few areas in the United States, Canada, Europe, the USSR, Argentina, Australia, and New Zealand. These countries account for about 80% of world wheat production, yet have a total of only about one-third of the population (Kim and Ruiter, 1969). Wheat production in the developing countries is generally on a low scale and is often hampered by poor soils, bad climate, disease and pests. The yields are therefore low in most of cases and have to be supplemented by importation, which is expensive and uses up valuable foreign currency reserves, thus worsening the balance of payments.

Developing countries can reduce this problem by adopting composite flour technology, which provides the possibility of extending the utilization of the limited wheat supplies for bread and other wheat-based foods through mixed flours, including commonly available non-wheat sources (Kim and Ruiter, 1969; Blaise and Okezie, 1980). Protein flours from oil seeds, such as sunflower, cottonseed, peanut, soya and several types of beans and peas can be used to substitute for part of the wheat flour in bread formulations to make good and acceptable bread. Similarly, starch flours from tropical tubers and cereals can be used.

Composite flours can be formulated to improve the diet (MacConell *et al*., 1974 ; Hoover, 1975; Fleming and Sosulski, 1977). Officially recommended levels of minerals and vitamins (Gage, 1978) may also be added. When wheat flour has strong gluten, compositing may be necessary to dilute the gluten in order to obtain a flour of desired baking end use. Starchy flours can be very useful in this particular requirement.

Pure wheat bread has attractive organoleptic properties which have made it a popular food worldwide. Composite bread, being less expensive than wheat bread, would be economically more desirable in poorer nations. But in order for composite bread to be acceptable to the consumers, it should have organoleptic properties close to those of pure wheat bread.

2. OBJECTIVES OF THE INVESTIGATIONS

The main objective of the investigations was to determine the possibility of using starches from some tropical root crops in breadmaking. Such bread would need to have qualities acceptable to consumers.

2.1 Determination and Comparison of the Physico-chemical Properties of Starches from some Tropical Root Crops and Canadian Wheats

Tropical root crops, unlike wheat, are not customarily used for breadmaking. It was therefore necessary to determine and understand the physical and chemical properties of the root starches in order to relate them to those of wheat.

Arrowroot, cassava, sweet potato, taro and yam starches were selected for the study. Flours and starches of Neepawa (superior bread making) and Fielder (inferior bread making) Canadian spring wheat, were included

The properties investigated for every starch were: grain size distribution and morphology; amylose and mineral contents; grain swelling power and solubility; gelatinization behaviour; retrogradation with storage time; complexing with monoglycerides; affinity for gluten; and role in breadmaking.

2.2 Breadmaking with Root Starches and Gluten Composite Flours and its Comparison with Bread made from Spring Wheat Flours

The dry matter content of flour for baking is mainly starch (75-80%) and gluten (11-15%). In order to investigate the compatibility and role of root starches in bread, composite flours consisting of 85% starch and 15% gluten were made and used throughout the study. Interference from the other ingredients usually present in bread formulations was avoided by making bread intended for instrumental analysis from a lean formula of flour, sugar and salt, while bread for panel tasting and overall quality assessment had shortening included in its formulation in order to improve its organoleptic properties. Of particular interest were the handling properties of the composite doughs and the shelf life of their corresponding breads.

2.2.1 Determination and Comparison of the Dough Rheological Characteristics of Wheat and Composite Flours

Prior to using the composite flours in breadmaking, it was necessary to determine the rheological properties of their doughs during mixing. Knowledge of the handling properties of the doughs during mixing was required in order to make doughs of equivalent consistencies by subjecting each to its optimal mixing requirements. Hence, the optimal flour water absorption; dough arrival, development, stability and departure times; and mixing tolerance under standard farinographic conditions were determined for each composite flour and compared with those of wheat flours

2.2.2 Determination and Comparison of the Shelf Life Properties of Bread from Wheat and Composite Flours in Absence and Presence of Monoglycerides

Starting soon after baking, chemical and physical changes occur in bread, making it stale. Stale bread is firm and has very poor organoleptic properties. As a result, it has low consumer acceptability, thereby inflicting economic losses on processors and retailers of bread.

Since monoglycerides are known to reduce the tendency of bread to firm during storage, they are widely used in the bread industry. Breads containing monoglycerides or none at all was made from composite flours and compared with similar bread from wheat flour. Experiments to investigate their shelf life stability were designed to cover crumb compressibility, penetration resistance, and crystallinity of the starch in the crumb as a function of time.

2.3 Quality Evaluation of the Bread by Taste Panel

Knowledge of the quality of the composite bread, as judged by consumers, was needed. To provide this information, a taste panel was organized to evaluate and give organoleptic appraisal to the composite types of bread, and compare them with wheat bread according to the bread quality scoring and evaluation chart recommended by the

American Institute of Baking (Matz, 1960).

3. LITERATURE REVIEW

3.1 Tropical Root Starches

Several tropical root crops are known to be excellent sources of starch. The main examples are arrowroot, cassava sweet potato, cocoyams (taro and tannia), and yams. Examination of literature on tropical root crops (Shipman, 1967; Edmond and Ammerman, 1971; Onwueme, 1978; Tu *et al.* 1979; Wang, 1983) shows that cassava is by far the most industrially exploited root crop in terms of starch production. Sweet potato starch, according to Phillips (1974), is of more significant industrial importance in Japan than elsewhere due to political protection. Arrowroot provides a minor source for industrial starch production, while taro, tannia and yams are important staple foods in the tropical areas where they are grown, but have not been given serious examination for industrial starch production.

3.1.1 Occurrence

Synthesis of starch occurs first in the leaves of plants. Starch cannot however be directly translocated within the plant. It must therefore first be broken into sugars, usually sucrose and glucose, to facilitate translocation to the amyloplasts (plastids) for resynthesis and storage (Badenhuizen and Dutton, 1956; Porter, 1962). Such starch acts as a stored energy resource capable of being remobilized by enzyme action whenever needed by the plant.

For tropical root crops, starch storage occurs in the plastids of the tuberous roots of cassava, yams and sweet potatoes as well as in the arrowroot rhizomes and in the tannia and taro corms.

Starch may be deposited as a single granule or several granules per amyloplast. Starch is said to be simple in the former case and compounded in the latter (Buttrose, 1962; Badenhuizen, 1965). Cassava and sweet potato are examples in which compounded starches occur. In most cases, compounded starches are disintegrated during the starch Isolation process.

The various root crops contain different amounts of starch, depending on type of crop, cultivars, soils, climate and age of the crop. Fresh, mature arrowroots contain 22-28% starch (Shipman, 1967). Mature cassava contains about 32% when tubers are peeled (Knightly, 1969), and about 20-25% in unpeeled fresh roots (Purseglove, 1968). Wijeratne (1974) reported that Sri Lankan cassava varieties contain 22-23% starch. Sweet potatoes contain up to 30% starch (Knightly, 1969). Keitt (1909) reported the lowest starch content of 14.43-16.46% and the highest content of 16.46-19.07% for American sweet potatoes. Taro corms contain 13-29% carbohydrates, of which 77.7% is starch (Coursey, 1968; Oyenuga, 1968; Onwueme, 1978). Carbohydrates form about 1/4 the mass of fresh yam tubers; 28% having been reported for *Dioscorea alata* (Onwueme, 1978).

3.1.2 Starch Isolation from Tubers

Production of starch from cassava tubers and arrowroot rhizomes follows the same process (Shipman, 1967). Fresh tubers or rhizomes are washed with high pressure water jets. The cleaned roots are rasped into a pulp, which is suspended in plenty of clean water and sent to a series of shaker or rotary type screens for separation of the fibrous debris. Sulfur dioxide (0.2% -- Shipman, 1967; 0.05% -- Onwueme, 1978) is added to the final screening and washing steps in the process to improve the color of the starch, aid in settling and hinder the actions of molds and bacteria on the starch. In addition, SO_2 keeps the screens free of gummy substances which would otherwise block them (Shipman, 1967).

The starch milk is passed through a cyclone to remove sand and other debris. The starch is then recovered from the milky suspension by centrifugation or settling, and is then dried to a moisture content of 10-14% (Shipman, 1967; Knightly, 1969; Onwueme, 1978). The starch is usually pulverized before bagging.

Sweet potato starch is isolated in a process in which an alkaline pH (9) is maintained with calcium hydroxide solution (Knightly, 1969). After washing and maceration, the pulp is forced through screens. SO_2 is added to prevent formation of melanin color from tyrosine. The starch is washed and separated from the pulp in centrifuges lined with screens. Further cleaning is achieved in centrifuges before sending the starch milk through hydrocyclones for purification. Water is removed and the starch dried (Knightly, 1969).

Literature on utilization of taro and yams for starch production is scanty. Starch from yam tubers may, however, be produced using the same process as for potatoes, with appropriate pH adjustment. Starch from the taro corms can be obtained using the same process as for arrowroot and cassava.

3.2 Wheat Starch Properties

From 75 to 85% of the wheat kernel is made up of the endosperm. The endosperm consists of starch grains embedded in a matrix of gluten-forming proteins. During wheat milling, the endosperm is scraped out, being separated from the bran and the germ before grinding to flour (Britton, 1969; Ziegler and Green, 1971; Alf, 1975; Jenkins, 1975).

The starch content of wheat kernels and flour varies inversely with the protein content (Hopkins and Graham, 1935), the total amount being affected by soils and climatic conditions (Pomeranz, 1980). Hard wheats contain less starch than soft wheats. Starch content in flour is affected by the degree of extraction and refinement (D'Appolonia *et al.* 1971). For instance, 80% extraction flour with 14% moisture has 65-71% starch (Herd and Kent-Jones, 1931; Hopkins and Graham, 1935, Dimler *et al.* 1944; Fraser and Holmer, 1956; Pomeranz, 1980). On a dry basis, bread making wheat flours have 75-80% starch (Tipples, 1969).

3.2.1 Isolation of Starch from Wheat Kernels

Earlier methods of starch isolation from wheat, for instance the Halle process, aimed at destroying the wheat protein. Whole wheat kernels were softened by steeping in water followed by one to four weeks of fermentation in which the gluten was broken down by chemical and biochemical reactions (Radley, 1953; Anderson, 1967). Dissolved protein was eliminated as soluble waste by decantation. The starch was separated in revolving screens, and purified by repeated agitation in water, sedimentation and decantation. The clean starch was then dried (D'Appolonia *et al.* 1971).

The Halle process was superceded by the Alsation process by which starch and gluten could both be isolated from the wheat kernels. Wheat was squeezed in net bags through a series of rollers, the starch being washed out at the same time with water, then recovered from the suspension and dried. Gluten was recovered from the residue in the bags. The process was quite laborious (Radley, 1953; Anderson, 1967).

Modern starch isolation from wheat uses the Martin or Batter processes, both of which start with wheat flour. The cleaned wheat kernels are tempered (AACC, 1982, method 26-95) before milling. Tempering is necessary to toughen the bran on the kernels and condition the endosperm moisture content to facilitate clean and more complete isolation and separation of the endosperm from the bran and the germ (Britton, 1969; Ziegler, 1971; Alf., 1975; Jenkins, 1975).

The endosperm is then reduced to flour by rollers.

In the Martin Process, a dough is made and starch is washed out from it with plenty of water. The gluten left behind is carefully dried to save its vitality. The starch is centrifuged from the slurry and flash dried to about 10-12% moisture content (Knightly, 1969; Anderson, 1967; D'Appolonia *et al*. 1971).

The Batter process differs from the Martin process in that a slack dough is made and disintegrated in a large amount of water. Gluten forms into small curds and the starch is suspended in the water. The gluten and starch are separated by screening. The gluten is then washed and dried, and the starch is recovered as in the Martin process (Knightly, 1965, 1969; Anderson, 1967; D'Appolonia, 1971).

Chemical methods using 0.1% NaOH (Knightly, 1969), 0.3%N NaOH (Dimler *et al*. 1944) or 0.2N NH_4OH (Phillips, 1966) for the solubilisation of protein from wheat flour, leaving starch behind, have been described. The starch produced by the Martin and Batter processes is, however, purer than that obtained by the chemical processes.

3.3 Starch Properties

For almost five decades starch researchers have been interested in the properties of native starches and their functionality in foods (Alsberg, 1935; Pulkki, 1938; Sandstedt *et al*. 1939; Harris and Sibbit, 1941, 1942; Burham and Clapp, 1942; Whistler *et al*. 1955; Schoch and Maywald, 1956; Schock, 1965; Medcalf and Gilles, 1965; D'Appolonia and Gilles, 1971; Hosney *et al.* 1971; Dahle, 1971; Kulp, 1972; Rasper *et al.* 1974; Sterling, 1978; Pomeranz, 1980; Hoover and Hadziyev, 1981; Christianson *et al.* 1982; and many others).

Several properties of starch have received intensive investigation. These include: grain size distribution and morphology; composition and structure of the grain; starch swelling power and solubility; viscosity of the starch pastes; gelatinization characteristics; retrogradation; affinity for gluten; and complexing with monoglycerides to counteract the effect of retrogradation. These properties affect the texture and quality of foods containing starch. They are reviewed further below in relation to root crops and wheat starches.

3.3.1 Starch Grain Size Distribution and Morphology

Starches from different sources are so characteristic in size and shape that they can be identified this way (Schoch and Maywald, 1956; D'Appolonia *et al.* 1971). In addition to size and shape, other properties of interest are the presence or absence of hilum, its position, and whether it is centric or acentric. The presence or absence of striations is also an important feature in relation to whether or not they surround the hilum. The appearance of the granule when viewed in polarized light, normally called birefringence, is also important.

3.3.1.1 Arrowroot Starch

Arrowroot starch grains vary in size from 5-50 µm (Seidemann, 1964). This size range is larger compared to 3.9-15.6 µm reported by Ciacco and D'Appolonia (1977). These researchers reported arrowroot starch to have a centric polarization cross. The grains had a circular appearance under polarized light.

3.3.1.2 Cassava Starch

Cassava starch grain size distribution has been presented as 0-5 µm (7.3%); 6-10 µm (21.3%); 11-15 µm (19.63%); 16-20 µm (36.0%); 21-25 µm, (8.52%); 26-30 µm (4.24%); 31-35 µm (2.68%); and 36-40 µm (0.2%) [Seidemann, 1963]. Wivinis and Maywald (1967) described cassava starch grains as round, truncated-egg, and cap-shaped, with moderate polarization crosses. Ciacco and D'Appolonia (1977) found them to vary from 7.8-19.5 µm in size and they were round in polarized light. Onwueme (1978) reported cassava starch grains to be 3-35 µm in size, while Pyler (1979) reports an average size of 20 µm and describes them as round or oval in shape, characterized by an indentation on one side and the presence of a fissured centric hilum.

3.3.1.3 Sweet Potato Starch

According to Keitt (1912) and Thurber (1933), the grains of sweet potato starch are similar to those of cassava. Matwejew (1958), cited by Seidemann (1966), found that sweet potato starch grains varied in size from 0-10 µm

(64-89%); 11-40 µm (10-36%); and 41-70 µm (0.07%). This agreed with the work of Reichert (1913) and of Seidemann (1963). The granules of sweet potato starch have been described as round and polyhedral, some them having rounded facets. The hilum is centric. Polarization crosses vary from strong in the rounded ones to weak in the polyhedral ones (Wivinis and Maywald, 1967).

3.3.1.4 Taro Starch

Payne *et al.* (1941) reported the size of taro starch grains to vary from 2.5-9.3 µm. This was corroborated by Amin (1955), whereas Seidemann (1966) reported a size distribution of 3-15 µm, with a few large ones going up to 21 µm. Wivinis and Maywald (1967) found that all taro starch grains were less than 1 µm in size. Radley (1940) more recently, Higashihara *et al.* (1975) and Griffin 9) concluded that taro starch grains vary in size from 6.5 µm. According to Seidemann (1966), the grains are similar in shape regardless of species. They are ompounded in groups of 2-6 or more grains. Individual rains result from the disintegration of the compound granules. Individual grains have weak polarization crosses and acentric fissures.

3.3.1.5 Yam Starch

Yam starches have been reported to range in size from 1-70 µm Seidemann (1964). Some species of yam vary greatly, while others are quite similar in size and morphology of their starch grains. According to Onwueme (1978) the largest starch grains are located in the pith of the tuber, decreasing in size towards the tuber ends and surface.

The starch grains of *Dioscorea alata* vary in size in the ranges 5-20, 21-40, 41-50, and 51-70 µm (Planchion and Juillet, 1909). Rao and Beri (1955) found them to be 36 µm long and 21 µm wide on average. Ciacco and D'Appolonia (1977) reported them to be 25.4-31.2 µm in width and 27-50 µm in length, homogeneous in shape, being mainly triagonally rounded and possessing an acentric polarization cross. Seidemann (1964) described the grains as elongated, oval, partly rounded or slightly curved, triangularly rounded or ellipsoidal. Onwueme (1978) reported an average of 55 µm for the granule size.

Dioscorea rotunda starch grains vary in size from 5-20, 21-55, and 56-60 µm (Ching-Shen, 1955). They are elongated, oval, egg- or ellipsoidal-shaped (Seidemann, 1964). The starch grains of *D. batatas* are similar to those of *D. rotunda*.

D. dumentorum, *D. hispida* and *D. esculenta* have very small grains of starch, all 1-5 µm (Seidemann, 1964). Onwueme (1978) reported an even smaller size range of 1-2 µm for *D. esculenta*.

D. bulbifera has starch grains of 5-45 µm, the majority being 20-40 µm. The size ranges for *D. cayenensis* are 3-10, 10-20 and 20-25 µm. The two species are very similar morphologically. The starch grains are rounded, triangular or trapezoidal, with a pronounced hilum (Seidemann, 1964; Onwueme, 1978).

3.3.1.6 *Wheat Starch*

Hoyer (1911) found the size of wheat starch grains to be from 30-55 µm, while Remenovsky (1921) found the limit to be 57 µm. Brehmer (1928) examined several wheat varieties and reported starch grain size ranges of 14-39 µm (*T. turgidum*); 15.4-39.6 µm (*T. Spelta*); 11.1-30.1 µm (*T. dicoccum*); and 12-27 µm (*T. monocuccum*).

The presence of equatorial grooves on some wheat starch grains was reported by Burham and Clapp (1942), Sandstedt (1955), and many others afterwards. Kerr (1950) differentiated wheat starch grains in two categories: small donut-like ones of size 2-10 µm and large lenticular ones of size 20-35 µm. According to Lentner (1956), small starch grains up to 10 µm in size account for about 88.4% of all starch in wheat, while about 6.2, 5.2 and 0.8% of the grains are found in the size ranges of 11-20; 21-30; and 31-45 µm, respectively. MacMasters and Waggle (1963) asserted that there is no discrete size division of wheat starch grains into large and small, but that there is a gradual continuous change in the size distribution. Many reseachers, including Seidemann (1966) and Pyler (1979), tend to generally support Kerr's findings.

Some of the larger lenticular starch grains have a faint centric hilum, the surface being smooth with no striations (Whistler, 1965; D'Appolonia *et al.* 1971). Pyler

(1979), however, reported that the hilum is acentric. Although large granules form only about 12.5% of all the starch in wheat, they account for most of the weight and surface area of free wheat starch (Grewe and Bailey, 1927; Stamberg, 1939; Hanssen *et al*. 1953). Stamberg (1939) reported that the specific surface area of 1.0 g of wheat starch is 2,004 cm^2.

3.3.2 Starch Granule Composition and Structure

The starch granule is made up of basically two polysaccharide polymers. Amylose has a straight chain configuration, containing D-glucose units linked through α-1,4-glucosidic bonds. Amylopectin is a branched chain polymer of D-glucose units, connected as in amylose but through the α-1,6-glucosidic bonds at the junctions (Hough and Jones, 1953; Greenwood, 1956; Wolfrom and ElKhadem, 1965; Schoch, 1961, 1962).

Amylose contains 500-2000 units of D-glucose and has an average molecular weight range of 80,000-320,000 (Schoch, 1961; Pyler, 1979). Amylopectin has about 20-30 glucose units per link and contains several hundreds of such links. For wheat starch, Potter and Hassid (1948) found that branching in amylopectin occurred after every 23 glucose units. According to D'Appolonia *et al*. (1971), these values only indicate the overall degree of branching. They do not show the inner or outer chain length of amylopectin. Lee *et al*. (1968) asserted that there was in fact no symmetrical branching in amylopectin. The total molecular weight of amylopectin has been estimated at one million or over (Schoch, 1961; Pyler, 1979).

Minor branchings have been noticed and reported at some of the carbon 2 and 3 positions of the glucose units in the chains (Fruton and Simmonds, 1958).Leach and Schoch (1962) also reported the existence in corn of an intermediate, slightly branched polymer in addition to amylose and amylopectin. D'Appolonia *et al.* (1971), however, state that these observations are minor to the established presence of only amylose and amylopectin in the starch granule.

The starch granule as a whole is a spherocrystal. Inside the granule, amylose and amylopectin chains are organized in concentric radial shells (Badenhuizen, 1959). Adjacent amylose and amylopectin chains become bundled tightly into crystalline, randomly distributed regions called micelles, which are held together by hydrogen bonding. A single amylose or any of the free amylopectin chains may be involved in more than one micelle. Hence, micelles hold the starch granule firmly together and are responsible for birefringence observed as a polarization cross when starch is viewed in a light polarizing microscope. They are also responsible for the X-ray diffraction patterns observed on starch. Evidence provided by Montgomery and Senti (1958) tends to suggest that it is amylopectin which is the major participant in micelle formation.

Amorphous regions occur radially within and tangentially between shells where the amylose and amylopectin chains are less closely packed. These areas are not birefringent and are easily penetrated by water. Further submicrostructure of the starch grain has been detailed by Whistler and Turner (1955) and Nikuni (1957, 1977).

The amylose content of starch may be determined by potentiometric iodine titration (Bates *et al*. 1943; Schoch, 1964) or by a colorimetric method based on blue color formation of an amylose-iodine complex (McCready and Hassid, 1943). Using these methods, especially the former one, the amylose contents of several types of starches have been determined. Bates *et al*. (1943) reported an amylose content of 24% in wheat starch. Schoch (1945) found 26% using pentasol precipitation of amylose. Deatherage *et al*. (1955) found in several American and foreign wheats a range of 17-29% amylose. More recently, Medcalf and Gilles (1965) found wheat starch to have 23.4-27.5% amylose, which agrees with the range of 23.4-26.9 reported by Ciacco and D'Appolonia (1977).

Greenwood *et al*. (1955) found 20.5, 16.7 and 17.8% amylose in arrowroot, cassava and sweet potato starches, respectively. Onwueme (1978) reported 17% amylose in cassava starch. According to Ciacco and D'Appolonia (1977), arrowroot, cassava, and yam starches contain 13.8; 14.5 and 23.3% amylose, respectively. Onwueme (1978) reported taro starch to contain 17-28% amylose.

3.3.3 Starch Grains Swelling, Gelatinization, Solubility and Paste Viscosity

Swelling, gelatinization, solubility and paste viscosity of starch in an aqueous system are interrelated starch characteristics which have been reviewed extensively by Leach (1965) and D'Appolonia *et al.* (1971).

Native starch grains are insoluble in cold water despite of their molecules being highly hydroxylated. This is due to the presence of an internal micellar network holding the starch granule firmly together through hydrogen bonds. The starch granules, however, are able to absorb water (and other solvents), swelling in the process. In a cold aqueous system, the swelling is limited and reversible. If the starch grains are heated with sufficient water, they remain unchanged in appearance until a critical temperature is reached at which point some of the grains begin to swell tangentially and irreversibly. They are said to be gelatinizing (Leach, 1965).

Schoch (1964) devised a method for determining the swelling power (SP) and solubility of starch. It involves heating and stirring at 200 rpm 0.5 g of starch in a total of 180 g of distilled water in a 250 ml centrifuge bottle at a controlled temperature for 30 minutes. Stirring is stopped and the stainless steel paddle rinsed clean into the bottle with a little distilled water followed by addtion of water to a total of 200 g water. The bottle is then corked and the contents mixed by inversion before centrifugation at 3000 rpm for 15 min. Dissolved starch is determined as a percentage from 50 ml aliquots of the centrifugate by evaporation The swelling power of the starch is determined from the paste residue in the bottle after correction for dissolved starch. It is expressed as grams of starch paste per gram of starch on dry basis.

$$SP = \frac{(\text{g. starch paste x } 100)}{(\text{Wt of sample, g}) \times (100\text{-\% solubles, db})}$$

Swelling power, gelatinization, starch solubility and viscosity are functions of temperature, and vary with different starches.

Gelatinization does not occur at one temperature, but proceedes over a temperature range which is characteristic of starch species, and even varies between granules of the same starch. This is due to differences in the internal three dimensional molecular associations in the starch grains. Also larger grains of starch swell and gelatinize more easily than the smaller ones (Leach, 1965; Sterling, 1974, 1976; Chung and Hudziyev, 1980).

Gelatinization entails rupture of the hydrogen bonds inside the starch granules. This action results in increased diffusion of water into the granules, where it hydrates the starch molecules on the hydroxyl groups set free by the cleavage of the hydrogen bonds. The starch grains swell, but still retain their outlines (Schoch, 1965).

Gelatinization and swelling begin in the amorphous areas of the starch granule where bonding is weaker than in the crystalline micellar areas. In fully gelatinized granules, the crystalline structure is completely disarrayed, as shown by x-ray diffraction analysis and the absence of birefringence (Leach, 1965).

The fully hydrated linear starch fraction diffuses from the swollen grains into the aqueous medium. Shorter chains leach out preferentially (Leach, 1965). At pasting temperature, the swollen starch grains begin to form a cohesive paste, the viscosity of which starts to rise exponentially, mainly due to the swelling of the starch granules as they absorb water. If the paste is stirred, then some of the swollen granules are broken, thus the final viscosity of the paste is a balance in consistency due to the unbroken swollen grains, broken fragments and dissolved starch (Anker and Geddes, 1944; D'Appolonia *et al.* 1971). Maxamum viscosity is recorded when the maximum number of swollen grains exist in the paste, there after, the viscosity drops as the number of broken swollen grains increases (D'Appolonia *et al.* 1971). The viscosity of a paste is influenced by concentration, temperature, the type of starch and the environmental conditions during formation of the starch (Alsberg and Rask, 1924; Mangels and Bailey, 1933, 1934; Anker and Geddes, 1944). Popular instruments for measuring starch paste viscosity are the Brabender amylograph, Corn Industries and the Haake viscometer.

Several methods exist for studying gelatinization of starch. Amylographic methods depend on vicosity (Bean and Osman, 1959). Optical methods utilize photopastegraphy

(Seidemann, 1967), and disappearence of birefringence in the polarized light (Watson, 1964; Miller 1973). Differential scanning calorimetry (DSC) involves thermal analysis of a sample over a selected temperature range including temperatures above 100°C, where other methods are not applicable (Stevens and Elton, 1971; Donovan, 1979; Wootton and Bamunuaracchchi, 1979; Donovan and Mape, 1980; Biliaderis *et al.* 1980; Hoover and Hadziyev, 1982). DSC enables one to work with different water/starch ratios without the problems of moisture loss control. It facilitates better determinations of transition temperatures and enthalpies.

Donovan (1979) showed that gelatinization was a function of the water present in starch. In excess water the amorphous areas and the crystallites gelatinized completely, giving one endotherm peak. At lower water levels, the crystallites do not become completely hydrated to cleave the hydrogen bonds. As a consequence, they melt at higher temperatures, giving a shoulder endotherm to the main gelatinization endotherm. At low water volume fractions of less than 0.5, the gelatinization endotherm becomes progressively smaller as the crystallites' melting endotherm increases. The presence of clathrates in cereal starches (e.g wheat) results in a melting endotherm near 100°C. This is absent in root and tuber starches.

The gelatinization enthalpy of starch in the presence of excess water represents the total of enthalpies required for swelling, hydration of molecules and melting of crystallites. When the water content is not sufficient, the enthalpy changes are mainly due to melting of the crystallites (Donovan, 1979). According to Stevens and Elton (1971), the decrease in the enthalpy of gelatinization observed as the water fraction in starch/water systems becomes smaller is due to a reduction in the degree of disorder inside the starch granule.

Several factors affect the swelling power, gelatinization, solubility and paste viscosity of starches. Starches high in amylose are more resistant to swelling and gelatinization due to a high level of internal association. Their paste viscosities are also low (Leach *et al*. 1959; Leach, 1965). Waxy starches have higher swelling powers than normal starches. Evidence provided by Leach and Schoch (1961) indicates that amylopectin is the one responsible for swelling power since starches from which amylose had been digested enzymatically still had normal swelling power.

Cereal starches swell less than root starches, while root starches swell less that tuber starches (Leach, 1965). The presence of chemical adjuncts, ionized esterified phosphate groups, natural and added surfactants and monoglycerides, fatty acids, compounds that compete for water and derivatization influence the starch swelling power and gelatinization. Solubility and viscosity are consequently affected (Leach, 1965; D'Appolonia *et al.* 1971).

Sodium nitrate, urea, sodium hydroxide, ammonium hydroxide, potassium thiocyanate, potassium iodide and similar chemicals which cleave hydrogen bonds reduce the internal molecular association of starch granules. The result is reduced gelatinization temperatures and higher swelling powers. Depending on the severity of the treatment, such starches may swell and gelatinize at room temperature. Since the granules are internally weakened, they break easily under shear stirring force and hence have low paste viscosity. Similarly, treatment of granular starches with warm dilute acid and hypochlorite below their gelatinization temperatures results in starch of low paste viscosity and high solubility. Desolvating agents such as sodium sulphate will inihibit swelling of starch grains. In fact they are used in derivatizations where swelling and gelatinization of starch granules are not required (Leach, 1965; Roberts *et al.* 1965).

Excessive swelling and solubility in white potato starch has been attributed to the presence of ionized estersified phosphate groups which repel each other as a result of like charge (Leach, 1965).

Naturally occurring fatty acids and added surfactants and monoglycerides interact with starch to form clathrates, resulting in reduced swelling power and solubility. Starch so affected is very resistant to gelatinization and has low water binding ability (Leach and Schoch, 1961; Gray and Schoch, 1962; D'Appolonia *et al.* 1971; Longley and Miller, 1971; Lonkhuysen and Blankestijn, 1974; Ohashi *et al.* 1979; Pomeranz, 1980; Chiasi *et al.* 1982; Hoover and Hadziyev, 1982).

The size of starch grains also affects their gelatinization temperature. Sterling (1974, 1976) and Chung and Hadziyev (1980) observed that larger starch granules gelatinize at lower temperature than smaller ones.

Esterification and etherification of starches results in reduced internal attraction forces of the starch granule. Consequently, these starches have high swelling ability and reduced gelatinization temperatures. They also have higher solubility and viscosity. The higher the degree of substitution, the greater the effect (Leach, 1965; Wurzburg and Szymanski, 1970)

Reactions of sodium trimetaphosphate, epichlorhydrin, phosphorus oxychloride and several other polyfunctional compounds, including anhydrides of adipic and acetic acids, react with starch granules to produce cross-bonded starches which resist gelatinization. Cross-bonding can be controlled to produce starches of different properties (Leach, 1965; Roberts, 1965; Knightly, 1965, 1967; Osman and Elizabeth, 1967; Wurzburg and Szymanski, 1970).

Organic substances, such as sugar, competing for water reduce the hydration capacity and swelling power of starch. They also delay gelatinization (Bean and Osman, 1959).

3.3.4 Starch Retrogradation

Glucose molecules in amylose chains have three free hydroxyl groups through which association by hydrogen bonding between neighboring chains can occur (Schoch, 1961; Pyler, 1979). If a hot dilute aqueous solution of amylose is cooled slowly, the amylose chains realign and form a precipitate. If the solution is cooled rapidly, the ability of the (amylose chains) to realign completely is hindered. A gel is formed which consists of randomly distributed sacs of fluid in a network of amylose chains held together through small micellar regions in which only parts of the amylose chains participate, the rest remaining as free loops (Meyer, 1950; Schoch, 1961). This physical instability of hydrated amylose molecules, resulting in precipitate and gel formation, is known as retrogadation (Katz, 1928, 1930; Schoch 1942, 1961, 1965; Hellman *et al.* 1954; Collison, 1968; Hellendoorn, 1971; Pyler, 1979).

A cooked paste of starch contains the swollen starch granules, amylose leached out of the granules and fragments of the broken granules. Retrogradation in this case involves intermolecular bonding within and between the swollen starch granules, their fragments and the free amylose (Meyer, 1942, 1950).

Retrograded starch is crystalline, and has the 'B' type X-ray diffraction patterns (Katz and Itallie, 1930; Foster, 1965). It has reduced swelling power, solubility, water binding capacity, iodine affinity and hydrolysis by acids and enzymes (Volz and Ranstad, 1952; Sterling, 1957). Retrograded cereal starches can be completely resolubilized [illegible] high temperatures of about 125°C (Bechtel *et al.* [illegible]e waxy starches can be resolubilized at lower temperatures of 50-100°C (Osman and Cummisford, 1959; S[illegible] 1965; Pyler, 1977).

According to Katz (1928) and Sterling (1960), maximum retrogradation occurs at -2°C, while the minimum rate is at or below -20°C; and at or above 60°C. Odd cases have been reported where the retrogadation rates at 37 and 62°C were the same (Lampitt *et al.* 1948), while the rate at 70°C was greater than at room temperature (Sterling, 1960). Kalb and Sterling (1961) observed that the retrogradation rate was reduced if the starch was originally gelatinized at a higher temperature.

Retrogradation of starch is strongly accelerated by higher concentration of amylose and low molecular weight. The shorter the length of the amylose chains, the higher the starch retrogradation rate (Lampitt *et al.* 1948; Whistler and Johnson, 1948; Lansky *et al.* 1949; Radley, 1953; Loewus and Briggs, 1957; Schoch, 1965; Whistler, 1965). Furthermore, Lampitt *et al.* (1948) and Pyler (1979) reported that chain uniformity played an important role in accelerating the rate of retrogradation. Several researchers have reported on the infuence of pH. Retrogradation is favored by adjusting pH to 5.0 before gelatinization (Hollo, 1960; Kalb and Sterling, 1961) and to 1.3-2.2 after gelatinization (Schoch, 1941; Kalb and Sterling, 1961). Pyler (1979) reported a pH of 7 to favor retrogradation most, while Foster (1965) reported that the retrogradation rate was faster at pH 6.5 than at pH 4, where it was almost non existent.

According to Hellendoorn (1971), the rate of retrogradation in mashed potato products increased as the moisture content decreased, to a maximum at 30% moisture. Duckworth and Smith (1963) found that the absolute minimum rate for retrogradation existed at monomolecular layer moisture content.

The presence of monovalent anions and cations, especially iodide and potassium, retard the rate of retrogradation, while polyvalent anions and cations accelerate it (Loewus and Briggs, 1957). Ciasco and Fernandes (1979) have reported that the rate of retrogradation is progressively increased by anions I^-, Br^-, Cl^-, and F^-, while similar increases for cations are in the order of K^+, Li^+ and Na^+.

Formation of clathrates due to interaction of starch with fatty acids and surfactants reduces starch hydrophilicity and hence hinders retrogradation (Zobel, 1963). Greenwood and Hourston (1967) reported that starch derivatization through esterification and etherification introduced substitues in the starch granule, making it difficult for the amylose and the free end chains of amylopectin to realign and retrograde. McIver *et al.* (1968)

reported that retrogradation rate decreased as a function of time. Their findings were confirmed by Brennan and Sodah-Ayenor (1973) and Knightly (1977). It has been observed that starch gels contract and exude water as the amylose molecules align and associate during retrogradation. The gels become opaque as they age.

3.3.5 Starch Complexing with Monoglycerides

Knowledge of the nature of monoglycerides is necessary in understanding their reactions with starch.

A monoglyceride is an ester of one fatty acid with glycerol. Esterification to any of the end carbons produces 1(3)-α monoglycerides while esterification on the central carbon always produces β-monoglycerides. (Doerfert, 1968; Pyler 1979).

The fatty acid chain is lipophilic and is easily dispersed in oils and fats, while the glycerol group is hydrophilic, hence is easily dispersed in water. Consequently, monoglycerides possess a hydrophilic -lipophilic character, which is however, not evenly balanced because of the nature of the fatty acid and glycerol (Griffin, 1949; Krog, 1981).

The hydrophile - lipophile balance (HLB) represents the ratio of size and strength of the polar (hydrophilic) to nonpolar (lipophilic) groups. It is expressed on a numerical scale on which the monoglyceride becomes more lipophilic the smaller below 9 its HLB becomes and more hydrophilic as its

HLB grows bigger than 11.0 (Griffin, 1949). Commercial monoglycerides have an HLB of 2.8-3.5 (MacDonald, 1964). This low HLB renders them excellent in softening bread and hence retarding the staling process (Knightly, 1968). They are however not good dough strengtheners because of the low HLB (Del Vecchio, 1975). Special monoglycerides with increased HLB have been made by introduction of organic acids such as lactic, tartaric, succinic and fumaric into their structure through ethoxylation and hydroxylation (Pitt, 1971).

Monoglyceride molecules arrange themselves into crystals with the terminal methyl group of the fatty acids on the surface and the glycerol groups at the center. They are said to be in their β-crystallinity form (Birnbaum, 1971). If a monoglyceride in its β-crystallinity form is heated near its melting point in aqueous medium with appropriate pH and then allowed to cool down to room temperature, the hydrated monoglyceride molecules reverse their orientation: the polar glycerol groups are on the surface and fatty acids chains in the centre of the crystal. The monoglycerides are in their α-crystallinity form when they assume this orientation (Wren, 1968; Krog and Jensen, 1970; Langendijk and Penning, 1970; Lankhuysen and Blankestijn, 1974, 1976; Hoover and Hadžiyev, 1982). The use of α and β-in the structure of monoglyceride molecules is therefore different from their meaning when used in describing monoglyceride crystals.

Commercial monoglycerides are manufactured by direct esterification of fatty acids, interesterification, or glycerolysis of fats at 200°C in an excess of glycerol and in the presence of an alkaline catalyst (Pyler, 1974). Glycerolysis of fats is more commonly used for manufacture of food grade monoglycerides (MacDonald, 1974; Lauridsen, 1976). The alkali is neutralized, while the excess glycerol is removed by vacuum (Pitt, 1977). The process gives about 50% monoglycerides, which are concentrated to 90-95% by molecular distillation under high vacuum (Birnbaum, 1965). At least 90% of the concentrate consists of α-monoglycerides (Brokaw *et al.*, 1955).

Several factors affect the reaction between starch and monoglycerides. They include type of monoglyceride and its physical state, type of starch and its amylose content, and temperature.

According to Krog (1981) and Hoover and Hadziyev (1982), the length and unsaturation of the fatty acid chain significantly affects the ability of a monoglyceride to combine with starch. Previously, it had been found that glyceryl-monopalmitate was more reactive with starch than -monomyristate, -monolaurate, -monostearate, -monoarachidate, -monooleate, and -monolinoleate (Lagendijk and Pennings, 1970). It was also found that the amount of amylose-monoglyceride complex formed decreased with the degree of unsaturation. This was explained by the fact that a saturated monoglyceride has a straight chain of about 4 Å outer diameter and fits well into the amylose helix, which has an inner diameter of about 6 Å (Rundle and French, 1943). In comparison, unsaturated monoglycerides have bent chains due to double or more bonds and, as a result, are not readily fully accommodated by the amylose helix. In their work, Lagendijk and Penning (1970) also reported that the quantity of clathrates formed by a monoglyceride was favored by long fatty acid chains.

From previous work, Krog and Jensen (1970) had found that α-crystallinity form monoglycerides were more reactive than the same monoglyceride in β-crystallinity form. Their finding was confirmed by Lagendijk and Penning (1970); Lonkhuysen and Blankestijn (1974, 1976) and Hoover and Hadziyev (1982).

Osman *et al.* (1961) reported that wheat starch amylose bound more monoglyceride per gram than cassava starch amylose. This was confirmed by Lonkhuysen and Blankestijn (1974, 1976), who also reported that, while wheat starch bound more monoglycerides at 30°C, gelatinized cassava starch bound more monoglyceride than gelatinized wheat starch. According to their work, surface area of starch did not appear to be a significant factor influencing ability of starch to bind monoglycerides. They were of the opinion that other structural factors were important. Gelatinized cassava starch was found to disintegrate to a higher degree on gelatinization than wheat starch. Exposure of more reactive sites accounted for the ability of gelatinized cassava starch to bind more monoglycerides than gelatinized wheat starch (Lonkhuysen and Blankestijn, 1974, 1976).

Jongh (1961) observed that a suspension of starch was flocculated by added monoglycerides. This was confirmed by Lonkhuysen and Blankestijn (1976). Observations made by these three researchers as well as those of Krog (1970) and Lagendijk and Penning (1970), that starch treated with monoglycerides was firmer and resisted gelatinization more than starch without monoglycerides, support Schoch (1965) who indicated that monoglycerides are able to penetrate into the starch granules and clathrate with amylose. This immobilizes the amylose inside the granules. This interaction reduces the hydration capacity of amylose and the linear end chains of amylopectin, resulting in reduced swelling power of the starch. Hoover and Hadziyev (1982), working with potato starch, reported that monoglycerides absorbed by potato starch grains reduced their swelling power, solubility, rehydration rates, water holding capacity and iodine affinity.

3.3.6 Starch Affinity for Gluten

Starch affinity for gluten refers to the ability of starch to associate with gluten in the dough and in the crumb. The association is pH and heat sensitive.

Yoshima and Matsumoto (1966) showed that wheat proteins were positively charged and behaved as colloids at pH 5 and 6. Dahle (1971) reported that wheat starch and protein associated better in acid to neutral pH and that the affinity between the two decreased with the increase in pH. He observed that both starch and gluten had negative charges in alkaline pH and this reduced affinity between them due to repulsion.

Bennet and Ewart (1962) showed that the rheological properties of dough were sensitive to pH. They reported that dough extensibility decreased as pH increased, indicating increased affinity within the system. Hlynka and Chanin (1957) showed that loaf volume was affected by pH of the dough. Minimum loaf volume was obtained at pH 7 and maximum at pH 5.7. Loaf volume decreased at pH 5.3 and 4.7. Takuechi (1969) and Dahle (1971) reached a similar conclusion that the association between starch and gluten in the dough was due to attraction between oppositely charged colloids within the system.

Dennett and Sterling (1979) found that there was no affinity between raw gluten and ungelatinized starch. Gelatinized starch had, however, the highest affinity for raw gluten in a system simulating the early baking stage in bread making. The affinity of gelatinized starch for gluten dropped by 30-50% when the gluten was denatured in a system simulating fully baked bread. This seemed to corroborate observations made by Dahle (1971) that heated flour had poor bread making properties and decreased protein solubility.

Dennett and Sterling (1979) also found that the amylose content of starch had a direct influence on the affinity of starch for gluten. Since affinity between starch granules and gluten is a surface phenomenon, amylose must therefore be able to modify the surface of the granules to enhance the affinity. Lowry *et al*. (1951) found that amylose had greater affinity for gluten than amylopectin.

Since there is no affinity between ungelatinized starch and native gluten (Dennett and Sterling, 1979), it is implied that gelatinization and swelling of starch granules is necessary for the development of affinity for gluten. Swelling of the starch grains therefore seems to increase their porosity, while at the same time exposing a maximum number of hydrophilic sites for bonding with gluten.

The starch granules swell during gelatinization and absorb water from the gluten matrix. Hence, the gluten is dehydrated and denatured during baking. Gluten in this state has reduced hydrophilicity and therefore reduced affinity for the gelatinized starch. This has the advantage of resulting in softer and more flexible crumb. In fact a negative correlation between affinity of starch for gluten and both the fractional volume changes and firmness has been observed (Dennett and Sterling, 1979). High starch affinity for gluten in the early baking stage plays an important role of ensuring optimal association between starch and protein hence maximum development of the dough before the protein is denatured (Dahle, 1971).

3.3.7 Role of Starch in Bread Making

Starch constitutes about 65-70% of flour (Pomeranz, 1980) and plays a significant role in bread making. Its functions in this process have been outlined by Sandstedt (1961). It dilutes the wheat protein such that the wheat flour is of good consistency for baking. Some of the starch granules get damaged during milling. A low level of starch damage is acceptable (Tipples, 1969) as it provides an easily available substrate for enzymatic activity to produce sugars used by the yeast during dough mixing and fermentation. Too much starch damage destroys both the baking quality of the starch and its products (Alsberg and Griffing, 1925). Damaged starch granules absorb water and swell excessively during dough mixing and fermentation (Sandstedt, 1955), being completely hydrolysed by the combined action of α and β amylases. Intact starch granules are resistant to β amylase activity (Sandstedt *et al.* 1960) and are only slowly attacked by α amylase (Sandstedt and Gates, 1954).

Starch provides an active surface for gluten to adhere to during bread making operations. Dough rheological and crumb properties are significantly influenced by this association (Takuechi, 1969; Dahle, 1971; Dennett and Sterling, 1979).

Starch granules orientate themselves in the protein matrix lining the gas-cell walls (MacMasters, 1961). As the starch granules gelatinize during baking, they swell, but do not disintegrate due to limited water availability (Farrand, 1972). Limited water absorption renders them flexible, which in turn extends the elasticity of the gas-cell walls in the crumb. They absorb water from the gluten matrix in which they are embedded and cause it to set, hence providing support for the whole crumb structure.

The functionality of starch in baking thus depends on its gelatinization in a protein matrix to form porous and elastic crumb. Factors affecting starch gelatinization will therefore affect its function in bread making. In addition to those already mentioned above, a few more merit to be mentioned.

Small size starch grains have higher gelatinization temperature and hydration capacities (Kulp, 1973; Dennett and Sterling, 1979). An inverse relationship between loaf volume and size of starch granules has been reported (Ponte *et al.* 1963). Starches high in amylose content are more resistant to gelatinization (Medcalf, 1968; Kulp, 1973). Yasanuga *et al.* (1968) found that time-temperature relationship were important in influencing starch gelatinization. Furthermore different starches respond somewhat differently (Sandstedt, 1961). Harris and Sibbit (1941, 1942) found that starches from different wheats differed in their baking trials with gluten. This observation was confirmed by Hoseney *et al.* (1971). Additives such as sugar (Leach, 1965) and monoglycerides (Yasanuga, 1968) reduce starch swelling capacity by competing for water or affecting the ability of starch to absorb water.

Firming of bread is due to starch retrogradation. This is an undesirable behavior since it results in staling of the bread.

3.3.8 Gluten

Gluten is the main wheat protein deposited in the kernel endosperm. It forms the protein matrix in which the starch granules are embedded (Bradbury *et al.* 1956; MacMasters *et al.* 1971). On milling, the endosperm is separated from the bran, followed by reduction to flour. The flour contains from 11-15% protein (Tipples, 1969), of which gluten is 85% and nongluten proteins 15% (Pomeranz, 1980). Gluten may then be isolated from the flour using either the Martin or Batter processes (Knightly, 1965, 1967). The extract consists of 75-80% gluten, 5-15% residue starch, 5-10% lipids and a small amount of minerals (Pyler, 1979).

3.3.9 Composition and Behavior of Gluten

Based on solubility in different solvents, gluten has been separated into its components by Osborne (1907). They consist of gliadin and glutenin, which account for the properties of gluten. These two constitute 85% of all the protein in wheat flour. The nongluten-forming protein fraction consists of albumins, globulins, peptides, amino acids and flour enzymes. These proteins are soluble in water or dilute salt solutions, and foam and coagulate relatively easily (Holme, 1966). The presence of a large number of aliphatic and aromatic groups in the nonpolar side chains results in their observed hydrophobic bonding in aqueous medium.

The polypeptide chains in gliadin and glutenin are bound together by disulfide bonds. In gliadin, they are mainly intramolecular, connecting parts of the same polypetide chain into folds; while in glutenin, most occur between polypeptide chains, resulting in large molecular aggregates. This difference is due to the amino acid sequences in gliadin and glutenin (Pence and Nimmo, 1964).

About one third of protein exists in aggregates which cannot be extracted by dilute acetic acid (Mecham *et al.* 1962; Seckinger and Wolf, 1970). Dough mixing or addition to it of reducing agents, such as glutathione and cysteine, cleaves the disulfide bonds and disaggregates the protein globules into smaller units which are more easily extracted (Tsen, 1970). In addition, mixing straightens them out into chains. Disaggregation of globular proteins in flour is, therefore, a prerequisite to the formation of gluten films and matrix in the dough. Disaggregation involves mainly the scission of inter-chain disulfide groups and is related to the sulfhydryl-disulfide interchange reactions during dough mixing.

Sulfhydryl (-SH) groups were first reported by Sullivan *et al.* (1936). Sulfhydryl groups contained in the amino acid cysteine play a role in dough development by formation of disulfide bonds (-SS-) through the oxidising activity of flour oxidants such as iodate and bromate. Crosslinks are made if the -SH groups from different polypeptides are oxidised. The dough becomes more rigid as the network of cross-bonded polypeptides forms (Sokol and Mecham, 1960). Compounds that react with sulfhydryl groups for example iodoacetamide suppress disulfide bonds formation resulting in reduced dough resistence to mixing and accelerated breakdown (Binger, 1965). Such treatment inactivates oxidising agents in the dough. As they are mixed in air, stable doughs lose their sulfhydryl groups faster compared to weaker ones (Sokol *et al.* 1960).

Gliadin is soluble in 70% alcohol and has a molecular weight of 25,000-100,000. It is extensible with low elasticity when hydrated and forms a viscous fluid mass. It is soluble in acids and bases.

Glutenin is dispersible in dilute alkaline solutions. It has a high molecular weight of over 100,000. It is elastic, but has low extensibility and hence forms a tough rubbery mass when hydrated. It complexes readily with lipids.

MacDonald and Gilles (1967) reported that gliadin and glutenin contain high levels of glutamic acid and appreciably high amounts of proline. Helical formations in gluten protein molecules were found to be much limited as compared to other proteins due to the presence of proline which introduces a bend in the amino acid chains. The cohesiveness and elastic characteristics of the gluten were ascribed to the presence of a high level of glutamic acid (Dimler, 1963). Low solubility for gliadin and glutenin is accounted for by their deficiency in basic and acidic groups responsible for solubilization of most proteins.

The concentration of sulfhydryl and disulfide groups in flour is very low. Bloksma (1964) reported only one micromole of sulfhydryl and 10 of disulfide bonds per gram of flour. In spite of their low concentration, only a fraction of sulfhydryl groups is available for oxidation during dough mixing (Bushuk, 1961). A similar condition exists for the disulfide bonds, for which intra- and intermolecular bonds are important. Intermolecular -SS- bonds have been found to be the more reactive and hence play a significant role in influencing dough rheological properties. As the dough is mixed, some of the disulfide bonds are broken, but getreformed by interacting with the sulfhydryl groups within or between protein molecules. Strain is thus reduced between protein fragments and as a result, dough breakdown is delayed as mixing procedes (Goldstein, 1957). Furthermore, sulfhydryl-disulfide interchanges during mixing of dough generate sulfhydryl groups which may be oxidised or participate in further [illegible]rchange reactions. As such, sulfhydryl groups are never used up, but keep on being regenerated. Hence very few sulfhydryl groups can produce extensive changes in dough consistency.

3.3.10 Role Played by Gluten in Bread Making

When water is added to wheat flour, the proteins gliadin and glutenin become hydrated and form gluten on mixing (Jenkins, 1975; Pyler, 1979; Pomeranz, 1980). Hydrated, well-mixed gluten is a tenacious colloidal system. It is responsible for retaining carbon dioxide in the dough during fermentation. That accounts for the superiority of wheat flour over flour from other cereals or root crops in processing of leavened products.

Gluten forms the background matrix in which starch is embedded in the dough and bread crumb. It is denatured during baking to form a resilient internal grid that supports the bread structure. The amount of water absorbed by flour during dough preparation is a function of gluten quality and quantity (Bushuk, 1975; Jenkins, 1975). It is high for flours containing a high percentage and good quality gluten. Volume and texture of bread are similarly functions of gluten quality and quantity (Bushuk *et al*. 1968). Flours high in quality gluten content are better able to withstand the deleterious effects of damaged starch in the dough and bread (Tipples, 1969). Dough properties are at their best when the dough has sufficient gluten of good quality. The resulting bread has better shelf life and consumer acceptability.

3.3.10.1 Flour Baking Performance

The baking performance of wheat flour is dependent on several quality factors. Investigations have shown that the factors are all interdependent. They include maturity of the flour since milling, quantity and quality of the gluten, starch content and degree of its damage during milling, levels of α and β amylases, flour lipids and the presence of flour additives.

Freshly milled flour has been found unsuitable for baking because it imparts a yellow pigment to the bread. The bread is also shrunken in volume (Jenkins, 1975). Color is due to the presence of pigments in the fresh flour. These get bleached over time by atmospheric oxidation, but current practice utilizes bleaching agents such as chlorine, chlorine dioxide, ammonium chloride, acetone peroxide and benzoyl peroxide. Shrunken volume of bread from fresh flour is due to inelasticity of proteins in freshly milled flour. Storage up to about six weeks removes the inelasticity. Storage is avoided by using flour maturing agents. Except for benzoyl peroxide, the above named bleaching agents are also flour maturing agents or dough improvers. Additional dough improvers cited in the literature are ascorbic acid, potassium bromate, ammonium persulfate, azodicarbonamide, 1-cysteine and monocalcium sulfate (Pratt, 1971; Jenkins, 1975).

A good flour for baking absorbs a large optimal quantity of water and forms a dough that develops in a reasonable time during which it is stable to mixing (Wehrli and Pomeranz, 1970; Bushuk, 1975; Jenkins, 1975; Pyler, 1979; Pomeranz, 1980). The percent water absorption of flour is affected by the quality of protein present in it. An inverse relationship exists between them. The starch present also affects the water absorption. Sandstedt (1955) reported that dry undamaged starch absorption is increased if the starch is damaged, the increase being proportional to the degree of starch damage (Tipples, 1969). Excessive water absorption due to damaged starch results in sticky doughs that are difficult to handle. Flours with low protein content and quality are affected most. The excess water has been found to decrease later during fermantation (Halton, 1961) and in the oven during baking (Atkinson and Fueher, 1960).

The amylase content of flour plays an important role in dough behavior and bread quality. Normal wheat flours have less α- than β- amylase contents. If flour is made from sprouted wheats, it will contain more α- and β-amylases. This is an abnormal situation because it results in excessive gasing and dextrinization of starch. Since cereal α-amylase is still active when starch gelatinizes, dextrinization of starch during baking has been found to be proportional to α-amylase present, but not to starch damage (Tipples, 1969). The crumb becomes sticky and the loaf tends to curve in and collapse. In addition, dextrinization reduces the water binding capacity of starch. Only a limited degree of dextrinization is beneficial.

Lipid-gluten interaction in dough is essential to good quality in bread. In the dough, the interaction helps to seal in gas during mixing and fermentation periods. During baking, the lipids interact with starch and promote freshness in bread (Hoseney *et al*. 1970). It has been reported that polar lipids improve the crumb softness better than nonpolar lipids (Pomeranz *et al*. 1966; Pomeranz *et al*. 1969; Wehrli and Pomeranz, 1969). Flours from which lipids have been extracted have insoluble proteins and perform badly in baking (Chung *et al*. 1977). Some limited proteolysis to mellow gluten during fermentation is desirable.

3.3.10.2 Flour Additives in Bread making

The essential components of a bread formula are flour, water, yeast and salt. In order to improve the quality of the bread, several other additives have been found necessary (Pomeranz and Shellenberger, 1971; Tipples, 1975; Jenkins, 1975; Pyler, 1979).

Fats for baking may be in the form of lard, regular shortening and emulsified shortenings. According to Pyler (1979), fats have a beneficial influence on bread quality, although their contribution to the general characteristics of bread is of limited significance. Fat is totally omitted in sponge cakes, while the level at which it is used in yellow, white and pound cakes, some cookies and pastries is considerable as it plays an important role in their structural development.

Usage of fat in baking improves the aeration and handling properties of doughs. Fat gives tenderness to the product and increases its eating and keeping qualities. Bread with fat has a fine grain and tender texture. Stability in cake batters is significantly improved by the presence of fat. But the level of fat in the dough must be controlled up to about 3% since an excess leads to weaker doughs, reduced fermentation rate, as a result of fat coating on yeast and yeast food, and creamy crumbs.

Emulsified shortenings increase the water absorption capacity of the dough. Most of the water is retained during baking (up to 35%), and results in softer crumbs. Incorporated monoglycerides interact with starch to retard bread staling. Dough improvers such as succinylated monoglyceride (Meisner, 1969), sodium stearyl fumarate (Geminder *et al.* 1965; Brachfeld *et al.* 1966), tartaric acid esters of mono and diglycerides (Birnbaum, 1955) and acyl lactilates, for example calcium stearoyl-2-lactylate (Marnett and Tenney, 1961), are used to strengthen the dough against mechanical breakdown during mixing and handling. Dough improvers also called dough conditioners, have a lipophilic chain that binds amylose and a negatively-charged moiety that reacts with active positively-charged sites in gluten. The gluten and the starch are bound more closely, bringing about strength in the dough as a whole. The grain and texture of the crumb are improved. Volume of the bread and its resistance to staling are increased.

Salt is added in order to improve the ability of gluten to absorb water. Doughs made without salt are slack and sticky. These conditions disappear when salt is added and mixed in well (Jenkins, 1975). Commercial dough improvers already mentioned have a similar effect. Salt can be added up to 3% in order to impart a characteristic flavor to bread.

Sugar is added in order to augment the sugars already in the flour for yeast nutrition and for color development during baking. In North America, excess sugar is added wherever sweet bread is preferred. Yeast needs sugar to produce carbon dioxide required for leavening the bread. Yeast food, providing required salts and nitrogen for yeast cellular development, is added in the form of ammonium salts, which are provided with starch as a filler. The yeast itself is added at a level of about 3% on flour.

Sometimes a flour is deficient in α amylase activity. In this case bacterial α amylase is added to offically recommended levels to ensure uniform gassing required for optimal grain and loaf volume.

Non-fat dry milk addition to flour has the best benefit in weaker doughs, where it lightens the dough in a similar manner as does salt. If used with stronger flours, water absorption has to be increased to remove excess dough tightening and to obtain better consistency for handling and fermentation. Proteins from the milk additive increase the nutritional value of the bread. Lactose in the milk additive is not yeast-fermentable, but contributes to good crust color development. Addition of milk solids to flour is particularly beneficial where a long fermentation period is used and where the flour lacks amylolitic activity.

Eggs are used as additives in special baked products that fetch a higher price. Egg proteins reinforce flour proteins and as with the addition of milk solids, will tighten dough consistency. This is corrected by adjusting the water absorption accordingly. It has been reported (Jenkins, 1975) that egg whites used instead of additional gluten produce thin and crisp crust in baked products without excessive volume changes observed when gluten is added, which agrees with the fact that egg proteins do not entrap as much gas as gluten.

Enrichment in terms of officially recommended levels of vitamins and minerals may be included in bread formulation (Gage, 1978). Mold inhibitors are added so as to delay spoilage of the baked goods.

3.3.10.3 The use of Composite Flours in Bread Making

There is an increasing need for composite flours because the demand for bread and other baked products based on wheat flour has risen rather sharply in many areas of the world, especially in the developing nations, without a corresponding increase in wheat production in those areas (Kim and Ruiter, 1969; Seyam and Kidman, 1975; Olatunji and Akinrele, 1978; Blaise and Okezie, 1980). To reduce expenditure on imported wheat grain, utilization of composite flours that involve local sources of starchy flours and oil seed flours high in protein is a reasonable approach to extend the use of the available wheat.

In compositing the flour, it is necessary to balance out the nutritional requirements as set by FAO standards (Seyam and Kidman, 1975). Too much starch and too little protein is a situation to be avoided (Milner, 1974). Fortification using locally available protein flours from beans, cotton seed, sunflower and others should be encouraged (MacConnell and Bushuk, 1974). Addition of vitamins and minerals (Gage, 1978) and limiting amino acids should be considered to give consummers a more nutritionally balanced product. But in order for high protein bread to have a significant contribution in diets, it must be visually and organoleptically acceptable, otherwise ~~few will~~ buy or consume it (Fleming and Sosulski, 1977).

Research in composite flour technology has concentrated mainly on the influences of partial substitution of wheat flour with pure starch, plant protein concentrates, or flours high in starch or plant protein content on dough rheological properties and bread quality. Composites with soya bean flour have been investigated by

Pomeranz *et al*. (1969), Tsen and Tang (1971), and Tsen and Hoover,1973. Composites with chick pea flour have been studied by Shehata and Fryer (1970), while Hussein *et al*. (1974) investigated composites of wheat flour with broad bean flour. Jeffers *et al*. (1978) studied composite flours of field pea and wheat flours. Blends of fababean and wheat flour have been studied by Lowerenz *et al*. (1979), and navy bean and wheat flour blends by D'Appolonia (1978). Fleming and Sosulski (1977) studies involved the use of composite flours of defatted soya flour, dehulled and defatted sunflower flour, fababean and field pea protein concentrates. They reported that acceptable bread could be made using 12% sunflower flour or 15% soy, fababean and field pea concentrates. However, they found it necessary to include in their formulations 2% vital gluten and 1.0-1.5% dough conditioner to restore the quality of the composite bread.

Cassava and yam have been considered potentially useful in composite flours (Kim and Ruiter, 1969; Pringle *et al*. 1969; Dendy *et al*. 1970). Rasper *et al*. (1974) found cassava starch superior to yam in composite flours for baking. They attributed this to the closeness in pasting temperature of cassava and wheat starches. The performance of cassava flour was, however, found inferior to yam flour in composites with wheat flour for baking which led them to conclude that other components in the non-wheat flours had functional properties of significant influence in baking qualities of the flours.

D'Appolonia (1977) found that the baking quality of tuber starches was a function of their physico-chemical properties. Hahn and Rasper (1974) reported that nonstarch water soluble polysaccharides from tuber flours increased bread volume, while the insoluble fractions had a deleterious effect. The presence of fiber in cassava flour was reported as responsible for poor quality of bread with cassava flour composites as compared to composites with pure cassava starch (Hudson and Ogunsua, 1976).

Ciacco and D'Appolonia (1977) showed that, although yam and cassava flours had only 7.8 and 1.2% protein compared to 11-15% in wheat, they were richer in some amino acids, especially lysine, histidine, arginine, aspartic acid, threonine, and alanine. Yam flour alone was better than wheat flour in its contents of serine, glycine, valine, isoleucine, leusine and phenylalanine. But wheat flour was found to contain much higher levels of glutamic acid, proline, cystine and tyrosine. The same investigators reported in 1978 that acceptable bread could be made from blends of 15% cassava starch or yam flour. Good bread could be obtained from 10% cassava flour in the blend, but dough handling problems became limiting. Good French-type bread was made from blends containing 10% yam flour, while blends with 5 and 10% cassava starch produced good white pan bread. The internal properties of bread containing cassava starch were improved by addition of 0.5% sodium stearoyl-2-lactylate. They found that blends with cassava starch were more amenable to continuous processing methods than blends with yam. They observed that cassava starch always produced better bread than cassava flour irrespective of the processing method.

Ciecco and D'Appolonia (1977) found that cassava and arrowroot starches gelatinized during baking to greater extents than wheat or yam starches. They concluded that pasting temperature is an important factor for tuber starches when used in baking, which corroborated findings by Anker and Geddes (1944) and Seyam and Kidman (1975).

Olatunji and Akinrele (1978) studied yam, cocoyams (taro and tannia), cassava and breadfruit flours in a composite bread making with wheat flour. They concluded that 10% substitution level of wheat flour by any of the other flours gave bread acceptably close in quality to pure wheat bread.

Addition of starch or non-wheat flours to wheat depresses loaf volume, weakens the dough and results in harsh crumb texture. Deleterious effects in the crumb can be corrected by proper handling of the dough and use of additives such as gluten, dough conditioners of high HLB, and emulsifiers that react with starch and retard retrogradation. Rheological changes accompanying partial substitution of wheat flour with non-wheat flours, starch or plant protein concentrates are discussed below.

3.3.11 Dough Rheological Properties

The rheological properties of a dough refer to its physico-mechanical characteristics. As a whole, a dough is a composite system consisting of distinct phases that differ in their rheological properties (Bloksma, 1971).

The swollen gluten continuous phase is, however, considered responsible for nearly all the physico-mechanical properties of a dough during its mixing and development. On the other hand, starch accounts for about 60% of the volume fraction of a dough, hence Hanssen *et al*. (1952) and Sandstedt (1954) have stated that, due to the high concentration of starch in the dough, rheological properties are more likely influenced by the interaction between starch and gluten, but not gluten alone. In fact the presence of starch makes the dough system more rigid.

Dough rheological properties are important in the baking industry as they significantly influence the quality of bread and other baked products (Bloksma, 1971). As dough is mixed, air is trapped in its protein continuous phase (Baker and Mize, 1946). The dough becomes coherent and begins to withdraw from the mixing equipment as it develops. Development is complete when the dough is fully elastic and is smooth and dry to the touch (Bushuk *et al*. 1968). Further mixing beyond this stage results in dough breakdown, which is shown by gradual loss in elasticity accompanied by an increase in dough extensibility, stickiness and fluidity.

Doughs of flours from different sources or of different blends respond differently to mixing. Their mixing characteristic are affected by additives such as salt, oxidising and reducing agents (Bushuk and Hlynka, 1961), monoglycerides and dough conditioners (Pyler 1979).

In conventional dough mixing, additional development of the protein structure is afforded by fermentation, punching and molding. Gluten lamellae are formed between gas-cells by the stretching and folding operations. The starch granules are entrapped in the gluten lamellae around the gas-cells (Burhans and Clapp, 1942). These operations are less important in mechanical dough development where the gluten is already highly developed by mechanical action at the end of the mixing operation.

Dough rheological properties can be followed and measured by the Brabender farinograph (Locken *et al*. 1960), the Swanson and Working mixograph, and other mixer-recorders (Swanson and Working, 1933; Lamour and Working, 1939; Johnson *et al*. 1946; Voisey *et al*. 1963, 1966; Shuey and Gilles, 1966).

Dough extensibility, strength and resistance to extension can be measured by the Brabender extensigraph (Halton, 1949); the Chopin extensigraph [alveograph] (Chopin, 1957; Bennett *et al*. 1956; Maes and Pirotte, 1956); or the Halton extensigraph [research extensometer] (Halton, 1949).

The research extensometer is similar to the Brabender extensigraph. One advantage the Brabender extensigraph has over the Chopin extensigraph is that it can show the effects of added dough improvers, which the Chopin extensigraph and the Brandender farinograph can hardly do.

The rheograph graphically records the rheological changes occurring in dough as it is subjected to mechanical development. Doughs of 700 g are mixed until the fatigue point in reached. The time required to reach the fatigue point in characteristic of a flour and is influenced by such factors as gluten content and strength, milling, and dough ingredients (Pyler 1979). The Patterson mixatron can be used to electronically measure the instantaneous consistency of the dough during mixing and the mixing time (Selman, 1949; Pyler, 1979).

The Brabender farinograph is the most commonly used instrument in the determination of the rheological properties of dough. It involves rapid addition of water to and mixing of flour of 14% moisture basis at a constant temperature and speed with a pair of z-shaped mixers in the mixing chamber of the instrument. The consistency of the dough in Brabender units (BU) is recorded against time.

The curve (farinogram) just straddling the 500 BU line represents dough with maximum consistency. The water absorbed to effect this consistency is read off as percent water absorption, which is characteristic of a particular flour. Other rheological properties provided by the farinogram are dough arrival and development times, dough stability, mixing tolerance, and degree of breakdown after 20 min. of mixing (Pyler, 1979).

The Brabender extensigraph is used in measuring dough extensibility, resistance to extension and strength (Bloksma, 1971; Pyler, 1979). A sample of 150 g of dough prepared in the Brabender farinograph is scaled-off, molded, and fermented for 45 min. The dough is clamped and a hook stretched downwards through it until it snaps. The force exerted is transmitted through an arm to the stylus and is recorded on a chart. The dough is reshaped and the process repeated twice after 45 and 90 min. fermentation time to simulate the fermentation period and dough punching.

The vertical axis of the chart represents force in Brabender units, while the horizontal axis represents the extensibility in mm. The height of the curve at 50 mm from the start of stretching represents the resistance to extension.

Maximum resistance is taken at the peak of the curve. The area under the curve represents both the total force used in stretching the dough and the strength of the dough. Good doughs show good resistance to extension. They also have good extensibility (Harris, 1943; Pyler, 1979). For maximum gas retention of a particular dough, some extensibility/resistance ratio exists which is represented by a particular extensigram. Oxidation decreases extensibility, hence increases the ratio (Bloksma, 1971).

Rheological studies on composite flours have shown that water absorption, mixing tolerance index in BU, and resistance to extension of a dough increase as the level of substitution of the wheat flour by the non-wheat flour, starch or protein concentrate increases (Seyam and Kidman, 1975; Olatunji and Akinrele, 1978; Sathe *et al*. 1981).

Ciacco and D'Appolonia (1977), however, found that, whereas substitution of wheat flour with arrowroot and cassava starches raised the mixing tolerance index, substitution with yam reduced it. Lorenz (1978), using unshelled sunflower meal flour, observed a drop in water absorption in the blends with wheat flour, yet Flemming and Sosulski (1977) observed an increase in water absorption by using dehulled and defatted sunflower flour.

Partial substitution of wheat flour has been reported to reduce dough development times and stability (Seyam and Kidman, 1975; Ciacco and D'Appolonia, 1977, 1978; Olatunji and Akinrele, 1978; Lorenz, 1978; Lorenz *et al*. 1979; D'Appolonia and MacArthur, 1979; Sathe *et al*. 1981). Lorenz *et al*. (1979), however, noted that substitution with fababean flour to a level beyond 5% resulted in increased arrival times. A similar observation was made with substitution with fababean protein concentrate.

Ciacco and D'Appolonia (1977) observed that blending wheat flour with yam starch raised peak time and stability of the dough. Arrowroot and cassava starches had the opposite effect. Ciacco and D'Appolonia (1978) also observed that arrival and dough development times rose if cassava flour was used for substititution, but not in the case of the starch.

Using yam flour for the substitution at 10% and above reduced arrival times, while dough development time did not start to fall until 15% or more substitution level. Stability of the dough varied with level of substitition. It rose above the control at 5%, was equal to the control at 15%, but dropped at 20% substitution levels with yam flour.

According to the same investigators, addition of 0.5% sodium steaoryl-2-lactylate decreased the water absorption at all levels, including the control. Arrival and dough development times increased in the control, but dropped in the case of cassava flour and starch. For yam flour, a decrease in the same properties was observed at and above a 15% level of substitution.

3.4 Dough and Crumb Hydration Capacities

Hydration capacity of a dough or bread crumb is defined as the water uptake per gram of dry matter (Yasunaga *et al.* 1968; Dennett and Sterling, 1979). The difference between dough and crumb hydration capacities represents hydration due to gelatinization (Dennett and Sterling, 1979).

Yasanuga *et al.* (1968) found that the hydration capacity of bread crumb is influenced by several factors. Dough moisture content, time, and temperature of baking were found to have direct influence on the degree of gelatinization and, consequently, the crumb hydration capacity. The staling of bread decreased the crumb hydration capacity. The presence of monoglycerides and shortening reduced the rate of decrease in the hydration capacity of the crumb during storage time. Physical damage to starch granules increased crumb hydration capacity. A similar observation was made when malt was added to the baking formula.

Dennett and Sterling (1979) examined the hydration capacities of dough and crumbs made from composites of 85% starch and 15% vital gluten in a formula containing 4.0% sugar, 1.5% salt, and 3.0% yeast. They found that dough from amylomaize, potato, wheat, maize, tapioca, rice, and amioca starch/gluten composites had hydration capacities corresponding to 1.2, 1.1, 0.9, 0.8, 0.8, 0.8, and 1.1 g water/g dry matter. Similarly, the respective bread crumbs had hydration capacities of 2.2, 3.3, 2.9, 3.1, 5.4, 4.8, and 4.3 g water/g dry matter.

Further studies indicated that there was a statistically significant negative correlation between amylose content and crumb hydration capacity. A significant positive correlation was found between soluble amylose content and crumb hydration capacity.

3.5 Dough and Crumb Microstructure

The structure of the dough developed during mixing, fermentation, punching and proofing is maintained in the crumb after baking.

The dough is not homogeneous in its microstructure. Unleavened dough consists of protein, starch, and gas-cells, while leavened dough has yeast-cells in addition.

The development of the dough depends on optimal hydration, optimal mixing and stretching of gluten, and the presence or absence of oxidising and reducing agents (Evans *et al.* 1981) Hydrated gluten forms a continuous phase consisting of a network of thin protein films between gas-cells. The starch granules are embedded in the gluten films and line the gas-cell walls (Burhans and Clapp, 1942; Baker and Mize 1946; Sandstedt *et al.* 1954; Hanssen, 1957).

The protein network of developed gluten is interconnected with hydrogen and occasional disulfide bonds which confer to it viscoelastic properties. The resilience of the structure as a whole depends on the number and strength of the bonds. Electrostatic bonds, Van der Waalls forces, and protein chain entanglements are also thought to contribute to the strength of the whole system (Bloksma, 1971). If the gluten is overmixed, the protein films rupture and become filamented (Grosskreutz, 1961).

Flour lipids and added shortenings do not occur as distinct phases within the dough, but as films on the starch granule surfaces (Barhans and Clapp, 1942). Pomeranz, (1973) indicated that lipids interact mainly with gluten in the dough and mainly with starch during baking as the crumb is forming thus accounting for the freshness of bread.

Studies by Grosskreutz (1961) of hydrated gluten structure led him to postulate that developed gluten consist of 2-5% lipoprotein and that the proteins in the hydrated gluten consists of folded polypeptide chains in the α-helix conformation arranged in plateletes of about 70 Å thickness. These orientate themselves in bimolecular leaflets bound to the outer surfaces of bimolecular phospholipid films through salt linkages between the acidic groups in the phospholipids and basic sites on the proteins.

Horseney *et al.* (1970) reached the conclusion that gliadin and glutenin, the main components of gluten, are bound to each other through glycolipid membranes, with the free polar lipids connected to the gliadin through hydrophilic bonds.

Wehrli and Pomeranz (1970) supported the conclusion of Horseney *et al.* (1970) by reporting that infrared spectroscopy had demonstrated the existence of hydrogen bonds between glycolipids and gelatinized starch or glycolipids and gluten components. Similarly, Van der Waal's forces were reported between glycolipids and gluten components. Nuclear magnetic resonance spectra were reported by the same investigators to have indicated hydrophobic bonding between glutenin and the glycolipids. A conclusion was made that binding of polar lipids to both gliadin and glutenin played a role in perfecting the ability of gluten to retain gas in the dough.

Flemming and Sosulski (1979), in their studies on the effect of concentrated plant proteins on bread crumb microstructure, observed that foreign proteins disrupted the well-defined protein-starch complex as seen in the pure wheat flour bread. The supplemented bread crumbs had thick cell walls with small pores scattered in them. These pores could have accounted for loss of gas from the supplemented breads, which had reduced loaf volumes, compact or coarse crumb grains and firm textures.

3.6 Bread Staling

Bread staling refers to all the physico-chemical changes that occur in bread after baking. It has been the subject of many reviews (Herz, 1965; Waldt, 1968; Elton, 1969; Zobel, 1973; Willhoft,1971, 1973; Maga, 1975; Kim and D'Appolonia, 1977; Knightlyly, 1977; D'Appolonia and Morad, 1981; Roewe *et al.*, 1982).

Changes in bread caused by staling are undesirable. The bread crumb becomes firm during storage. The fresh bread crust, which is normally dry, crispy, and brittle, becomes soft and leathery. The bread loses its fresh pleasant aroma and develops a faintly bitter taste, especially in the crust (Pyler, 1979).

Staling of bread was first associated with starch retrogradation by Lindet (1902). Katz (1928) reported that bread with sufficient moisture staled as a function of temperature. He observed that bread remained fresh at 60°C or higher temperatures, as was observed earlier by Boussingault (1852) Bechtel *et al*. (1953) and von Bibra (1961), who observed that at least 30% moisture in the bread was necessary for this to occur. The bread became progressively more stale with decrease in temperature to the freezing temperature of bread (about 6.7°C) (Pence *et al*. 1956). Bread stored at -10°C or lower remained fresh. X-ray diffraction analysis showed fresh bread to have the 'V' pattern typical of amorphous starch, while stale bread had the 'B' pattern typical of crystalline starch. These observations were confirmed by other researchers (Prentice *et al*. 1954; Bechtel, 1959; Zobel and Senti, 1959).

Schoch and French (1945) established that staling of bread was due to gradual and spontaneous aggregation of the free linear chains of amylopectin. This formed crystalline structures throughout the crumb, but they could be dissociated by heating at 50-60°C, as opposed to higher temperatures of about 125°C required for breaking similar, but stronger association involving amylose. In a follow up, Schoch (1965) explained that during baking amylose diffuses out of the starch granules into the inte[illegible]l areas between starch granules within the crum[illegible] amylose chains associate so fast that they are already retrograded by the time the bread is cooled. Further retrogradation would therefore be due to amylopectin within the starch granules. Pomeranz (1980) confirmed Schoch's work by reporting that staling was due to both amylose and amylopectin in the first day after baking, thereafter being influenced only by amylopectin. McIver *et al.* (1968), using differential scanning calorimetry, also confirmed that amylopectin was more responsible for bread staling than amylose.

Cornford *et al.* (1964) used the Avrami equation to study and relate bread crumb firming to crumb elastic modulus, time , and various temperatures above the freezing point of bread. It was observed that the extent of crystallization could be measured by the increase 'E' in the crumb elastic modulus relative to its limiting or the final value 'E_1', during storage time. For a linear relationship, the uncrystallized fraction θ after a time of storage 't' could be quantified by $\theta=(E_1-E_t)/(E_1-E_0)$ where 'E_0' is the intial modulus. This function was found to follow the equation $\theta=\exp(-kt^n)$ in which 'k' is a constant characteristic of crystal growth, while 'n' is an integer (1-4) designating the mode of nucleation. They showed that above the freezing temperature of bread, the relative rate of modulus increase become greater with decreasing temperatures. Concommitant decreases in the time constant (time required for a given fraction of the crumb to become stale) were also observed. It was concluded that firming in bread crumb as it stales is a physical process involving ordered arrangement of atoms or molecules as occurs in crystallization. The process was attributed to crystallization of starch as it retrogrades. Similar observations were made in later studies by Cornford *et al.* (1964); Axford *et al.* (1968); McIver *et al.* (1968); Colwell *et al.* (1969), and Kim and D'Appolonia (1977). Their work gives firm support to observations reported above after Schoch and French (1945) and Schoch (1965).

According to Willhoft (1971, 1973) denaturation of gluten during baking causes structural changes, reducing the ability of gluten to bind water. There is a transfer of water from the denatured gluten to the gelatinized starch during staling. The softening of starch resulting from such water transfer is compensated for by firming due to retrogradation. Taylor *et al.* (1959), however, reported that the starch gel lost from 58-51% of its moisture-soprption capacity over seven days storage, while gluten maintained its capacity. Cornford *et al.* (1964) also found a negative temperature coefficient for bread staling. They concluded that diffusion of moisture from gluten to starch during staling was not a primary occurrence. The softening of the bread crust during staling seems to indicate a decisive transfer of moisture from the crumb to the crust.

Several factors affect the staling of bread. Factors that reduce loaf specific volume enhance staling (Elton *et al.* 1969; Axford *et al.* 1968). Flours high in good quality protein produce bread with high specific volume. Such bread had a lower tendency to stale as compared to bread made from flour low in quantity and quality of protein. Chorleywood Process bread was found to stale less than conventional process bread. Properly fermented bread was found to stale less than over or under fermented bread. Optimum hydration of the dough slowed down the rate of staling in bread (Swortfiguer, 1971).

Water soluble and water insoluble pentosans slow the rate of retrogradation by affecting the amylopectin and amylose fractions of starch, hence reducing the total amount of starch available for retrogradation (Pomeranz, 1980; D'Appolonia and Morad, 1981).

The presence of non polar lipids has been found to reduce crumb firming only slightly (Pomeranz and Chung, 1979,) while free polar lipids were observed to reduce it significantly (Pomeranz, 1969). Surfactants combine with starch and reduce its tendency to stale. Monoglycerides reduce staling by penetrating the starch granule and immobilising in it the the unleached amylose fraction (Schoch, 1965). Several investigators (Hutchinson, 1936; Platt and Powers, 1940; Carlin, 1947) have found that the presence of shortening in bread reduces staling.

Freezing of bread is the most effective way of prolonging bread storage for any length of time. Development of bad aroma is the only limiting factor (Bailey, 1932; Cathcard, 1939; Cathcart, 1941; Pence *et al.* 1956). Staling of bread has been investigated using changes in crumb compressibility (Bailey, 1930; Stramb and Hirsch, 1935; Platt and Powers, 1940; Noznick and Geddes, 1943; Pence *et.al.* 1955; Waldt, 1968; Marston and Short, 1969; Maleki *et al.* 1981; Roewe and Kulp; 1982). Kim and D'Appolonia (1977) followed retrogradation by measuring the solubility of starch in the crumb to estimate the degree of staling. Crumb x-ray diffraction analysis has also been employed in the analysis of retrogradation (Dragsdorf and Marston, 1979). Other investigators have used starch susceptibility to amylase attack. Bechtel and Meisner (1952) used changes in crumbliness of the crumb to measure its level of retrogradation.

3.7 Bread Quality Evaluation

The reasons for bread quality evaluation are to access consumer acceptability, routine quality checks on the suitability of raw materials used in the formulations, and regulation of the production process to achieve specified quality standards in the product.

The bread is examined for external and internal properties. The external properties of interest are loaf volume, crust color, symmetry of form, character of the crust, and break and shred. The internal characteristics are crumb grain, crumb color, aroma, taste, mastication (chewability), and texture (Matz, 1960; Pyler, 1979).

The characteristics of the bread can be analysed by any of the sensory tests (difference analysis, ranking difference, and preference evaluation) coupled with statistical analysis where necessary (Fleming and Sosulski, 1977; Sosulski and Fleming, 1979; Blaise and Okeizie, 1980).

In the triangle difference analysis test, panelists are asked to identify the odd sample from a set of three, two of which are identical. The degree of difference is then judged as extreme, much, moderate or slight.

In ranking difference test, the characteristic of interest, for example, crumb color, crust color, crumb grain or crumb texture, is examined in different loaves of bread. The loaves are then ranked according to the panelists' preference based on the degree of the differences observed.

As regards the preference test, bread characteristics are evaluated according to a hedonic scale of numerals. The level of preference for a characteristic is indicated by numerals selected from the scale of, for example, 1-10, where 10 is the perfect score and 1 represents a poor score or unacceptable quality (Ciacco and D'Appolonia, 1977, 1978; D'Appolonia and MacArthur, 1979). Investigators have selected scales they find suitable. Olatunji and Akinrele (1978) used a scale of 1-100, with 81-100 scores representing acceptable and 56 or below being unacceptable. Sosulski and Fleming (1979) used a 5-point scale to evaluate flavor, texture and overall acceptability.

Numerical scores from the various panelists are then subjected to statistical analysis of variance and Duncan's multiple range test (Sokal and Rohlf, 1969; Lamond, 1970).

According to the American Institute of Baking the external properties of a loaf account for 30% of the total score, of which volume is allocated a maximum score of 10 and color of the crust a score of 8. The other external properties are each assigned a maximum score of 3 for the best quality. Of the 70% scores allocated to the internal properties, taste and texture account for 15 scores each for the best quality. The rest of the internal properties are accessed individually on a maximum score of 10 for the highest quality. Bread loaves lose scores if specified faults are detected in any of the properties.

4. EXPERIMENTAL

4.1 Materials

Arrowroot Starch

Native arrowroot (*Maranta arundinacea*) starch was isolated from the flour of a Kenyan cultivar.

Cassava Starch

Native cassava (*Manihot utilissima*) starch was isolated from flour of a Kenyan cultivar and tubers of a Fijian cultivar. Commercially available (A.E. Staley Manufacturing Co., Decatur, Illinois) tapioca starch was also used.

Sweet Potato Starch

Native sweet potato (*Impomoea batatas*) starches were isolated from the tubers of the cultivars Centennial, Porto Rico and Georgia Red.

Taro Starch

Native taro (*Colocasia esculenta*) starch was extracted from tubers of a Jamaican cultivar.

Yam Starch

Native yam (*Dioscorea cayenensis*) starch was extracted from tubers of a Jamaican cultivar.

Wheat Flour and Starch

Wheat flours were obtained by milling hard red spring (cv. Neepawa) and soft white spring (cv. Fielder) Canadian wheats. Wheat starch was then isolated from the flours.

Vital Wheat Gluten

Vital wheat gluten, Whetpro-80 (Industrial Grain Products Ltd., Montreal), consisting of 80.0% protein, 11.5% carbohydrates, 6.5% moisture, 1.0% fat and 1.0% ash, was used in composite flours with all starches.

Yeast

Active dry yeast (Standard Brands Canada Ltd.) was locally obtained.

Sugar and Salt.

Commercial food grade sugar and salt were used.

Shortening

Crisco (Procter and Gamble Inc., Toronto), a hydrogenated vegetable oil shortening consisting of mono- and diglycerides, was used.

Monoglycerides

Types C_{16} and C_{18} distilled monoglycerides, at least 90%, prepared from hydrogenated palm oil with palmitic acid enrichment, and edible saturated cottonseed oil were obtained from Vauxhall Foods Ltd., Alberta and Eastman Kodak Co., NY.

Photographic Paper and Dry Mounting Tissue

Photographic papers and dry mounting tissue were all Kodak brand.

Chemicals

Kodak type Dektol developer and fixer were used

Tri (dimethyl amino methyl) phenol-DMP-30 and Araldite (502) resin were obtained from Ladd Research Industries, Inc. (Burlington, CT).

Dodecenyl succinic anhydride (DDSA) was obtained from Ernest Fullum, Inc. (Schenectady, NY).

Propylene oxide was obtained from Eastman Kodak Co. (Rochester, NY).

Other chemicals used were reagent grade obtained from Fisher Scientific Co.

4.2 Equipment

Precision balances made by Metter, Zurich. CH, were used in taking accurate weights of chemicals, samples and materials.

Ovens: Vacuum oven (National Appliances Co., Portland, OR) was used in all moisture content determinations. Iso-temp draft oven (Fisher) was used for drying purposes. White Westinghouse domestic oven was used for baking bread at 210°C. Still air oven was used for storing bread at 24°C.

Waring blendor Model 702 BAW (Waring Products Corp., Winsted, CT) with variable autotransformer (Superior Electric Co., CT) was used in the isolation of the starches.

Centrifuges: International centrifuge size 2 (International Co., Boston, MA) and Beckman Model J21B with rotors JA-14 and JA-20 (Beckman Instrument Inc., Palo Alto, CA) were used in starch and starch-monoglyceride clathrate isolation steps.

Cyclone sample mill (UD Corporation, Boulder, CO) was used in preparation of whole wheat flour.

Buehler laboratory flour mill - type MLU-202 (Buehler Brothers Ltd. Engineering Works, Uzwil, Switzerland) was used in milling tempered wheat grain to white straight grade flour.

Camfro type RZR1-64 stirrer (Camfro Ltd., Wiarton, Ontario) and Lo-temptrol water bath (Precision Scientific Co., Chicago., IL) were used in the determination of starch swelling power and solubility.

Control temperature water bath with Thermix 1441 stirrer (Braun Melsungen Ag, W. Germany) was used in providing constant temperature when required.

Potentiometric titrimeter (Fisher Scientific Co) was used in the determination of amylose content of the starches.

Technicon autoanalyser II, (Technicon Industrial Systems, Tarrytown, NY) was used in the determination of the phosphorus content of the starches.

A Haake rotovisço model RV3 with NV sensor system (Haake, Karlsruhe, Germany) was used in all starch viscosity determinations.

Spetrophotometers: A Beckman DU-8, UV-visible spectrophotometer (Beckman Instruments Inc., Irvine, CA) was used in the determination of amylose complexing indices of monoglycerides. A Perkin-Elmer 297-1R spectrometer (Perkin Elmer Ltd, Beaconsfield, Buckinghamshire, UK.) was used in the examination of the structure of the α-and β-monoglycerides. A Perkin-Elmer 503 atomic absorption spectrophotometer (Perkin-Elmer Ltd, Toronto,) was used in determining the mineral contents except phosphorus of the starches.

Controlled enviroment incubator shaker (New Brunswick Scientific Inc., Edison, NJ) was used in maintaining constant temperature and shaking during determination of the starch monoglyceride interactions.

Microscopes: Light microscope (Ernst Leitz Wetzlar, W. Germany) with a calibrated dark field was used in the determination of the starch granule size distribution. Scanning electron microscrope (SEM), Stereoscan 150, Cambridge Scientific Instruments Ltd. (Cambridge, England) was used in studying the morphology of the starches, dough and crumb.

A transmission electron microscope ultramicrotome (Reichert "OM U2", Reichert Optische Werke AG, Vienna, Austria) was used in sectioning samples for the transmission electron microscope, Philips EM type PW 6000 (Philips Scientific Instruments, Netherlands)

Differential scanning calorimeter, Du Pont model 900 with the 910 cell base (Du Pont Co., Wilmington, DE), was used in the determination of the gelatinization properties of all the starches and the retrogradation of concentrated aged starch gels.

Farinograph type FA/R-Z (C.W. Brabender Instruments Inc., Hackensack, NJ) was used in the determination of percent water absorption of flour and the rheological properties of the doughs.

Hobert mixer type KM32 CDN (Braun AG Frankfurt/M, W.t Germany) was used in mixing doughs for breadmaking.

Temperature-humidity chamber model 417530 (Holpack Canada Ltd, Waterloo) was used during dough fermentation and pan proofing at 35°C and 80% humidity.

Freeze drier (Virtis Co. Inc., Gardiner, NY) was used in freeze drying samples for X-ray diffraction analysis.

X-ray diffractometer: Philips model PW-1730 X-ray generator, with PW-1710 diffractometer control unit and PM-8110 and PM-8203 one line recorders, was used in examining crystallinity in aged starch gels, starch-monoglyceride clathrates and starch isolated from aged bread crumb.

Textrometer model SL14 Minarik speed control unit (Minarik Electric Co., Los Angeles, CA) with speed reducer Type NSH-12RG (Bodine Electric Co. Chicago, IL), Honeywell Electronic 19 chart recorder and type 93 strain gage transducer input module, model 3001D (Daytronic), was used in crumb compressibility and crumb penetration resistance determinations.

4.3 Methods

4.3.1 Isolation of Starch from Fresh Tubers

The tubers were washed in tap water and peeled in deionized water containing about 100-150 ppm of $NaHSO_3$. They were then diced and homogenized at medium speed in a Waring blender in deionized water containing as above. The resulting slurry was filtered through 100 mesh polyester filter cloth. The filtrate was collected, while the residue was recycled through the waring blender until all starch had been extracted from it. The starch in the filtrate was allowed to sediment for 1 to 2 hr, after which the supernatant was removed by syphoning.

The starch was cleaned by being resuspended in a little water and centrifuged at 3000 rpm for 15 min in 250 ml centrifuge bottles. The supernatant and the upper brown layer of impurities were eliminated. Any debris at the bottom of the starch layer was also eliminated. The process was repeated (2-3 times) until a clean sample of starch was obtained.

The starch was finally washed with 95% ethanol, followed by another washing with acetone in a Buchner funnel lined with Whatman No. 1 filter paper and connected to an aspirator. The starch was dried at 40°C for 3 hr in a forced draft Iso-temp oven. Its moisture content was determined by drying weighed samples in a vacuum oven at 60°C overnight, followed by cooling for 1 hr over P_2O_5 in a dessicator, reweighing and expressing the weight loss as percent moisture content.

For moisture determination, all weights were taken on a precision balance.

4.3.2 Isolation of Starch from Arrowroot and Cassava Flours

A thin slurry of flour was made in water and screened through 100 mesh polyester cloth. The residue was resuspended in water a second time and rescreened through the polyester cloth. This was repeated until practically all starch had been washed out. Starch recovery from the filtrate and subsequent cleaning were performed as given above. Moisture content was determined.

4.3.3 Isolation of Starch from Wheat Kernels

4.3.3.1 Wheat Milling

Wheat kernels were tempered as given in AACC method 26-95 on experimental milling. The grain was then milled using the Buehler laboratory mill. Whole wheat flour was obtained using the cyclone sample mill.

4.3.4 Isolation of Starch from Wheat Flour

Dough from wheat flour was made with cold tap water and given a rest of about 20 min. Starch was then washed out of the dough with water. The gluten was discarded. The starch in the water suspension was recovered and cleaned as given in section 1.3.1. The moisture content of the starch was then determined.

4.3.5 Determination of Starch Grain Size Distribution

The field of a Leitz Wetzlar light microscope was calibrated with a scale at selected low or high magnifications. An eye piece of magnification 10x carrying a blank scale was mounted and matched with the microscope field calibration.

The value in microns of each division of the blank eye piece scale was determined. The microscope field calibrating scale (mounted on a slide) was removed and replaced with a slide carrying starch a sample. The sizes of 100 random starch grains were measured. Percent size distribution of the starch grains was then determined.

4.3.6 Determination of the Starch Grain Morphology by Scanning Electron Microscopy (SEM)

Native starch was defatted in the Soxlet apparatus overnight with 95% ethanol, dried in an Iso-temp draft oven for 2 hr at 40°C, and then mounted on aluminium stubs with conductive silver paste. The starch grains were sputter coated twice with 20 nm of gold at 900 V and 40 mA in a vacuum. The morphological properties of the starches were then viewed in a Cambridge stereoscan 150 differential scanning electron microscope at an electrical acceleration potential of 15 kv. Photomicrographs of the starch grains were made.

4.3.7 Determination of the Starch Amylose Content

Amylose content of each starch was determined by potentiometric titration of an aliquot of solubilized starch solution with standard iodine solution, as described by Schoch (1964).

4.3.8 Determination of the Starch Mineral Content

Technicon Autoanalyser II Industrial Method No. 369-75A/A (November, 1975) was used.

To 1.0 g of starch in the Kjeldhal digestion test tube, were added 15.0 g K_2SO_4 and 0.50 g red HgO (catalyst) and the tube was shaken gently to mix well. Concentrated H_2SO_4 (20 ml) was added. The digestion tubes were again shaken gently to disperse the contents. Hydrogen peroxide (to break down organic matter and minimise foaming) was added in small amounts of about 2.0 ml to avoid excessive reaction, until the contents in the digestion tubes became light in color. Three plain henger boiling chips were added to each tube. Digestion was first done at 250-260°C for 2-3 hr, followed by final digestion at 380°C for 6-8 hr until all digests became clear. The tubes were cooled and the contents of each diluted to 75 ml.

From the solutions, Na^+ and K^+ were determined by flame emission, Ca^{++} and Mg^{++} by atomic absorption, and P by Technicon autoanalyser. The results were converted to percent on dry basis of starch. Atomic absorption conditions for Ca^{++} and Mg^{++} determination were as follows:

Condition	Calcium	Magnesium
Wavelength	422.7 nm	285.2 nm
Slit	0.7 nm	0.7 nm
Sensitivity	0.092 mg/L	0.0078 mg/L
Flame	Air-Acetylene (oxiding, lean and blue)	same as for calcium
Stock Standard solution	500 mg/L in deionized water acidified with 10 ml of HCl/L	1000 mg/L in dilute HCl

Flame emission conditions for the determination of sodium and potassium .

Condition	Na^+	K^+
Wavelength	589.0 nm	776.5 nm
Slit	0.2 nm	0.4 nm
Flame	Air-acetylene	Air-acetylene
Stock standard solution	1000 mg/L in deionized water	1000 mg/L in deionized water

Phosphorus determination by Technicon autoanalyser technique is presented in Technicon Autoanalyser Industrial methods No. 329-74W/B and No. 369-75A/A. The determination is based on the formation of the blue phosphomolybdenum complex from the reaction between orthophosphate, molybdenum ion and antimony ion followed by reduction with ascorbic acid in acidic pH. The complex absorbance was determined at 660 nm.

4.3.9 Determination of Starch Swelling Power and Solubility

The method followed in determining the starch swelling power and solubility is described by Schoch (1964).

4.3.10 Starch Viscosity Determination

Suspensions of starch (1% w/v) in distilled water were gelatinized and held at 85°C for 30 min. The viscosities of the resulting slurries were determined at 25, 30, 35, 40, 50, 60 and 70°C for 5 and 10 min runs of the Haake Rotovisco RV3 and NV sensing system at 1280 rpm. All results were reported in centipoises (cP).

4.3.11 Differential Scanning Calorimetry of Gelatinization Properties of Starch

The gelatinization properties of the starches were determined at water volume fractions of 3.0, 4.0, 5.0, 6.0, 7.0, and 8.0. All water volume fractions were calculated using 1.55 g/cm , as the average density of starch.

The appropriate volume of distilled water was added to a weighed quantity of starch in a small mortor. The starch was gently, but thoroughly dispersed and mixed with the water using a small glass pestle. Quantities of about 6 mg of the resulting slurry or paste were weighed accurately into the differential scanning calorimeter (DSC) pans; and sealed quickly and firmly in a DSC press. The pans were left at room temperature overnight before being heated in a DSC from 10°C to 150°C, over which temperature range the gelatinization properties of the starches were recorded. An empty DSC pan was used as reference in all determinations. DSC sensitivity was 10X (on the cell) and 5 mV/cm on the chart, with heating rate of 5C°/min and time base setting of

1 min/cm. The onset, peak and gelatinization temperatures, as well as the gelatinization temperature ranges in °C, for each starch were determined from the charts. The charts were also used in the calculation of the enthalpies of gelatinization in cal/g of each starch.

4.3.11.1 Calculation of Enthalpies of Fusion Gelatinization

The enthalpies of gelatinization per gram of starch were calculated from the formula given below

ΔHmcal/mg = A/M(60BE)Δqs

Where:

ΔHmcal/mg = Enthalpy of gelatinization in mcals/mg of starch

A = Peak area in in^2

M = Mass of the sample

B = Time base setting on the differential scanning calorimeter (1 min/0.4 in)

E = Cell calibration constant = 1.01.

Δqs = Y-axis setting on the DSC (0.5 mcal.S^{-1}

mcal/mg/1000 = cal/g

Applying the settings used on the DSC, ΔHcal/g = 4.5441 A/M cal/g starch.

4.3.12 Determination of Retrogradation in Gelatinized, Aged, Concentrated Starch Gels

Taking into account the moisture content of the starch, a total of 15 ml of distilled water was added to 10.0 g of starch, and the resulting slurries gelatinized at 95°C for 1 hr. The gelatinized starches were allowed to cool down and form gels, and the water contents were determined. The gels were stored at 24°C and their retrogradation followed by DSC and x-ray diffraction analysis of fresh, 2, 4, 6, and 10 day old gels.

4.3.12.1 Differential Scanning Calorimeter Determination

For DSC analysis, 10 mg of the starch gel were sealed in DSC pans and heated from 10-150°C using an empty sealed DSC pan for reference. DSC sensitivity was 10x (on the DSC cell) and 5 mV/cm on the chart. The heating rate was 5°C/min at a DSC time base setting of 1 min/cm.

4.3.12.2 X-ray Diffraction Analysis

For X-ray analysis, the starch gel samples were first dried at 45°C in a draft oven. The dry samples were then ground separately in a mortor with a pestle to a powder. The powder was densely compressed in the X-ray diffractometer aluminum sample holder and analysed with copper K α-radiation (1.5418 Å) at a scanning angular velocity of 1°(2θ) from 3° to 35° (2θ) with a time constant of 4 sec. Chart speed was 1 cm/min.

4.3.13 Determination of Starch Complexing with Monoglycerides

Types C_{16} and C_{18} Monoglycerides in their α-and β-crystallinity forms were used. All starches were lintnerized and then used in the investigations as ungelatinized, gelatinized or solubilized starch.

4.3.13.1 Conversion of Monoglycerides from β- to α-Crystallinity forms

The monoglycerides were purchased from the commercial supplier in their β-crystallinity form. They were converted to their more reactive α-crystallinity form by heating, for 20 min in a hot water bath at 65°C, a suspension of the monoglyceride in a measured volume of distilled water adjusted with dilute HCl to pH 2.3 for type C_{16} and pH [illegible].5 for type C_{18}.

4.3.13.2 Infrared Analyses of Monoglycerides

The structural characteristic of the β-and α-monoglycerides were checked by infrared analysis.

The β-monoglycerides were first converted to α-monoglycerides by heating 15 parts of monoglyceride in 85 parts distilled water adjusted for pH at 65°C for 20 min then cooling down to room temperature.

Samples for infrared analysis were then made in nujol and scanned from 600-2000 cm.

Samples for x-ray diffraction analysis were compressed in aluminum sample holders and analysed as in 4.3.12.2.

4.3.13.3 Starch Lintnerization

Slurries of 1:1.5 (w/v) native starch in 7.5% (v/w) HCl in water were hydrolysed at 40°C for 72 hrs in a controlled environment incubator-shaker set at 200 rpm. The starch was then washed thoroughly with distilled water to remove acid in a Buchner funnel lined with Whatman filter paper No.1 and connected to an aspirator. The clean starch was dried for 3 hr at 40°C in an Iso-temp forced draft oven. Moisture content was then determined.

4.3.13.4 Solubilization of Lintnerized starch

Five ml of N KOH were added to 1.0 g (db) samples of lintnerized starches in 35 ml test tubes. Each test tube was stirred by a vortex mixer until the starch was thoroughly dispersed in the KOH. Clear solutions of the starches in the KOH hydroxide were obtained after cooling in a refrigerator at 4°C for 30 min. The solutions were then neutralized with an equal volume of N HCl before interaction with monoglycerides.

4.3.13.5 Gelatinization of Lintnerized Starch

Weighed quantities (1.0 g db) of lintnerized starch were placed in 35 ml test tubes. Five ml of distilled water, or distilled water with pH adjusted to 2.3, or distilled water with pH adjusted to 6.5, were added, depending on whether the final gelatinized starch was going to be reacted with β-C_{16} and C_{18}; or α-C_{16} and C_{18}. The test tubes were corked, stirred on a vortex mixer and placed in a hot water bath at 95°C for 30 min to gelatinize the starch, uncorking 2-3 times to release pressure. The test tubes were then removed from the hot water bath and allowed to cool down to room temperature.

4.3.13.6 Starch-Monoglyceride Interaction

Lintnerized starch samples were interacted with the α-and β-crystallinity forms of C_{16} and C_{18} monoglycerides at levels of 0.0, 0.10, 0.20, 0.30, 0.40, 0.50, 0.80, and 1.0% (db) of starch. Three cases were considered for each starch. The first involved interaction of ungelatinized lintnerized starches with the monoglycerides. The second involved gelatinized starch while the third case covered the interaction of solubilized starch with the monoglycerides.

4.3.13.7 Starch and α-Monoglyceride Interaction Determination

Weights of 0.0, 0.10, 0.20, 0.30, 0.40, 0.50, 0.80, and 1.0 mg of either β-C_{18} or C_{18} monoglycerides were weighed seperately into 250 ml conical flasks. Five ml of distilled water, with pH appropriately adjusted were added to each flask.The monoglycerides were allowed to convert to the α-crystallinity form as given above.

Ungelatinized starch 1 g (db) was weighed into each flask and the volume made up to a total of 20 ml in each case with pH adjusted distilled water. The flasks were corked and kept for 12 hr at 45°C in a controlled environment shaker incubator at 200 rpm. The samples were centrifuged at 12,000 rpm after the interaction period. The supernatant was used for amylose complexing index determination, while the residue was dried at 40°C in an Iso-temp draft oven and used for X-ray diffraction crystallinity analysis.

Gelatinized or solubilized starches were similarly analysed in a similar manner to the above. After separate gelatinization or solubilization steps, the samples were transferred quantitatively into 250 ml conical flasks, making the total volume 20 ml with distilled water pH, 2.3 for C_{16} and pH 6.5 for C_{18}. The samples were then allowed to interact followed by centrifugation.The supernatent was collected for amylose complexing index determination and the residue dried for X-ray diffraction analysis.

4.3.13.8 Starch and β-Monoglyceride Interaction Determination

1.0 g (db) of ungelatinized starch was added to each of the 250 ml conical flasks containing 0.0, 0.10, 0.20, 0.30, 0.40, 0.50, 0.80 and 1.0 mg of either β-C_{16} or β-C_{18}. Twenty ml of distilled water were added and the reaction allowed to proceed as described above. After centrifugation, the supernatants and the residues were saved and used for amylose complexing index determination and X-ray diffraction analysis.

When gelatinized or solubilized starches were used, the β-monoglyceride C_{16} or C_{18} was added directly into the conical flasks containing the starch samples bring the total volume to 20 ml in each case with distilled water. Determination of the amylose complexing indices and X-ray diffraction analysis were performed as given above.

Determination of the Amylose Percent Complexing Indices of

Monoglycerides

The method of Gilbert and Spragg (1964) was followed, but was modified to give "percent complexing index" instead of the "blue value".

The steps followed were: 1.0 ml of a supernatant was diluted 1:1 (v/v) with distilled water in a 50 ml volumetric flask. 1N, 0.5 ml NaOH was added and the mixture heated for 3 min in a boiling water bath. After cooling, 0.5 ml N HCl was added to neutralize the sodium hydroxide. Potassium hydrogen tartrate buffer 0.09 g was added. Distilled water was added to the flask up to about 45 ml of the total volume. Iodine standard solution 0.05 ml containing 2 mg I_2/ml and 20 mg KI/ml, was added. Distilled water was added up to the 50 ml mark. The flask was corked and contents mixed by inverting the flask a few times. The solution was kept at 20°C for 20 min. The absorbance of the solution was taken at 680 nm in 1 cm cuvettes using the DU-8 Beckman Spectrophotometer with water as the reference. The amylose percent complexing index was calculated as given below.

(i) Soluble Starch samples

$$\%\text{Complexing Index} = 100 \times (A_{680_{TA}} - A_{680_{SS}}) / A_{680_{TA}}$$

Where:

$A_{680_{TA}}$ = The total absorbance at 680 nm of the complex between iodine and amylose from 1.0 g (db) of solubilized starch sample.

$A_{680_{SS}}$ = The absorbance at 680 nm of the iodine-amylose complex obtained after interacting the 1.0 g (db) of soluble starch sample with monoglycerides.

(ii) Ungelatinized and gelatinized starch samples

$$\%\text{Complexing Index} = 100 \times (A_{680_{GS}} - A_{680_{GMS}}) / A_{680_{TA}}$$

Where:

$A_{680_{GS}}$ = The absorbance at 680 nm of the complex between iodine and amylose from 1.0 g (db) ungelatinized or gelatinized starch before interaction with monoglycerides.

$A_{680_{GMS}}$ = The absorbance at 680 nm of the iodine amylose complex after the starch sample (1.0g db) has reacted with monoglycerides.

A plot of complexing index against percent monoglycerides indicated the optimum amount of monoglycerides for complexing amylose in each starch.

4.3.13.9 X-Ray Diffraction Analysis of the Starch-Monoglyceride Clathrates

The residues obtained after the starch-monoglyceride interactions were ground to powder in a mortor after drying and analysed for crystallinity by X-ray diffraction analysis as previously described.

4.3.14 Determination of Starch Affinity for Gluten in the Dough, Early and Fully Baked Stages of Bread making

The method of Dahle (1971) to examine the affinity between different starches and gluten was followed. Starch suspensions 0.5% in distilled water, and a gluten extract containing 102.60 mg protein/ml, determined by the Lowry method (Lowry *et al.*, 1951) on the centrifugates of 40 g gluten suspension in 200 ml of 0.1 N acetic acid, were reacted in a ratio of 2 ml to 2 ml to simulate protein-starch interaction in the dough. In order to simulate early baking starch-gluten interactions, the starch suspension was first gelatinized for 10 min in a boiling of water bath. Fully baked condition was simulated by denaturing the gluten extract and gelatinizing the starch suspension in a boiling water bath for 10 min and cooling before interaction.

Each sample was mixed and shaken for 2 min, followed by centrifugation for 10 min at 3000 rpm. The centrifugates were retained for further analysis. In the case simulating the dough condition, the unreacted protein in the centrifugate was determined by the Lowry *et al.* (1951) method.

$$\% \text{ Affinity} = \frac{100(1\text{-Residue soluble protein})}{(\text{original soluble protein})}$$

In the other two cases, the supernatants were appropriately diluted and reacted with 0.05 ml of standard iodine solution and the absorbance taken at 625 nm. Percent bound starch as affinity of starch for gluten was calculated from the formula given below.

$$\% \text{ Affinity}) = \frac{100(1\text{-Absorbance of residue soluble starch})}{(\text{Absorbance of original starch sample})}$$

In both calculations, the dilution factors employed in sample preparation for absorbance reading were taken into account.

4.3.15 Flour Water Absorption Determination

The flour water absorption was determined with the Brabender farinograph using 50 g of flour adjusted to 14.0% moisture basis as per AACC method 82-23.

The farinograph mixing chamber was maintained at a constant temperature of 35°C with circulating water from Lo-Temprol 154 constant temperature water bath. The appropriate quantity of the flour was placed in the mixing chamber and mixed at speed 2 for 1 min for the flour temperature to equilibriate with that of the chamber. Composite flours consisted of 85% starch and 15% vital gluten.

The farinograph chart was then started at zero time. At the same time water at 35°C from the farinograph burette was added to the flour. First, 25 ml of water was added continuously into the flour from the burette. The rest of the water was added in small amounts of about 2 ml and later dropwise until the farinogram just straddled the 500 BU line. The total amount of water used was read from the burette and recorded. A final determination was made in which all the required volume of water was added all at once from the burette to the flour. The determination was complete if the farinogram came to rest proportionally on the 500 BU line. The flour absorption was then read out from the burette as percent or in ml water/100g flour.

Sometimes the farinogram would not come to rest on the 500 BU line in the final determination. In such cases, more water at the rate of 0.5 ml per 20 BU was added, if the dough was too dry, until the farinogram came to the 500 BU line. If too much water had been added, the determination was repeated with 0.5 ml per 20 BU less water.

4.3.16 Determination of the Rheological Properties of the Doughs

The doughs were made from wheat as well as composite (85% starch + 15% vital gluten) flours containing 4%, 1.5% and 3% yeast.

Flour absorption, including the additives, was determined. Yeast 3% was weighed seperately in a 50 ml beaker, and activated for 5 min with 10.0 ml of distilled water at 35°C, the water being part of the percent absorption of a particular flour. The flour equivalent of 50 g on 14.0% moisture basis containing 4% sugar and 1.5% salt was put in the farinograph mixing chamber, mixed for 1 min and stopped. The activated yeast suspension was added to the flour in the mixing chamber, the beaker being rinsed once into the chamber with 10 ml of distilled water. The chart was set at zero time and started. The mixing was started at the same time. The water balance (% absorption - 20 ml) for each flour was added all at once from the farinograph burette.

Due to the presence of additives in the flour, the farinogram peaks were beyond the required 500 BU line level, requiring a correctional addition of 0.5 ml water per 500 BU beyond the 500 level. A fresh farinogram straddling the 50 BU line was run for 20 min after taking into account the correction. Dough rheological properties, arrival and development times, stability, mixing tolerance and breakdown in consistency after 20 min were determined from the farinograms.

4.3.17 Determination of Dough and Crumb Hydration Capacities

The method of Yasunaga *et al.* (1968), as modified by Dennett and Sterling (1979), was used in determining the hydration capacities of the wheat and composite flour doughs and bread crumbs. Samples, 20 g each of dough or bread crumb were homogenized for 1 min each in 100 ml of water in a Waring blender and transferred into a 250 ml beaker. The blender was rinsed with 100 ml more water which was again transferred into the 250 ml beaker. The slurry was stirred for 1 hr on a magnetic stirrer before being transferred into 250 ml weighed centrifuge bottles. The beaker was rinsed with 50 ml more water, which was also added into the centrifuge bottles, followed by centrifugation at 3000 x g for 10 min. The supernatant was carefully discarded and the bottles inverted on paper towels to drain for 5 min. The weights of the sediments were recorded. Dry matter in the doughs and the crumbs was determined by drying 1-2 g at 70°C in a vacuum to constant weight.

Hydration capacity was expressed as grams of water per gram of dry solids in the dough or the crumb.

4.3.18 Determination of the Dough and Crumb Morphology by Scanning Electron Microscopy

Small cubes of dough, about 2-3 mm in size, were removed from a dough which had been knocked back after fermentation for 1.5 hr. The dough pieces were mounted on aluminium stubs with conductive silver paste and proofed for 0.5 hr in a temperature - humidity chamber at 35°C and 80% humidity, followed by drying in a vacuum at 40°C overnight. About half of each dry sample on the stab was cracked open with a sharp scalpel to reveal fractured surfaces. The samples were then sputter coated with at least 20 nm of gold at 900 V and 40 mA in a vacuum. The morphological characteristics of the unfractured and fractured surfaces of the dough were examined by SEM at 15 kV. Sample photomicrographs were made for each surface.

4.3.19 Determination of Dough and Crumb Internal Structure by Transmission Electron Microscopy

Pieces of dough and crumb about 2 mm^3 each were fixed in 3% glutaraldehyde in phosphate buffer pH 7.4 at 4°C overnight. The samples were washed with buffer and post fixed in 2% osmium tetroxide in the same buffer at pH 7.4

for 4 hr followed by one washing with the buffer. The samples were dehydrated in 70% methanol overnight, then dehydrated further in 80, 90, 95.5 98.5 and 100% methanol series for 15 min at each concentration. The final washing was repeated twice before treatment for 15 min with 1:1 methanol/propylene oxide mixture, followed by two treatments for 15 min each with 100% propylene oxide.

The samples were next treated in a mixture of 50% propylene oxide and 50% of a mixture consisting of 27 ml araldite 502, 23 ml of dodecenyl succinic anhydride (DDSA) and 2 ml of tri (dimethyl amino methyl) phenol (DMP-30). The samples were left to fix in this solution solution overnight in a slowly rotating shaker. Samples were then imbedded in a resin mixture of 27 ml Araldite 502, 23 ml of DDSA and 2 ml of DMP-30 in rubber molds and the resin allowed to polymerize at 60°C for 2 days. The samples were sectioned into thin slices of 6-8 μm thick with an ultramicrotome. The sections were picked up onto 200 mesh copper grids coated with a plastic film of 0.25% formvar (polyvinyl formal) in ethylene dichloride, and dried on filter paper. The samples were stained in 1% uranyl magnesium acetate for 2 min, rinsed in distilled water and finally stained for 2 min in a solution of about 3% lead acetate, 6% sodium hydroxide and 0.3% potassium sodium tartrate (Kay, 1965). The grids were washed with distilled water, dried on filter paper and viewed through the Philips EM-200 type PW-6000 TEM at low magnification. Photomicrographs were made.

4.3.20 Bread Making

Bread was made for either instrumental analysis or for panel tasting using the straight dough method.

4.3.20.1 Formulations

Ingredient	Bread for Instrumental Tasting	Bread for Panel Tasting
Wheat flour or composite flour	100.0(%)	100.0(%)
Sugar	7.0	7.0
Salt	1.5	1.5
Shortening	-	3.0
Monoglycerides	-	0.5
Yeast	3.0	3.0

The amount of water added varied with the type of flour as given below.

	Water
Neepawa flour	68-70(%)
Neepawa starch/gluten flour	61-64
Fielder flour	57-58
Fielder starch/gluten flour	55-56
Root Starch/gluten flours:	
Arrowroot/gluten flour	83-85
Cassava/gluten flour	63-64
Sweet Potato/gluten flour	68-70
Taro/gluten flour	68-69
Yam/gluten flour	68-69

4.3.20.2 Dough Preparation and Baking

Yeast (3% flour basis) was weighed into a beaker, 10 ml of distilled water at 35°C added and left standing for 5 min to disperse and activate the yeast.

The flour and the rest of the dry ingredients were mixed for 1 min in a Hobart mixer at speed 2. The yeast suspension was then added and the beaker rinsed once into the Hobart mixer with 20 ml of water. The rest of the water required was added and the mixer run until the dough had achieved the desired consistency. The dough was fermented at 35°C and 80% relative humidity for 1.5 hr, punched, rolled and rested for 15 min before scaling known weights into pans greased with a film of shortening. The doughs were pan proofed for 30 min and baked at 210°C for 30 min in an oven. The bread was cooled down for 1.5 hr and wrapped in moisture-proof plastic bags.

4.3.20.3 Determination of Fractional Volume Increases from the Dough to the Bread

The volume (V_0) of the dough was taken immediately after panning, but before proofing, using the rape seed displacement technique. The volumes (V) of each of the resulting loaves of bread were determined after cooling for 1.5 hrs. using the same technique.

Fractional volume increases were calculated from:

$$\frac{V-V_0}{V_0} \text{ cm}^3$$

4.3.21 Bread Staling Investigations

Bread staling was investigated through experiments on changes in the crumb compressibility, penetration resistance to a standard probe and crystallinity.

4.3.21.1 Crumb Compressibility Determination

Crumb sections 8 mm thick were cut from the center of bread slices and the force required to compress each crumb from 8 to 6 mm recorded on the calibrated chart of the compressimeter. The force was calculated from the chart peak recordings for each crumb type against the chart range calibration and recorded as kg force/mm of the crumb compressed.

The compressimeter settings used were as follows:

Compression head speed	4 cm/min
Compression clearance	6 mm
Chart sensitivity (range)	0-4000.0 g
Chart speed	1 cm/16 sec.

Compressibility of bread crumb in the absence and presence of monoglycerides was examined for fresh bread and bread aged for 3.5, 6, and 9 days. Crumb compressibility was then plotted on a graph as a function of bread storage time.

4.3.21.2 Determination of the Crumb Penetration Resistance

Slices of bread 2 cm thick were cut from the centre of the bread, and the force to penetrate 0.5 cm with a standard probe into the crumb recorded. Compressimeter settings given above were also used, except that the compression head was replaced with the penetration probe.

Penetration resistances for fresh bread crumb in presence and absence of monoglycerides and for bread aged 3.5, 6 and 9 days were determined. Crumb penetration resistance in kg force/mm was plotted on a graph as a function of bread storage time.

4.3.21.3 X-Ray Diffraction Analysis of Starch Isolated from Fresh and Aged Crumb

Starch from fresh or aged crumb was isolated by homogenizing about 20 g of crumb in 100 ml water in a Waring blender for 1 min at medium speed. The slurry was transferred into a 250 ml beaker and stirred for 1 hr with a magnetic stirrer, followed by screening through 100 mesh polyester sieve cloth. The starch isolated was separated from the filtrate by centrifugation at 3000 rpm for 10 min. The recovered starch was freeze dried and ground to a powder which was compactly compressed in the aluminum X-ray diffraction sample holder for analysis. The diffractograms obtained were used in describing crystallinity development in the crumb as a function of storage time.

4.4 Bread Quality Evaluation by Panel Tasting

Bread for panel tasting was baked and cooled to room temperature. The volumes of the bread loaves were first determined by rapeseed displacement in a container of known volume. The loaves were then given external and internal quality evaluation by a panel consisting of trained students and support staff members using the American Institute of Baking method for bread quality evaluation and scoring (Matz, 1960).

5. RESULTS

5.1 A. Starch

5.1.1 The Size Distribution and Morphology of Starch Granules

5.1.1.1 Starch Granules Size Distribution

The particle size distribution of starch granules from wheat (cvs. Neepawa and Fielder), arrowroot, cassava, sweet potato, taro and yam are presented in Table 5.1.

Arrowroot and taro had the smallest starch granules, all below 4µm in size. Yam had the largest starch granules; the smallest being at least 10µm in size and ranging up to 40µm. The majority of the yam starch granules ranged between 16-30µm in size, with the peak between 21-25µm.

Most of the sweet potato starch granules (83%) were less than 10µm in size. The largest ones were 20µm. Almost half (49%) the cassava starch granules were 5-10µm with only 10% less than 5µm, 31%, 11-15µm and 9%, 16-20µm. No cassava starch granules larger that 25µm were observed.

Soft white spring wheat (cv. Fielder), had more numerous small granules (47%) of size less than 5µm than Canadian west red spring wheat, cv. Neepawa, with 36% of its starch granules <5µm. The granule distribution was reversed significantly in the 5-10µm size range, where Neepawa had more starch granules (40%) than Fielder(30%). Starch granules of size greater than 25µm were not found in

Table 5.1 Starch Granule Size Distribution (%)

	Granule Size in µm							
Type of Starch	<4	5-10	11-15	16-20	21-25	26-30	31-35	36-40
Root								
Arrowroot	100							
Taro	100							
Sweet Potato	30	53	8	9				
Cassava	10	49	31	9	1			
Yam	-	-	3	25	39	19	12	2
Wheat								
cv. Fielder*	47	30	5	7	8	1	1	1
cv. Neepawa**	36	40	6	12	6			

*SWSW - Soft White Spring Wheat

**CWRSW - Canadian Western Red Spring Wheat

Neepawa wheat starch, while Fielder had larger starch granules distributed up to 40μm. The effect of starch granule size ditribution and starch damage on bread are discussedunder dough rheology, microstructureand bread volume.

5.1.1.2 The Morphology of Starch Granules by Scanning Electron Microscopy

Scanning electron photomicrographs portraying the morphologies of the different starches are given in Plates 5.1 to 5.6, representing arrowroot,taro, sweet potato, yam, cassava (2 Plates), and wheat starches.

Arrowroot (Plate 5.1) and taro (Plate 5.2) starch granules were observed to be polygonal. Most displayed sharp edges between the facets, which in turn possessed curved depressions, made probably by pressure from other starch granules during development. Similar observations were evident with sweet potato starch granules, which also had several rounded facets (Plate 3, a and b). Yam starch granules displayed in Plate 3 (c and d) were ellipsoidal and smooth on the surface. A few had their ellipsoidal outlines expanded and rounded at one end.

Cassava starch granules (Plates 4 and 5) were round or truncated in appearance. The truncated surface was concave, culminating in a sharp sunken central point. Compounded starches were also observed.

Wheat starches (Plate 5.6) were small Platelete, donut-like types or larger ones, lenticular in shape. The

Plate 5.1. Scanning Electron Micrographs of Arrowroot Starches From Kenya – a, x 6,900; b, x 4,500; c, x 4,200 and d, x 7,000.


a
b
c
d

Plate 5.2. Scanning Electron Micrographs of Taro Starches - a, x 3,300; b, x 6,400; c, x 6,400 and d, x 6,500.

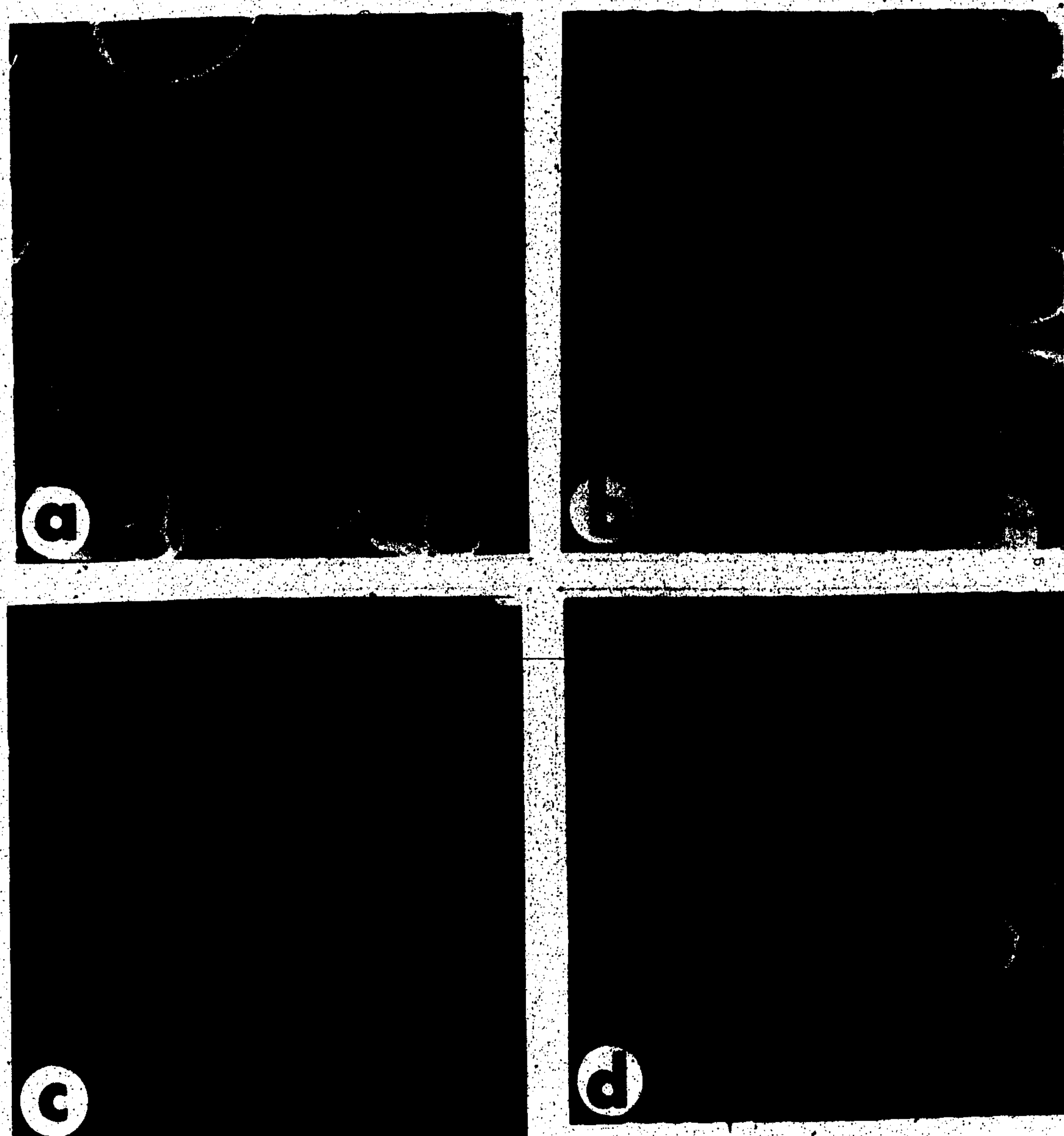

a
b
c
d

Plate 5.3. Scanning Electron Micrographs of Sweet Potato (a, x 2,600; b, x 3,300) and Yam (c, x 620; d, x 1,280) Starches.

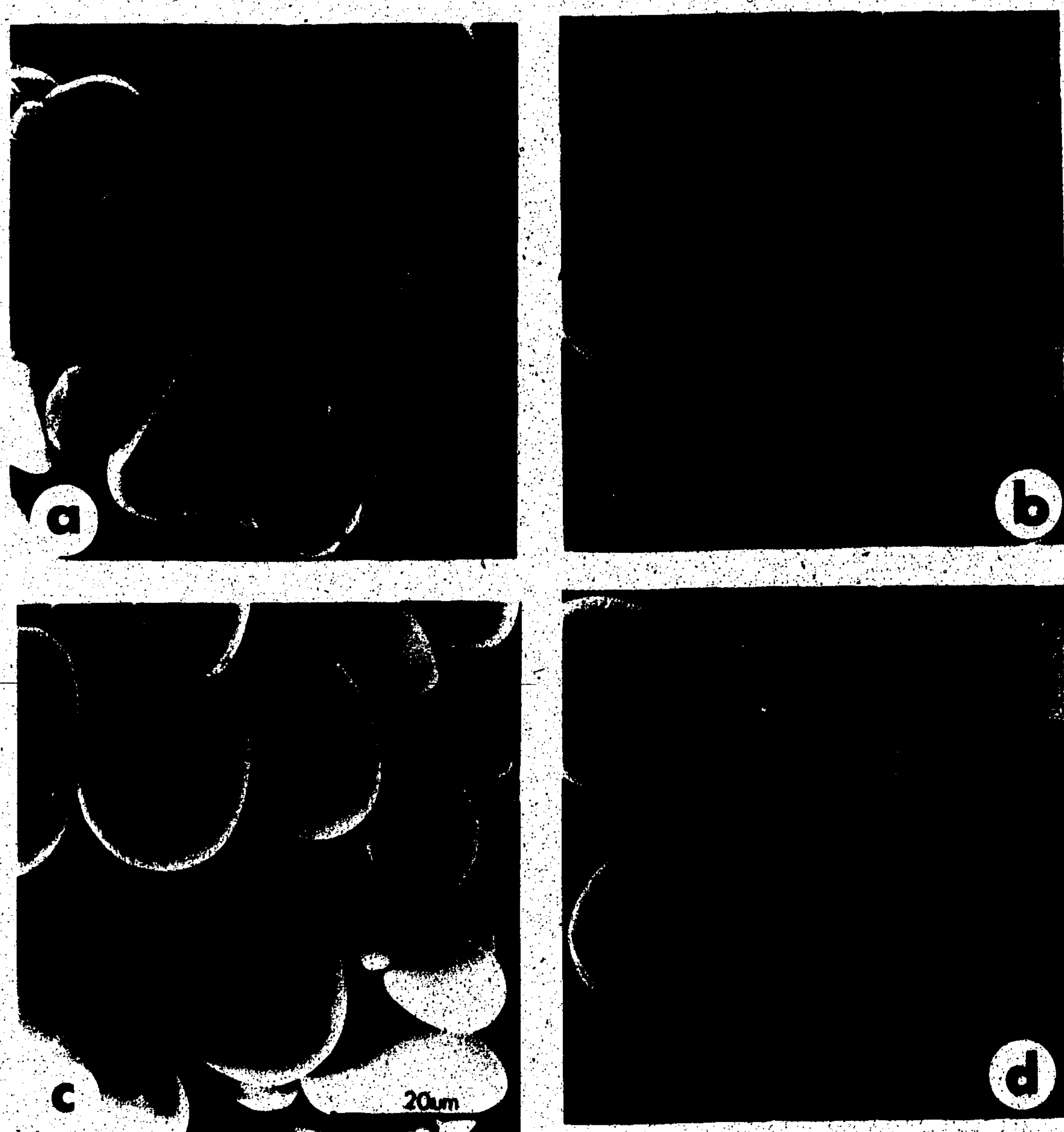

a
b
c
20um
d

Plate 5.4. Scanning Electron Micrographs of Cassava Starches of Commercial (a, x 2,800; b, x 3,700), A.E. Staley Manuf. Co., Decatur, IL., and Kenyan (c, x 5,200; d, x 4,500) Origins.

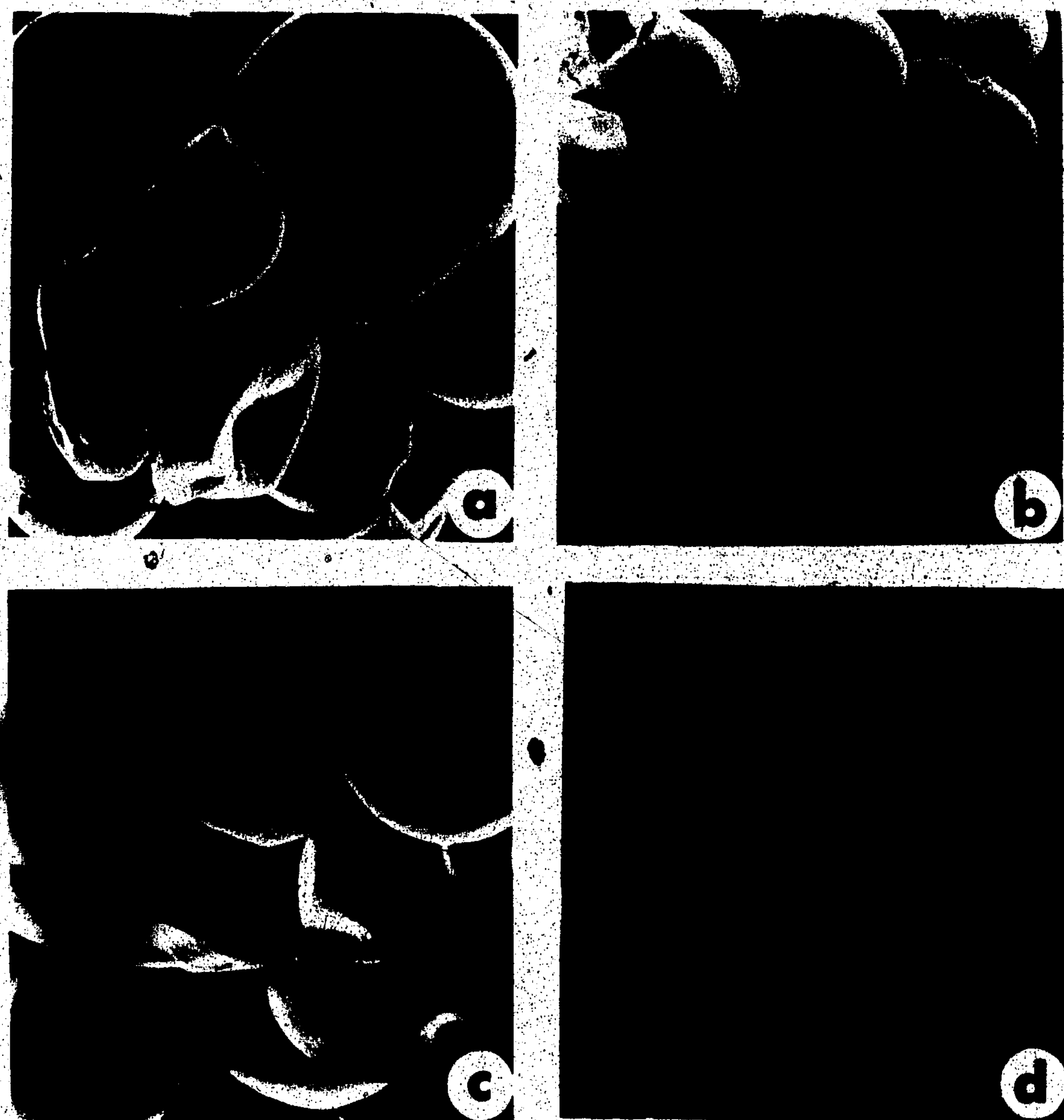

a
b
c
d

Plate 5.5. Scanning Electron Micrographs of Cassava Starches of (a) Commercial (A.E. Staley Manuf. Co., Decatur, IL.), (b) Fijian and (c) Kenyan Origins with Magnification Range of x 2,000 - x 2,500.

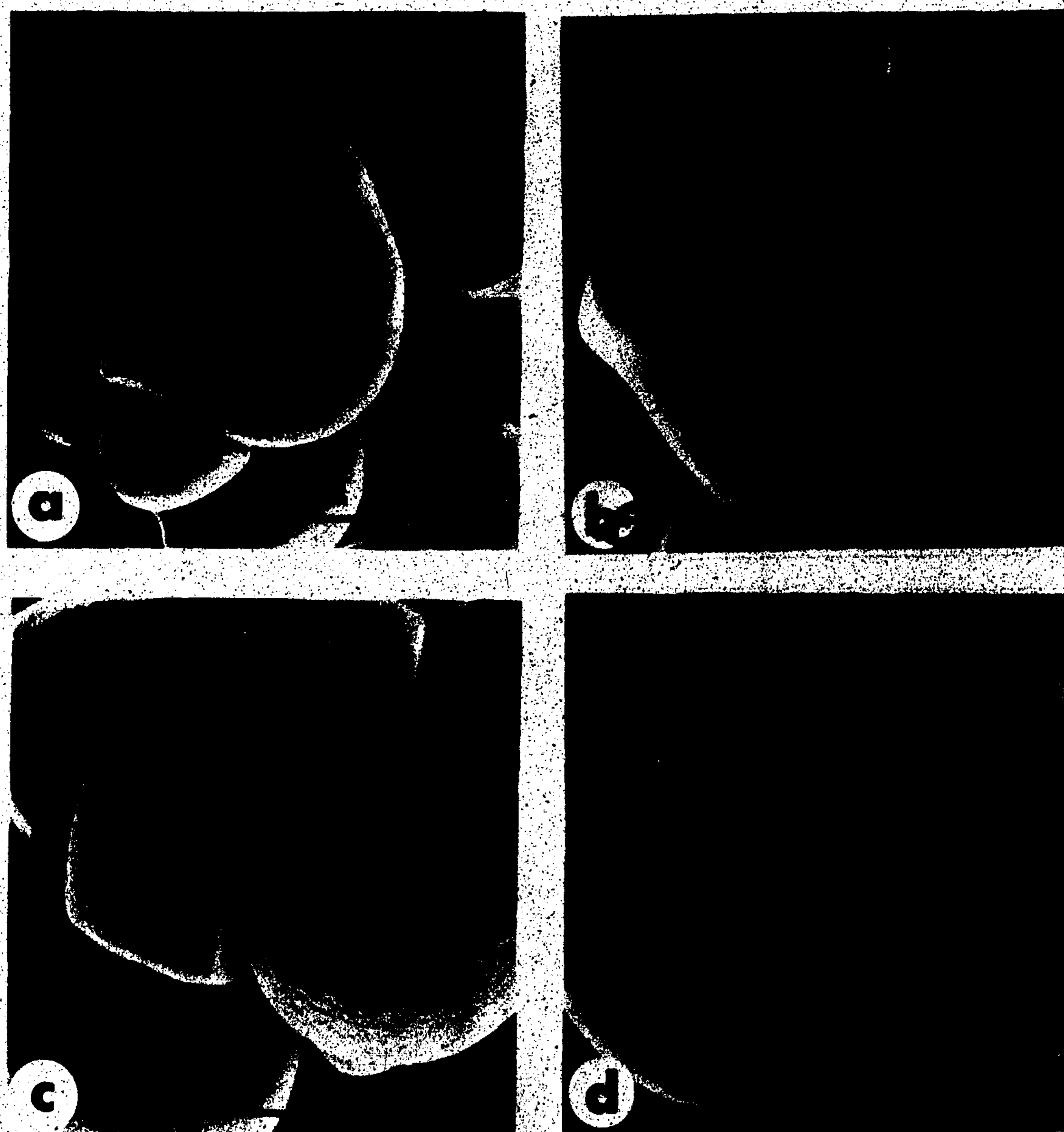
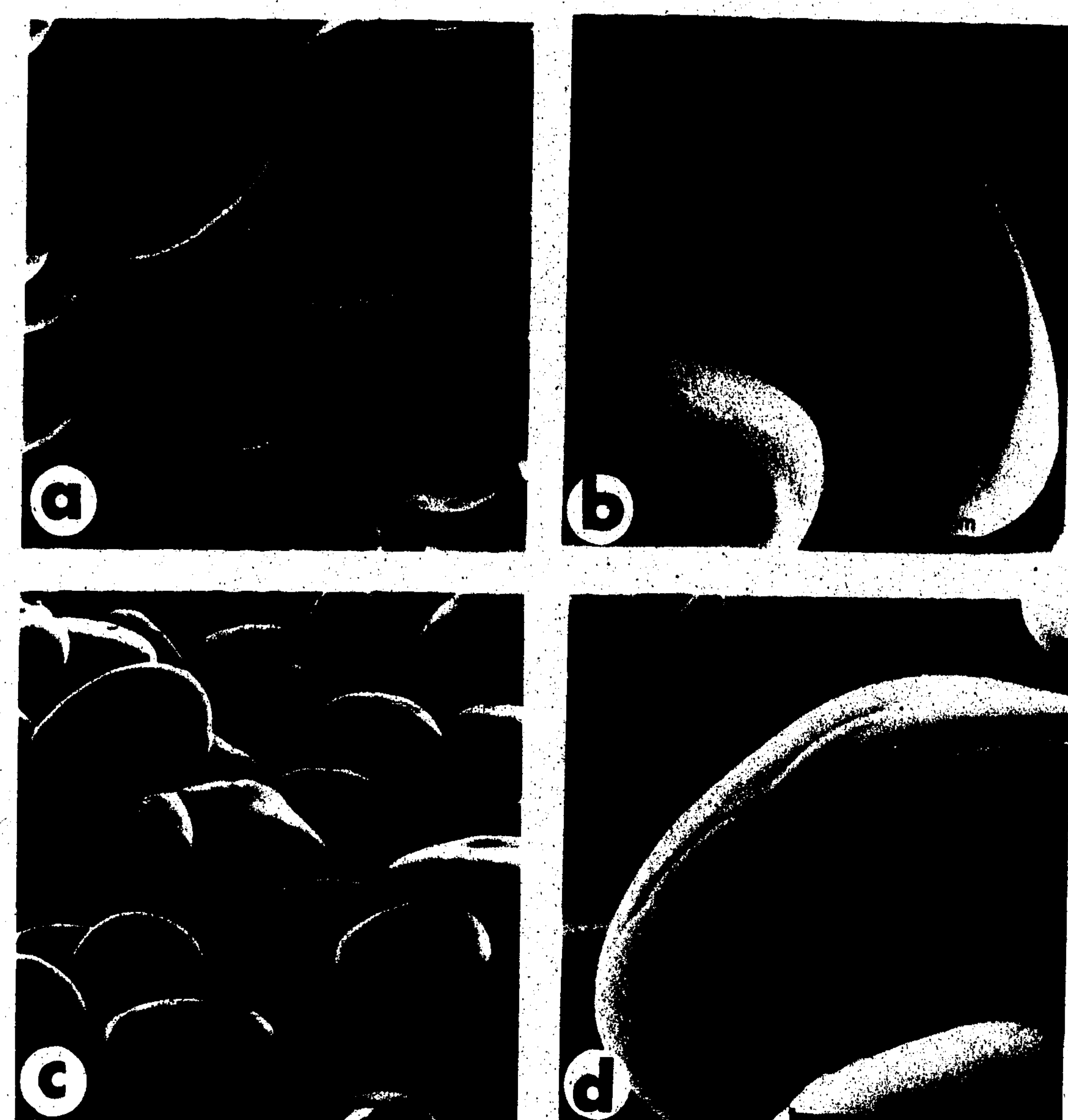

a
b
c
d

Plate 5.6. Scanning Electron Micrographs of Wheat Starches, cv. Fielder (a, x 1,120; b, x 2,600); and cv. Neepawa (c, x 1,300; d, x 2,630).


a
b
c
d

majority of the larger ones possessed pronounced equatorial grooves (Plate 5.6, b and d).

5.1.2 Determination of Amylose Content in Starch

The standard curve for amylose determination in starch by potentiometric titration is given in Figure 5.1.

Figure 5.2 shows typical potentiometric titration curves in presence of arrowroot, cassava and wheat (cv. Neepawa) starches.

Figures 5.3 and 5.4 represent plots for bound iodine versus free iodine in potentiometric titrations involving cassava and wheat (cv. Neepawa) starches. Other starches had similar plots.

Table 5.2 shows the amylose contents of the starches. Also given are the amylose/amylopectin ratios of the various starches.

Wheat (cv. Neepawa) starch had the highest amylose content (27.29%), followed by yam (25.00%) and wheat (cv. Fielder, 23.04%) starches. All the other root starches had less amylose content than the wheat starches. Taro starch had the lowest amylose content (14.93%), next to arrowroot starch (16.73%). Sweet potato and cassava starches had intermediate amylose contents ranging from 18.98-21.0%. The amylose/amylopectin ratios corresponded in magnitude to their respective amylose contents.

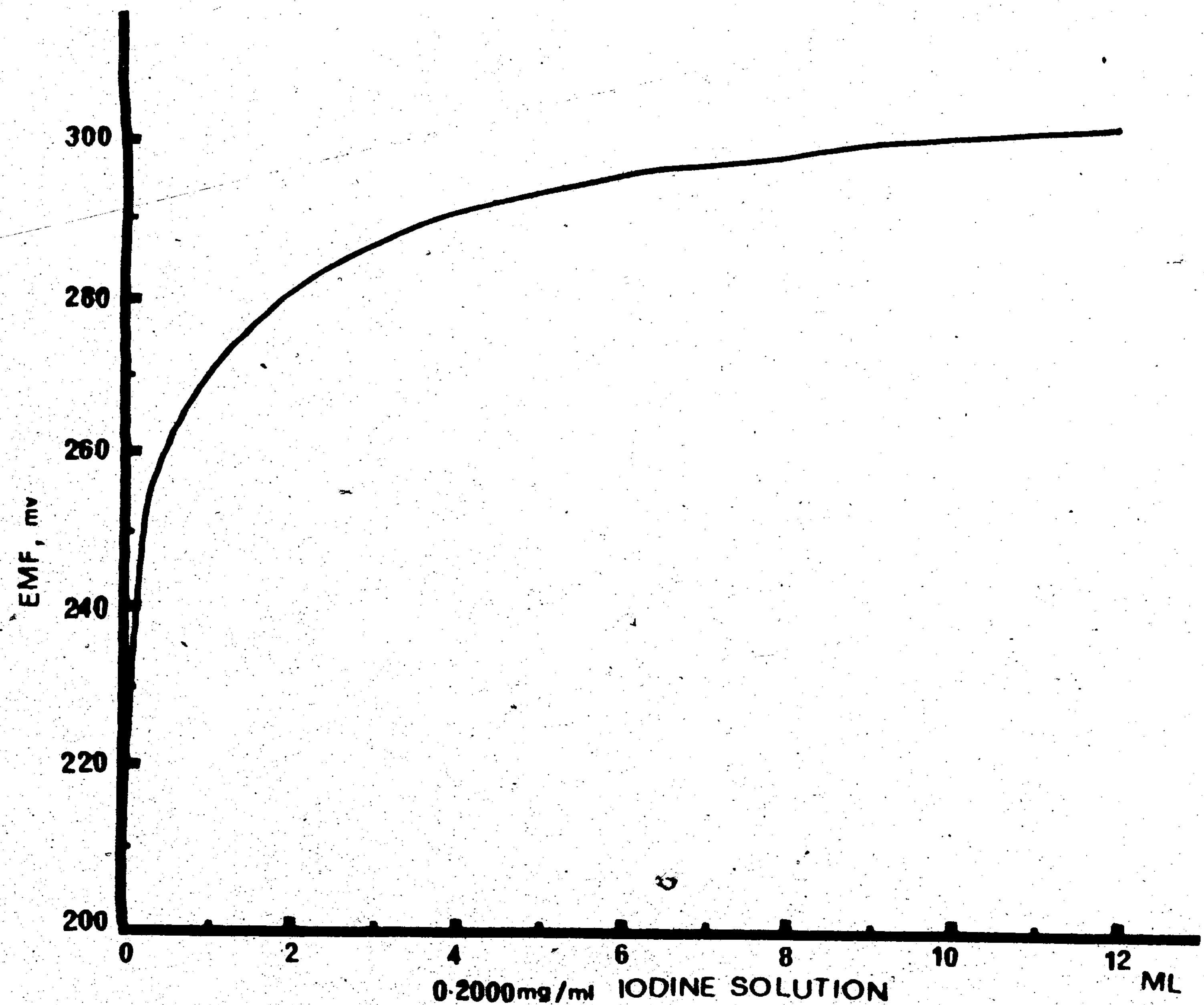


Figure 5.1. Standard Curve of EMF as a Function of Free Iodine Content at 30°C.

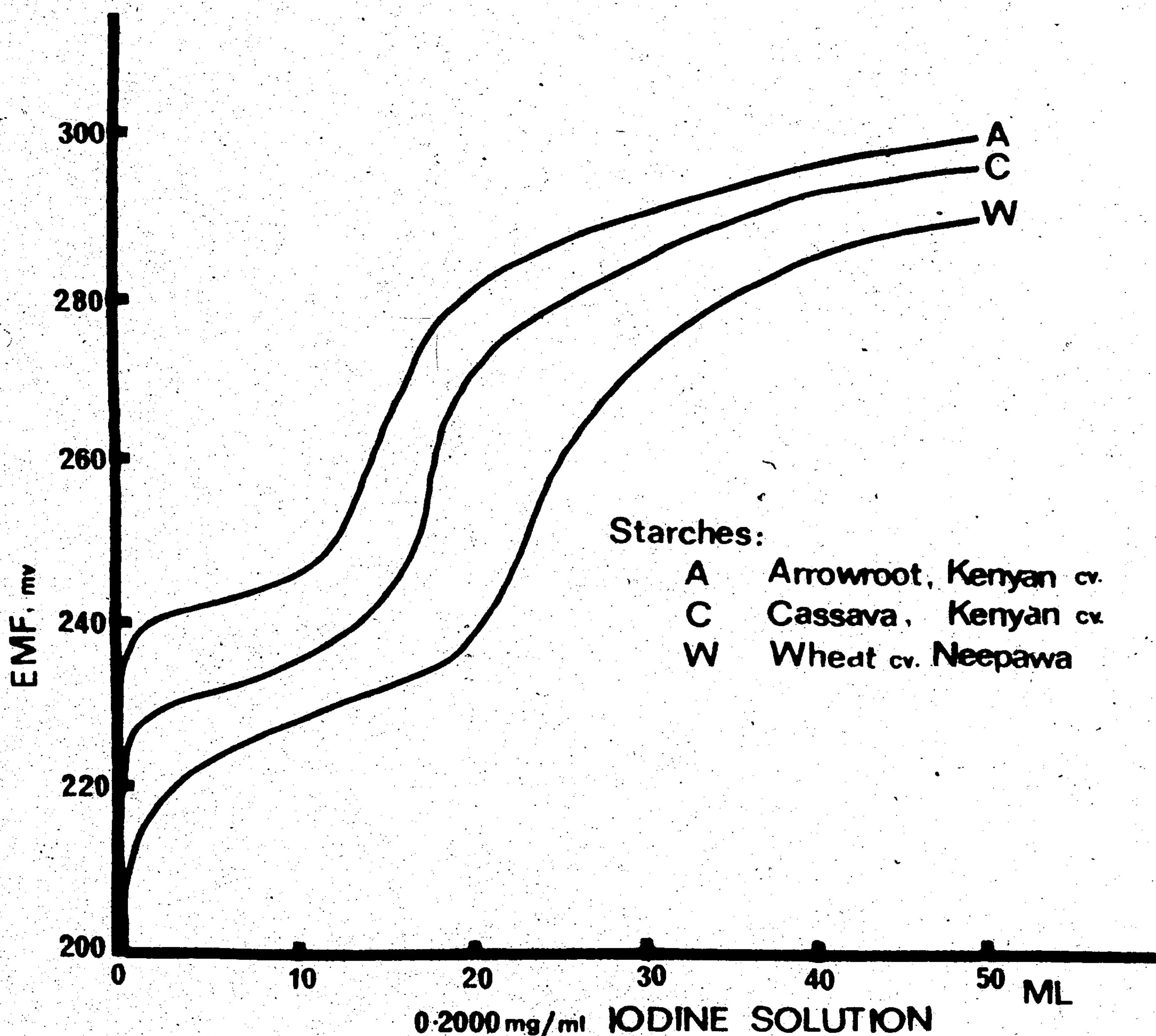


Figure 5.2. Pontentiometric Titration of Arrowroot, Cassava and Wheat, cv. Neepawa, Starches with Iodine at 30°C.

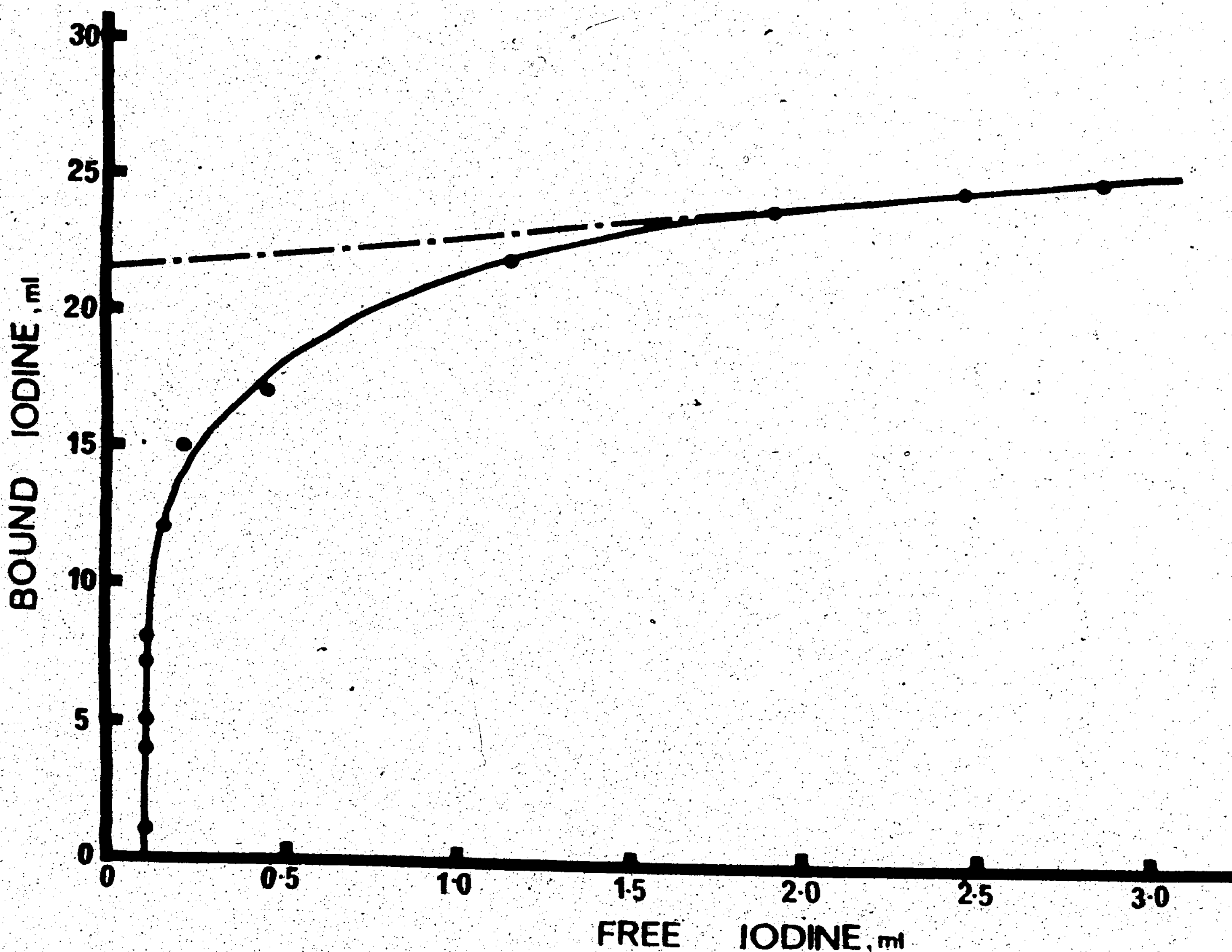


Figure 5.3. Plot of Cassava Starch, Bound versus Free Iodine at 30^{o}C.

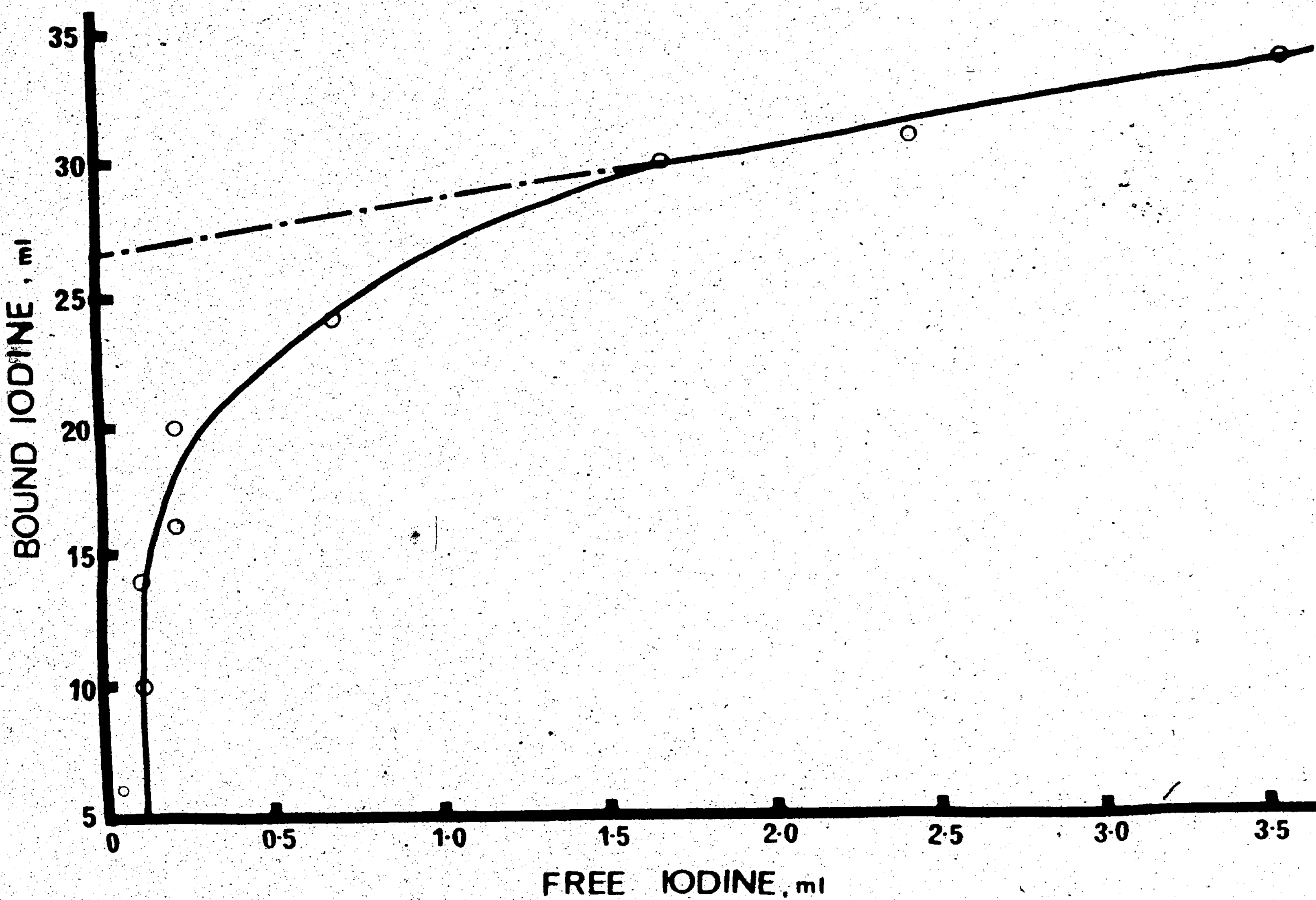


Figure 5.4. Plot of Wheat, cv. Neepawa Starch, Bound versus Free Iodine at 30^{o}C.

Table 5.2 Amylose Contents and Amylose-Amylopectin Ratios of Some Wheat and Tropical Root Starches

Type of Growth	Amylose	Amylose-Amylopectin Ratio
Root:		
Taro		
cv. Jamaican	14.93 ± 0.63	0.176
Arrowroot		
cv. Kenyan	16.73 ± 0.34	0.200
Cassava		
cv. Fijian	18.98 ± 1.51	0.234
cv. Kenyan	21.00 ± 0.67	0.266
Sweet Potato		
cv. Georgia Red	19.66 ± 0.48	0.245
cv. Porto Rico	19.71 ± 0.61	0.246
cv. Centennial	20.00 ± 0.21	0.250
Yam		
cv. Jamaican	25.00 ± 0.35	0.333
Wheat:		
cv. Fielder	23.04 ± 0.62	0.299
cv. Neepawa	27.29 ± 1.53	0.375

5.1.2.1 Starch Mineral Composition

In Table 5.3. are presented the mineral contents of arrowroot, cassava, sweet potato, taro, yam and wheat (cvs. Fielder and Neepawa) starches.

Amongst the root starches, taro and arrowroot, with the smallest starch granule size, had the highest phosphorus contents - approximately twice the amount of phosphorus found in cassava, sweet potato, and wheat (cv. Neepawa) starches. Wheat (cv. Fielder) starch was intermediate in its content of phosphorus. Yam, with the largest granule size had the lowest phosphorus content (0.0064%). Extraction of the wheat starches with water saturated butanol to remove lipid-phosphate complexes reduced their phosphate content from about 0.05% to 0.016 and 0.013% in cvs. Fielder and Neepawa.

All the starches had very low Ca^{++} and Mg^{++} contents. The wheat starches contained no calcium. In contrast, all the starches had higher contents of K^{+} and Na^{+} comparedto their contents of ca^{++} and Mg^{++}.

5.2 Swelling Power of the Starches

The swelling powers (SP) of arrowroot, cassava, sweet potato, taro, yam, and wheat (cvs. Fielder and Neepawa) starches as a function of temperature are shown in Figure 5.5. and Tables 5.4-5.7.

Table 5.3 Mineral Contents of Some Wheat and Tropical Root Starches

Type of Starch	Moisture, %	Mineral Content in Percent				
		P	Ca	Mg	K	Na
Taro cv. Jamaican	8.53 ± 0.15	0.0256 ±0.0008	0.0021 ±0.0011	0.0042 ±0.0004	0.0925 ±0.0071	0.0255 ±0.0006
Arrowroot cv. Kenyan	8.24 ± 0.09	0.0227 ±0.0019	0.0081 ±0.0002	0.0072 ±0.0008	0.0936 ±0.0001	0.0321 ±0.0007
Sweet Potato cv. Centennial	8.28 ± 0.31	0.0126 ±0.0017	0.0094 ±0.0017	0.0046 ±0.0008	0.0336 ±0.0008	0.0259 ±0.0036
Cassava cv. Kenyan	8.98 ± 0.22	0.0106 ±0.0008	0.0067 ±0.0005	0.0034 ±0.0004	0.0366 ±0.0007	0.0254 ±0.0006
Yam cv. Jamaican	9.10 ± 0.08	0.0064 ±0.0012	0.0003 ±0.0001	0.0024 ±0.0001	0.0156 ±0.0004	0.0194 ±0.0004
Wheat*						
cv. Fielder	8.45 ± 0.16	0.016 ±0.006	---	0.0050 ±0.0002	0.0220 ±0.0007	0.0249 ±0.0007
cv. Neepawa	8.25 ± 0.45	0.013 ±0.002	---	0.0048 ±0.0006	0.0221 ±0.0006	0.0187 ±0.0008

*Refluxed 2 times for 3 hrs with water saturated butanol. If the extraction step was omitted the wheat starch P amounted to 0.05±0.007.

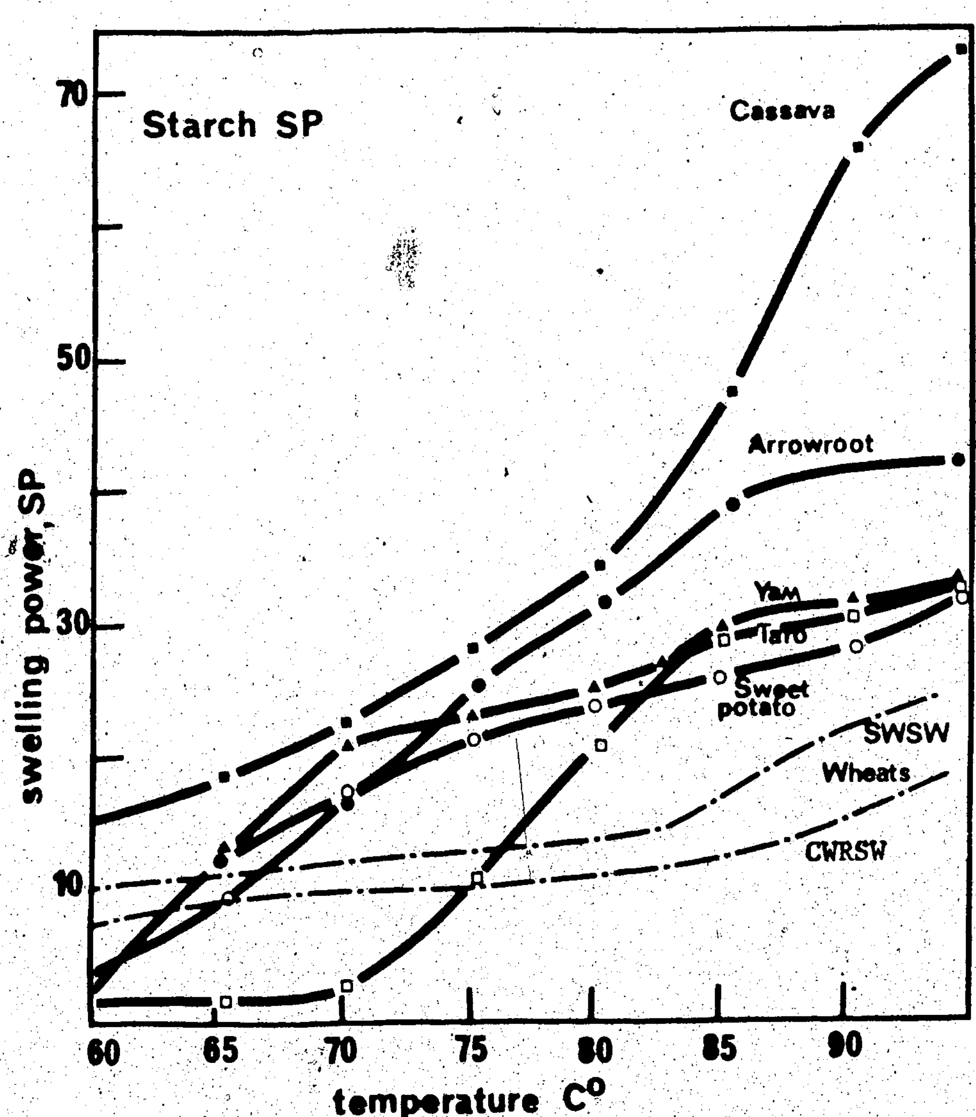


Figure 5.5. Swelling Power as a Function of Temperature and Tropical Root starches for Some Wheat

Table 5.4. Swelling Po[illegible] Some [illegible]pical Root [illegible]

Type of Starch	Temperature °C							
	60	65	70	75	80	85	90	95
Arrowroot (Kenyan cv)	3.57±0.42	12.50±0.74	17.34±1.17	26.11±1.55	31.04±2.42	39.31±1.55	43.22±1.03	40.02±0.46
Taro (Jamaican cv)	2.26±0.07	2.25±0.17	2.56±0.11	11.87±1.63	21.52±1.34	30.09±1.69	30.73±1.19	33.00±2.02
Yam (Jamaican cv)	2.19±0.19	11.99±0.17	21.15±0.81	22.46±1.28	24.68±1.08	29.05±1.32	30.10±1.01	33.82±0.17

Table 5.5. Swelling Power of Some Cassava Starches

Types of Starch	Temperature °C							
	60	65	70	75	80	85	90	95
Cassava:								
Commercial Sample	2.75±0.27	13.53±0.73	25.47±0.79	29.45±2.02	35.59±2.30	40.34±0.91	36.85±1.91	39.06±0.64
Fijian cv.	9.88±0.30	24.60±0.14	29.29±0.72	35.42±1.92	48.29±0.36	50.71±1.25	50.97±2.14	66.99±4.95
Kenyan cv.	15.57±1.76	19.66±1.06	22.45±1.06	29.24±0.80	34.50±2.00	47.45±3.62	66.77±2.80	73.43±4.17

Table 5.6. Swelling Power of Some Sweet Potato Starches

Type of Starch	Temperature °C							
	60	65	70	75	80	85	90	95
Sweet Potatoes								
Centennial cv.	4.17 ±0.26	9.49 ±0.43	17.68 ±0.65	21.68 ±0.58	23.40 ±0.98	25.84 ±1.05	28.34 ±0.38	32.83 ±0.70
Geogria Red cv.	2.04 ±0.07	3.34 ±0.21	16.25 ±1.08	22.28 ±0.48	24.44 ±1.11	27.47 ±0.92	30.94 ±0.69	36.68 ±0.47
Porto Rico cv.	4.64 ±0.36	9.00 ±0.49	16.57 ±0.54	20.31 ±1.09	24.26 ±1.14	25.46 ±0.96	27.75 ±1.12	31.40 ±1.06

Table 5.7. Swelling Power of some Wheat Starches

	Temperature ^{o}C							
Type of Starch	60	65	70	75	80	85	90	95
Neepawa	7.12±0.45	10.00±0.99	10.50±1.15	9.71±0.98	11.44±2.00	12.43±1.40	15.04±2.0	18.83±1.89
Fielder	10.04±0.65	11.01±1.40	12.73±0.98	13.17±0.12	13.04±1.10	16.04±0.67	21.94±2.09	24.52±1.84

Cassava starch had the highest SP at all temperatures. Hard red, followed by soft white, spring wheat starches had the lowest swelling power at temperatures beyond 75°C.

Swelling powers of arrowroot, yam, taro and sweet potato starches were intermediate between cassava and wheat starch swelling powers, but decreased in magnitude from arrowroot to yam, taro, and sweet potato starches at temperatures greater than 85°C. The swelling power of the wheat starches remained fairly constant from 60-85°C, rising only from about 7-10 to 12-16 g of paste/g starch DWB. It then rose fairly slowly from about 15-20 to 18-24 g paste/g at 95°C.

Taro starch did not show any signs of swelling between 60-70°C, after which its swelling power rose steadly almost to a peak at 85°C. It exhibited a sigmoid behavior of its swelling power in relation to temperature.

Yam starch swelled quickly from 2 to 21 g paste/g of starch at 60-70°C and then increased gradually after that to a peak value of about 34 g paste/g of starch. A similar trend was observed for sweet potato starch.

Arrowroot starch rose gradually in its swelling power as a function of temperature up to 85°C then nearly leveled off to a peak value, while cassava continued to rise sharply in its swelling power with further increase of temperature.

5.2.1 Starch Solubility

Starch solubility curves as a function of temperature for arrowroot, cassava, sweet potato, taro, yam, and wheat (cvs. Neepawa and Fielder) starches are presented in Figure 5.6, and in Tables 5.8-5.11.

Like with swelling power, cassava starch had the highest solubility at all temperatures. At low temperatures, root starches had higher solubilities than the wheat starches. At temperatures higher than 83°C the solubility of wheat starches increased at a greater rate than those observed for the root starches. At about 87°C, the solubilities of the wheat starches exceeded the solubilities of the root starches, except that of cassava which they equalled only at 95°C.

At all temperatures, hard wheat had lower solubilities than soft wheat. Taro starch solubility as a function of temperature rose in a sigmoid manner as observed for swelling power. Yam and sweet potato starches were very close in their solubility characteristics. Their solubilities rose steadly over the whole temperature range; 60-95°C. Cassava and arrowroot solubilities rose with the highest, but decreasing rates as a function of temperature as indicated by the curves in Figure 5.6.

The solubility of a starch depended on its swelling power. Thus the highest solubility for wheat starches was observed over the temperature range 85-95°C. Solubility rates for taro starch were hightest between 70-85°C

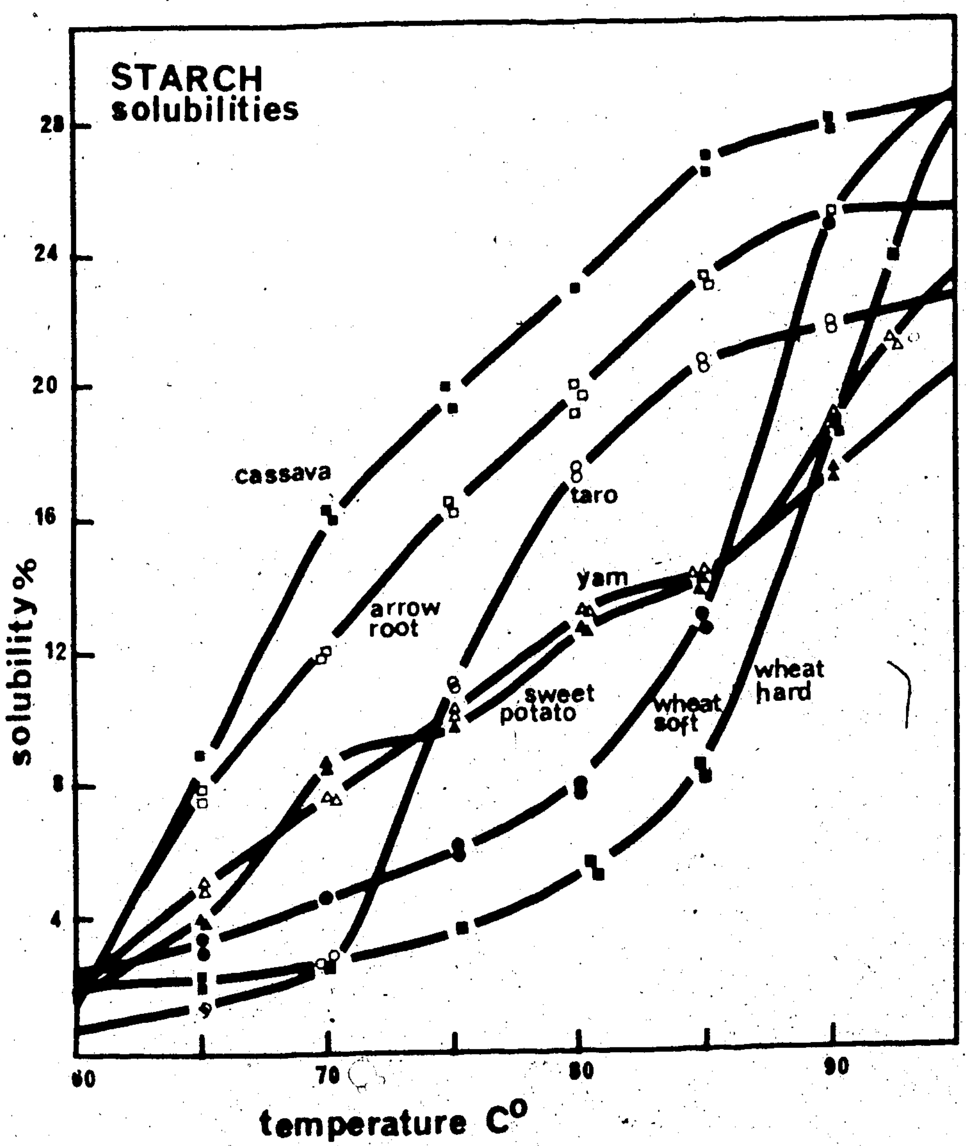


Figure 5.6. Starch Solubility as a Function of Temperature for Some Wheat and Tropical Root Starches.

Table 5.8 Solubility of Arrowroot, Taro and Yam Starches as a Function of Temperature

Types of Starches	Temperature °C							
	60	65	70	75	80	85	90	95
Arrowroot (Kenyan cv)	1.47±0.30	7.93±0.99	12.04±0.38	16.38±0.29	19.01±0.83	23.28±0.31	25.28±0.29	24.72±1.0
Taro (Jamaican cv)	0.67±0.11	1.33±0.17	2.29±0.27	11.06±1.35	17.51±1.39	20.87±1.13	17.79±1.32	22.4±2.14
Yam (Jamaican cv)	2.19±0.18	5.26±6.88	7.47±0.63	9.68±1.06	13.37±0.21	12.89±0.68	18.94±0.69	23.31±0.39

Table 5.9. Solubilities of Some Cassava Starches as a Function of Temperature

Types of Starches	Temperature °C							
	60	65	70	75	80	85	90	95
Cassava:								
Commercial Sample	1.49±0.24	8.92±0.79	16.4±0.36	19.14±0.85	22.89±0.61	27.04±0.27	27.51±0.26	28.60±0.20
Fijian cv.	2.83±0.16	10.98±0.14	14.18±0.48	17.23±0.97	23.10±1.27	28.25±2.16	33.72±2.50	35.26±1.97
Kenyan cv.	3.31±0.29	7.16±0.52	6.92±0.29	10.05±0.46	14.96±1.76	20.34±1.33	31.14±0.85	30.36±0.66

Table 5.10. Solubilities of Some Sweet Potato Starches as a Function of Temperature

Types of Starch	Temperature °C							
	60	65	70	75	80	85	90	95
Sweet Potatoes:								
Centennial cv.	2.02±0.58	3.39±0.29	8.76±0.33	8.97±0.99	12.69±0.18	13.93±2.29	17.44±0.63	20.46±0.81
Georgier Red cv.	0.61±0.09	1.07±0.12	4.24±1.37	10.22±0.98	11.87±0.84	12.85±0.49	17.07±0.38	17.14±0.52
Porto Rico cv.	1.67±0.31	2.79±1.33	6.67±0.82	10.39±0.44	15.84±0.47	16.64±0.33	17.48±0.72	18.64±0.32

Table 5.11. Solubilities of Wheat, cvs. Neepawa and Fielder starches as a Function of Temperature

Types of Wheat	Temperature °C							
	60	65	70	75	80	85	90	95
Neepawa	2.07±0.30	1.98±0.09	3.20±0.20	3.55±0.68	5.59±0.34	9.88±0.17	18.91±0.76	28.56±0.51
Fielder	2.37±0.59	3.21±0.51	4.65±1.27	6.17±1.05	7.78±1.08	12.85±0.51	25.12±0.76	28.75±1.10

5.2.2 Starch Viscosity

Viscosity curves as a function of temperature for arrowroot, cassava, sweet potato, taro, yam and wheat (cvs. Neepawa and Fielder) starches are provided in Figures 5.7-5.10, and in Tables 5.12-5.15.

For all the starches, there was practically no difference between the viscosities after 5 and 10 minute runs of the Haake rotoviscosmeter.

The cassava starches, especially the Fijian cultivar, had the highest viscosities, followed by taro, yam, arrowroot, sweet potato and wheat starches. Of the sweet potato starches, the Porto rico cultivar had the lowest viscosity. Soft wheat (cv. Fielder) was observed to have higher viscosities at all temperatures than hard wheat (cv. Neepawa).

5.2.3 Starch Gelatinization Properties

Gelatinization thermograms and data as a function of temperature and water volume fraction, v_1=0.3-0.8, for some tropical root and wheat starches are given in Figures 5.11-5.13; Tables 5.16-5.20 and Appendices 1-4.

The thermograms obtained showed that the root starches had a gelatinization onset temperature range of 52-63°C, a peak temperature range of 58-68°C, and an end of gelatinization range of 65-73°C. Taro starch was the exception, with a high onset of 74.5°C, a peak of 79°C, and an end of gelatinization temperature of 83.7°C. CWRSW and

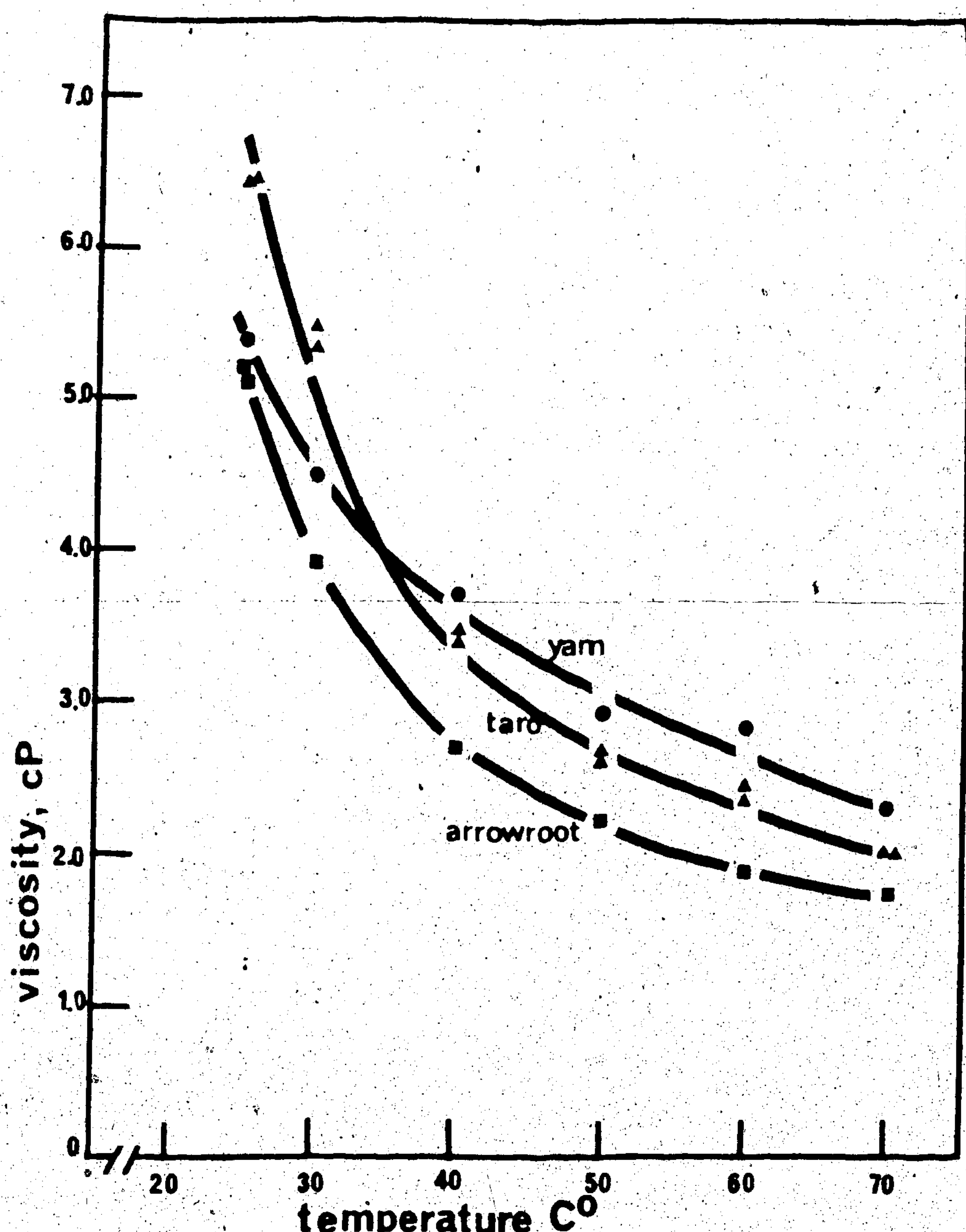


Figure 5.7. Viscosity as a Function of Temperature for Arrowroot, Taro, Yam Starhes

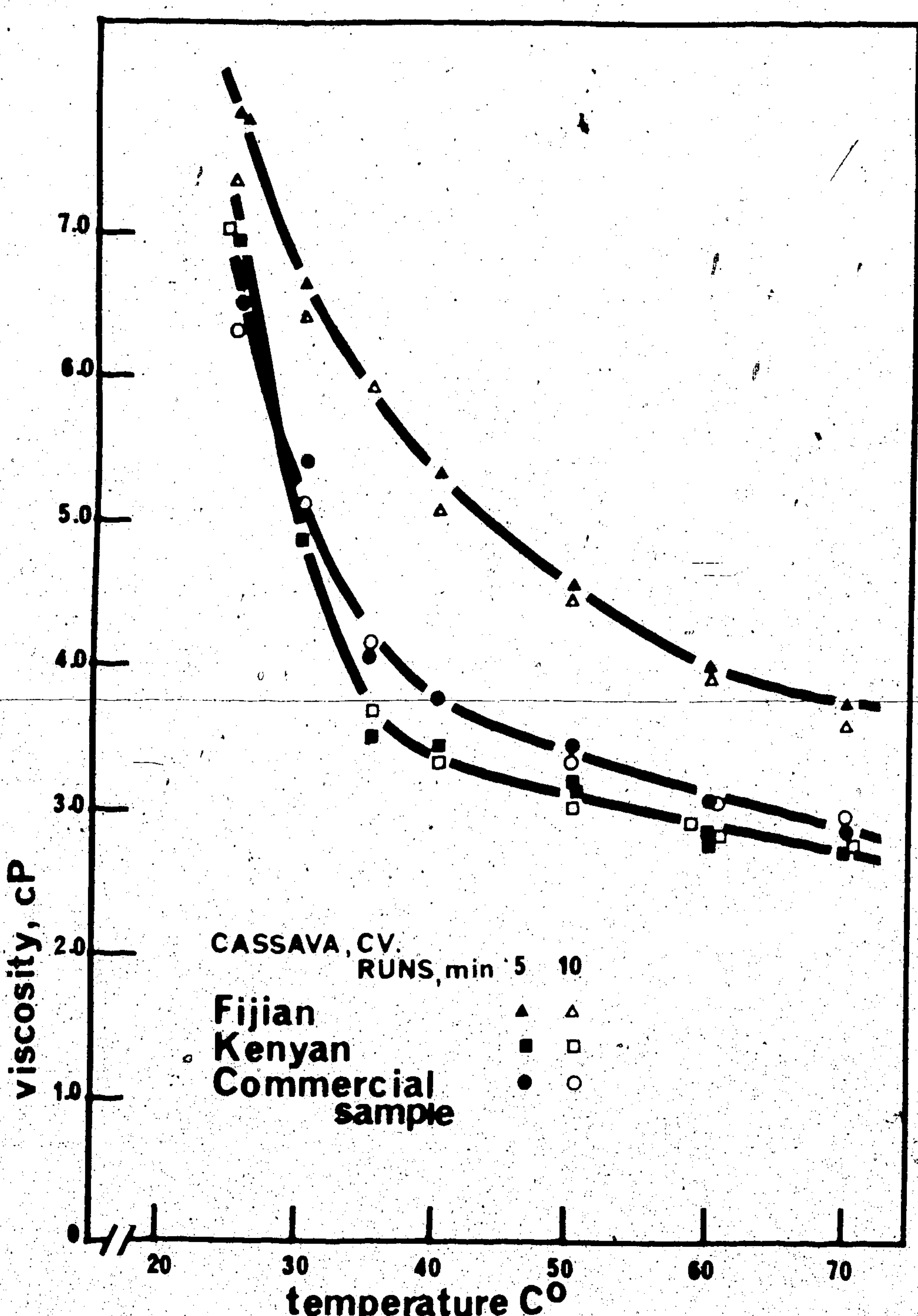


Figure 5.8. Viscosity as a Function of Temperature for Some Cassava Starches

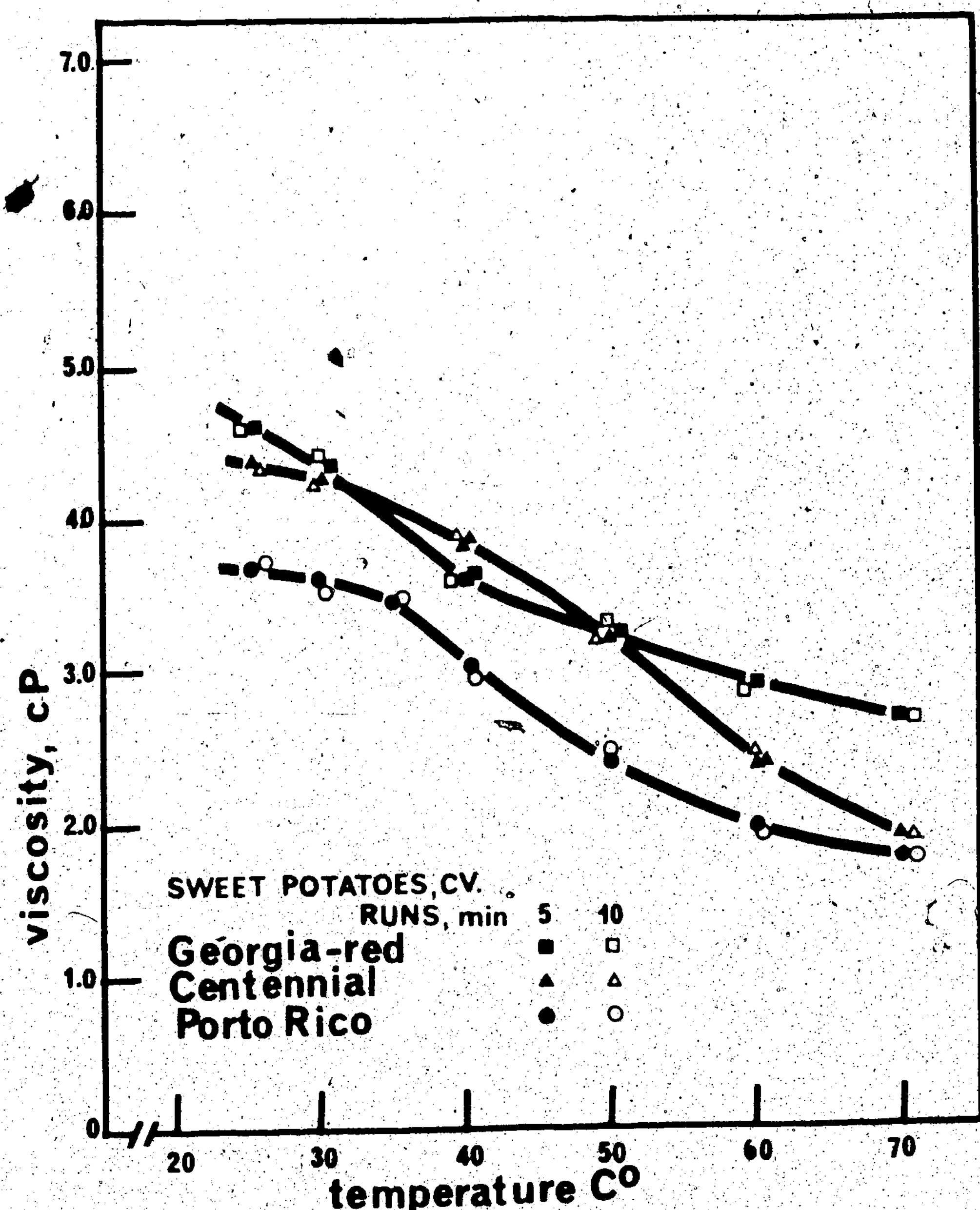


Figure 5.9. Viscosity as a Function of Temperature for Some Sweet Potato Starches

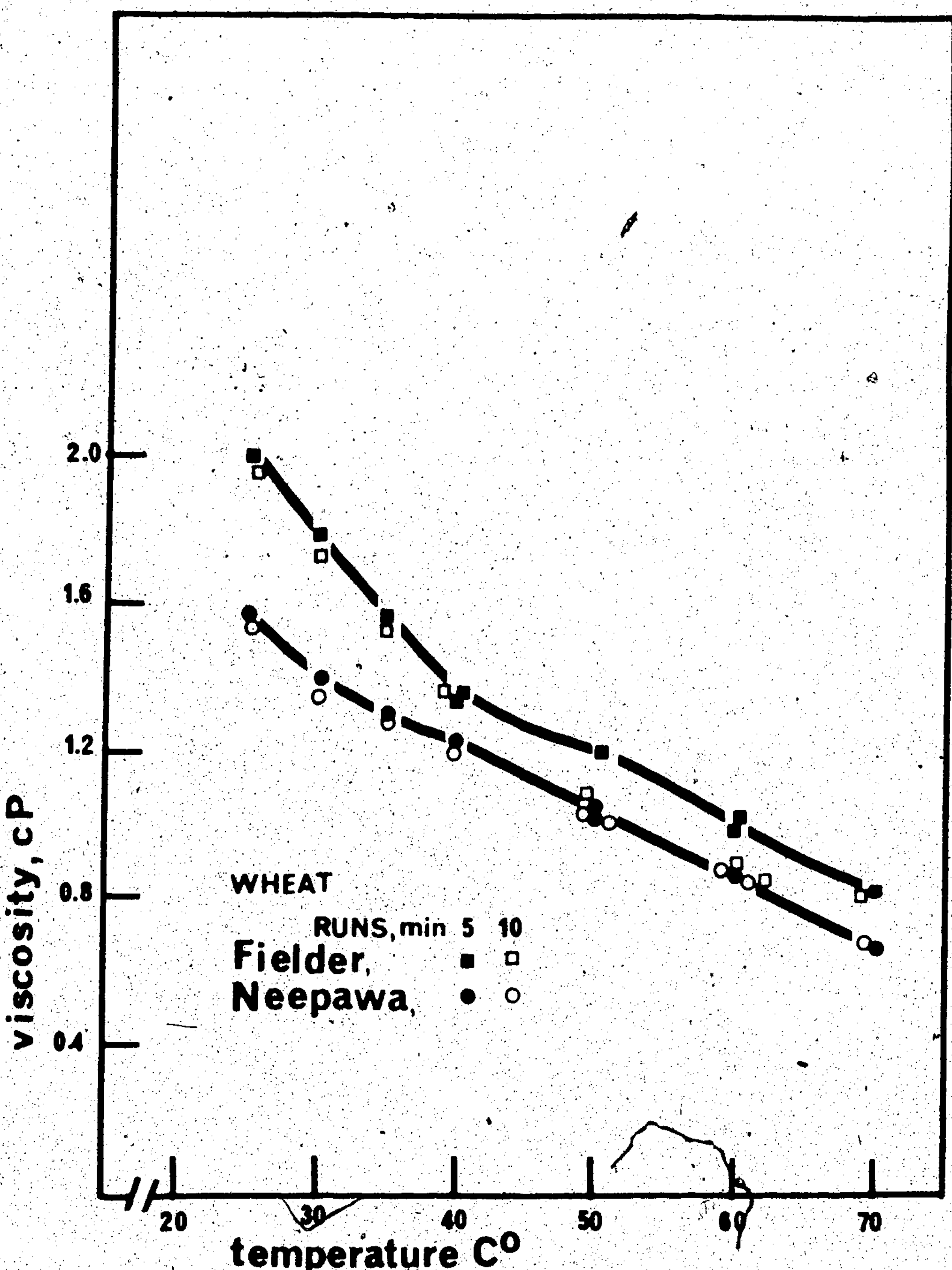


Figure 5.10 Viscosity as a Function of Temperature for Some Wheat, cvs. Fielder and Neepawa.

Table 5.12. (Viscosity as a Fucntion of Temperature for Arrowroot, Taro and Yam Starches

Starch*	Duration of Viscometer Run, Min.	Temperature, °C						
		25	30	35	40	50	60	70
Arrowroot cv. Kenyan	5	5.25±0.25	3.90±0.18	3.28±0.04	2.69±0.05	2.22±0.16	1.89±0.09	1.70±0.22
	10	5.08±0.25	3.83±0.18	3.26±0.06	2.63±0.07	2.17±0.16	1.84±0.16	2.39±0.22
Taro cv. Jamaican	5	6.44±0.16	5.43±0.10	3.88±0.07	3.60±0.25	2.59±0.12	2.46±0.13	2.05±0.05
	10	5.98±0.27	5.22±0.15	3.76±0.06	3.38±0.17	2.43±0.15	2.28±0.11	3.01±0.04
Yam cv. Jamaican	5	5.45±0.13	4.47±0.09	3.9±0.23	3.71±0.15	2.90±0.43	2.86±0.21	2.30±0.14
	10	5.39±0.13	4.40±0.11	3.83±0.09	3.66±0.16	2.85±0.35	2.85±0.10	2.98±0.14

*In this and following tables, 1% w/v starch suspension was gelatinized at 85°C for 15 min and then cooled prior to viscosity determination at the given temperature.

Table 5.13. Viscosity as a Function of Temperature for Some Cassava Starches

Starch*	Duration of Viscometer Run, Min.	Temperature, °C						
		25	30	35	40	50	60	70
Cassava								
cv. Kenyan	5	6.95±0.22	4.86±0.16	3.38±0.06	3.45±0.11	3.23±0.04	2.75±0.02	2.71±0.13
	10	6.72±0.24	4.74±0.10	3.31±0.12	3.40±0.10	3.17±0.05	2.71±0.02	2.75±0.10
cv. Fijian	5	7.86±0.24	6.65±0.27	6.34±0.09	5.31±0.13	4.59±0.18	4.01±0.19	3.78±0.27
	10	7.28±0.28	6.40±0.12	5.96±0.04	5.05±0.21	4.47±0.12	3.95±0.22	3.58±0.28
Commercial Sample	5	6.80±0.07	5.46±0.02	4.02±0.14	3.76±0.13	3.44±0.15	3.08±0.07	2.86±0.26
	10	6.30±0.14	5.24±0.03	3.99±0.16	3.72±0.08	3.36±0.15	3.04±0.01	3.01±0.22

*In this and following tables, 1% w/v starch suspension was gelatinized at 85°C for 15 min and then cooled prior to viscosity determination at the given temperature.

Table 5.14. Viscosity as a Function of Temperature for Some Sweet Potato Starches

Starch*	Duration of Viscometer Run, Min.	Temperature, °C						
		25	30	35	40	50	60	70
Sweet Potato								
cv. Centennial	5	4.35±0.13	4.25±0.06	4.10±0.07	3.81±0.04	3.18±0.19	2.34±0.09	1.85±0.07
	10	4.47±0.15	3.97±0.07	3.86±0.08	3.77±0.04	3.17±0.21	2.33±0.09	1.80±0.10
cv. Porto Rico	5	3.66±0.09	3.60±0.01	3.44±0.11	3.01±0.05	2.39±0.14	2.00±0.05	1.75±0.19
	10	3.63±0.06	3.63±0.06	3.39±0.15	2.99±0.04	2.34±0.14	1.97±0.02	1.75±0.11
cv. Georgia Red	5	4.63±0.02	4.35±0.05	4.00±0.08	3.55±0.08	3.21±0.11	2.89±0.16	2.65±0.13
	10	4.54±0.09	4.34±0.16	4.00±0.10	3.50±0.07	3.19±0.15	2.87±0.13	2.65±0.15

*In this and following tables, 1% w/v starch suspension was gelatinized at 85°C for 15 min and then cooled prior to viscosity determination at the given temperature.

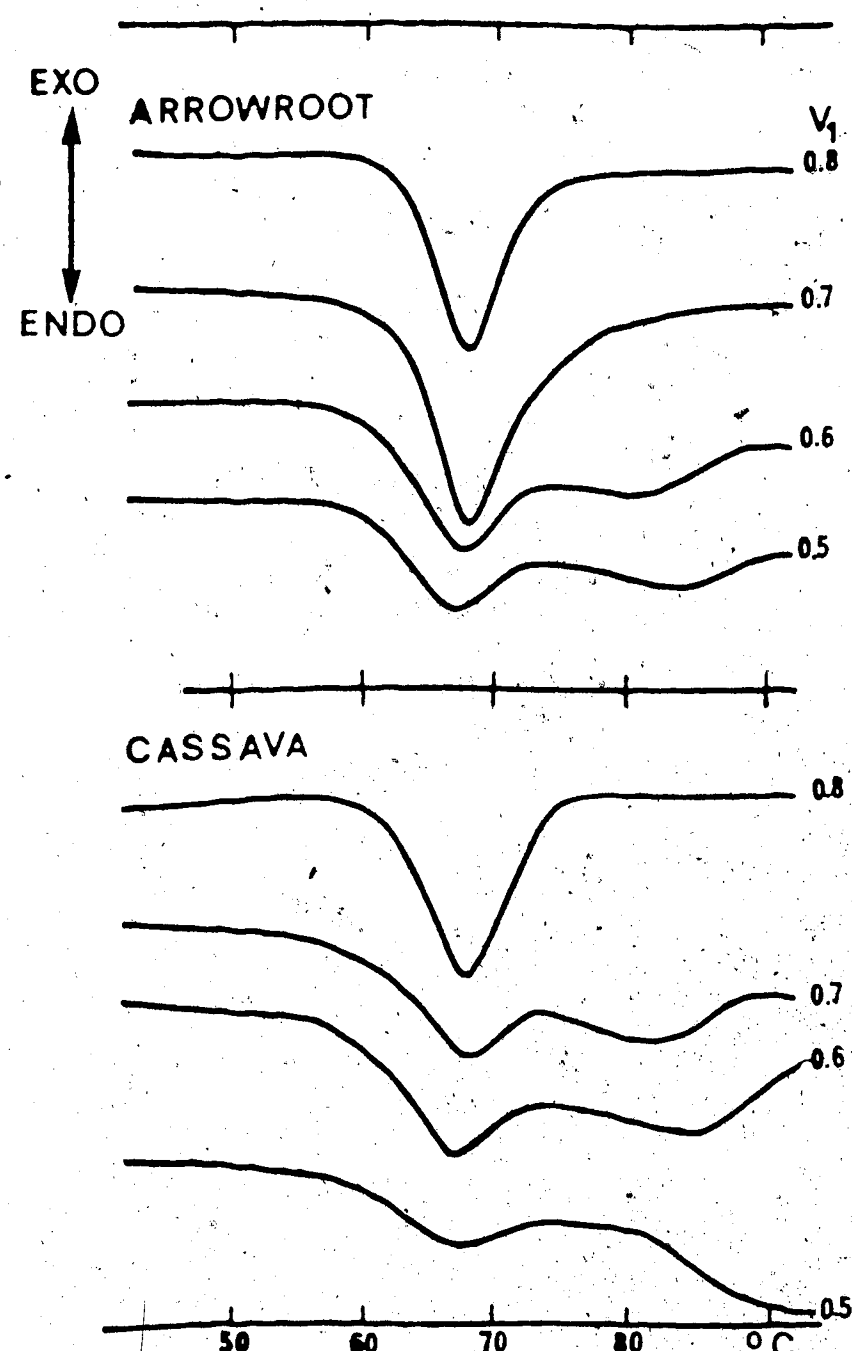


Figure 5.11. DSC-Thermograms for Arrowroot and Cassava Starches as a Function of Temperature and the Water Volume Fraction.

Table 5.16. DSC- Gelatinization Characteristics of Arrowroot and Cassava Starches as a Function of Temperature and Water Volume Fraction

STARCH TYPE	V_1 WATER VOLUME FRACTION	(G) GELATINIZATION ENDOTHERM					(M_1) CRYSTALLITES ENDOTHERMS				
		°C T_{ONSET}	°C T_{PEAK}	°C T_{END}	CM^2*	ΔH**	°C T_{ONSET}	°C T_{PEAK}	°C T_{END}	CM^2*	ΔH**
ARROWROOT	0.80	62.25±0.29	67.30±0.57	72.25±0.65	3.37±0.18	4.08±0.12	-	-	-	-	-
	0.70	61.10±0.85	67.98±0.39	73.5±0.71	4.08±0.68	4.93±0.22	71.0±0.35	76.75±0.35	80.5±2.88	0.55±0.10	0.67±0.05
	0.60	60.25±0.35	67.75±0.35	71.75±0.35	3.04±0.10	3.68±0.15	72.0±0	79.75±1.77	87.75±3.10	0.63±0.10	0.77±0.05
	0.50	60.0±0	67.13±0.13	73.0±0.71	2.17±0.24	2.63±0.27	73.0±0.0	83.75±1.10	95.25±3.9	1.53±0.22	1.85±0.05
	0.40	60.0±0	67.25±0.21	73.0±0	1.77±0.10	2.14±0.11	74.0±0	87.5±2.8	97.5±0.0	1.41±0.30	1.71±0.05
	0.30	-	-	-	-	-	91.5±2.50	119.0±3.9	140±5.0	7.0±2.0	8.47±0.10
CASSAVA	0.80	52.89±0.88	60.75±0.35	71.25±0.53	3.79±0.31	4.59±0.03	-	-	-	-	-
(KENYAN CV.)	0.70	53.38±0.18	58.25±0.35	65.25±1.06	4.05±1.25	4.90±0.05	67±0.71	75.75±0.35	80.75±0.35	0.65±0.03	0.79±0.05
	0.60	53.25±1.06	58.34±0.53	64.0±0.35	3.10±0.31	3.75±0.08	70.75±.35	82.25±6.72	89.25±5.3	3.63±0.16	4.20±0.09
	0.50	52.0±0.71	58.0±0.35	65.0±0.71	1.97±0.42	2.38±0.10	74.0±1.41	88.5±4.24	96.63±4.10	1.56±0.06	1.89±0.03
	0.40	54.5±0	66.75±3.18	77.0±3.89	1.73±0.66	2.09±0.05	80.25±3.89	106.25±6.0	124.75±0.35	6.23±0.22	7.54±0.07
	0.30	60.2±1.5	79.0±2.0	88.0±2.5	1.38±0.50	1.67±0.17	89.5±0	131.75±5.3	139.03±3.57	8.48±0.45	9.87±0.11

*ENDOTHERM AREA.

**ENTHALPY OF FUSION (cal/g STARCH).

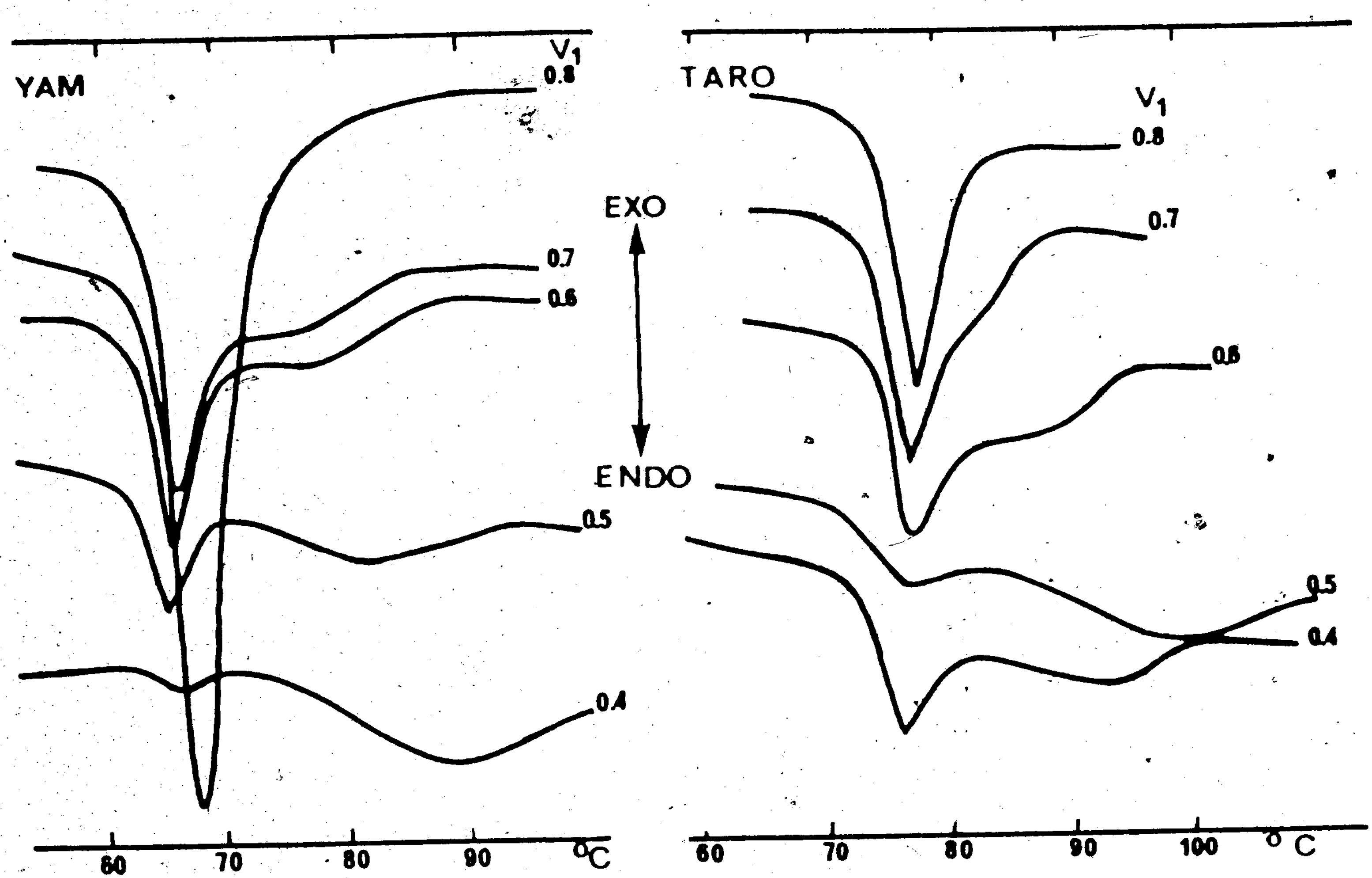


Figure 5.12. DSC - Thermograms of Yam and Taro Starches as a Function of Temperature and the Water Volume Fraction

Table 5.17. DSC- Gelatinization Characteristics of Yam and Taro Starches as a Function of Temperature and Water Volume Fraction.

STARCH TYPE	V_1 WATER VOLUME FRACTION	(G) GELATINIZATION ENDOTHERM					(M_1) CRYSTALLITES ENDOTHERMS				
		°C T_{ONSET}	°C T_{PEAK}	°C T_{END}	CM^{2*}	ΔH**	°C T_{ONSET}	°C T_{PEAK}	°C T_{END}	CM^{2*}	ΔH**
YAM	0.80	62.75±0.35	67.42±0.63	71.88±1.59	4.88±0.93	5.91±0.50	-	-	-	-	-
	0.70	62.5±0	66.5±0	70.0±0	3.77±0.01	4.56±0.19	70.0±0	76.25±0	85.5±0	3.12±0.13	3.78±0.40
	0.60	62.5±0	65.75±0	69.5±0	3.20±1.0	3.87±0.25	69.75±0	78.0±0	87.5±0.35	3.47±0.35	4.20±0.08
	0.50	61.17±0.58	65.0±0.5	68.5±0	1.81±1.0	2.19±0.14	70.75±0.35	77.17±3.33	91.0±0	1.44±.43	1.75±0.35
	0.40	60.5±0	64.0±0	67.5±0	0.31±0	0.37±0	73.25±0.25	87.0±0	99.0±0	3.41±0.04	4.12±0.11
	0.30	-	-	-	-	-	89.5±0	103.7±3.01	112.5±2.30	4.65±0.52	5.62±0.25
TARO	0.80	75.25±0.25	78.5±0.25	83.25±0.25	4.37±0.21	5.29±0.25	-	-	-	-	-
	0.70	74.50±0.71	78.0±0.50	83.75±0.25	5.28±0.35	6.38±0.35	81.5±0	86.5±0	96.5.±0	1.25±0.05	1.51±0.08
	0.60	74.50±0	78.5±0	84.0±0.5	4.72±0.40	5.71±0.52	82.0±0	90.0±0	95.0±0	2.71±0.15	3.71±0.20
	0.50	74.5±0.25	79.0±0	83.25±1.1	2.00±0	3.97±0	83.5±1.0	101.0±5.57	109.0±0	3.11±0.27	3.88±0.05
	0.40	-	79±0	87.5±0	1.76±0.07	2.12±0.09	81.5±0	117.25±3.18	123.25±3.9	3.59±0.25	4.34±0.15
	0.30	-	-	-	-	-	95.5±0	136.0±0	146.0±0	5.19±1.01	6.28±0.19

*ENDOTHERM AREA.

**ENTHALPY OF FUSION (cal/g STARCH).

Figure 5.13. DSC-Thermograms of Wheat, cv. Neepawa Starch as a Function of the Temperature and the Water Volume Fraction.

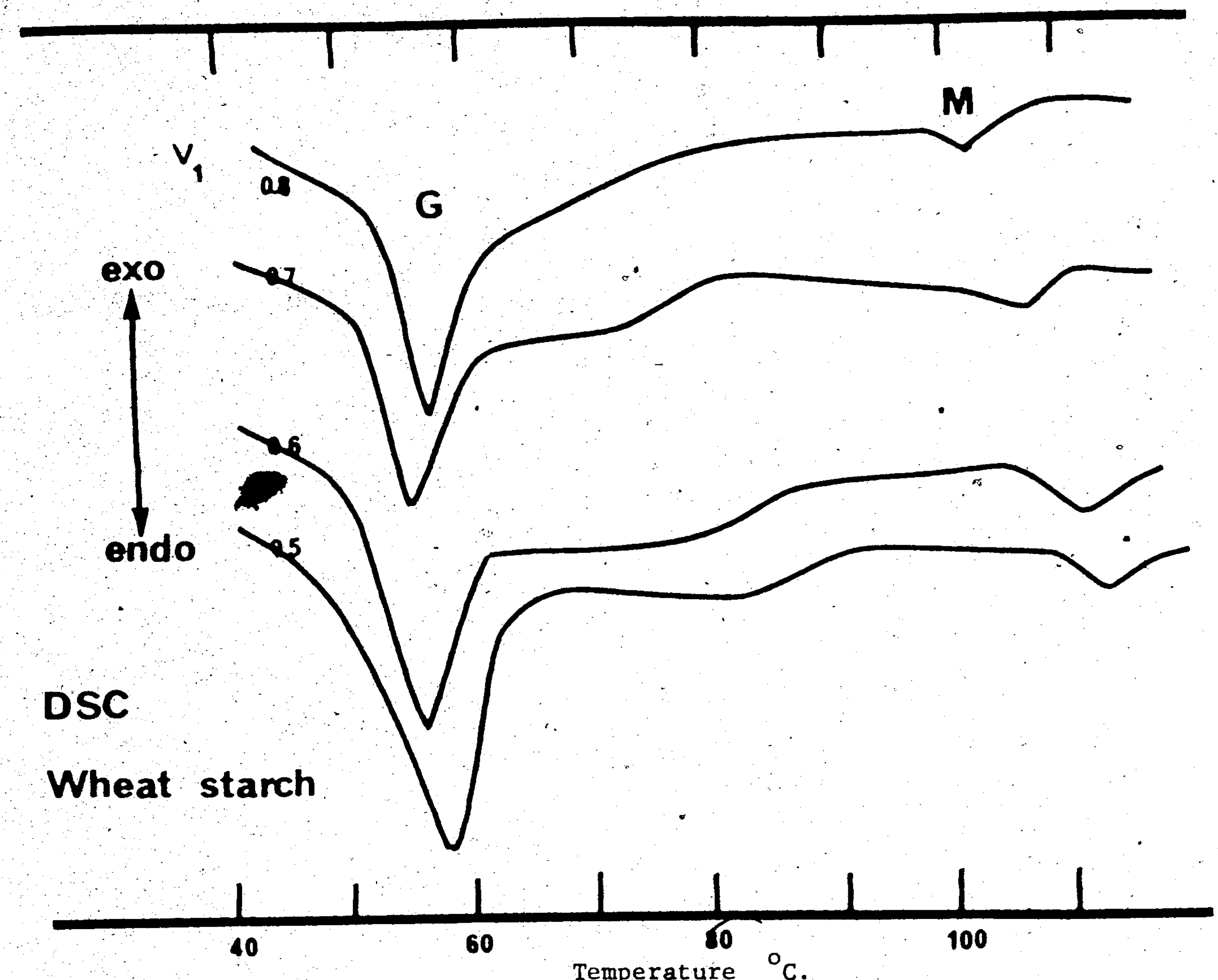


Table 5.18. DSC - Gelatinization Characteristics of Wheat, cv. Neepawa Starch as a Function of the Temperature and the Water Volume Fraction

		Endotherms							
		Gelatinization (g)				Crystallite (m_1)			
Type of Starch	Volume fraction	t^oC Onset	t^oC Peak	t^oC End	ΔH/Cal/g*	t^oC Onset	t^oC Peak	t^oC End	ΔH/Cal/g*
Wheat:	0.8	51.04 ±0.78	56.08 ±0.74	62.04 ±1.15	0.410 ±0.005	-	-	-	-
cv. Neepawa	0.7	50.12 ±1.21	55.36 ±1.18	61.22 ±1.79	0.200 ±0.003	62.75 ±0.35	75.50 ±4.95	83.00 ±0.59	0.110 ±0.050
	0.6	49.63 ±0.50	56.40 ±0.50	62.17 ±2.02	0.590 ±0.004	65.25 ±0.35	77.75 ±0.35	91.75 ±1.77	0.180 ±0.040
	0.5	50.50 ±0.01	56.00 ±0.02	58.75 ±0.35	0.220 ±0.008	73.5 ±1.4	84.101 ±2.60	101.00 ±3.30	0.210 ±0.020
	0.4	47.75 ±1.41	52.25 ±0.00	58.75 ±0.09	0.05 ±0.003	84.0 ±7.8	102.30 ± 1.06	112.25 ±2.50	0.260 ±0.030
	0.3	--	--	--	--	--	--	--	--

*Enthalpy of Fusion.

Table 5.19. DSC- Wheat Starch-Lipid Clathrates' Melting Characteristics as a Function of the Temperature and the Water Volume Fraction.

Wheat:	Water Volume Fraction (V_1)	Clathrate Endotherms (m_2)			
		t°C Onset	t°C Peak	t°C End	ΔH Cal/g.*
cv. Fielder					
	0.8	93.25 ± 3.89	98.75 ± 3.89	103.50 ± 4.95	0.023 ±0.001
	0.7	97.75 ± 3.18	103.25 ± 3.89	107.75 ± 3.18	0.041 ±0.003
	0.6	105.75 ± 1.06	111.75 ± 0.45	115.75 ± 1.06	0.058 ±0.005
	0.5	--	--	--	--
	0.4	122.25 ± 1.78	128.75 ± 1.06	132.00 ± 0.10	0.060 ±0.004
	0.3	--	--	--	--
cv. Neepawa.					
	0.8	97.50 ± 1.00	100.50 ± 1.00	105.00 ± 2.00	0.160 ±0.010
	0.7	97.50 ± 1.00	100.50 ± 1.00	106.50 ± 1.00	0.220 ±0.010
	0.6	107.00 ± 1.00	114.50 ± 1.50	120.50 ± 2.50	--
	0.5	--	--	--	--
	0.4	--	--	--	--
	0.3	--	--	--	--

* Enthalpy of Fusion

Table 5.20 Comparison of Gelatinization Characteristics of Some Wheat and Tropical Root Starches

Type of Starch	Onset*	Peak*	End	Enthalpy* of Fusion cal/g starch
Wheat				
cv. Neepawa	50.08±0.91	55.18±0.82	60.90±2.02	0.66±0.10
cv. Fielder	50.12±1.21	55.36±1.18	61.22±1.79	0.20±0.31
Cassava				
Kenyan cv.	53.20±0.90	58.84±1.28	66.38±2.90	4.90±0.05
Fijian cv.	59.16±2.61	65.42±1.92	74.54±2.80	5.09±0.81
Sweet Potato				
Porto Rico	52.72±1.89	57.92±0.59	65.50±0.71	3.49±0.05
Centennial cv.	53.63±1.01	61.58±1.69	70.16±2.59	2.59±0.20
Georgia Red	62.02±0.81	66.47±1.14	72.20±3.08	3.32±0.86
Arrowroot				
Kenyan cv.	60.72±0.97	67.48±0.36	72.70±1.79	4.93±0.22
Yam	61.88±0.99	65.73±1.32	69.48±1.65	4.56±0.19
Taro	74.69±0.38	78.60±0.42	84.35±1.79	6.38±0.35

*At water fraction = 0.7.

SWSW had similar endotherms, with an onset temperature of 50°C, a peak of 55.3°C, and an end of 61°C.

Root starches had higher enthalpies of fusion than root starches ranging from 0.3 cal/g starch DWB for v_1=0.4 in yam to 6.38 cal/g starch in taro at v_1=0.7 for the "G" endotherm. The enthalpy of fusion was highest in arrowroot and taro starches, indicating stronger forces within their granules than in other starches. Low enthalpy was found for the wheat starches; 0.66 and 0.20 cal/g of starch, DWB, for cvs. Neepawa and Fielder respectively.

The gelatinization endotherm "G" was shouldered by crystallite melting endotherm M_1 between v_1=0.3-0.7. The M_1 endotherm became greater at the expense of the "G" endotherm as v_1 decreased.

The M_1 onset, peak and end of gelatinization temperatures were irregular and not as well defined as for the "G" endotherm. Wheat starches, but not root starches, had an additional endotherm M_2 near 100°C, revealing the presence of starch-lipid clathrates (Figure 5.13, and Table 5.19). Onset, peak and end of gelatinization temperatures for the M_2 were also irregular (Table 5.19). Its enthalpy of fusion was small, ranging from 0.023 to 0.06 cal/g of starch, DWB for cv. Fielder and 0.16 to 0.22 for cv. Neepawa for v_1=0.7.

Data in Table 5.20 compare the gelatinization endotherm characteristics of wheat and root starches. Cassava starch of Kenyan origin and sweet potato starch, cv. Porto rico, had gelatinization properties close to wheat starch.

5.2.4 Retrogradation of Gels

5.2.4.1 DSC Thermograms

Retrogradation of starch gels, as revealed by DSC thermograms for arrowroot, cassava, sweet potato, taro and wheat (cvs. Fielder and Neepawa) is presented in Figures 5.14-5.16.

It was observed that 60% fresh gels did not have any DSC endotherms. The root starches after two days of storage showed the presence of an endotherm between 50-60°C. The intensity of the endotherm increased with aging time (Figures 5.14-5.15). The wheat starches did not show any endotherm development until after the 6th day in storage at 24°C (Figure 5.16).

Arrowroot, cassava and sweet potato gels exhibited a second set of endotherms between 90-100°C for arrowroot, 78-83°C for cassava and 75-80°C for sweet potato. These were absent in gels of taro, yam and wheat starches.

5.2.4.2 X-Ray Diffraction Patterns

X-ray diffractograms for cassava and wheat (cv. Neepawa) starch gels in Figures 5.17 and 5.18 show that the X-ray diffraction patterns became sharper and more defined with storage time.

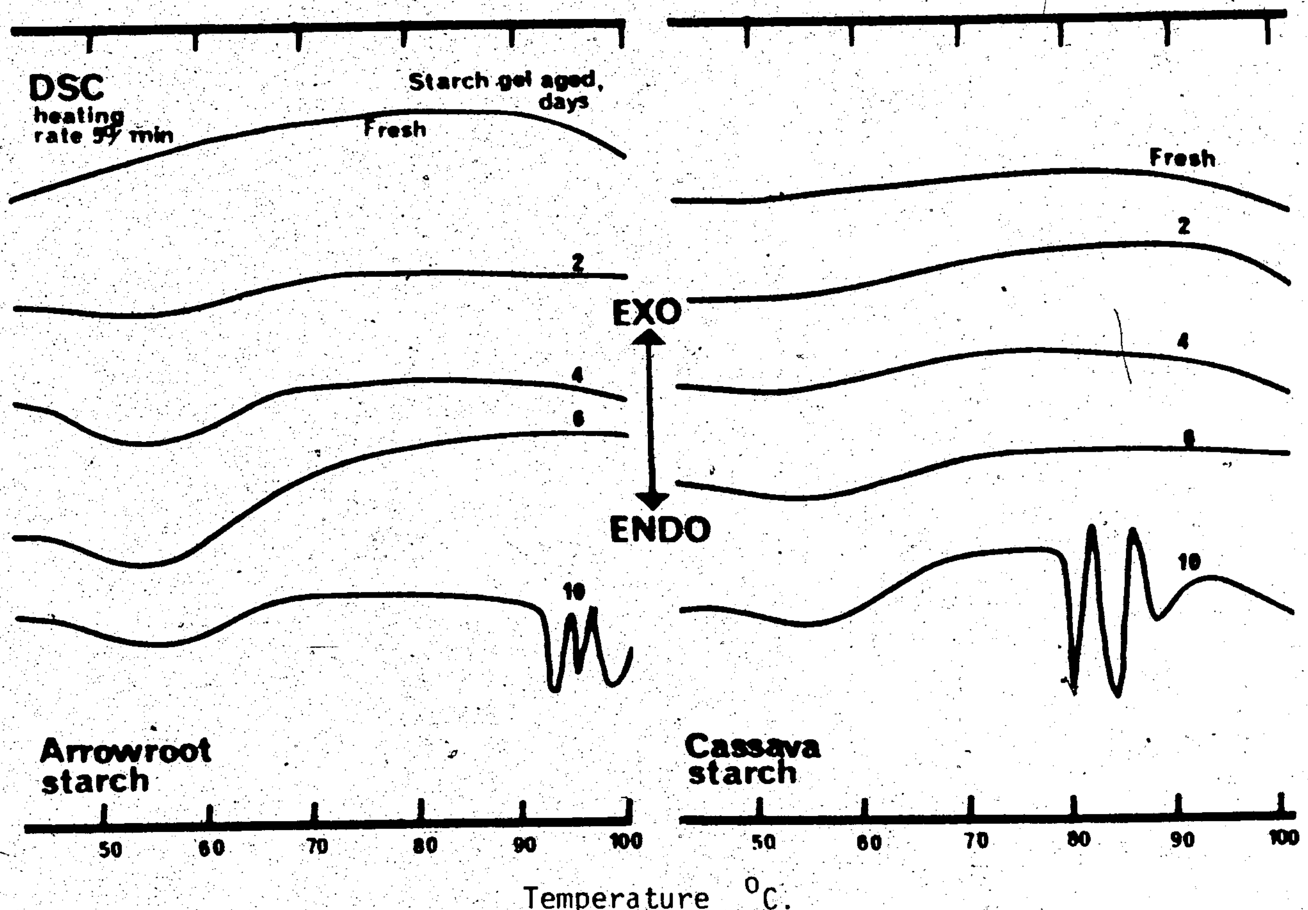


Figure 5.14. DSC- Thermograms of Arrowroot and Cassava Fresh and Aged Starch Gels.

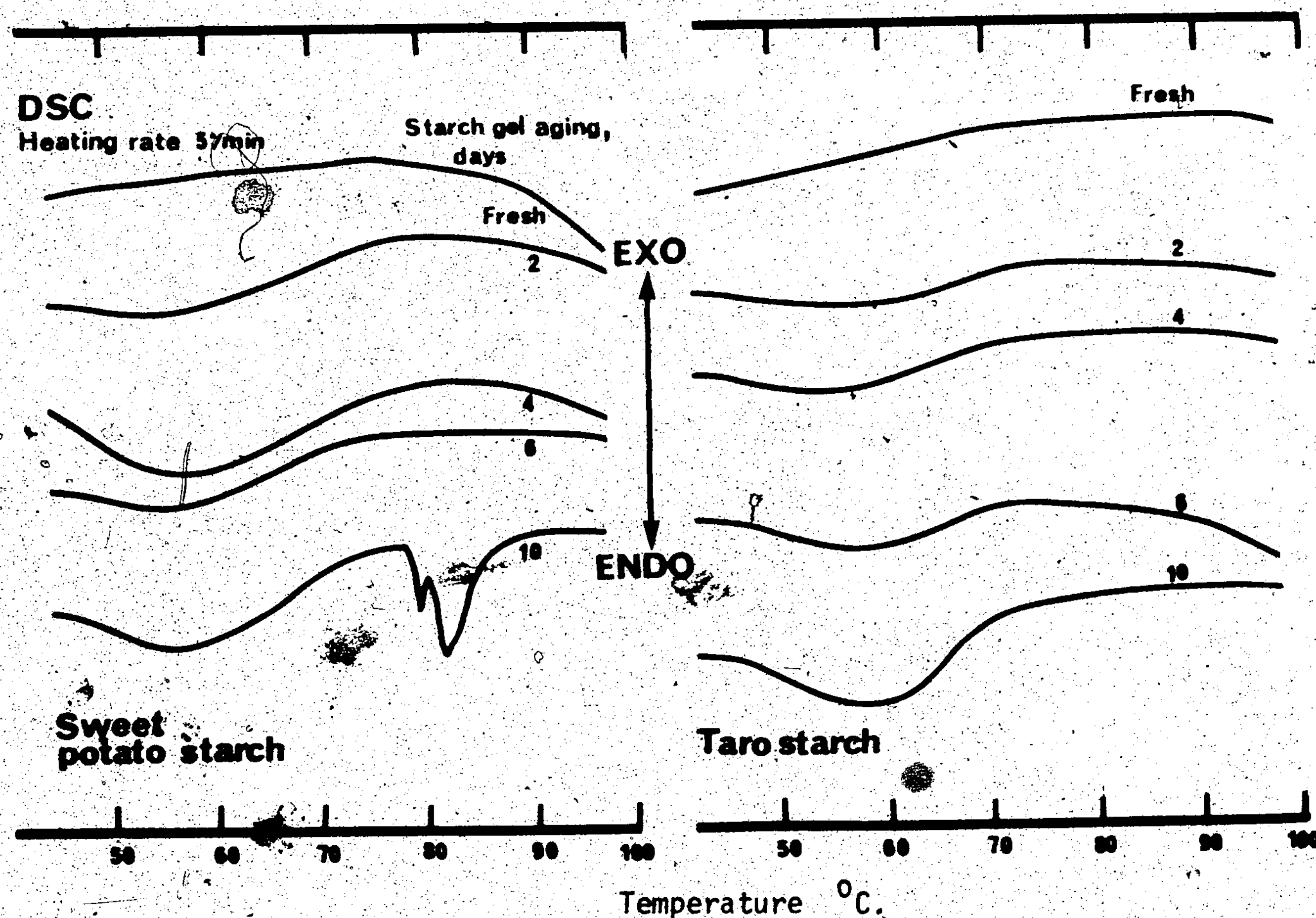


Figure 5.15. DSC- Thermograms of Sweet Potato and Taro Fresh and Aged Starch Gels.

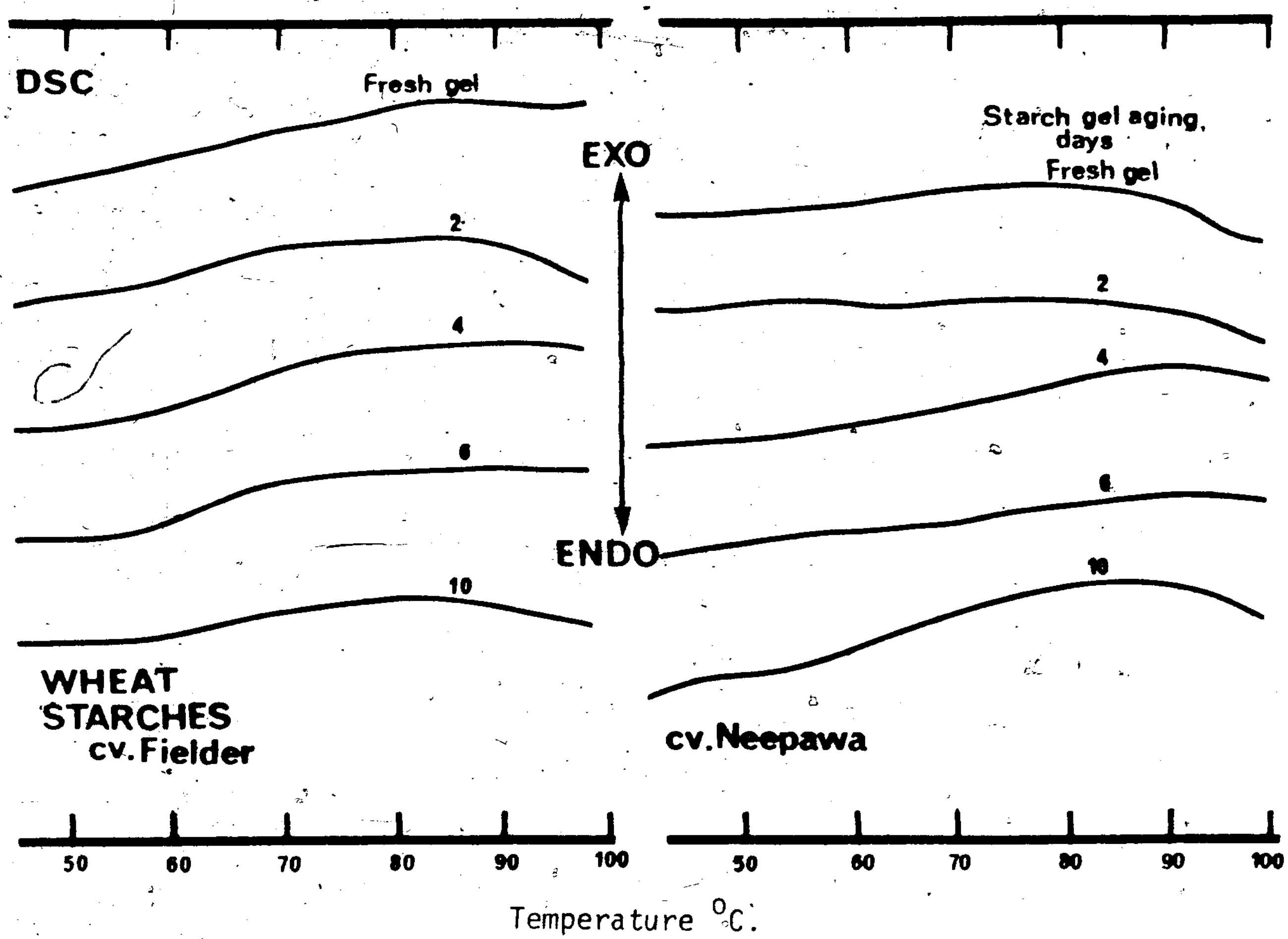


Figure 5.16. Dsc-Thermograms of Wheat, cvs. Fielder and Neepawa Fresh and Aged Starch Gels.

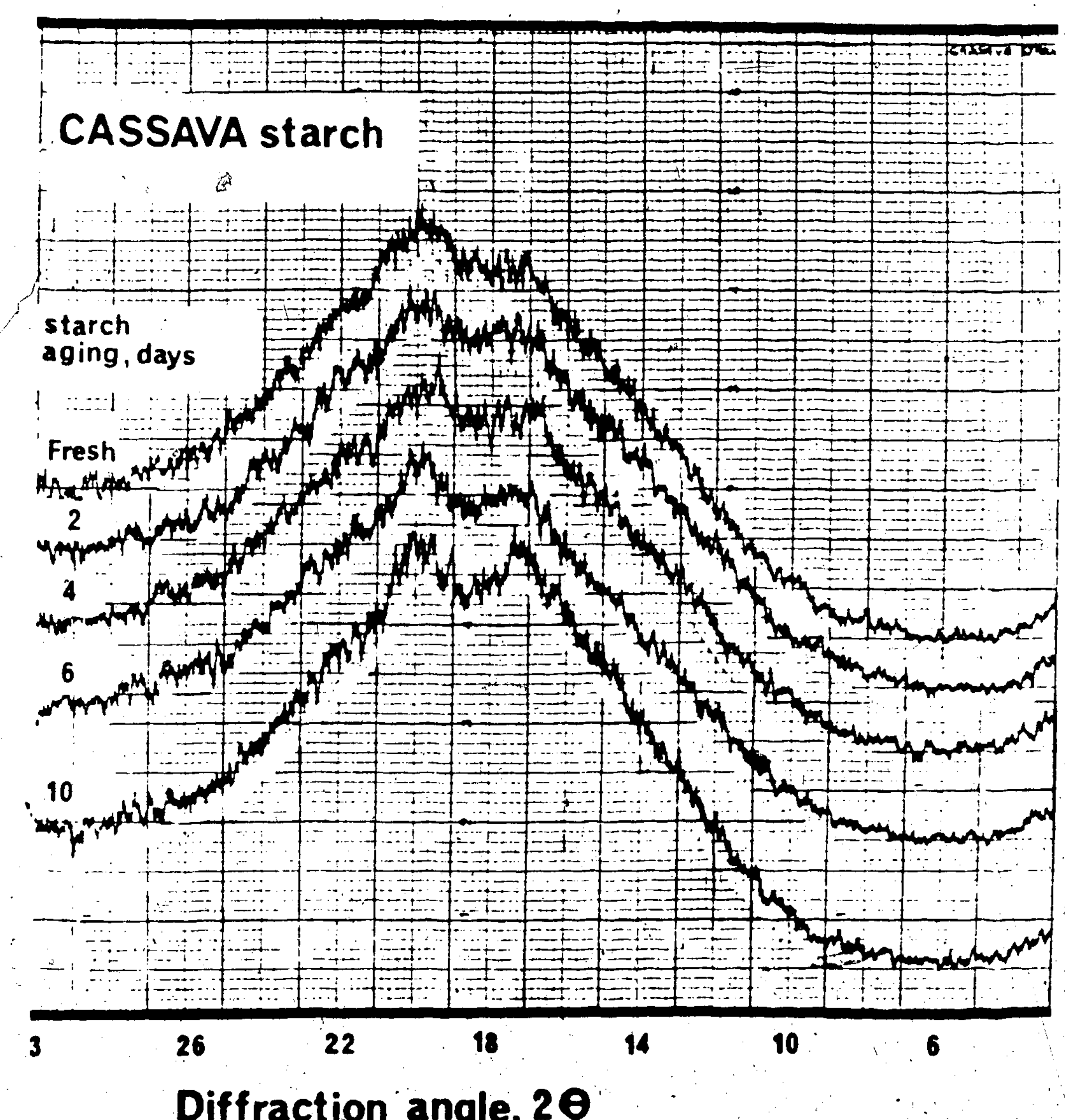


Figure 5.17 X-Ray Diffractograms of Gelatinized Starch Gels as a Function of Storage Time

Table 5.21. X-Ray Diffraction Patterns of Gelatinization and Aged Kenyan Cassava Starch

			Starch Gel Aged, Days											
Fresh			2			4			6			10		
2θ*	d, Å**	Intensity cps***	2θ	d, Å	Intensity cps	2θ	d, Å	Intensity cps	2θ	d, Å	Intensity cps	2θ	d, Å	Intensity cps
9.917	8.9188	123	12.265	7.2160	202	12.460	7.1037	201	17.170	5.1644	398	11.904	7.4345	204
13.244	6.6848	256	14.868	5.9581	320	16.801	5.2767	401	19.918	4.4575	436	14.973	5.9167	361
17.075	5.1926	419	16.783	5.2824	397	17.634	5.0293	407	21.480	4.1369	373	16.228	5.4618	433
19.361	4.5845	462	17.781	4.9882	418	19.392	4.5772	418	22.664	3.9232	338	17.220	5.1493	476
19.792	4.4857	427	19.698	4.5068	435	20.207	4.3944	402				19.665	4.5144	478
23.302	3.8173	325	21.985	4.0429	365	21.761	4.0840	358				21.913	4.0561	374
28.540	3.1275	221	23.985	3.7101	287	23.445	3.7943	292				27.374	3.2580	221
			27.356	3.2601	217	25.523	3.4899	231						
						26.561	3.3559	224						

*2θ, Two theta degrees of the angle of diffraction.

**d, Interplanar spacings in Angstrom units.

***Diffraction line intensity in cycles per second.

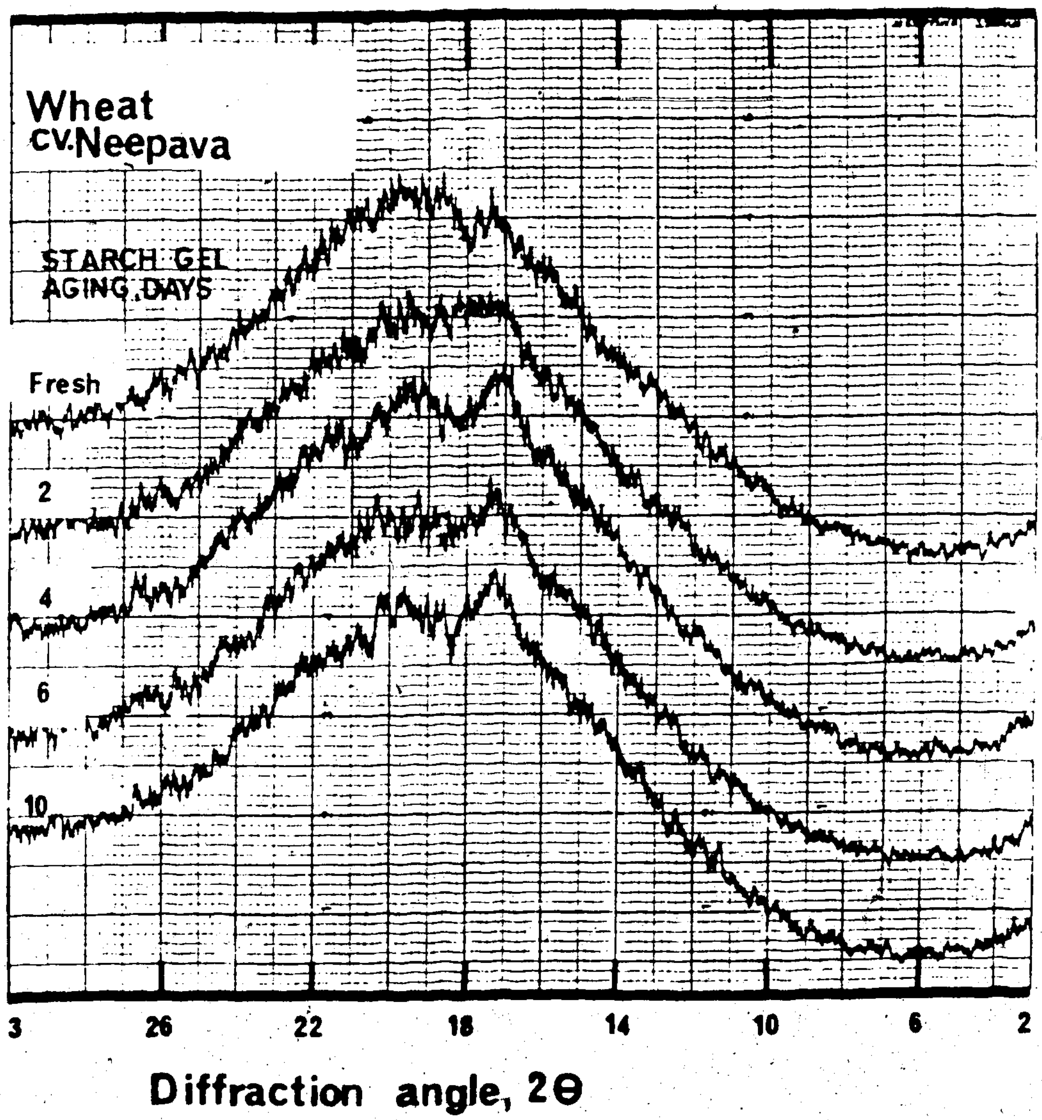


Figure 5.18. X-Ray Diffractograms of Gelatinized Wheat, cv. Neepawa Starch Gels as a Function of Storage Time

Table 5.22. X-Ray Diffraction Patterns of Gelatinized and Aged Wheat, cv. Neepawa, Starch

Starch Gel Aged, Days														
Fresh			2			4			6			10		
2θ*	d, Å**	Intensity cps***	2θ	d, Å	Intensity cps	2θ	d, Å	Intensity cps	2θ	d, Å	Intensity cps	2θ	d, Å	Intensity cps
10.266	8.6165	143	12.416	7.1290	203	5.471	16.1519	82	12.715	6.9620	207	14.377	6.1604	332
15.904	5.5724	353	15.443	[illegible].7376	330	14.232	6.2229	290	16.942	5.2331	387	15.132	5.8550	380
17.395	5.0981	408	17.008	5.2131	408	17.114	5.1809	442	17.445	5.0835	385	17.040	5.2033	451
18.843	4.7094	416	19.293	4.6004	407	19.019	4.6661	426	20.263	4.3825	418	19.972	4.4457	444
19.579	4.5340	426	20.175	4.4013	409	20.265	4.3820	413	24.243	3.6712	278	22.086	4.0246	371
29.146	3.0638	214	21.739	4.0880	359	21.385	4.1549	381	28.235	3.1605	201	27.517	3.2414	234
			23.638	3.7638	301	22.032	4.0343	365						
						26.464	3.3679	243						

The data in Tables 5.21 and 5.22 show the diffraction angle in "° (2θ)", the interplanar spacings "d" in "Å" and the intensities in cycles per second "cps" of the diffracted lines. Of characteristic interest were the peaks occurring in the neighborhood of diffraction angles 17-19° (2θ) and 20-21° (2θ).

5.2.5 Complexing with Monoglycerides

5.2.5.1 Analysis of Monoglycerides

Infrared Spectra of C_{16} and C_{18} α-and β-Crystallinity Monoglycerides.

Infrared spectra absorption bands of the α- and β-Crystallinity form of C_{16} and C_{18} monoglycerides are presented in Figure 5.19 and Table 5.23.

The absorption bands specific to only α- or β-crystallinity forms of monoglycerides are presented in Table 5.24.

According to Chapman (1965), different polymorphic types of 1-monoglycerides provide different infrared spectra. On the contrary, the 2-isomer monoglycerides have only one polymorphic form, hence there is no change in their infrared spectra.

Figure 5.19 shows that α- and β-crystallinity forms of C_{16} and C_{18} monoglycerides have similar infrared spectra. The bands at 1730-1740 cm^{-1} represent the carbonyl stretching of the ester groups. The bands at 1460-1480 cm^{-1} represent -C-H bending of methylene and methyl groups.

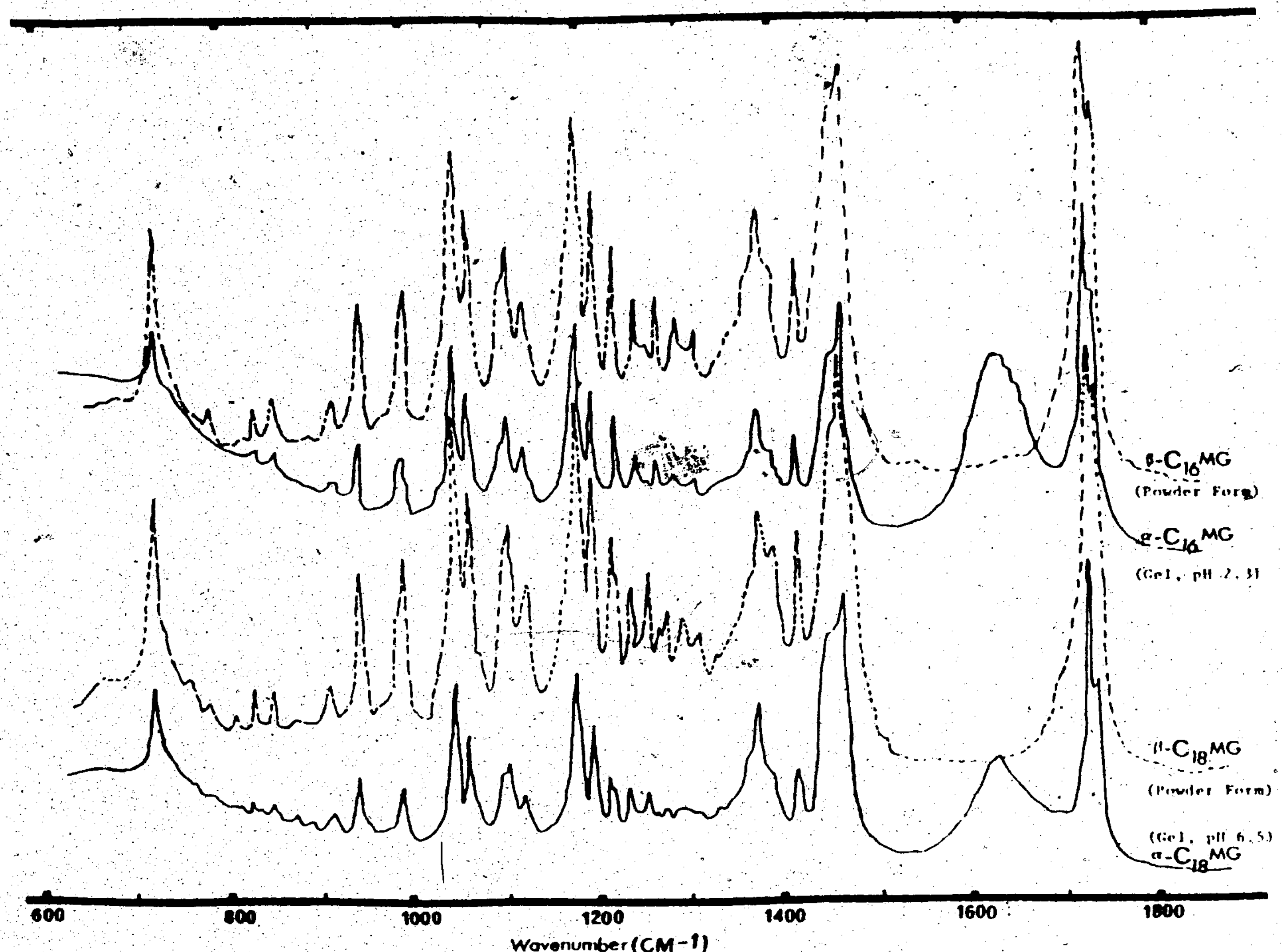


Figure 5.19. Infrared Spectra of The α-and β-Crystallinity Forms of the C_{16} and C_{18} Monoglycerides

Crystallinity	Bands, cm^{-1}									
α-C_{16}, Gel pH 2.3	1737	1630	1468	1375	1288	1181	1062	993	851	722
	1728		1415	1309	1277	1125	1048	945	831	
					1244	1105		915		
					1221					
					1200					
α-C_{18}, Gel pH.6.5	1739	1630	1468	1375	1255	1197	1062	991	851	720
	1729		1415		1235	1180	1048	945	841	
					1215	1125		915		
						1105				
β-C_{16}, Microbeads	1736		1468	1375	1288	1198	1062	992	851	782
	1728		1415	1308	1265	1180	1048	945	830	722
					1244	1122		915		
					1220	1105				
β-C_{18}, Microbeads	1737		1468	1390	1292	1195	1061	991	851	782
	1728		1415	1375	1272	1180	1048	944	830	721
				1329	1268	1122		912	810	
				1310	1255	1105				
					1242					
					1235					
					1215					

Table 5.23. The Major Infrared Spectra Absorption Frequency Bands of the α and β-Crystallinity Forms of C_{16} and C_{18} Monoglycerides.

Table 5.24 Monoglyceride Infrared Spectra Absorption Bands Specific to the α or β-Crystallinity Forms

Type C_{16} Bands, α-		Type C_{16} Bands, β-		Type C_{18} Bands, α-		Type C_{18} Bands, β-	
Absent	Present	Absent	Present	Absent	Present	Absent	Present
782			782		782	782	
				830			830
				810			810
	915	915					
1198			1198				
							1292
				1272			1272
				1268			1268
	1265	1265					
				1242			1242
	1200	1200					
				1390			1390
				1329			1329
				1310			1310
	1630	1630			1630	1630	

Symmetrical C-H band of methyl groups occurs at 1380 cm^{-1}. C-O stretching of primary and secondary -OH groups occur at 1050, 1064, and 1180 cm^{-1}. Bands ranging from 940-995 cm^{-1} are due to C-C single bond stretch. Rocking vibrations of the methylene group occur at 720 cm^{-1}.

In spite of similarities, the β-crystallinity form is characterized by the C-O stretching of the primary -OH groups at 1062 cm^{-1}, which is absent in α-crystallinity form. The α- and β- forms are also differentiated at 1705 cm^{-1} due to carbonyl-water hydrogen bonding which is present only in the α-form. Hence, the presence or absence of these bands can be used to distinguish between the two crystallinity forms of the monoglycerides.

X-Ray Diffraction Patterns of α-and β-Crystallinity Forms of C_{16} and C_{18} Monoglycerides

The X-ray diffraction patterns of the monoglycerides are presented in Figure 5.20. Corresponding data are presented in Tables 5.25 and 5.26.

Medium peaks at 6.048 or 6.141° (2θ) and very strong ones at 21.316 or 21.357° (2θ) were characteristic of α-crystallinity forms of C_{16} and C_{18} monoglycerides. The latter had an extra weak peak at 5.312° (2θ).

β- C_{16} had only one weak peak at 10.132° (2θ), strong peaks at 7.399°, 512° (2θ) and very strong peaks at 19.452 and 22.601° (2θ), shouldered by smaller, but very strong peaks at 20.250 and 21.903° (2θ).

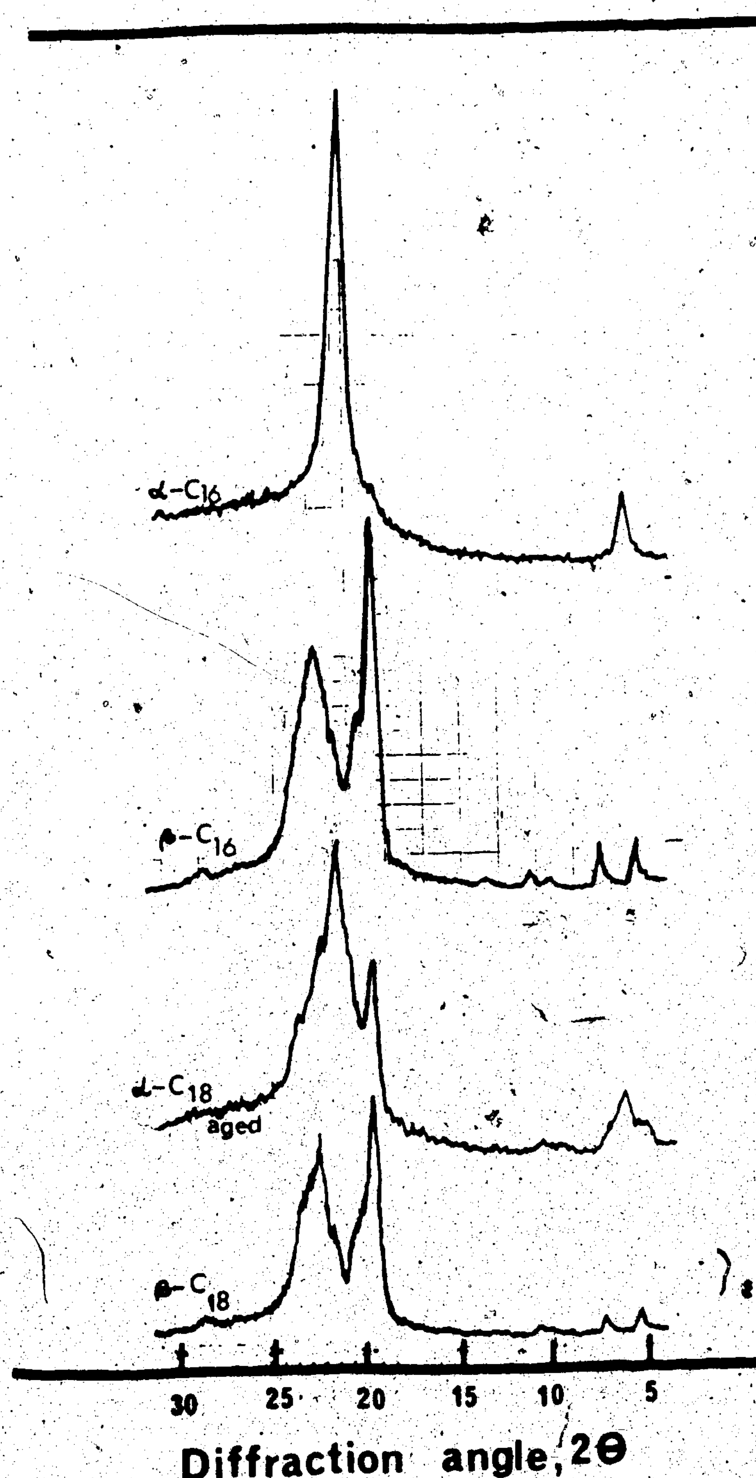


Figure 5.20. X-Ray Diffractograms of α- and β-C_{16} and C_{18} Monoglycerides

Table 5.25 X-Ray Diffraction Patterns of α- and β-Crystallinity Forms of C_{16} Monoglyceride

α-C_{16} Monoglyceride			β-C_{16} Monoglyceride		
°2θ	d, Å	Intensity cps	°2θ	d, Å	Intensity cps
6.048	14.6126	327	5.512	16.0327	450
21.316	4.1682	1957	7.399	11.9474	529
24.569	3.6233	338	10.132	8.7301	197
25.890	3.4413	329	11.156	7.9313	280
			13.505	6.5562	212
			19.452	4.5633	3755
			20.250	4.3937	1777
			22.601	3.9341	2518
			21.903	4.0578	1481
			28.479	3.1341	359

In this and the following tables, the diffusion line intensity

strong (s) > cps 400
medium (m) 200-399
weak (w) < 200

Table 5.26. X-Ray Diffraction Patterns of α- and β-Crystallinity Forms of C_{18} Monoglycerides

α-C_{18} Monoglyceride			β-C_{18} Monoglyceride		
°2θ	d, Å	Intensity cps	°2θ	d, Å	Intensity cps
5.312	16.6375	162	5.465	16.1697	212
6.141	14.3929	283	7.266	12.1666	173
10.468	8.4505	114	10.703	8.2655	120
19.562	4.5378	814	13.462	6.5772	96
21.357	4.1604	1261	15.990	5.5426	131
23.151	3.8419	624	19.718	4.5023	2308
26.469	3.3674	292	22.643	3.9269	1812
29.182	3.0601	239	26.879	3.3169	255
			28.699	3.1105	252

β-C_{18} X-ray diffractogram had more weak peaks than C_{16} located at 7.266, 10.703 and 13.462° (2θ). It had two strong peaks at 19.718 and 22.643° (2θ) without the existence of shoulder peaks as obseved for β-C_{16}.

Amylose Complexing Indices

Monoglyceride complexing with starches, expressed as percentage, is presented in Figures 5.21 and 5.22 for α- and β-C_{16}, and for C_{18} with arrowroot starch. The corresponding data are provided in Tables 5.27 and 5.28.

The percent complexing indices of a monoglyceride for starch increased from ungelatinized to gelatinized and solubilized starches. Monoglycerides in their α-crystallinity were more reactive than in their β-crystallinityforms. The differences between the two were, however, small for ungelatinized starch, but widened for the gelatinized and even further for the solubilized starch. Palmitic acid monoglycerides tended to complex more with starch than stearic acid monoglyceride.

Data for cassava, sweet potato, taro, yam and wheat (cvs. Fielder and Neepawa) starches were similar to arrowroot, but of different magnitude. They are presented in Appendices 5-16. Optimum complexi[illegible] observed in the presence of about 0.5% monoglycerides on DWB of starch (Figures 5.21 and 5.22).

X-Ray Diffraction Analysis of Starch-Monoglyceride Clathrates

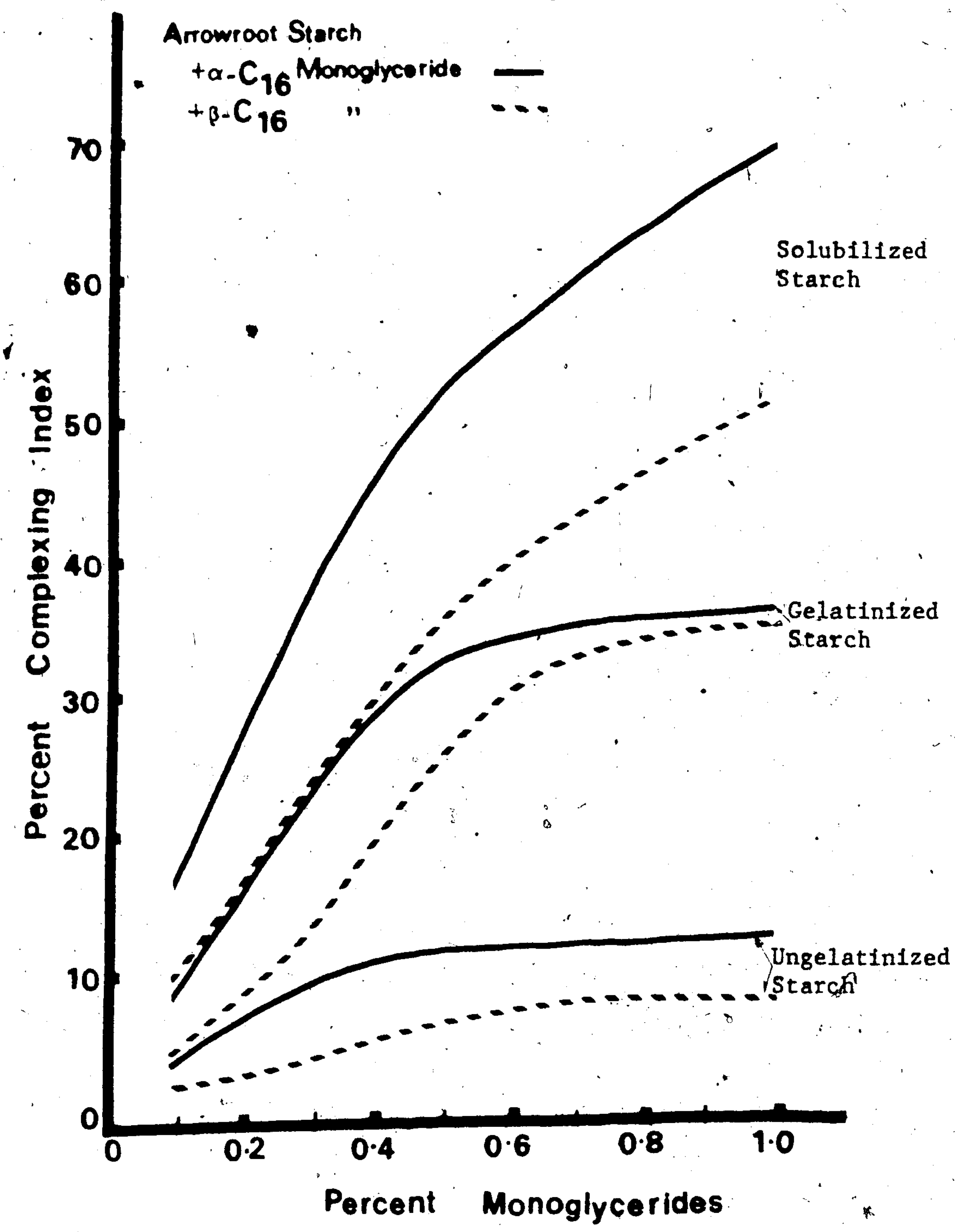


Figure 5.21, Arrowroot Starch Interaction with Type C_{16} Monoglycerides

Table 5.27. Percent Complexing Indices for the Interaction of the α-Crystallinity Forms of C_{16} and C_{18} Monoglycerides with Arrowroot Starch

	Arrowroot Starch*					
	Ungelatinized		Gelatinized		Solubilized	
% MG***	C_{16}	C_{18}	C_{16}	C_{18}	C_{16}	C_{18}
0.1	3.97±0.58**	3.77±0.41	8.48±0.17	5.86±0.08	16.96±2.13	13.33±0.41
0.2	7.16±1.36	6.96±0.82	16.95±0.30	12.53±2.13	29.17±1.39	27.60±0.78
0.3	10.43±1.14	10.15±0.40	23.10±0.77	16.23±0.82	37.50±0.97	37.02±0.94
0.4	11.13±1.44	11.59±0.01	29.82±1.03	21.02±1.03	47.73±1.93	44.50±0.21
0.5	11.72±1.25	12.20±0.04	33.09±1.54	24.38±0.86	52.18±0.25	49.71±0.61
0.8	12.03±1.36	12.46±0.00	35.64±1.03	31.45±0.21	64.32±2.64	53.94±0.45
1.0	12.25±1.36	12.73±0.04	37.42±0.57	34.20±0.82	70.18±1.03	55.75±0.96

*In this and following tables: the starch was previously lintnerized with 7.5% HCl at 40°C for 72 hrs.

**Complexing Index (A_{680} nm), percent = $\frac{A_{TA}-A_{RA}}{A_{TA}} \times 100$

where A_{TA}, absorbance$_{680nm}$ of starch amylose complex with iodine, before starch interaction with monoglycerides, and A_{RA}, absorbance of residual amylose complexed with iodine after starch interaction with monoglycereides, per gram dry matter of ungelatinized, gelatinized or solubilized starch samples.

*** MG, Monoglyceride

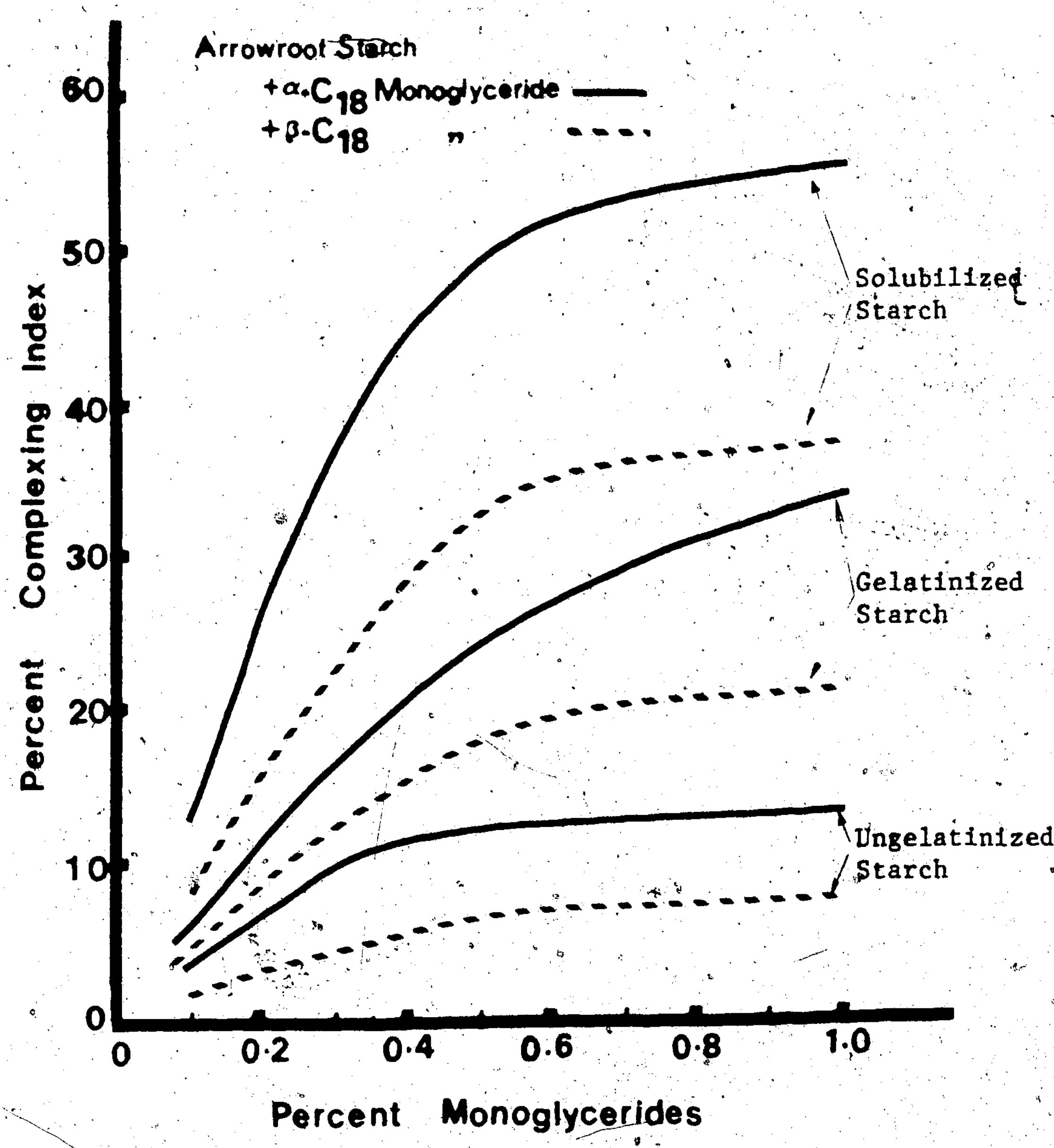


Figure 5.22. Arrowroot Starch Interaction with Type C_{18} Monoglyceride

Table 5.28 Percent Complexing Indices for The Interaction of the β-Crystallinity Forms of C_{16} and C_{18} Monoglycerides with Arrowroot Starch

	Arrowroot Starch					
	Ungelatinized		Gelatinized		Solubilized	
%MG	C_{16}	C_{18}	C_{16}	C_{18}	C_{16}	C_{18}
0.1	1.67±0.58	1.37±0.01	4.37±0.24	3.60±0.91	10.24±0.69	7.78±1.06
0.2	2.87±0.81	2.67±0.39	9.04±1.15	8.05±0.06	15.36±0.45	15.91±0.87
0.3	4.06±1.06	4.17±0.05	12.81±1.26	12.08±0.90	22.87±0.55	23.38±1.30
0.4	5.25±1.31	5.14±0.06	19.64±2.18	15.25±0.60	29.70±0.45	29.59±2.56
0.5	5.90±1.29	6.13±0.16	26.47±1.94	18.43±0.90	36.53±0.14	32.84±2.41
0.8	7.64±0.82	7.29±0.07	34.47±2.11	20.55±0.09	51.35±0.09	35.36±1.54
1.0	8.33±0.81	7.44±0.09	42.21±3.32	21.82±0.90	61.43±0.88	39.36±0.05

Gallant *et al.* (1982) stated that native starches have either an A, B, or C X-ray diffraction pattern. Pattern A is commonly given by cereal starches and is referred to as the 'cereal type'. The B pattern occurs mainly in tuber starches and is referred to as the 'tuber type'. The C pattern is intermediate between A and B.

The A pattern has two peaks between 16 and 18° (2θ) and one peak at 24°(2θ). Type B pattern has one peak at at 17°(2θ) and two peaks at 23 and 24, and one at 5°44'(2θ).

If fat-amylose complexes are present, they give an X-ray pattern with a strong peak at 4.4 Å d spacing (Varriano-Marston *et al.* 1980). Amylose interaction with surfactants or monoglycerides give the v-type X-ray diffraction pattern. It is characterised by another strong peak at d spacing of 6.8 Å (Ghiasi *et al.* 1982).

X-ray diffractograms of ungelatinized, gelatinized, and solubilized arrowroot starch with α-C_{16} monoglyceride are presented in Figure 5.23. The corresponding data for the X-ray diffraction patterns are provided in Table 5.29.

Similar patterns for wheat (cv. Neepawa) starch are provided in Figure 5.24 and Table 5.30 for comparison.

X-ray diffractograms to compare wheat (cv. Neepawa) and yam starch clathrates with α-C_{16} and β-C_{18} monoglycerides are given in Figure 5.25 and Tables 5.31 and 5.32.

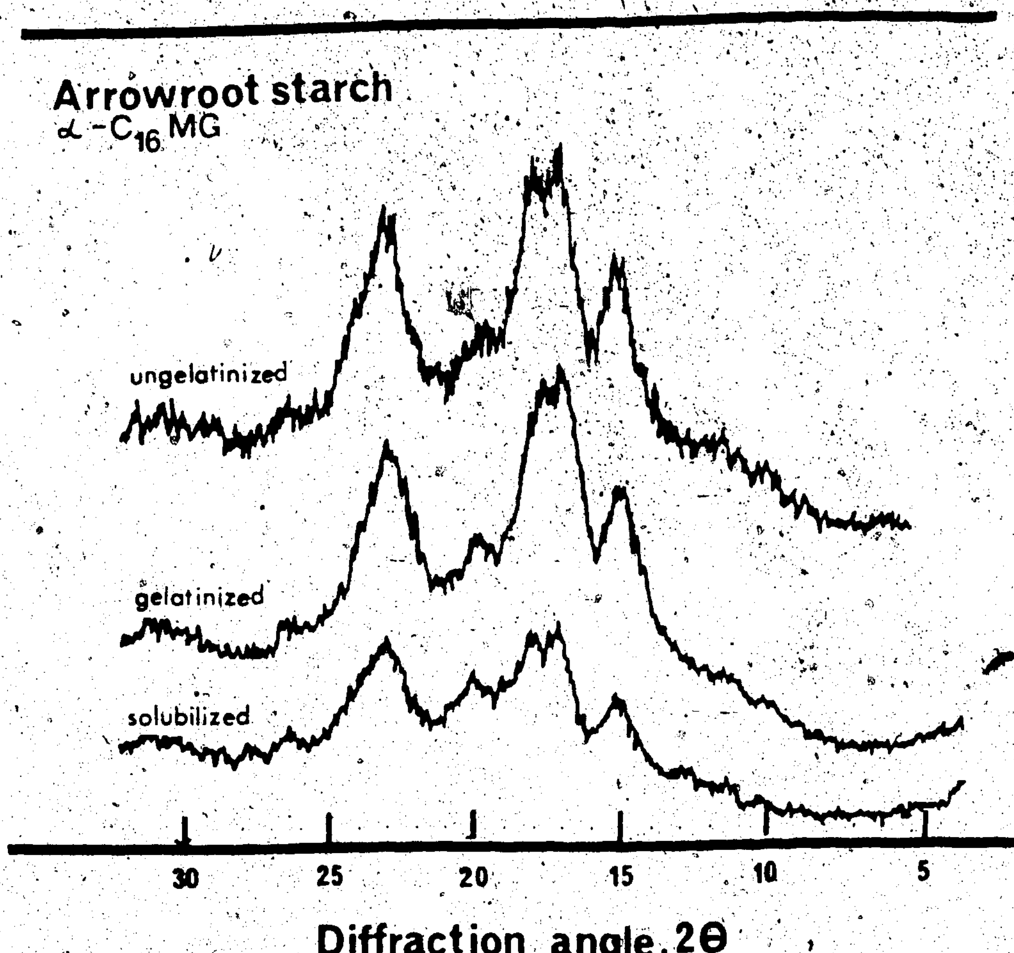


Figure 5.23. X-Ray Diffractograms of Arrowroot Starch Clathrates with α-C_{16} Monoglyceride

Table 5.29. X-Ray Diffraction Patterns of Arrowroot Starch Clathrates with α-C_{16} Monoglyceride

Arrowroot Starch								
Ungelatinized			Gelatinized			Solubilized		
°2θ	d, Å	Intensity cps	°2θ	d, Å	Intensity cps	°2θ	d, Å	Intensity cps
9.932	8.9057	148	14.997	5.9073	389	10.190	8.6808	87
11.572	7.6469	191	17.140	5.1731	524	14.936	5.9312	199
14.983	5.9127	404	17.633	5.0295	522	17.135	5.1746	299
17.046	5.2015	538	19.832	4.4766	329	18.046	4.9156	277
19.620	4.5246	330	26.326	3.3853	403	20.060	4.4262	247
22.918	3.8803	448	23.646	3.7625	326	23.373	3.8058	260
26.227	3.3978	243	26.535	3.3591	224	26.425	3.3728	171
28.835	3.0961	219	31.188	2.8678	230			
30.352	2.9447	224						

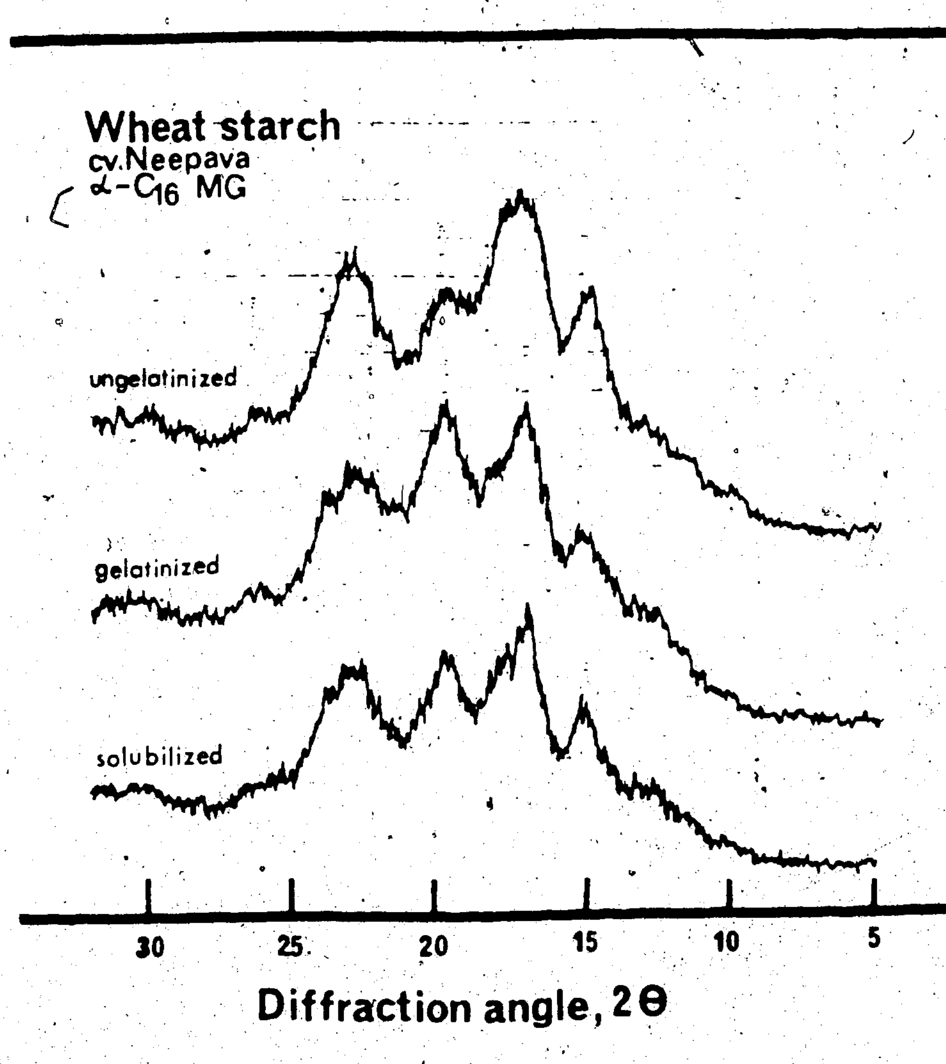


Figure 5.24. X-Ray Diffractograms of Wheat, cv. Neepawa Starch Clathrates with α-C_{16} Monoglycerides

Table 5.30. X-Ray Diffraction Patterns of Wheat, cv. Neepawa Starch Clathrates with α-C_{16} Monoglycerides

Wheat, cv. Neepawa Starch								
Ungelatinized			Gelatinized			Solubilized		
$^o2\theta$	d, Å	Intensity cps	$^o2\theta$	d, Å	Intensity cps	$^o2\theta$	d, Å	Intensity cps
9.939	8.8989	116	11.687	7.5720	158	13.216	6.6989	185
11.549	7.6621	155	12.614	7.0176	195	14.968	5.9187	262
15.063	5.8817	353	15.274	5.8007	301	16.997	5.2163	383
17.082	5.1908	446	17.136	5.1744	462	17.710	5.0079	348
19.804	4.4830	359	19.769	4.4908	458	19.584	4.5328	325
22.964	3.8727	388	22.440	3.9619	376	22.584	3.9370	320
26.233	3.3970	206	23.706	3.7532	348	23.033	3.8612	318
28.794	3.1005	193	26.041	3.4217	234	23.785	3.7408	299
29.929	2.9854	214	31.391	2.8496	221	28.206	3.1637	163
31.009	2.8839	218						

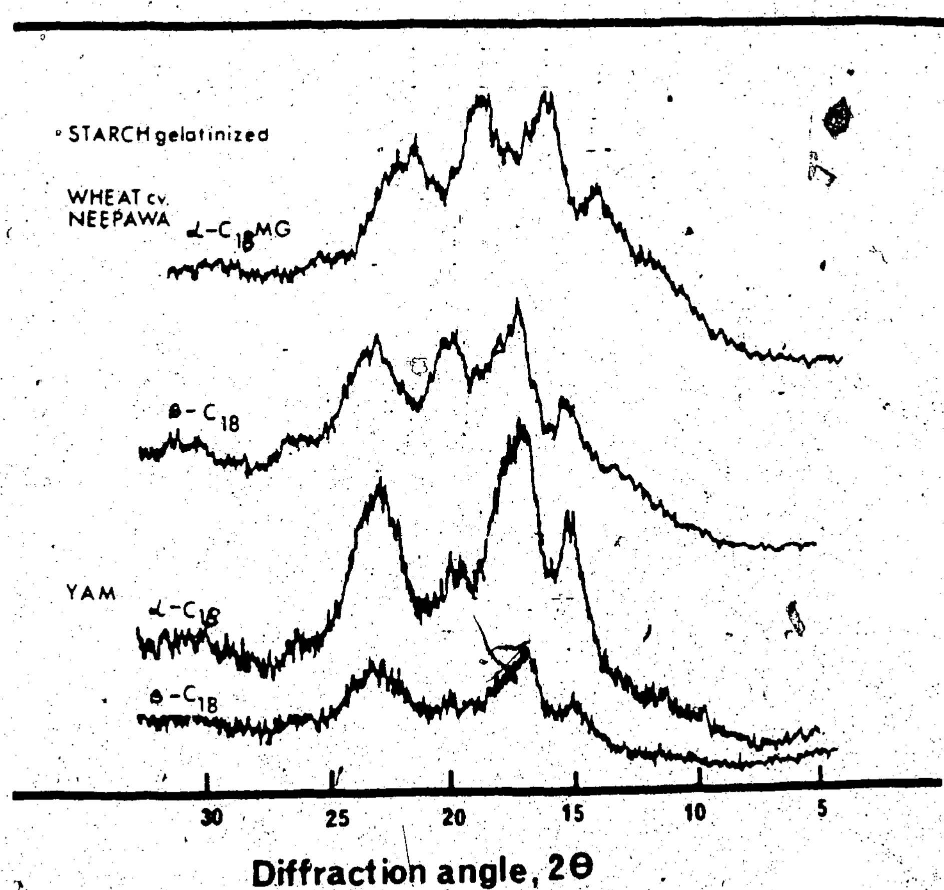


Figure 5.25. X-Ray Diffractograms of Gelatinized Wheat, cv. Neepawa and Yam Starches Clathrates with α-C_{16} and β-C_{18} Monoglycerides

Table 5.31 X-Ray Diffraction Patterns of Gelatinized Wheat, cv. Neepawa Starch Clathrates with α- and β-C_{18} Monoglycerides

α-C_{18} Monoglyceride			β-C_{18} Monoglyceride		
°2θ	d, Å	Intensity cps	°2θ	d, Å	Intensity cps
11.664	7.5866	166	13.253	6.6805	180
12.822	6.9041	214	15.222	5.8206	273
14.231	6.2235	262	17.103	5.1844	411
15.116	5.8610	331	17.881	4.9606	362
17.233	5.1454	452	19.692	4.5081	376
19.734	4.4988	452	22.929	3.8785	376
22.480	3.9549	397	26.420	3.3734	228
23.182	3.8368	361	30.133	2.9656	225
26.238	3.3964	225	31.121	2.8738	220

Table 5.32. X-Ray Diffraction Patterns of Gelatinized Yam Starch Clathrates with β- C_{16} and C_{18} Monoglycerides

Yam Starch, Gelatinized					
β-C_{16} Monoglyceride			β-C_{18} Monoglyceride		
$^{o}2\theta$	d, Å	Intensity cps	$^{o}2\theta$	d, Å	Intensity cps
15.395	5.7553	305	15.174	5.8386	123
17.350	5.1112	448	17.055	5.1988	190
19.730	4.4996	283	20.095	4.4186	143
23.228	3.8292	373	23.353	3.8091	191
26.471	3.3671	206	24.069	3.6973	171
31.073	2.8781	216			

Clathrates obtained from ungelatinized, gelatinized and solubilized cassava, sweet potato, taro and yam starches with α-C_{18} were found similar to arrowroot or wheat starch clathrates. Their X-ray diffractograms and patterns are presented in Appendices 17-24.

The X-ray diffraction patterns as a whole showed that the diffractogram peaks became more defined when interaction with monoglyceride was preceeded by geletinization or solubilization of the starch. Some peaks originally present in the ungelatinized starch disappeared or became diminished in the gelatinized and solubilized starch. This was observed in both root and wheat starch clathrates with the monoglycerides.

5.2.6 Starch Affinity for Gluten

The affinities of ungelatinized and gelatinized starch for gluten in systems simulating the dough, early and fully baked stages of bread making for wheat (cvs. Fielder and Neepawa), and for arrowroot, cassava, sweet potato, taro and yam starches are presented in Table 5.33.

Wheat starches were observed to have lower affinities for gluten in the dough than root starches. The affinity values of the wheat starches for gluten however tripled (CWRSW) or more than trippled (SWSW) in early baking, but declined to about 1.5 times of their initial values in the fully baked systems.

Table 5.33 Starch Affinity for Gluten

Starch	Percent Affinity		
	Undenatured Gluten		Denatured Gluten
	+ Ungelatinized Starch (A)***	+ Gelatinized Starch (B)	+ Gelatinized Starch (C)
Wheat (cv. Neepawa)*	31.82 ± 3.99	88.61 ± 1.79	45.11 ± 0.78
Wheat (cv. Fielder)**	24.91 ± 0.81	89.57 ± 1.75	41.29 ± 0.39
Arrowroot	50.27 ± 2.02	83.57 ± 2.86	41.01 ± 1.33
Cassava	48.46 ± 7.46	82.05 ± 2.9	49.04 ± 2.99
Taro	41.37 ± 4.02	89.95 ± 1.60	40.99 ± 1.48
Yam	40.79 ± 2.47	91.49 ± 2.74	28.46 ± 1.53
Sweet Potato	39.92 ± 2.19	89.12 ± 1.40	43.99 ± 0.86

*CWRSW - Canadian Western Red Spring Wheat

**SWSW - Soft White Spring Wheat

***A represents the dough, B the early baking, and C the fully baked stages of breadmaking.

Root starches doubled their dough affinity for gluten values in early baking, hence equalling the wheat starches, but declined to about their initial values in fully baked stage. Exceptions were arrowroot and yam,whose affinities for vital gluten were lower in the fully baked system than in the dough.

5.3 B. BREAD

5.3.1 Dough Rheological Properties

Farinographic rheological data for the root starch/vital gluten composite doughs are presented in Table 5.34. Similar data for wheat (cvs. Neepawa and Fielder) flours and their starch/vital gluten composite doughs are provided in Table 5.35. Representative farinograms for starch/vital gluten doughs of arrowroot, cassava and wheat (cv. Neepawa) are given in Figures 5.26, 5.27, and 5.30 respectively. For comparison, farinograms for wheat (cvs. Neepawa and Fielder) flours are also given in Figures 5.28 and 5.29. Corresponding farinograms for sweet potato, taro, yam and wheat (cv. Fielder) starch/vital gluten composite doughs are provided in Appendices 25-28.

5.3.1.1 Water Absorption

Percent water absorptions of the various flours are included in Tables 5.34 and 5.35. Arrowroot starch/vital gluten composite flour had the highest water absorption (80.5%) while SWSW (cv. Fielder) starch/vital gluten

Table 5.34 Farinographic Data of Doughs from Tropical Root Starches with Vital Gluten Composite Flours

Sample	Percent Moisture Content	Percent* Absorption	Arrival Time in Minutes	Peak Time in Minutes	Dough Stability in Minutes	Departure Time in Minutes	Mixing** Tolerance Index (MTI)	20 Min Drop
Arrowroot Starch/Gluten Flour Composite	9.23±0.71	80.50±0.10	3.25±0.18	7.00±0.20	7.75±0.30	11.00±0.25	60.0±0.5	120.0±10.0
Cassava Starch/Gluten Flour Composite	14.23±0.41	64.70±0.10	2.00±0.16	4.50±0.25	8.25±0.20	10.25±0.30	60.0±0.7	130.0±10.0
Sweet Potato Starch/Gluten Flour Composite	8.96±0.26	68.80±0.20	2.50±0.10	3.50±0.10	4.20±0.10	6.70±0.20	145.0±5.0	190.0±10.0
Taro Starch/Gluten Flour Composite	13.51±0.26	68.4±0.15	3.00±0.15	3.80±0.18	1.80±0.20	4.80±0.20	120.0±5.0	190.0±10.0
Yam Starch/Gluten Flour Composite	10.35±0.22	68.50±0.10	2.30±0.20	4.00±0.10	10.20±0.10	12.50±0.10	48.4±3.0	80.0±5.0

*All farinographic data were based on a flour of 14% moisture.

**5 min after peak time.

Table 5.35 Farinographic Data of Doughs from Wheat Flours, and Their Starch-Vital Gluten Composites

Sample	Percent Moisture Content	Percent* Absorption	Arrival Time in Minutes	Peak Time in Minutes	Dough Stability in Minutes	Departure Time in Minutes	Mixing** Tolerance Index (MTI)	20 Min Drop
Neepawa Wheat Flour	8.91±0.13	68.40±0.20	3.80±0.15	6.00±0.20	6.70±0.10	10.50±0.20	26.0±5.0	45.0±5.0
Neepawa Starch/gluten Flour composite	9.82±0.38	60.40±0.10	1.75±0.10	6.50±0.10	11.75±0.15	13.50±0.15	25.0±3.0	45.0±5.0
Fielder Wheat Flour	11.67±1.55	56.80±0.49	0.80±0.10	1.20±0.10	0.90±0.10	1.70±0.10	120.0±5.0	150.0±10.0
Fielder Starch/gluten Flour composite	11.03±0.99	54.0±0.10	1.00±0.10	3.50±0.15	7.50±0.10	8.50±0.10	40.0±2.0	60.0±5.0

*All farinographic data were based on a flour of 14% moisture.

**5 min after peak time.

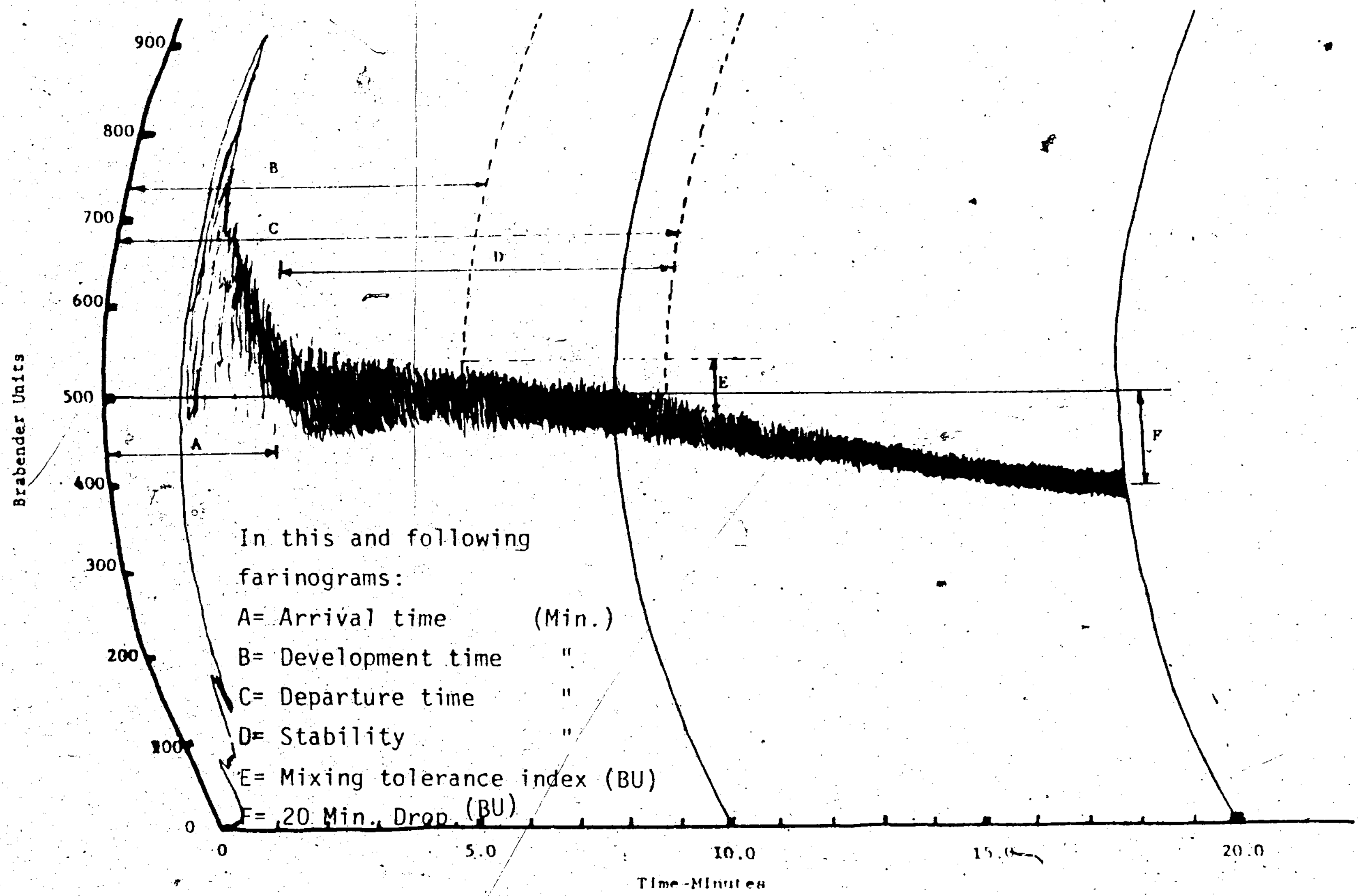


Figure 5.26. Arrowroot Starch-85%; Vital Gluten-15%, Composite Flour Dough Farinogram.

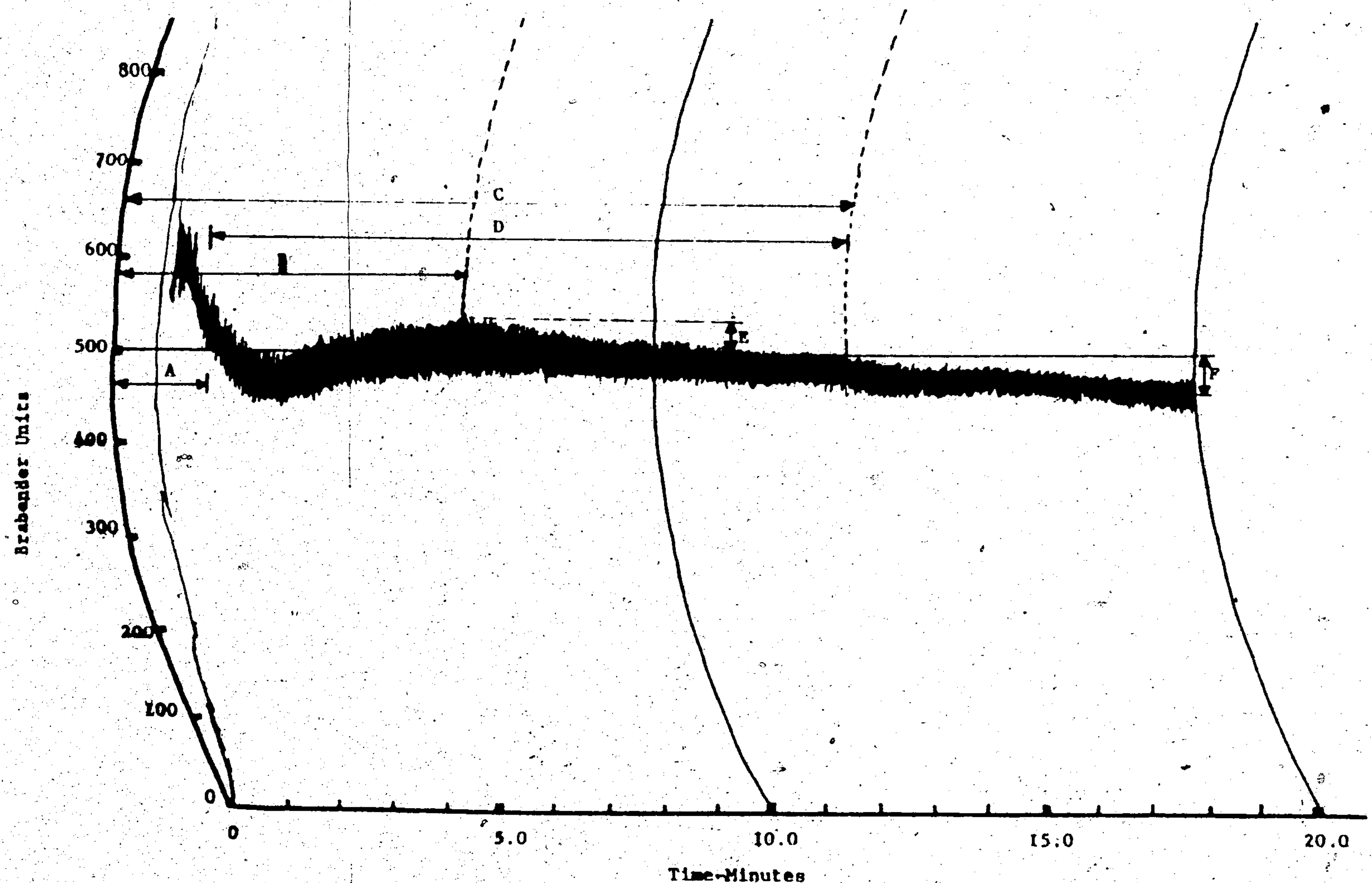


Figure 5.27 Cassava Starch-85%; Vital Gluten-15%, Composite Flour Dough Farinogram

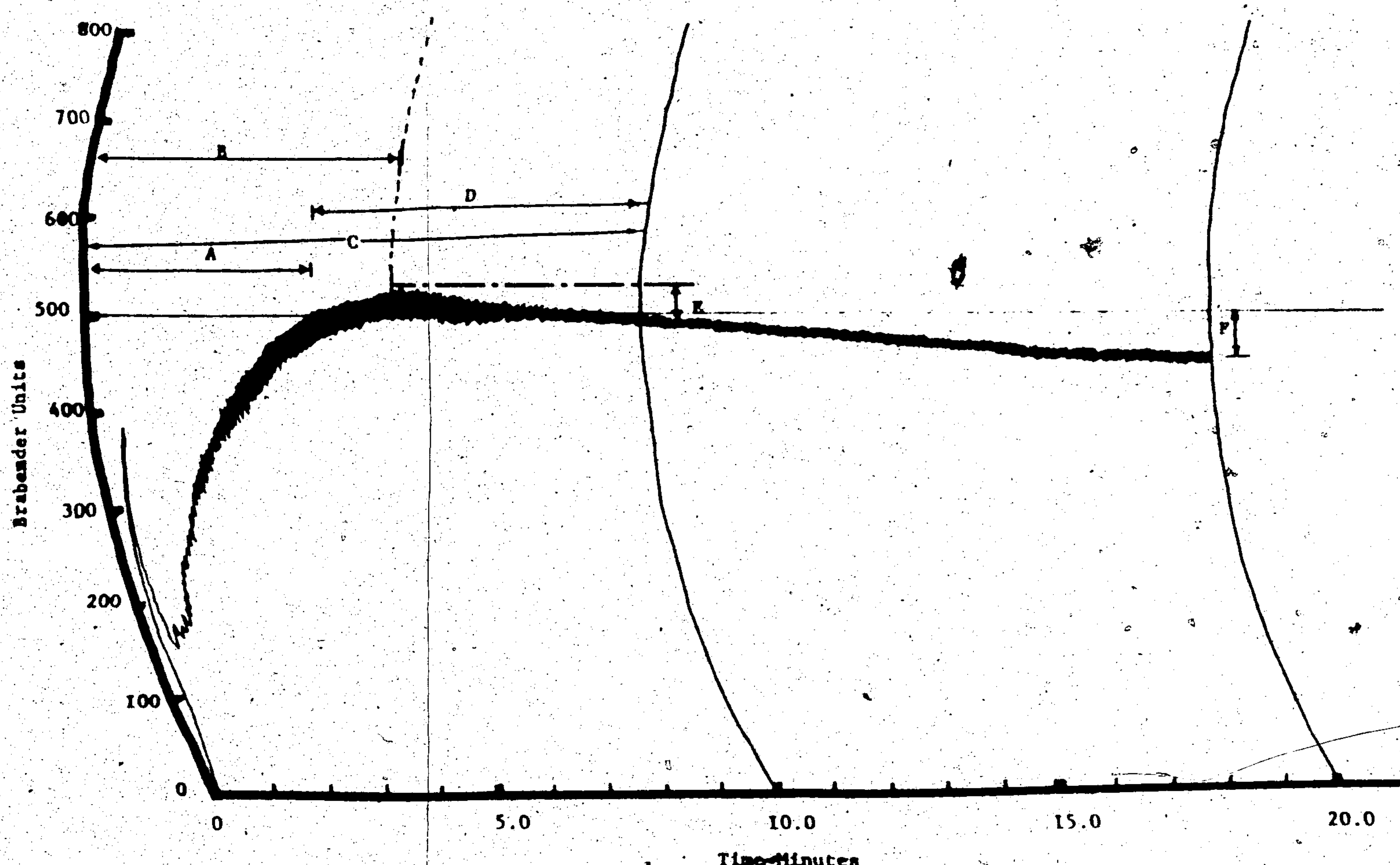


Figure 5.28. Wheat, cv. Neepawa, Flour Dough Farinogram

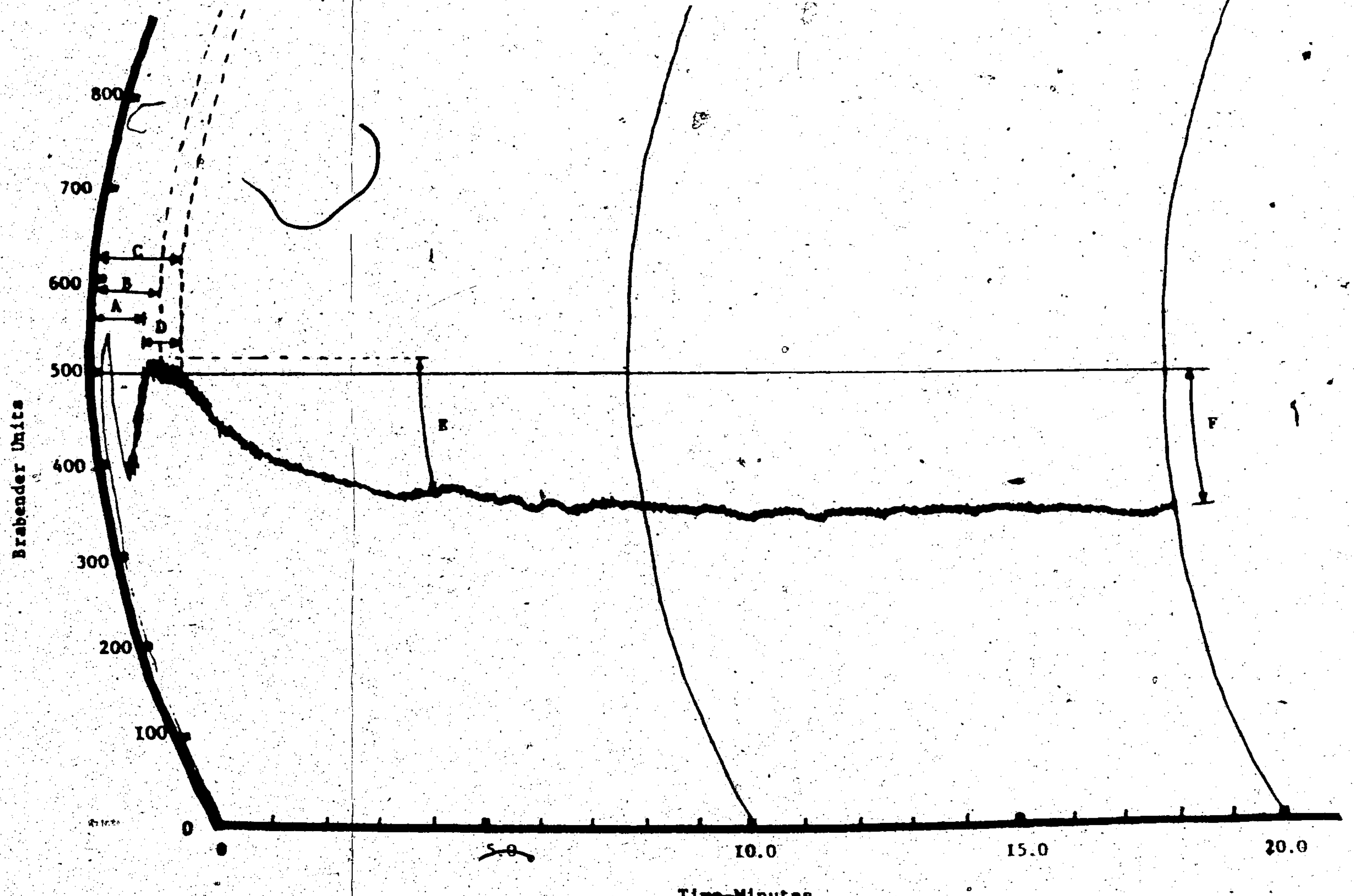


Figure 5.29 Wheat, cv. Fielder, Flour Dough Farinogram

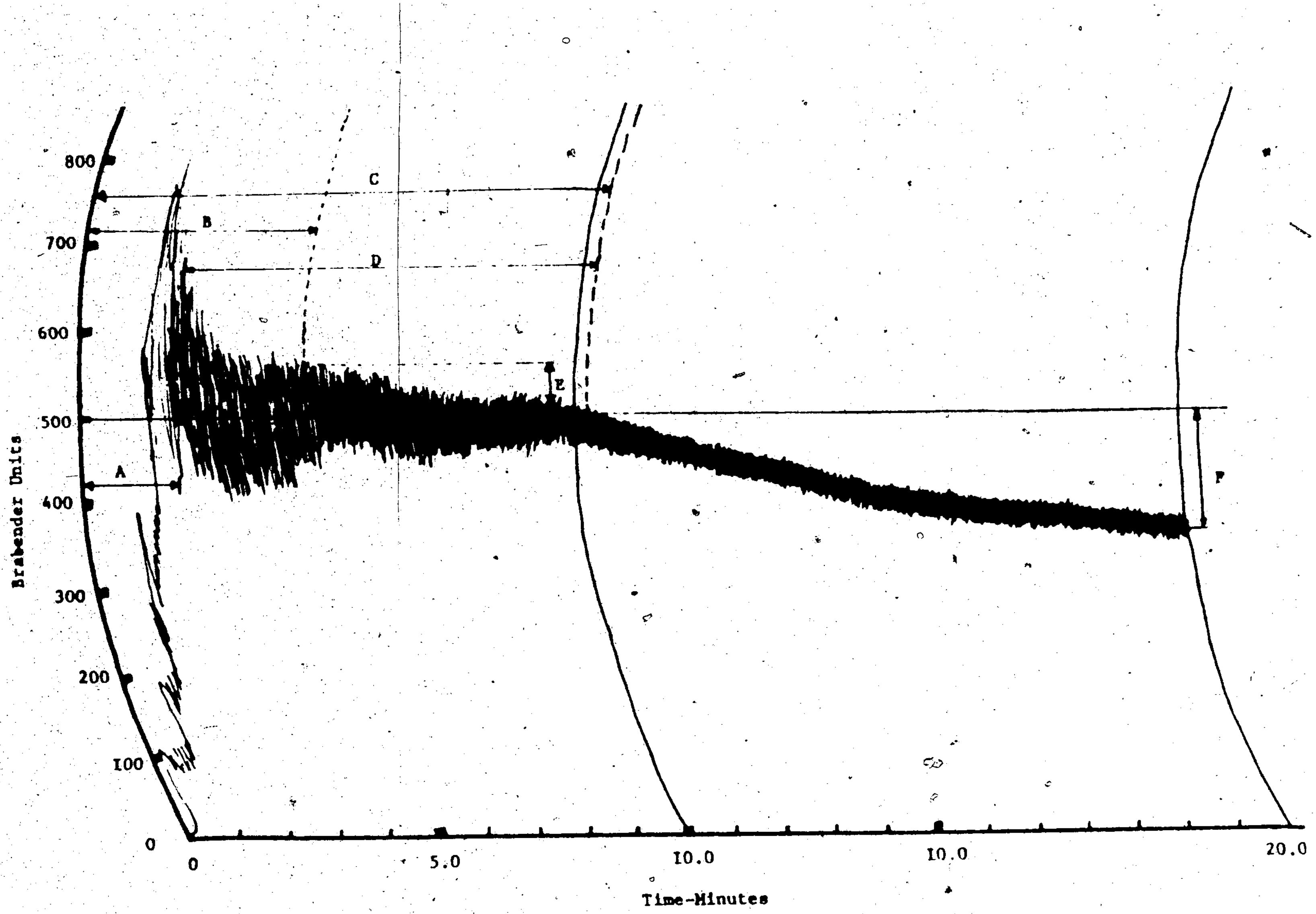


Figure 5.30 Wheat, cv. Neepawa Starch-85%; Vital Gluten-15%,

Composite Flour Dough Farinogram

composite flour had the lowest (54.0%). Similar composite flours with sweet potato, taro, and yam starches had practically the same water absorption (68.4-68.8%), which was similar to absorption by CWRSW (cv. Neepawa) flour (68.4%). Cassava starch/vital gluten composite flour had intermediate water absorption of 64.7%. Data in Table 5.35 show that the wheat flours had higher absorptions than their corresponding starch/vital gluten composites, but cv. Fielder flour and its starch composite with vital gluten had lower water absorption than their CWRSW (cv. Neepawa) counterparts.

5.3.1.2 Dough Physico-Mechanical Properties

CWRSW (cv. Neepawa) flour had the longest arrival time of 3.80 min., compared to the shortest arrival time of 0.80 min. for SWSW (cv. Fielder) flour. Root starch/vital gluten composite flours had longer arrival times (2.0-3.25 min.) than soft wheat flour, but shorter than the corresponding time for the hard wheat flour. The data in Table 5.35 show further that, whereas CWRSW starch composite with vital gluten had inferior arrival times in comparison to the flour, the opposite was true for SWSW.

Dough development times for CWRSW flour (6.0 min.) and its starch/gluten composite (6.5 min.) were found to be practically the same. There was however significant difference between the development times of SWSW flour (1.20 min.) and its starch/gluten composite (3.50 min.). Root starch/vital gluten composites required less time

(3.50-4.50 min.) than CWRSW flour or its starch/vital gluten composite to reach the same consistency. Arrowroot starch/vital gluten composite was the exception, with a development time of 7.0 min. Whereas Fielder flour dough required a shorter time to reach similar consistencies as the other doughs, its starch/vital gluten composite was close to similar composites involving the root starches.

It was further observed that starch/gluten composite dough of wheat starches had better stability than the respective flour doughs. The dough stability change of 0.9 min. for SWSW flour to 7.5 min. for its starch composite with gluten was large. A similar change from 6.70 min. for flour to 11.75 min. for starch/gluten composite dough, was observed for CWRSW.

Arrowroot and cassava starch composites with vital gluten doughs were close in stability to SWSW starch/vital gluten composite and CWRSW flour doughs. SWSW flour dough had the least stability, as shown in Table 5.35. CWRSW starch/vital gluten composite had the longest stability (11.75 min). Yam starch/vital gluten composite was close to CWRSW with a stability of 10.20 min. Of the root starch composites with vital gluten doughs, taro starch had the least stability (1.80 min), followed by sweet potato starch (4.20 min.).

In relation to the mixing tolerance, root starch/vital gluten doughs broke down faster in their consistencies than the CWRSW flour or its starch or SWSW starch/vital gluten composite dough. Composite doughs of vital gluten with sweet potato and taro starches had very poor stabilities (Table 5.34), as did SWSW flour dough (Tables 5.35).

5.3.2 Dough and Crumb Hydration Capacities

The dough and crumb hydration capacities are given in Table 5.36. All dough hydration capacities were very low as compared to their crumb hydration capacities.

Arrowroot and taro/vital gluten doughs had negative hydration capacities. The other doughs and all their bread crumbs had positive hydration capacities.

Wheat (cv. Fielder) and yam starch composites with gluten doughs had the highest hydration capacities. It was observed that wheat flour doughs had lower hydration capacities than their respective starch/vital gluten composite doughs. Furthermore, SWSW flour dough had higher hydration capacity than the CWRSW flour dough. A similar relation was evident in the case of their starch vital/gluten doughs.

CWRSW (cv. Neepawa) flour bread crumb had lower hydration capacity than corresponding crumb from SWSW. The reverse relationship was observed for their starch/vital gluten composite bread crumbs. Although yam starch/vital gluten dough had higher hydration capacity than all others, except SWSW starch/vital gluten dough, its crumb had the lowest hydration capacity (2.65g/g DMB). The highest hydration capacity of 6.557g/g DMB was obtained for taro

Table 5.36 Dough and Crumb Hydration Capacities - Water, g/g Dry Solids

	Dough**	Crumb	Gelatinization*** Hydration
Wheat flour, cv. Neepawa	0.061 ± 0.010	3.640 ± 0.060	3.579.0
Wheat flour, cv. Fielder	0.092 ± 0.003	4.480 ± 0.120	4.388.0
Wheat starch cv. Neepawa + gluten*	0.125 ± 0.025	5.370 ± 0.120	5.245.0
Wheat starch cv. Fielder + gluten	0.269 ± 0.025	4.030 ± 0.020	3.761.0
Arrowroot starch + gluten	0.083 ± 0.012+	3.290 ± 0.260	3.373.0
Cassava starch + gluten	0.043 ± 0.004	6.600 ± 0.143	6.557.0
Sweet potato starch + gluten	0.083 ± 0.008	4.120 ± 0.070	4.037.0
Taro starch + gluten	0.100 ± 0.001+	3.140 ± 0.200	3.240.0
Yam starch + gluten	0.253 ± 0.049	2.650 ± 0.140	2.397.0

*Starch and vital gluten were used at 85% and 15%,, respectively.

**Dough formulation: Flour 100% (or 85% starch + 15% vital gluten); sugar 7%; salt 1.5%; yeast 3.0%; water - variable to give doughs of same consistency.

***Gelatinization hydration = crumb hydration capacity - dough hydration capacity.

+Negative hydration capacity

starch/vital gluten bread crumb. In all cases, high increases in hydration capacity from a change of dough to the crumb system were observed.

5.3.3 Fractional Volume Increases

Volume changes (cm^3) from the dough to bread, expressed as a fraction of the original dough volume, are presented in Table 5.37.

Bread from CWRSW flour had the highest fractional volume increase (1.68 cm^3) followed by SWSW flour (1.65 cm^3. The composite of CWRSW starch with vital gluten had a higher fractional volume increase (1.49 cm^3) than the increase of 1.19 cm^3 observed for SWSW starch/vital gluten composite. Generally, wheat flours and starch composites with gluten showed higher volume changes from the dough to the bread than the composites of the root starches with vital gluten.

Of the composite involving the root starches, arrowroot had the highest fractional volume increase (0.96), while taro had the smallest (0.49 cm^3). Cassava, sweet potato and yam starch/vital gluten composites were close to each other in the extent of their fractional volume increases (0.64-0.7 cm^3).

5.3.4 Dough and Bread Crumb Microstructure

5.3.4.1 Dough Microscopy

Table 5.37 Fractional Volume Increases, cm^3

Type of Dough-Bread System	$\frac{V-Vo}{Vo}$ cm^3
Wheat flour, cv. Neepawa	1.68 ± 0.09
Flour, cv. Fielder	1.65 ± 0.09
Neepawa starch 85% + gluten 15%*	1.49 ± 0.23
Fielder starch 85% + gluten 15%	1.19 ± 0.19
Tropical starches 85% + gluten* 15%	
Arrowroot	0.96 ± 0.12
Cassava	0.70 ± 0.12
Sweet potato	0.64 ± 0.21
Taro	0.49 ± 0.13
Yam	0.67 ± 0.04

*Vital gluten.

**Vo = Volume of 50g of dough.

V = Volume of the bread loaf.

The microscopic surface properties of doughs derived from the various tropical root starch/vital gluten composites are presented in Plates 5.7, 5.8, and 5.9. In Plate 5.10 are portrayed dough surface properties of wheat (cvs. Neepawa and Fielder) flour doughs, while related wheat starch/gluten composite dough surfaces are given in Plate 5.11.

For each sample, micrographs of typical undisturbed and fractured surfaces are provided. The fractured surface micrographs elucidated the internal association between the gluten films and the starch granules (also see Plate 5.16).

5.3.4.2 Bread Crumb Microscopy

The tropical root starch/vital gluten composite bread crumb surfaces, as shown by SEM, are presented in Plates 5.12 and 5.13. Plates 5.14 and 5.15 show similarly related features of bread crumb surfaces of wheat, cv.Fielder starch/vital gluten, and cv. Neepawa starch/vital gluten; and their pure flours.

5.3.4.3 Transmission Electron Microscopy of Dough and Bread Crumb

Transmission electron micrographs of arrowroot starch/vital gluten dough and bread crumb are presented in Plate 5.16 as an example elucidating the internal association between gluten film and starch granules in the dough and bread crumb. Unswollen starch granules in the dough and swollen gelatinized granules in the bread crumb

Plate 5.7. SE-Micrographs of Arrowroot Starch/Vital Gluten (a, b), and Taro Starch/Vital Gluten (c, d) Composite Dough Surfaces. Typical Surfaces(a, x4,940; c, x1,260). Fractured Surfaces (b, x4,940; d, x1,210).

Plate 5.8. SE-Micrographs of Cassava Starch/Vital Gluten (a, b), and Sweet potato Starch/Vital Gluten (c, d) Dough Surfaces. Typical Surfaces (a, x1,260; c, x5,110). Fractured Surfaces(b, x1,280; d, x4,940).

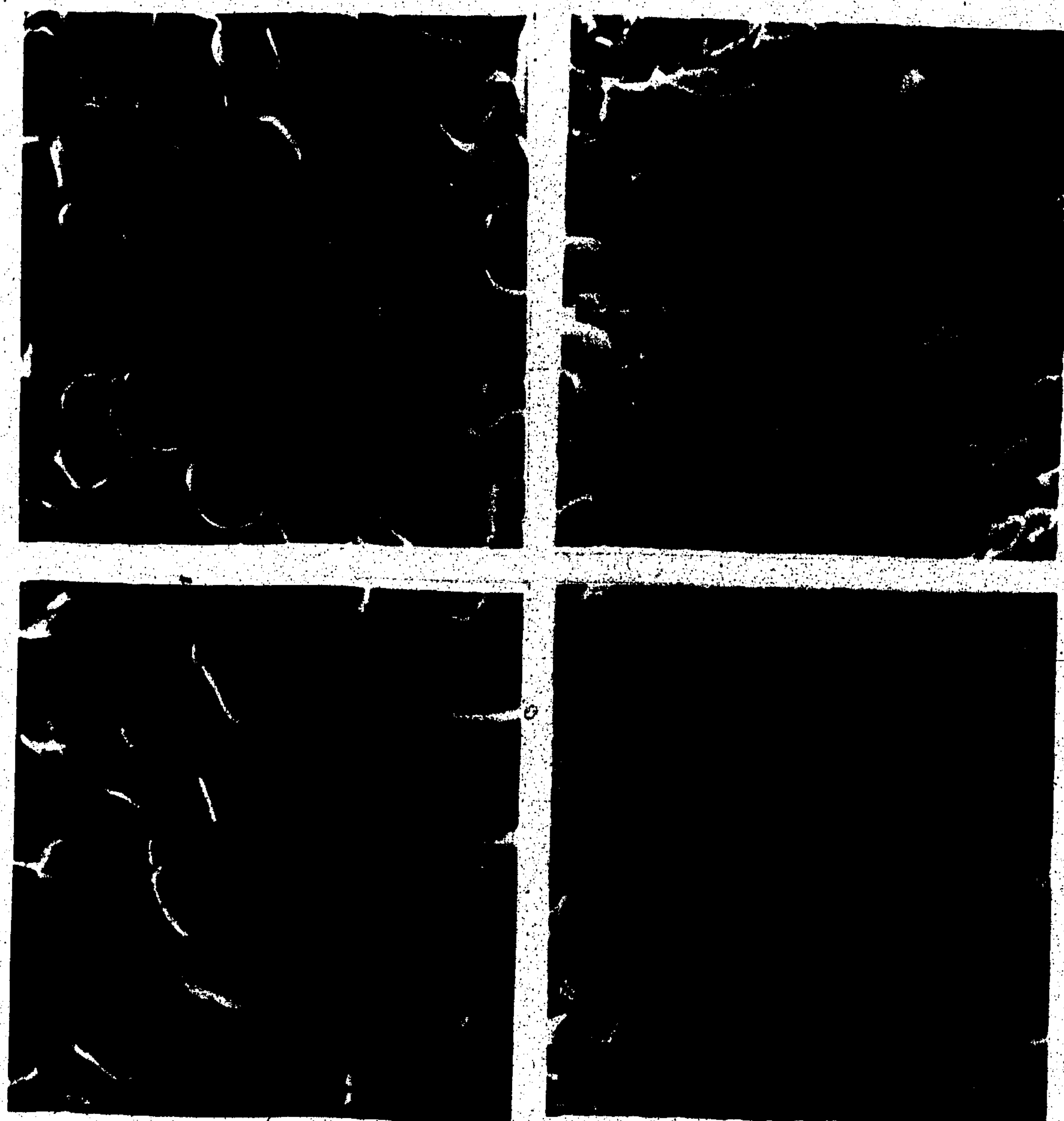


Plate 5.9. SE-Micrographs of Yam Starch/Vital Gluten Dough Surfaces. Typical Surfaces (a, x1,160; b, x3,010). Fractured Surfaces (b, x1,240; d, x5,040).

б

Plate 5.10. SE-Micrographs of Wheat, cvs. Neepawa (a, b), and Fielder (c, d) Flour dough Surfaces. Typical Surfaces (a, x2,510; c, x1,280). Fractured Surfaces (b, x2,420; d, x4,940).

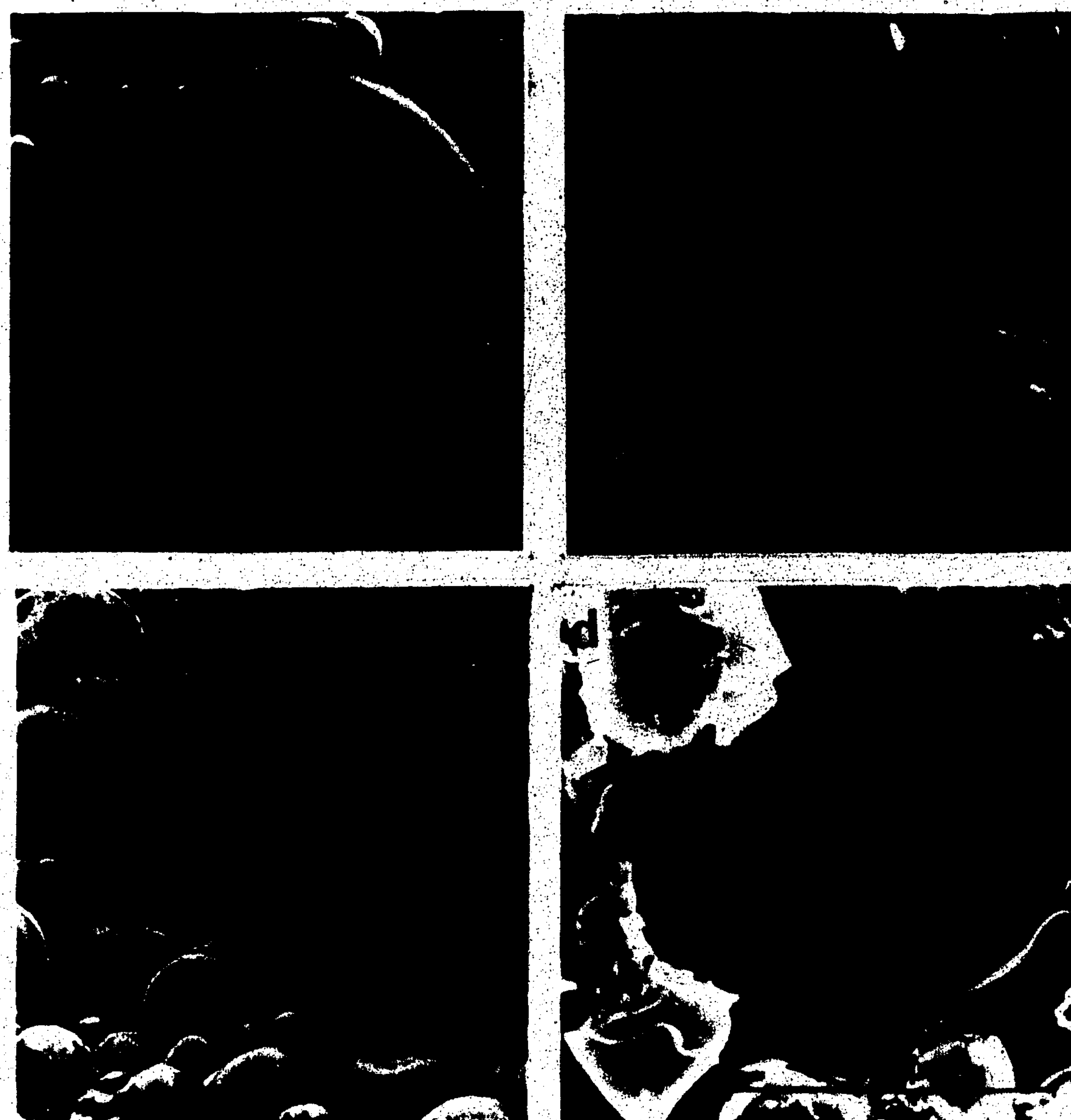


Plate 5.11. SE-Micrographs of Wheat, cv. Fielder (a, b, and c), and cv. Neepawa (d) Starch/Vital Gluten Dough Surfaces. Typical Surfaces (a, x1,260; c, x5,110). Fractured Surfaces (b, x1.250; d, x5,040).

Plate 5.12. SE-Micrographs of Bread Crumb Surfaces of Arrowroot/Vital Gluten Composite -a, x6,900; b, x6,400; c, x2,100 and d, x770.

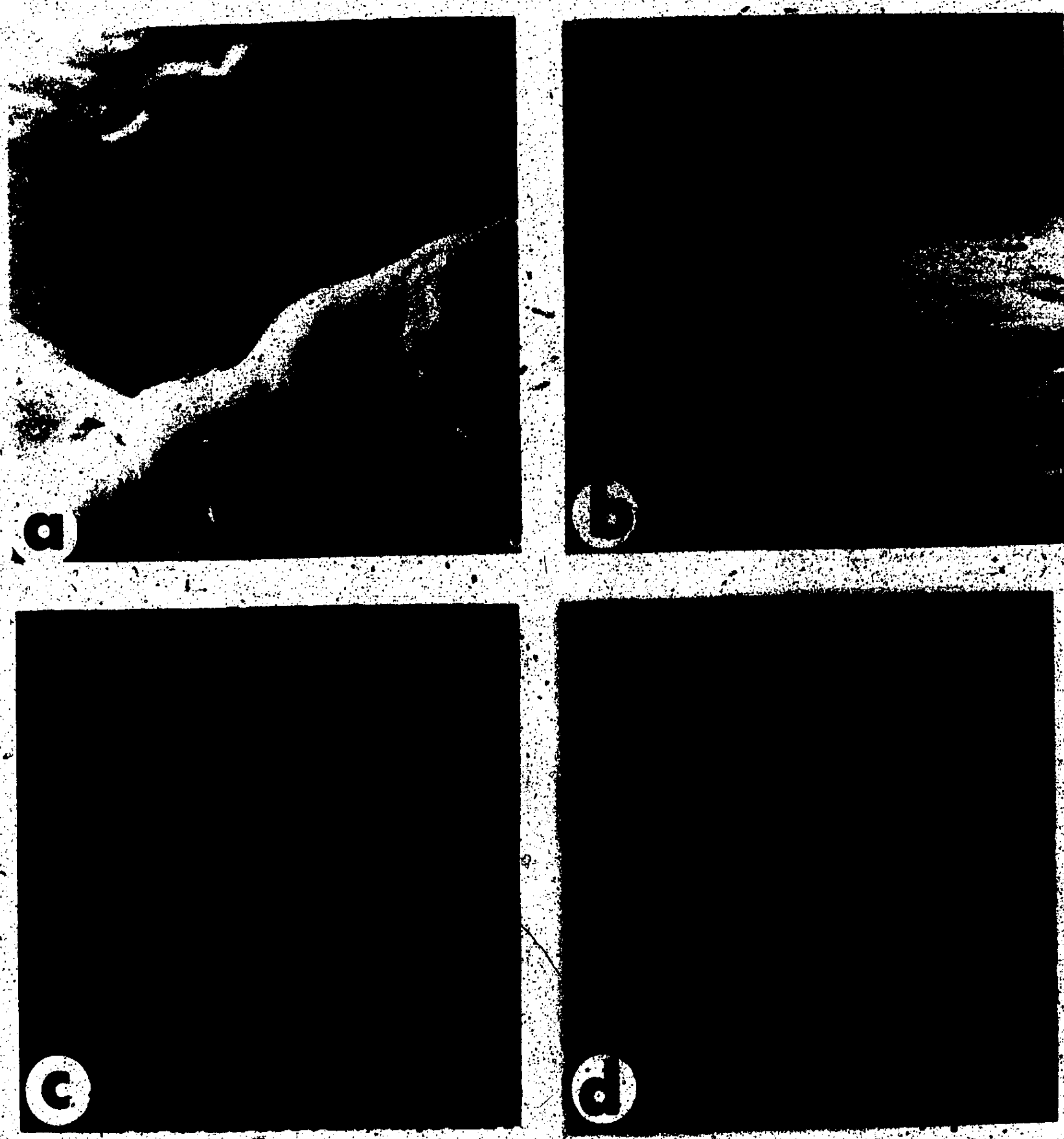

a
b
c
d

Plate 5.13. SE-Micrographs of Bread Crumb Surfaces of Srach/Vital Gluten Composites of Cassava- a, x1,700; Sweet potato- b, x1,700; Taro-c, x8000; and Yam- d, x960.

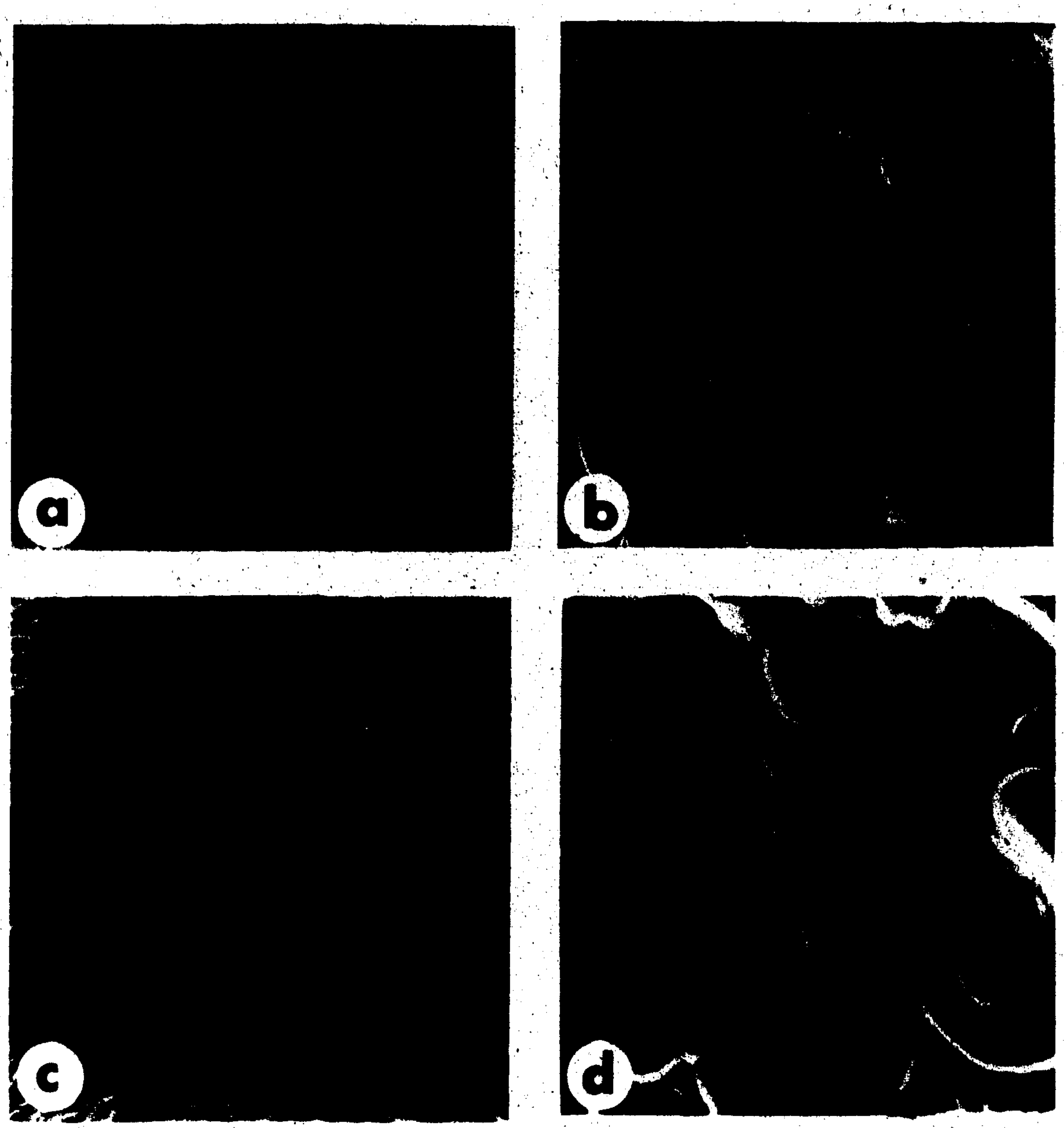

a
b
c
d

Plate 5.14. SE-Micrographs of Bread Crumb Surfaces of Wheat, cv. Fielder Starch/Vital Gluten Composite-a, x1,600; b, x870; and its Flour- c, 450; d, x1,600.

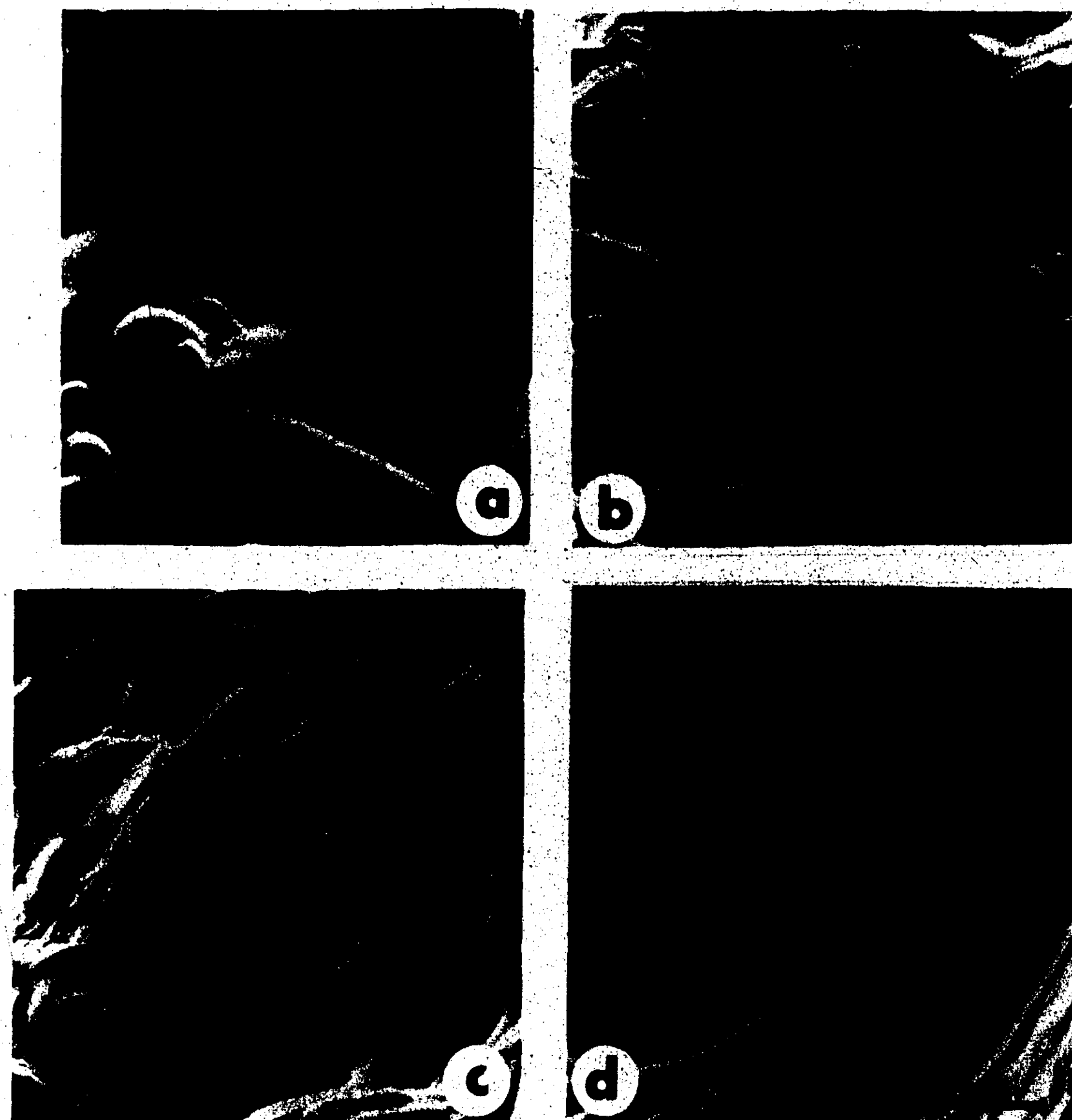

a
b
c
d

Plate 5.15. SE-Micrographs of Bread Crumb Surfaces of Wheat, cv. Neepawa Starch/Vital Gluten Composite- a, x1,700; b, x920; and its Flour-c, x930, d, x1,700.

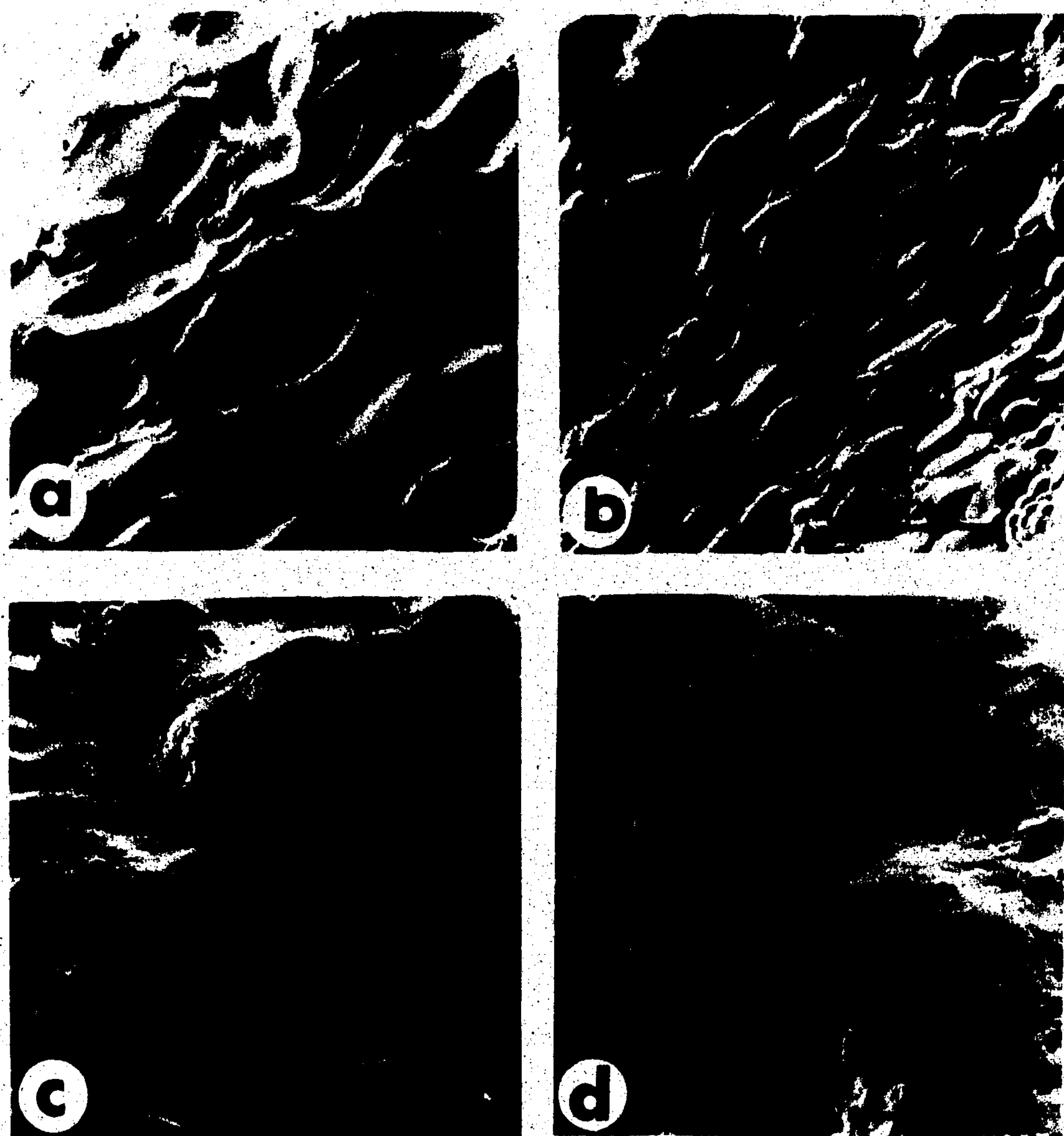

a
b
c
d

Plate 5.16 TE- Micrographs of Arrowroot Starch/Vital Gluten Dough (c and d, each x1000); and Bread Crumb (a and b, each x550).


a
b

were observed to be embedded in the gluten matrix.

5.3.5 Bread Keeping Properties

5.3.5.1 Bread Crumb Compressibility

Bread crumb compressibility curves and data in the presence and absence of monglyceride are presented in Figure 5.31 and Table 5.38 for composite crumb sconsisting of vital gluten and starches from arrowroot cassava, sweet potato, taro and yam. Corresponding curves and data for the wheat starch flours and their starch/vital gluten composites are given in Figure 5.32 and Table 5.39.

Crumb compressibility was observed to differ from one type of bread to the other. In each case compressibility decreased as a function of storage time towards a limit reached after about 4 days storage in bread containing no monoglyceride and latter than 8 days storage in bread containing monoglycerides. Monoglyceride used at 0.5% level on flour basis reduced significantly the rate and extent of firming in the bread crumbs, as shown in Figures 5.32 and 5.33.

In general, increases in compressibility as a result of the presence of monoglyceride in the crumb were more significant in the composites of vital gluten with root starches than in the crumbs of wheat flours and their starch/vital gluten composites. In presence of monoglycerides, crumb of yam starch had the smallest compressibility, followed by arrowroot, sweet potato, taro

Figure 5.31. Bread Crumb Comprenssibilities of Tropical Root Starch/Vital Gluten Composite Flours in Presence and Absence of Monoglyceride

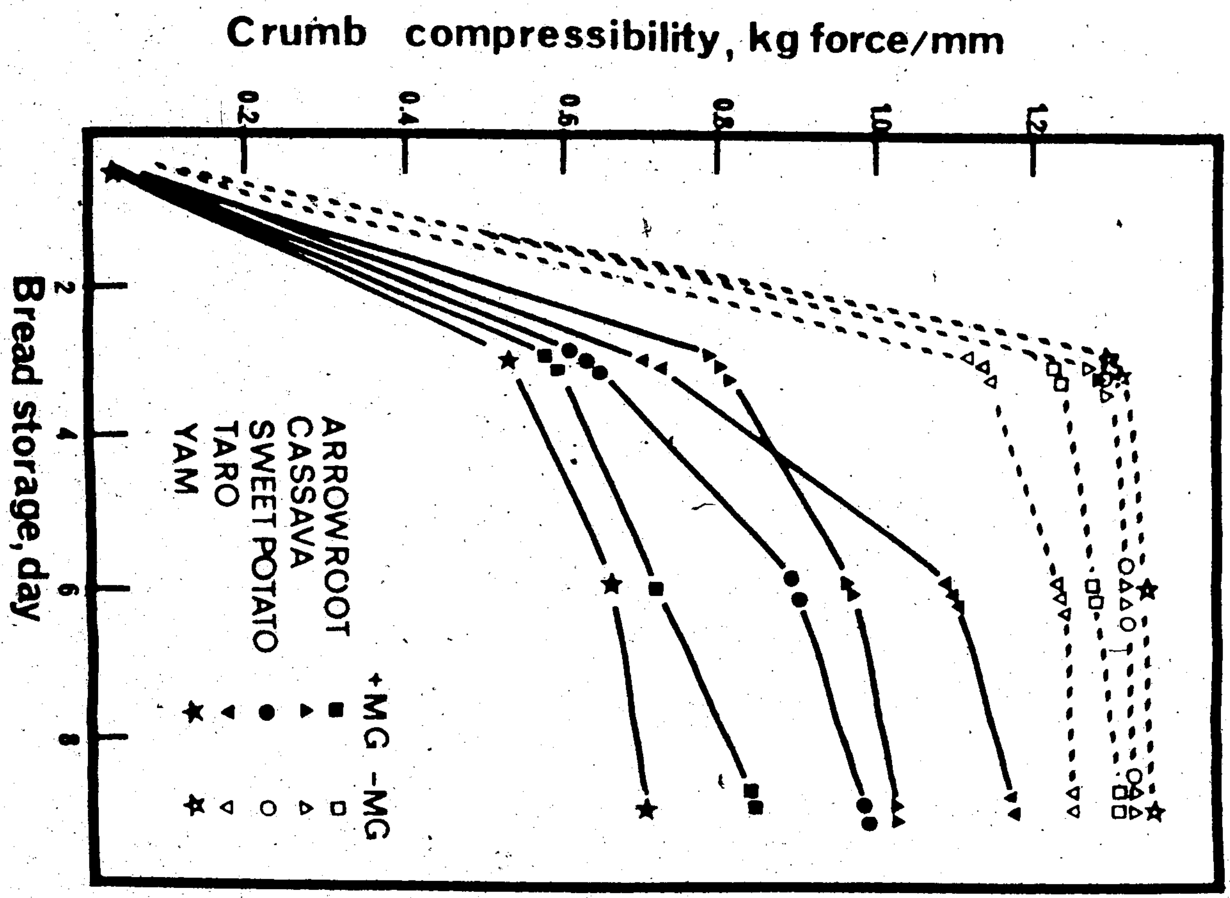


Table 5.38 Bread Crumb Compressibilities of Tropical Root Starch/VitalGluten Composite Flours in Presence and Absence of Monoglyceride

	Arrowroot		Cassava		Sweet Potato		Taro		Yam	
Storage, Days	+MG*	-MG	+MG	-MG	+MG	-MG	+MG	-MG	+MG	-MG
Fresh Bread (1/2 Day Old)	0.020 ±0.004	0.040 ±0.008	0.040 ±0.010	0.100 ±0.012	0.080 ±0.010	0.10 ±0.002	0.090 ±0.020	0.110 ±0.005	0.080 ±0.01	0.100 ±0.004
3	0.600 ±0.040	1.240 ±0.07	0.810 ±0.070	1.290 ±0.060	0.640 ±0.210	1.300 ±0.04	0.720 ±0.070	1.140 ±0.090	0.540 ±0.090	1.310 ±0.04
6	0.730 ±0.110	1.280 ±0.05	0.970 ±0.050	1.300 ±0.060	0.900 ±0.06	1.300 ±0.05	1.100 ±0.07	1.230 ±0.070	0.660 ±0.060	1.350 ±0.07
9	0.850 ±0.090	1.320 ±0.060	1.030 ±0.090	1.320 ±0.050	0.990 ±0.100	1.330 ±0.08	1.180 ±0.07	1.250 ±0.060	0.710 ±0.08	1.360 ±0.050

*MG, Monoglyceride (α -glycerol monopalmitate)

Figure 5.32. Bread Crumb Com[illegible]sibiliti[illegible] Starch/Vital Gluten Composite [illegible]ours in Presence and Absence of Monoglycerides

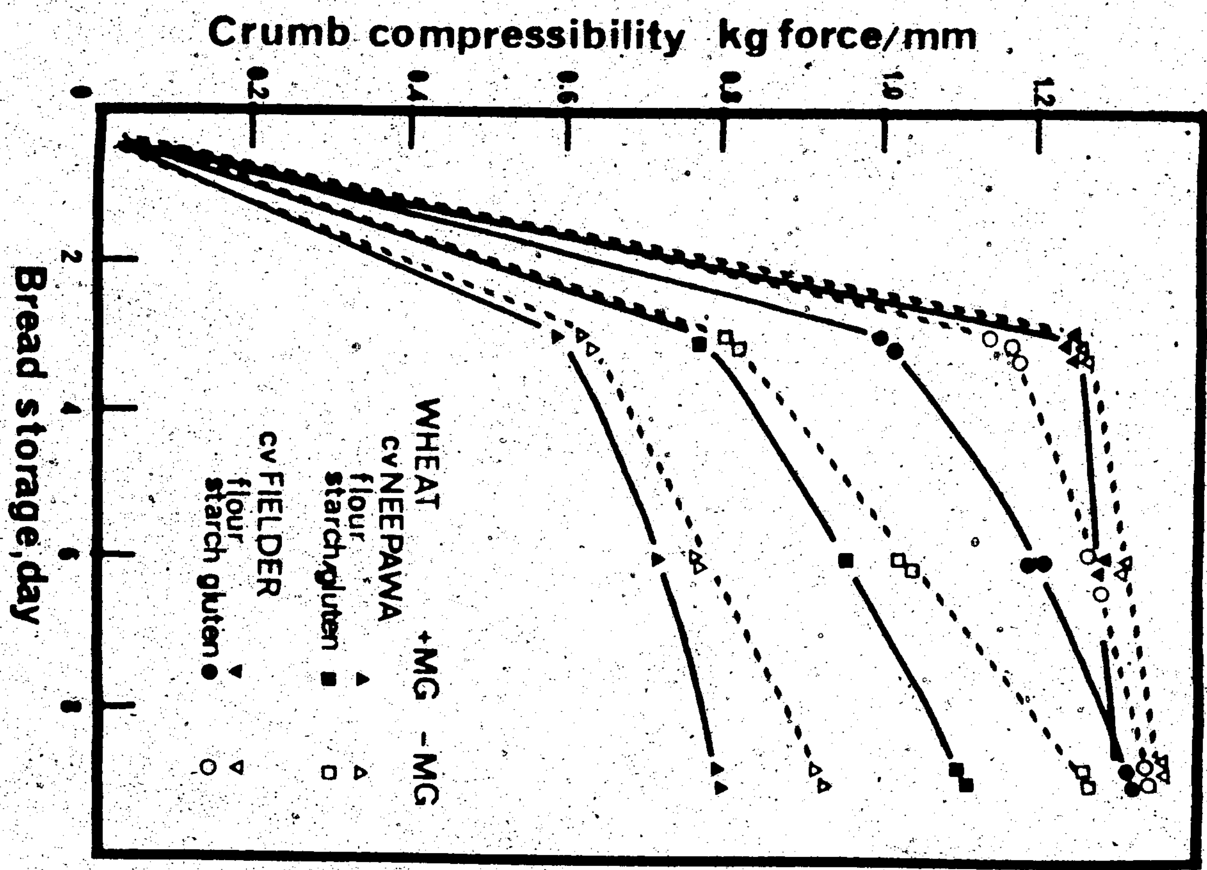


Table 5.39 Bread Crumb Cmpressibilities of Wheat and Wheat Starch/Vital Gluten Composite Flours in Presence and Absence of Monoglycerides

Storage, Days	Neepawa				Fielder			
	Flour		Starch/Gluten		Flour		Starch/Gluten	
	+MG*	-MG	+MG	-MG	+MG	-MG	+MG	-MG
Fresh Bread (1/2 Day Old)	0.030 ±0.004	0.060 ±0.030	0.040 ±0.006	0.050 ±0.010	0.060 ±0.001	0.110 ±0.005	0.06 ±0.008	0.070 ±0.007
3	0.590 ±0.080	0.620 ±0.040	0.770 ±0.090	0.800 ±0.035	1.000 ±0.080	1.160 ±0.040	1.250 ±0.070	1.250 ±0.080
6	0.720 ±0.060	0.750 ±0.010	0.950 ±0.007	1.020 ±0.140	1.210 ±0.060	1.270 ±0.070	1.270 ±0.030	1.320 ±0.150
9	0.790 ±0.060	0.930 ±0.221	1.100 ±0.040	1.270 ±0.03	1.320 ±0.060	1.340 ±0.05	1.290 ±0.050	1.340 ±0.040

*MG, α-glycerol monopalmitate.

(after 3 days), and cassava. In the absence of monoglyceride, yam bread had the firmest crumb, followed equally by sweet potato and cassava starch/vital gluten composites. Taro bread crumb, followed by arrowroot bread crumbs, had the least compressibility.

In absence or presence of monoglycerides, SWSW flour had firmer crumb than CWRSW. A similar observation was made for wheat starch/vital gluten composites.

5.3.5.2 Crumb Penetration Resistance

Plots for crumb penetration resistance to a standard probe and constant force as a function of storage time for the various tropical root starch/vital gluten bread composites are presented in Figure 5.33. The corresponding data are provided in Table 5.40. Similar plots and data for wheat flour breads and their starch/vital gluten bread composites are given in Figure 5.34 and Table 5.41.

The presence of monoglyceride in the crumb reduced the resistance to penetration of all crumbs as a function of time. The reduction was significant in all cases, as illustrated in Figures 5.33 and 5.34.

Among breads from the root starches, arrowroot bread was the most tender, followed by yam, taro, cassava and sweet potato in presence of monoglycerides. When no monoglycerides were incorporated, arrowroot bread still remained the most tender, followed by bread from taro, sweet potato, yam and cassava.

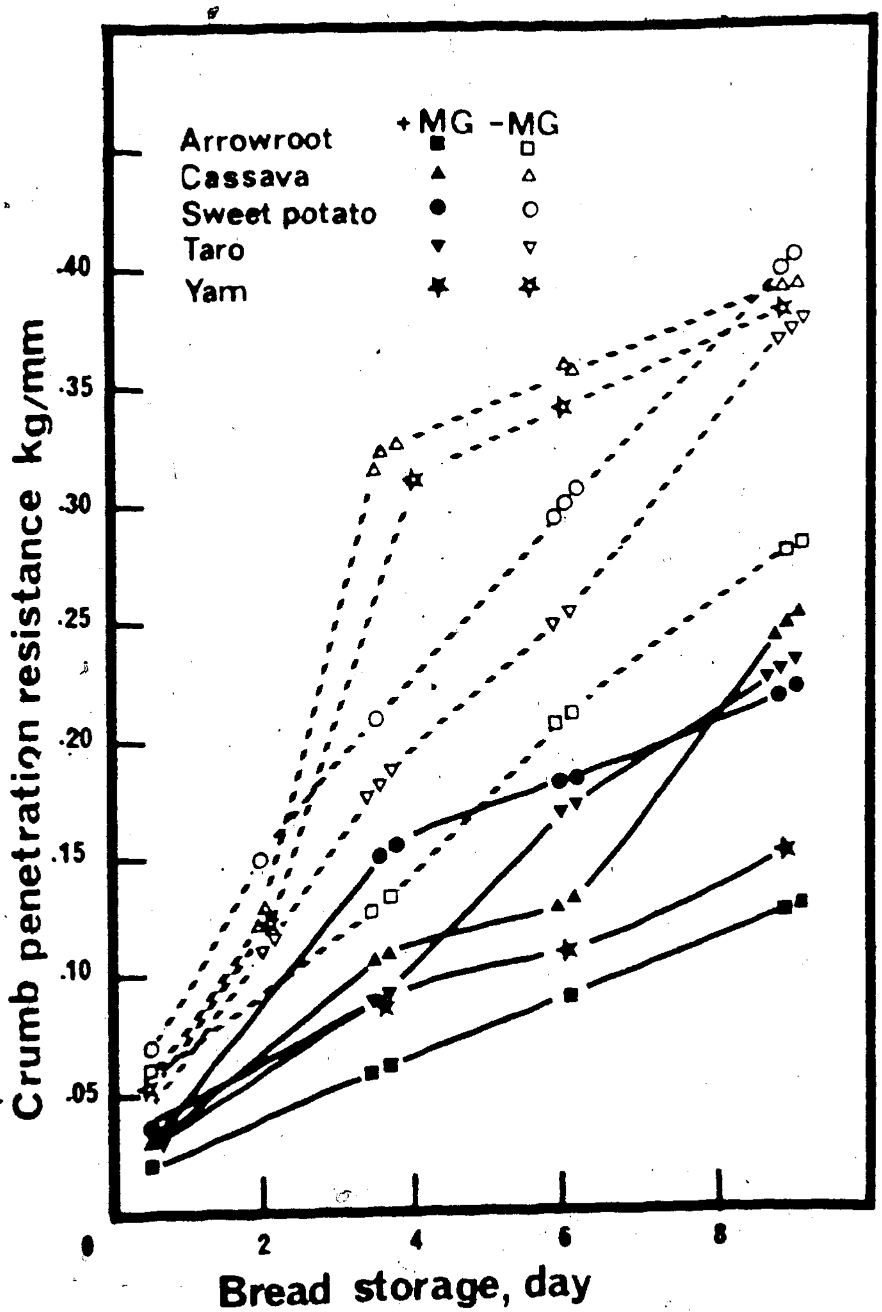


Figure 5.33. Bread Crumb Penetration Resistances of Tropical Root Starch/vital Gluten Composites in Presence and Absence of Monoglyceride

Table 5.40. Bread Crumb Penetration Resistance (kg-force/mm) of Tropical Root Starch /Vital Gluten Composites in Presence and Absence of Monoglycerides.

Storage, Days	Arrowroot +MG **	Arrowroot -MG	Cassava +MG	Cassava -MG	Sweet Potato +MG	Sweet Potato -MG	Taro +MG	Taro -MG	Yam +MG	Yam -MG
Fresh Bread (1/2 Day Old)	0.020 ±0.001	0.060 ±0.002	0.030 ±0.006	0.040 ±0.005	0.030 ±0.003	0.070 ±0.004	0.040 ±0.008	0.050 ±0.006	0.03 ±0.002	0.040 ±0.003
2	- -	0.110 ±0.011	- -	0.130 ±0.010	- -	0.15 ±0.050	-	0.110 ±0.010	- -	0.120 ±0.003
3 1/2	0.060 ±0.020	0.12 ±0.010	0.110 ±0.005	0.320 ±0.030	0.15 ±0.008	0.18 ±0.030	0.090 ±0.008	0.180 ±0.020	0.090 ±0.010	0.310 ±0.040
6	0.090 ±0.020	0.210 ±0.040	0.130 ±0.020	0.360 ±0.030	0.180 ±0.020	0.30 ±0.020	0.170 ±0.010	0.250 ±0.020	0.110 ±0.020	0.340 ±0.008
9	0.130 ±0.010	0.280 ±0.030	0.250 ±0.030	0.390 ±0.020	0.220 ±0.010	0.400 ±0.030	0.230 ±0.010	0.380 ±0.050	0.150 ±0.020	0.380 ±0.020

*Starch and vital gluten were used at 85 and 15%, respectively. For dough formulation see Table .

**MG, α-glycerol monopalmitate.

Figure 5.34 Bread Crumb Penetration Resistances of Wheat and Wheat Starch/Vital Gluten composites Flours in Presence and Absence of Monoglyceride

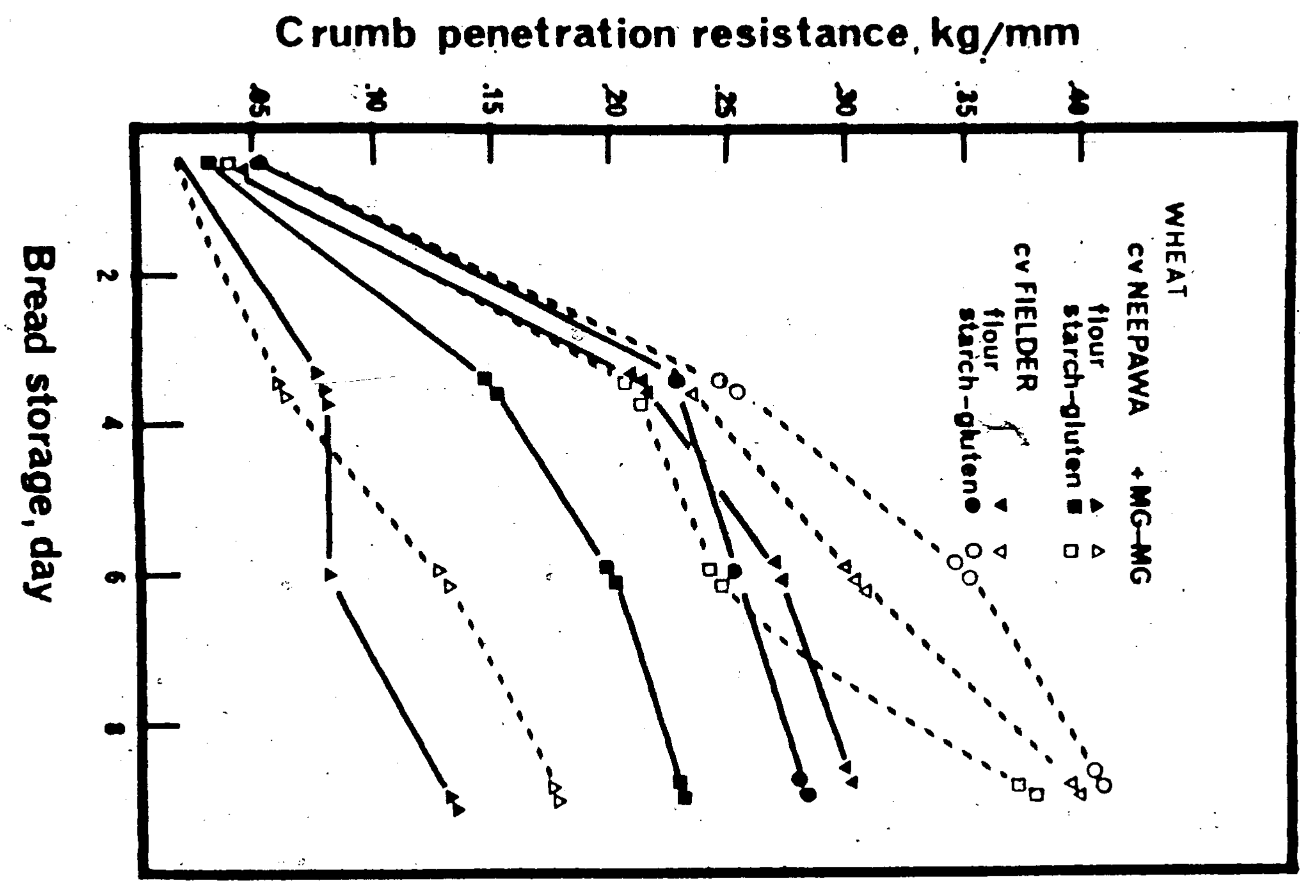


Table 5.41. Bread Crumb Penetration Resistances of Wheat Flour, and Wheat Starch /Vital Gluten Composite in Presence and Absence of Monoglycerides.

Storage, Days	Neepawa				Fielder			
	Flour		Starch/Gluten		Flour		Starch/Gluten	
	+MG**	-MG	+MG	-MG	+MG	-MG	+MG	-MG
Fresh Bread (1/2 Day Old)	0.020 ±0.002	0.018 ±0.003	0.030 ±0.002	0.030 ±0.003	0.030 ±0.004	0.035 ±0.005	0.040 ±0.005	0.050 ±0.007
3 1/2	0.080 ±0.010	0.060 ±0.006	0.150 ±0.010	0.210 ±0.020	0.210 ±0.020	0.230 ±0.006	0.230 ±0.040	0.250 ±0.030
6	0.08 ±0.010	0.13 ±0.040	0.200 ±0.030	0.240 ±0.030	0.270 ±0.030	0.300 ±0.002	0.250 ±0.040	0.350 ±0.01
9	0.130 ±0.013	0.160 ±0.010	0.230 ±0.030	0.380 ±0.030	0.300 ±0.010	0.400 ±0.040	0.280 ±0.006	0.410 ±0.02

*Starch and vital gluten were used at 85 and 15%, respectively. For dough formulation see Table .

**MG α-glycerol monopalmitate.

For the wheat cases, CWRSW (cv. Neepawa) flour bread containing monoglycerides, was more tender than bread from the corresponding SWSW (cv. Fielder) flour. Similarly, composite bread of starch and vital gluten involving CWRSW was more tender than corresponding bread from SWSW. The effect of the presence of monoglycerides in the crumbs was more pronounced in the case of SWSW flour and starch/vital gluten composites, than in the corresponding cases with CWRSW.

With the exception of the CWRSW (cv. Neepawa) wheat flour, the presence of monglyceride produced more pronounced effects in the root starch composites with gluten than in the other cases involving the CWRSW starch, SWSW flour and starch.

5.3.5.3 X-Ray Diffraction Analysis

Retrogradation in bread crumbs as a function of storage time, followed by X-ray diffraction crystallinity analysis of starch isolated from the crumbs during storage is portrayed in Figures 5.35-5.38 for composite bread from vital gluten and starch from arrowroot, cassava, and wheat (cvs. Fielder and Neepawa). Figure 5.39 shows, for comparison, similar X-ray diffractograms for wheat (cv. Neepawa) flour. Corresponding data for the X-ray diffraction patterns are given in Tables 5.42-5.45.

Similar X-ray diffractograms and patterns for starch isolated from aging bread crumbs made from taro, sweet potato, and yam starches and from wheat (cv. Fielder)flour

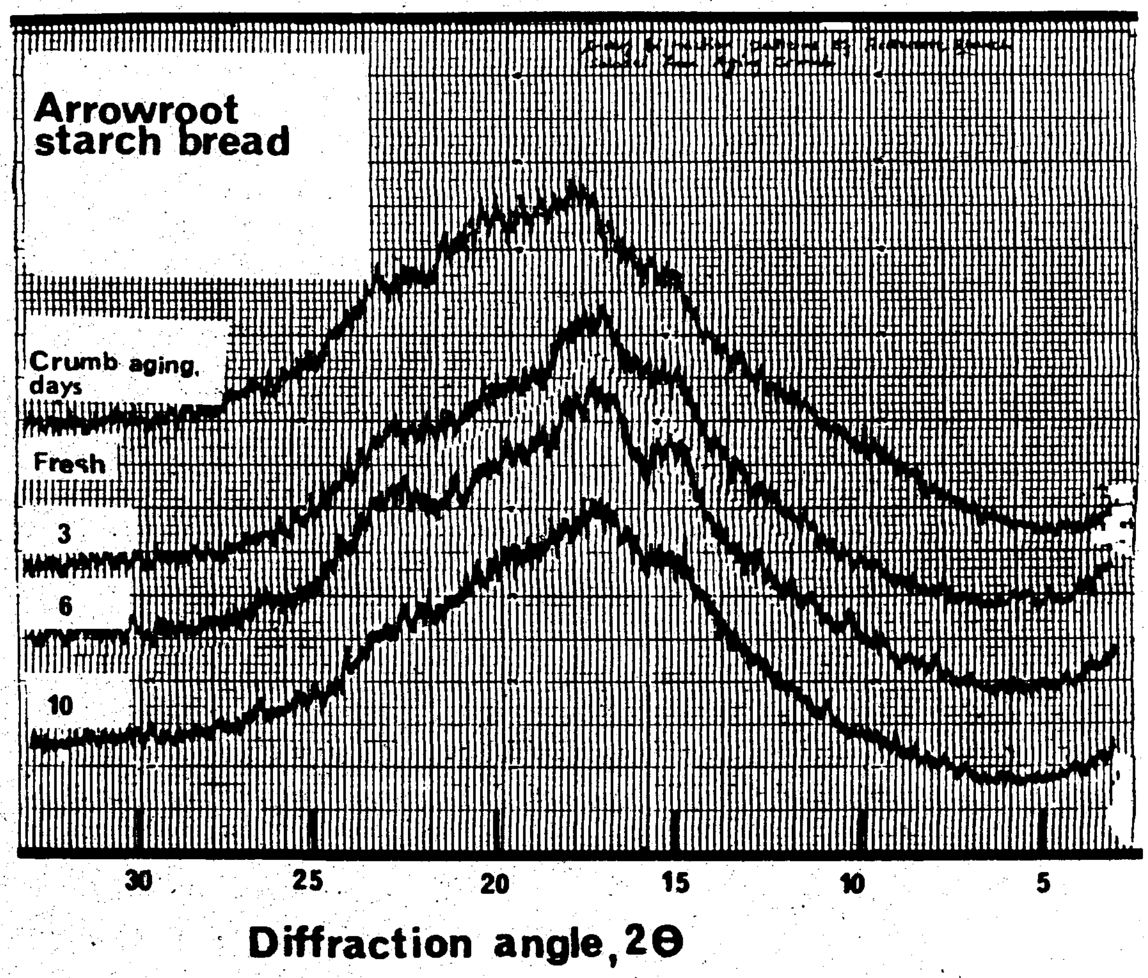


Figure 5.35. X-Ray Diffractograms of Starch Isolated From Aging Arrowroot Bread Crumbs.

Table 5.42. X-Ray Diffraction Patterns of Starch Isolated from Aging Arrowroot Bread Crumbs.

Bread Storage, Days											
1			3			6			10		
		Intensity			Intensity			Intensity			Intensity
$^{o}2\theta$	d, Å	cps	$^{o}2\theta$	d, Å	cps	$^{o}2\theta$	d, Å	cps	$^{o}2\theta$	d, Å	cps
15.163	5.8430	726	15.059	5.8831	674	10.322	8.5699	352	14.935	5.9318	657
17.455	5.0806	889	17.069	5.1945	831	11.407	7.7567	389	17.135	5.1746	772
20.100	4.4176	848	16.486	5.3770	772	14.929	5.9340	708	23.147	3.8426	496
21.235	4.1840	798	22.734	3.9114	562	17.070	5.1942	835	26.599	3.3511	336
23.154	3.8413	700				17.888	4.9585	795			
31.642	2.8276	390				21.201	4.1905	631			
						22.643	3.9269	626			
						26.424	3.3729	370			
						30.077	2.9710	343			

*Arrowroot starch composite flours had 15% vital gluten.

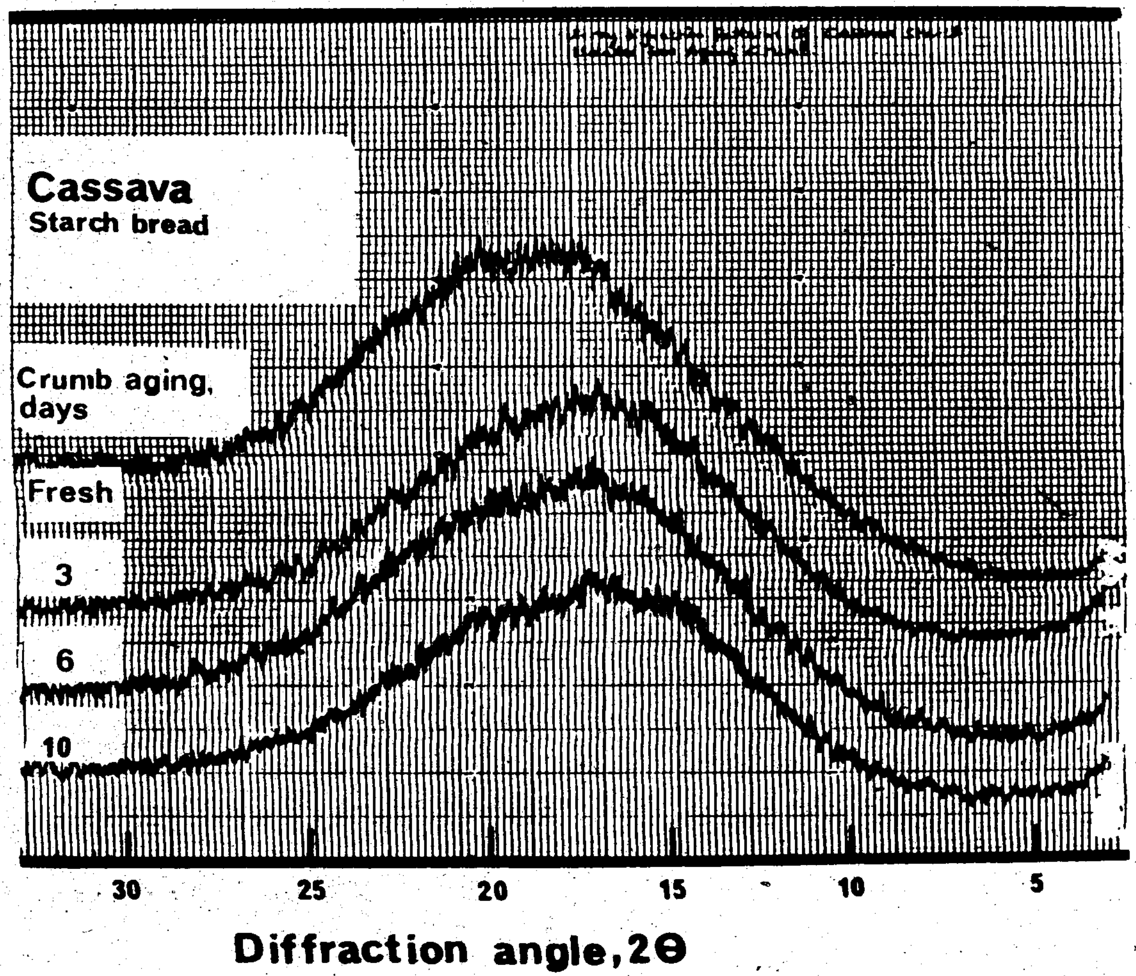


Figure 5.36 X-Ray Diffractograms of Starch Isolated from Aging Cassava Bread Crumbs

Table 5.43. X-Ray Diffraction Patterns of Starch Isolated from Aging Cassava Bread Crumbs.

Bread Storage, Days											
1			3			6			10		
		Intensity			Intensity			Intensity			Intensity
$^{o}2\theta$	d, Å	cps	$^{o}2\theta$	d, Å	cps	$^{o}2\theta$	d, Å	cps	$^{o}2\theta$	d, Å	cps
9.466	9.3431	244	12.489	7.0875	416	13.314	6.6499	507	13.732	6.4485	473
12.128	7.2977	402	14.561	6.0832	496	15.825	5.6000	720	14.892	5.9487	538
13.339	6.6374	497	14.728	6.0143	593	17.196	5.1565	775	17.231	5.1461	633
16.806	5.2753	802	15.527	5.7067	689	27.997	3.1869	333	18.479	4.8012	592
17.465	5.0778	830	19.289	4.6015	656				20.235	4.3885	542
18.390	4.8243	827	20.203	4.3952	633				22.678	3.9209	404
20.010	4.4373	821	22.542	3.9442	500						
21.176	4.1954	748	24.384	3.6503	379						
25.045	3.5555	500									
26.544	3.3580	417									
27.566	3.2357	419									
29.544	3.0234	389									

*Cassava starch composite flours had 15% vital gluten.

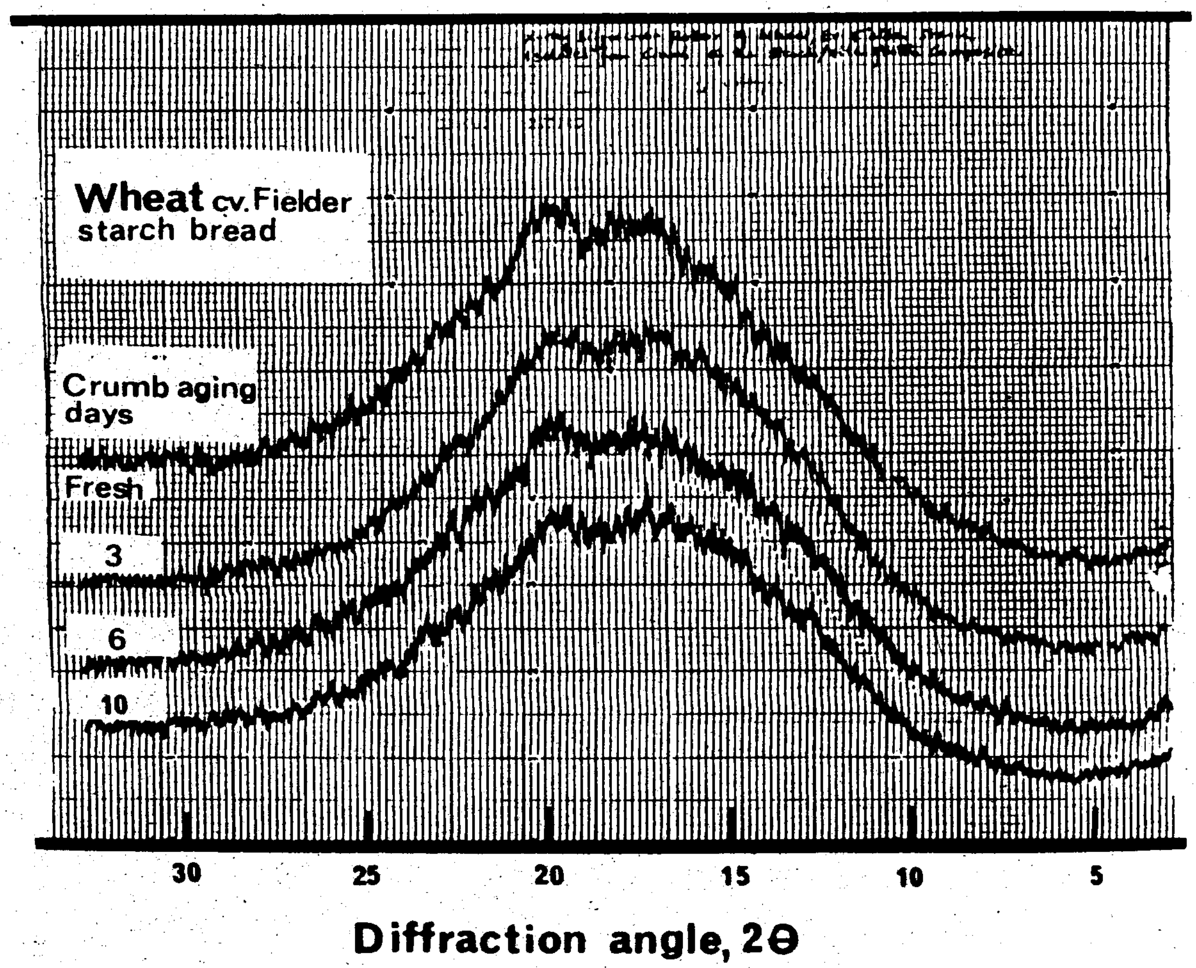


Figure 5.37. X-Ray Diffractograms of Starch Isolated From Aging Bread Crumbs of Wheat Starch,cv. Fielder.

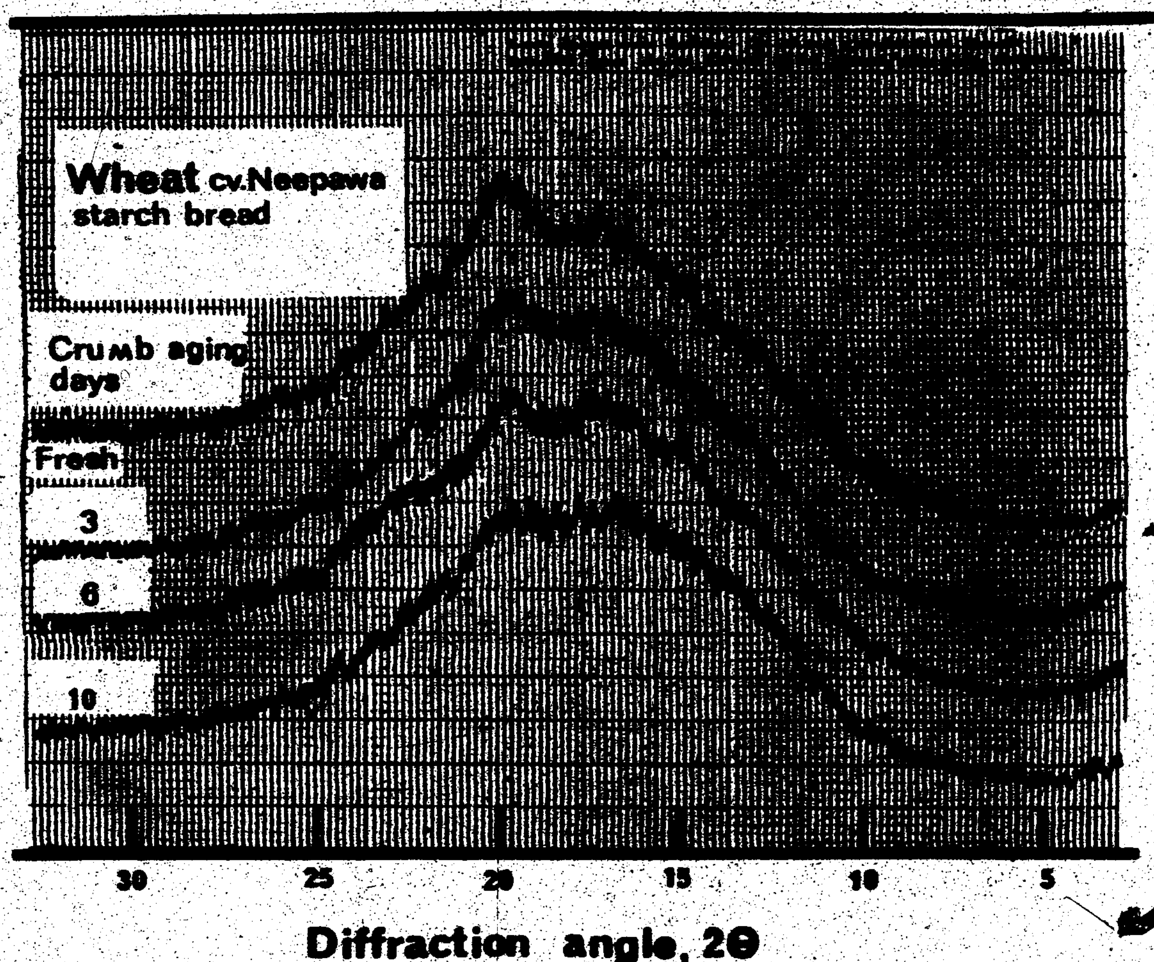


Figure 5.38. X-Ray Diffractograms of Starch Isolated From Aging Bread Crumbs of Wheat Starch,cv. Neepawa.

Table 5. 44. X-Ray Diffraction Patterns of Starch Isolated from Aging Bread Crumbs of Wheat, cvs. Fielder and Neepawa Starches.

Bread Storage, Days											
1			3			6			10		
°2θ	d, Å	Intensity cps	°2θ	d, Å	Intensity cps	°2θ	d, Å	Intensity cps	°2θ	d, Å	Intensity cps
Wheat Starch cv. Fielder											
15.605	5.6495	804	15.798	5.6094	803	12.760	6.9372	516	12.931	6.8463	534
17.184	5.1601	900	16.945	5.2324	853	13.417	6.5993	608	15.138	5.8525	642
18.062	4.9113	901	17.984	4.9322	851	15.319	5.7837	730	17.496	5.0686	761
19.436	4.5671	920	19.776	4.4892	855	16.773	5.2855	792	19.771	4.4903	728
22.964	3.8726	649	22.411	3.9670	624	17.692	5.0131	803	21.691	4.0970	566
						19.919	4.4574	849	23.483	3.7883	483
						21.763	4.0837	653	24.626	3.6130	402
						22.754	3.9080	602	26.257	3.3940	335
Wheat Starch cv. [illegible]											
[illegible]	4.1557	520	15.788	[illegible]	723	15.154	5.8463	702	16.741	[illegible]	767
[illegible]	[illegible]	[illegible]	17.332	5.1164	811	16.566	5.3511	787	[illegible]	4.4721	755
[illegible]	[illegible]	720	[illegible]	4.5203	[illegible]	[illegible]	[illegible]	797	[illegible]	[illegible]	[illegible]
[illegible]	5.1578	833	22.359	[illegible]	405	19.785	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	919	26.751	3.3324	355	[illegible]	[illegible]	335			
21.213	[illegible]	[illegible]				[illegible]	[illegible]	359			
[illegible]	[illegible]	[illegible]									
[illegible]	[illegible]	[illegible]									

[illegible] 15% vital gluten.

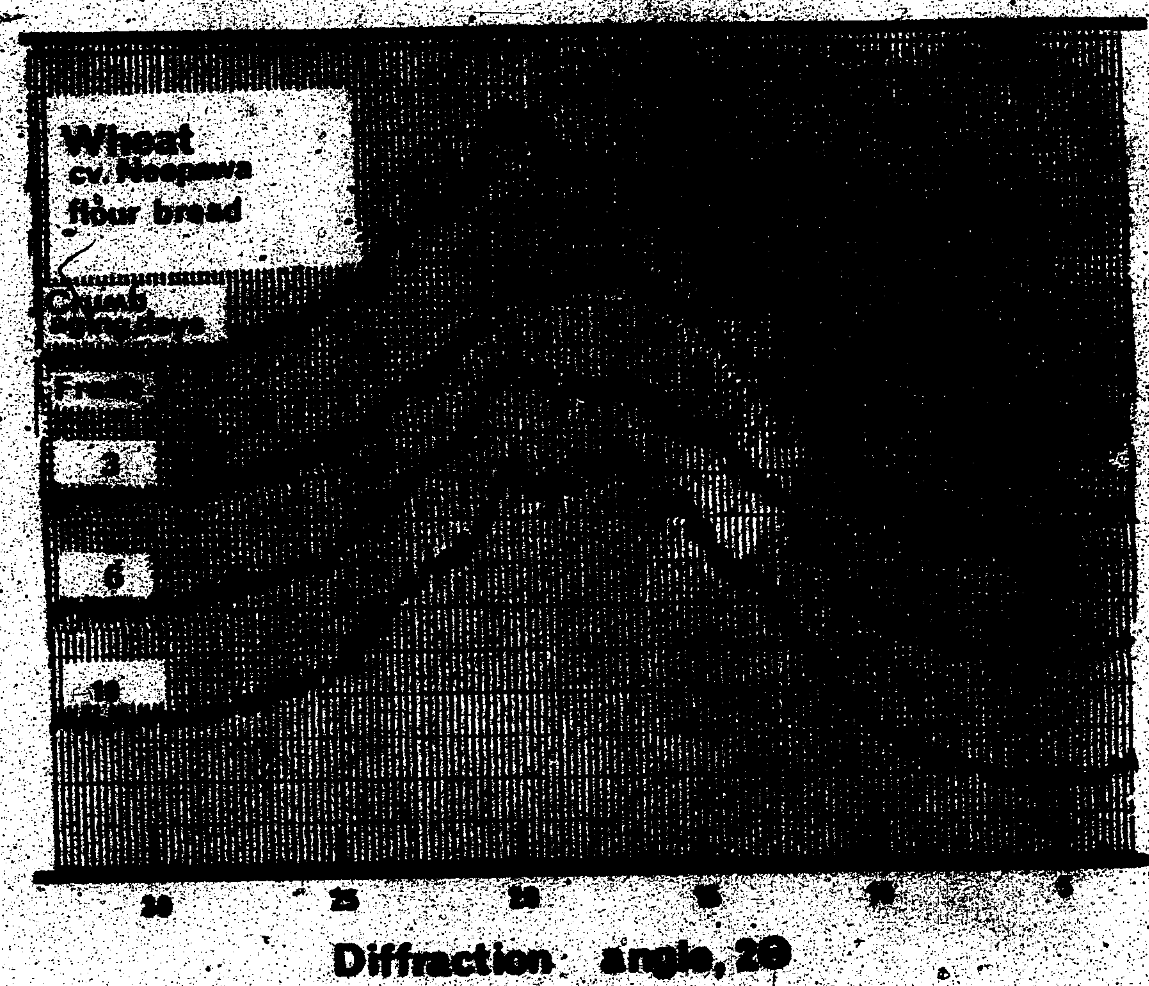


Figure 5.39. X-Ray Diffractograms of Starch Isolated from Aging Bread Crumbs made from Wheat Flour, cv. Neepawa.

Table 5.45 X-Ray Diffraction Patterns of Starch Isolated from Aging Bread Crumbs Made from Wheat Flour, cv. Neepawa

Bread Storage, Days											
1			3			6			10		
		Intensity			Intensity			Intensity			Intensity
°2θ	d, Å	cps	°2θ	d, Å	cps	°2θ	d, Å	cps	°2θ	d, Å	cps
13.045	6.7805	526	13.054	6.7818	595	12.748	6.9440	540	13.473	[illegible]	674
14.885	[illegible]	[illegible]	18.189	4.8773	753	15.339	5.7763	687	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	19.247	[illegible]	730	17.024	5.2051	782	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	19.946	4.4516	745	18.180	[illegible]	[illegible]	17.913	[illegible]	905
[illegible]	[illegible]	[illegible]	21.714	4.0927	509	19.950	[illegible]	[illegible]	19.910	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	22.685	[illegible]	[illegible]	22.386	[illegible]	[illegible]	22.943	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]				23.715	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]									
[illegible]	[illegible]	[illegible]									
[illegible]	[illegible]	[illegible]									

are given in Appendices 29-36.

In all cases the X-ray diffractograms of the starches became more defined the longer the crumb was stored. Characteristic strong intensity X-ray diffraction peaks were observed between 15-25° (2θ) angle of diffraction in all cases.

5.3.6 Bread Quality Evaluation

5.3.6.1 Loaf Volume, Mass and Specific Volume

Loaf volumes, masses and specific volumes of the different types of bread are presented in Table 5.46.

Canadian western red spring wheat (cv. Neepawa), bread, used as the standard, had the largest loaf volume. Its specific volume was also the largest. Neepawa wheat starch/vital gluten bread was second to the standard in these properties.

Sweet potato starch/vital gluten bread had the largest loaf volume amongst the root starch/vital gluten composites. It was closely followed by taro starch/vital gluten bread. Arrowroot starch/vital gluten bread had the smallest volume followed by yam starch/vital gluten bread. Cassava starch/vital gluten composite bread had an intermediate volume which was greater than that of the internal standard wheat (cv. Fielder) flour bread. Fielder wheat starch/vital gluten composite bread, however, had a larger volume, but a smaller specific volume than the cassava composite bread.

Table 5.46 Bread Volume, Mass and Specific Volume

Type of Bread	Volume cm^3	Mass g	Specific Volume [illegible]
Neepawa flour	1532.0 ± 3.0	435.0 ± [illegible]	[illegible]
Neepawa starch*	1302.0 ± 5.0	443.0 ± 4.0	[illegible]
Sweet potato starch*	1192.0 ± 4.0	426.0 ± [illegible]	[illegible]
Taro starch*	1172.0 ± 3.0	426.0 ± [illegible]	[illegible]
Fielder starch*	1122.0 ± 2.0	452.0 ± 2.0	[illegible]
Cassava*	1112.0 ± 6.0	426.0 ± 4.0	[illegible]
Fielder flour	1051.0 ± 7.0	[illegible] ± [illegible]	[illegible]
Yam*	1022.0 ± 2.0	[illegible] ± [illegible]	[illegible]
Arrowroot*	922.0 ± 3.0	[illegible] ± 4.0	[illegible]

*Plus vital gluten.

In general, the composite breads from the root starches with vital gluten were closer to the internal standard in their volumes and specific volumes than the actual CWRS wheat bread.

5.3.6.2 Internal and External Bread Qualities

The panelists' mean and total scores for the external (volume excluded), and internal properties of bread loaves from the wheat flours of cvs. Neepawa and Fielder, and from their starches as as well as root/starch composites with vital gluten are presented in Table 5.47.

Bread from wheat (cv. Neepawa) flour was arbitrarily given the perfect score for each property investigated, so that its total score was 90 since the score 10 for volume was not included due to volume having been given a separate analysis. This was done for convenience in the statistical analyses and comparisons. The total mean scores were found to be a suitable index for assessing the total preference of the composites breads in comparison to the standard.

The analysis of variance amongst the quality properties of the different bread loaves, also excluding volume, and the panelists' perceptions of the degree of difference between the various characteristics in different breads are presented in Table 5.48.

The analysis of variance showed that the variability amongst the panelists' perceptions of differences in the color of the crust, break and shred, character of the crust, grain and chewability were significant at both 95

Table 5.47 Bread Quality Evaluation[#]

[illegible]	Panelists' Mean Scores***										
[illegible]	[illegible]	[illegible]	Evenness of Bake	Break and Shred	Character of the Crust	Color of the Crumb	Grain	Aroma	Taste	Chewability	Texture	Total Score
[illegible]												
[illegible]	8.00	3.00	3.00	3.00	3.00	10.00	10.00	10.00	15.00	10.00	15.00	90.00
[illegible]	6.08	2.25	2.30	1.98	1.88	8.98	8.31	9.40	12.89	7.70	11.55	73.32
[illegible]	5.75	1.98	1.92	1.92	2.40	9.66	9.28	5.42	12.07	7.82	13.69	71.91
[illegible]	6.33	[illegible]	1.79	1.21	2.04	9.55	7.95	6.75	9.38	6.78	9.52	63.14
[illegible]	[illegible]	[illegible]	1.38	1.75	1.71	7.61	9.17	8.82	9.45	5.28	9.17	60.62
[illegible]	[illegible]	1.33	0.72	1.80	[illegible]	8.41	7.87	6.38	8.32	4.37	6.19	47.78
[illegible]	2.67	1.58	1.13	1.58	[illegible]	7.05	8.43	6.75	8.09	4.37	6.19	48.76
[illegible]	1.37	0.78	0.36	0.52	0.80	[illegible]	6.02	2.82	8.67	6.09	8.69	[illegible]
[illegible]	[illegible]	0.25	0.47	0.38	0.42	[illegible]	[illegible]	4.70	5.39	3.56	5.36	28.21

[illegible]

Table 5.48 Analysis of Variance in Scores for Loaf Characteristics* and Panelists' Perceptions of Characteristic Differences in Different Breads

Source of Variation		Sum of Squares	Degrees of Freedom	Mean of Squares (Variance)	F Value Calculated	F Value 95%	F Value 99%
1. Color of the crust:	Loaves**	498.51	8	62.31	70.81	2.05	2.74
	Panelists***	49.38	11	4.49	5.10	1.91	2.48
	Interaction	77.34	88	0.88			
2. Symmetry of form:	Loaves	59.99	8	7.50	19.32	2.05	2.74
	Panelists	10.27	11	0.93	2.40	1.91	2.48
	Interaction	34.16	88	0.39			
3. Evenness of bake:	Loaves	82.83	8	10.35	27.80	2.05	2.74
	Panelists	6.21	11	0.56	1.52	1.91	2.48
	Interaction	32.77	88	0.37			
4. Break and shred:	Loaves	52.13	8	6.52	14.44	2.05	2.74
	Panelists	21.80	11	1.98	4.39	1.91	2.48
	Interaction	39.71	88	0.45			
5. Character of the crust:	Loaves	75.64	8	9.46	42.51	2.05	2.74
	Panelists	9.90	11	0.90	4.05	1.91	2.48
	Interaction	19.57	88	0.22			
6. Color of the crumb:	Loaves	375.4	8	46.93	13.89	2.67	2.77
	Panelists	56.23	9	6.25	1.85	2.01	2.67
	Interaction	243.27	72	3.38			

Table 5.48 (Continued)

7. Grain:	Loaves	223.22	8	27.90	12.08	2.07	2.77
	Panelists	70.77	9	7.86	3.40	2.01	2.67
	Interaction	166.33	72	2.31			
8. Aroma:	Loaves	216.76	8	27.09	8.41	2.07	2.77
	Panelists	56.49	9	6.28	1.95	2.01	2.67
	Interaction	231.91	72	3.22			
9. Taste:	Loaves	498.36	8	62.29	9.03	2.07	2.77
	Panelists	137.12	9	15.24	2.21	2.01	2.67
	Interaction	496.98	72	6.90			
10. Chewability:	Loaves	258.49	8	32.31	11.41	2.07	2.77
	Panelists	87.34	9	9.70	3.43	2.01	2.67
	Interaction	203.96	72	2.83			
11. Texture:	Loaves	648.00	8	81.00	11.23	2.07	2.67
	Panelists	76.01	9	8.46	1.17	2.01	2.77
	Interaction	518.99	72	7.21			

*Total column not included.

**Variability amongst bread loaves.

***Variability amongst panelists' perceptions.

and 99% levels of significance. These characteristics were found to differ significantly amongst bread loaves and between each test loaf and the standard. The significance in difference was highest for color of the crust and decreased significantly through the character of the crust, break and shred and grain, to lowest in chewability.

Insignificant variability in the panelists' abilities to detect differences in evenness of bake, color of the crust, aroma and texture was observed at both 95 and 99% levels. Different breads were found to differ significantly in these characteristics. The significance in difference diminished progressively from the evenness of bake to crumb color, aroma, and texture.

Panelists differed less significantly at the 95% level in their abilities to perceive differences in the symmetry of form and taste between the different breads. The difference became insignificant at the 99% level. Significant differences were observed in all breads in these characteristics, less significant differences being observed for taste than for symmetry of form.

Calculated F-values for the bread quality attributes available in Table 5.48 showed that the magnitude of difference amongst the test loaves or test loaves and the standard wheat flour bread was contributed to by varying amounts from the various bread characteristics.

The list of the quality attributes and their corresponding calculated F-values in Table 5.49, in

Table 5.49 Bread Loaf Quality Attributes and their Calculated F Values

Quality Attribute	Calculated F Values*
External Loaf Properties	
Color of the crust	70.[illegible]
Character of the crust	42.51
Evenness of bake	27.[illegible]
Symmetry of form	19.32
Break and shred	14.44
Internal Loaf Properties	
Color of the crumb	13.99
Grain	12.08
Chewability	11.41
Texture	11.23
Taste	9.09
Aroma	8.41

*The greater the F value for a quality attribute, the greater was found to be the contribution of that attribute to the quality differences amongst the different composite breads and between composite breads and the standard wheat bread.

conjunction with panelists' mean scores in Table 5.47 and acceptability mean scores in Table 5.50, indicated that bread quality attributes with greater calculated F-values contributed more extensively to the quality differences amongst the test loaves and between such loaves and the standard wheat flourbread.

The acceptability scores provided in Table 5.50 were derived from data in Table 5.47. In Table 5.51 are summarized the means of the scores accorded to the different breads studied. The grand mean totals in the last row show the order of preference of the starch/vital gluten composite breads by the panelists.

Table 5.50 Bread Quality Attributes Acceptability Rating in Percent

Type of Bread Crumb	Color of the Crust	Loaf Symmetry	Evenness of Bake	Break and Shred	Character of the Crust	Color of the	Grain	Aroma	Taste	Chewability	Texture
	Acceptability Mean Scores As Judged by the Taste Panelists**										
Wheat											
cv. Neepawa Flour	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
cv. Neepawa*	71.88	66.00	64.00	64.00	80.00	96.66	92.80	54.20	80.47	78.20	91.27
cv. Fielder Flour	76.00	75.00	76.67	66.00	62.67	89.80	83.10	94.00	85.93	77.00	77.00
cv. Fielder*	79.13	61.33	59.67	40.33	68.00	95.50	79.60	67.50	62.53	67.8	63.47
Cassava*	53.13	62.67	46.00	58.33	57.00	76.10	91.70	88.20	63.27	52.90	61.13
[illegible]	28.13	51.00	24.00	53.33	17.00	84.10	74.70	63.90	55.57	43.70	61.13
[illegible]	22.13	33.33	12.00	30.67	25.67	45.90	80.20	48.20	57.80	60.90	57.93
Sweet Potato*	33.38	52.67	37.67	52.67	30.67	70.50	84.30	67.50	53.93	43.70	41.27
[illegible]	17.88	8.33	5.67	12.67	14.00	31.80	33.70	47.00	35.93	35.60	35.73

*90% starch and 10% vital gluten composites.

**Values for volume not included.

Table 5.51 Bread Quality Mean Sensory Tasting Scores

			Type of Bread						
			Type of Starch + Vital Gluten						
Bread Quality Attributes	Neepawa Wheat Four (Standard)	Fielder Wheat Flour (Internal Standard)	Wheat cv. Neepawa	Wheat cv. Fielder	Cassava	Yam	Sweet Potato	Taro	Arrowroot
Crust color	8	6.0833	5.7500	6.3333	4.2500	2.4546	2.9091	2.3636	2.1500
Symmetry of bake	3	2.2500	1.9750	1.8417	1.8750	1.6727	1.5833	1.1125	1.0000
Evenness of bake	3	2.3000	1.9167	1.7917	1.3750	1.0750	1.3500	0.8600	1.0000
Break and shred	3	2.1636	1.9167	1.3273	1.7500	1.9200	1.7273	1.3750	1.1250
Character of crust	3	1.9167	2.6917	2.1167	1.2778	1.200	1.5000	1.0000	1.7500
Crumb color	10	7.9000	8.5000	8.4000	6.7000	7.4000	6.2000	4.0000	3.5000
Grain	10	6.9000	7.7000	6.6000	7.6000	6.2000	7.0000	5.0000	3.8000
Aroma	10	7.8000	5.0000	5.6000	7.4000	5.8889	5.6000	4.0000	3.9000
Taste	15	11.000	10.3000	8.0000	8.1000	5.8889	6.9000	7.4000	5.1100
Texture	15	9.7000	11.5000	8.0000	7.7000	5.2000	5.2000	7.3000	5.6300
Chewability	10	6.7000	6.8000	5.9000	4.6000	3.8000	3.8000	5.3000	3.8800
Grand Mean Totals	90	64.81	64.05	55.91	52.63	44.70	43.77	39.71	32.55

6. DISCUSSION

6.1 Granule Size Distribution and Morphology

As reported by earlier investigators (Shoch and Maywald, 1956; D'Appolonia *et al*. 1971) it was found that starch granules were distinquishable in their size and morphology by which they could be identified.

Arrowroot and taro starch granules were the smallest (<5µm) and polygonal in shape. Some were compounded. Yam starch granules were the largest (>10µm) and oval in shape. Cassava and sweet potato starch granules were intermediate in size, with rounded edges and corners. Cassava starch contained a mixture of round and truncated granules. The truncated surfaces were concave with a point at the center, and some granules were compounded.

Starch granule sizes and morphologies were found comparable to similar results reported by Bradley, 1940; Amin, 1955; Matwejwe, 1958; Seidemann, 1963, 1964; Wivinis and Maywald, 1967; Shigashihara *et al*. 1975; Ciacco and D'Appolonia, 1977; and Onwueme, 1978. Some of the investigators found larger size distributions for arrowroot and taro. The differences observed in all starches were attributed to genetic and environmental influences.

Existence of large lenticular and small spherical granules in wheat starch (Kerr, 1950) was confirmed.However, different sizes of lenticular and spherical starch granules were observed. Based on this observation, it appeared that no size continuum existed between the two kinds of wheat starch granules, as asserted by MacMasters and Waggle (1963).

6.2 Amylose Content

The amylose contents for soft white and hard red spring wheat starches did not deviate from the ranges of 23.4-26.9% reported by Ciacco and D'Appolonia (1977) and 23.4-27.5% reported by Medcalf and Gilles (1955).

The amylose contents found for the root starches differed from those reported in the literature by Greenwood *et al.* (1955); Ciacco and D'Appolonia (1977) and Onwueme (1978). This might have been due to starches from different cultivars and environments being used in the investigations. It was found in this study, however, that starcheswith predominantly, small sized granules such, as arrowroot and taro, had lower amylose content than those with large sized granules, such as yam. Cassava and sweet potato starches, with intermediate granule size distributions, had intermediate amylose contents.

Soft white spring wheat starch, with a higher proportion of large starch granules than hard red spring wheat starch was, however, found to have a lower amylose content. This implied that granule size was not the only factor controlling amylose content of starch granules. Genetic and environmental backgrounds probably exert significant influences.

6.3 Mineral Contents

Removal of lipid-phosphate complexes from wheat starch granules as recommended by Morrison *et al.* (1975) [illegible] their phosphate content from about 0.05% to 0.01% and 0.01[illegible] for cvs. Neepawa and Bielder starches respectively. [illegible] starches had higher phosphate contents. This [illegible] increased their swelling power by repulsion of [illegible] phosphate groups carried by individual amylopectin [illegible]ules within the starch granules.

The above observation appeared to be supported by very low contents or no Ca^{++} and Mg^{++} in the starches. [illegible] levels of these cations would react with phosphate on [illegible] amylopectin and hence reduce starch granule swelling power by removing the repulsive charges partly responsible for excessive swelling power (Hayder *et al.* 1980).

Swelling power was however not proportional to phosphate content. Cassava starch, for example, with [illegible] phosphorus content had the higher swelling power at [illegible] temperatures than taro starch with the highest [illegible] content. As expected, wheat starches with less [illegible] content, swell less than the root starches as expected [illegible]

The above observations tended to suggest that [illegible] internal associations, such as the number of micelles and their strength within starch granules, [illegible] in controlling starch hydration and swelling power [illegible] than the repulsion within the granule due to the [illegible] ionized phosphate groups. The influence of [illegible] not clear.

6.4 Solubility and Swelling Power

It was observed that the solubility of the starches depended on the starch granule swelling power. Granule size and amylose content did not appear to have significant influence on the solubility.

Arrowroot and taro starches, with the smallest granules and close in amylose content, had widely different solubilities at their gelatinization midpoints. Starch from CWRSW, with a higher amylose content, was found to be less soluble than starch from SWSW, which is lower in amylose content and contains a higher proportion of large sized granules. Starch from CWRSW, with more amylose, and from taro, with less amylose content, were both equally poor in solubility at their gelatinization midpoints.

Since solubility was found to be directly correlated with swelling power, the observations made above did not fully support Leach *et al*. (1959); Leach (1965); Medcalf (1969) and Kulp (1973) in stating that starches high in amylose content were more resistant to swelling. It appeared that starch solubility and swelling power were more controlled by the degree of starch granule internal association and structural changes in the starch granule surface to permit free amylose to diffuse more easily from the granules.

Solubility curves showed rapid increase in solubility of taro and wheat starches after 70°C, implying rapid breakdown in granule structure resulting in extensive leakage of amylose from the granules. The process was [illegible] in taro, and became very extensive in wheat starches after 80°C. The change was gradual in sweet potato and yam starches, faster in arrowroot and [illegible] in cassava starches. These changes were closely correlated with swelling power.

Based on these observations, it seemed that swelling of hydrated starch granules during heating [illegible] at the surfaces of starch granules, the process being characteristic of a particular starch. Amylose diffusion from the starch granules followed this process very [illegible] according to the type of starch.

Rate and extent of disintegration in the associative forces within starch granules were different for each starch as judged by their solubility and swelling power characteristics during pasting.

Low initial solubility and swelling power for taro and wheat starches below 70 and 85°C, respectively, suggested a lag period during which energy input was necessary before accelerated changes in the granule structure [illegible] solubility and swelling power [illegible] Arrowroot, cassava, sweet potato [illegible] had [illegible] lag in swelling [illegible] an indication of differences [illegible] bonding of the starches.

6.5 Viscosity

It was found that the viscosity of gelatinized starch in water depended on the degree of granule swelling and the strength of the network formed by dissolved amylose interconnecting the granules. This observation was in agreement with similar observations reported by Miller *et al.* (1973) and Hoover and Hadziyev (1981).

The viscosity was found to be a function of temperature with a negative correlation. Numerous hydrogen bonds between the dissolved amylose chains rendered viscosity high at lower temperatures. Increase in temperature weakened the hydrogen bonding within the amylose network, as was shown by the drop in viscosity in spite of granule swelling.

The claim by D'Appolonia *et al.* (1971) that some swollen starch granules are disintegrated by the stirrer, hence partly accounting for decreasing viscosity with increasing temperature, may be true at higher temperatures.

Cassava starch, with the highest swelling power and solubility at all temperatures, exhibited the highest viscosities, as was also observed by Ciacco and D'Appolonia (1977). Arrowroot starch, next to cassava starch in swelling power and solubility, had surprisingly lower viscosity than taro starch, both of which had small starch granules (<4μm). This might be explained by differences in molecular sizes of the dissolved amylose and its tendency to form a firm or weak network through hydrogen bonding. Similar observations were made for yam and sweet potato starches.

The wheat starches, due to their lower swelling power had lower viscosities in comparison to the root starches. Lower viscosity in wheat starch slurries implied weaker hydrogen bonding than in the slurries of root starches.

6.6 DSC-Gelatinization Characteristics

Different starches were found to have specific onset, peak, and the end of gelatinization temperatures for the G endotherm for water volume fractions of v_1=[illegible].

Root starches had higher onset, peak, and end of gelatinization temperatures than the wheat starches. Taro starch had exceptionally higher onset (74.5°C), peak ([illegible]) and end (83.7°C) gelatinization temperatures, which implied very firm associative forces within the taro starch granules. This was corroborated by the highest enthalpy of fusion of 6.38 cal/g starch (DWB) observed for taro and 2.59-5.09 cal/g starch (DWB) for the other root starches and only 0.20 and 0.66 cal/g for SWSW and CWRSW, indicating weaker bonds or association existing within wheat starch granules.

All G endotherms became shouldered by M_1 endotherms representing the melting of crystallites [illegible]. The M_1 endotherm became greater at the expense of the [illegible] endotherm as v_1 decreased, and hence confirmed [illegible] by Donovan (1979) that gelatinization was a function [illegible] water present in the starch.

Wheat starches, but not root starches, had an additional N_2 endotherm near 100°C, revealing the presence of lipid-starch clathrates. Low enthalpy of fusion for the clathrates suggested the existence of only few clathrates within the wheat starch granules.

6.7 Gel Aging

Results indicated that root starch gels with 60% moisture retrograded faster than similar gels from wheat starches at 24°C. The existence of two sets of DSC-endotherms, the first at 50-60°C and the second at 90-100°C in arrowroot, 80-85°C in cassava and 78-82°C in sweet potato starches, revealed that two types of retrogradation were taking place in the gels.

The retrogradation with endotherm at lower temperature was weaker in nature by virtue of the lower temperature required to break it. The endotherm at higher temperature formed only after six days of gel storage. The second set of endotherms was absent in taro, yam and wheat starch gels.

These endotherms probably represented the small and large amylose molecular realignments, the smaller ones giving rise to endotherms at higher temperatures due to the tendency of smaller molecules to compact more firmly during aging. This might however also involve the realignment of long molecules, which is a time-dependent process.

X-ray diffraction cystallography confirmed DSC findings that crystallinity developed in aged starch gels. Diffracted line intensities and peak sharpness, especially at angle of diffraction ranges of 17.075-17.781 and 19.[illegible]-20.07° (2θ) implied that cassava starch gel retrograded more firmly than wheat starch gels during prolonged aging.

6.8 Complexing with Monoglycerides

6.8.1 Infrared analysis of Monoglycerides

In spite of similarity in infrared spetra of α- and β-crystallinity forms of C_{16} and C_{18} monoglycerides, it was possible to differentiate between the two crystallinity forms by C-O bond stretching band of primary -OH groups at 1062 cm^{-1} in the β-crystallinity powder form. The absence of this band in the α-crystallinity or the gel form might be due to formation of hydrogen bonds between the -OH groups and water.

Further identification between α- and β-crystallinity was based on the C=O bond stretching at frequency range of 1730-1739 cm^{-1}, which was consistent in the β-crystallinity form, but accompanied by a strong band at [illegible] cm^{-1} in the α-crystallinity form, probably due to the [illegible] hydrogen bonding in the α-, but not in the β-crystallinity form.

Hoover and Hadziyev (1981) noticed that aging the α-gels promoted the reappearence of the 1062 cm^{-1} band. This observation implied that the β-crystallinity form was the more stable.

6.9 X-Ray Diffraction Analysis of Monoglycerides

X-ray diffraction analysis showed that the αand β-crystallinity forms of the C_{16} and C_{18} monoglycerides were characteristically distinquishable. The distinquishable peaks for strong, medium and weak intensity diffracted lines were similar to earlier work reported by Hoover and Hadziyev (1981).

Of particular interest were the boldly strong diffracted lines at 4.1682 Å (21.316° 2θ) and at 4.1604 Å (21.357° 2θ) for α-C_{16} and α-C_{18}. While α-C_{16} had in addition only one medium peak at 14.6126 Å (6.048° 2θ), α-C_{18} had two additional ones at 14.3929 Å (6.141° 2θ) for the medium one, shouldered to the left by a weak one at 16.6375 A (5.112° 2θ).

The strong line at 4.5378 Å (19.562° 2θ) in the X-ray diffractogram of α-C_{18} indicated that the gel was already in the process of reverting to the β-C_{18} form, which had boldly strong lines at 4.5023 Å (19.718° 2θ) and at 3.9262 Å (22.643° 2θ) corresponding to others in β-C_{16} occurring at 4.5633 Å (19.452° 2θ) and at 3.9341 Å (22.601° 2θ).

While the β-crystallinity form had additional strong lines at 4.0578, 4.3927, 11.9474, 16.0327 Å, two medium ones at 7.9313 and 3.1341 Å, and a weak one at 8.7301 Å. β-C_{18} had only two additional medium, but less intense diffraction lines at 3.1105 Å and 16.1697 Å, and two weak ones, also less intense at 12.1666 and 8.2655 Å.

The β-crystallinity forms of C_{16} and C_{18} monoglycerides had more diffracted lines due to their higher level of crystallinity than their α-crystallinity forms. Both α and β-C_{16} monoglycerides however proved to be more crystalline than their corresponding counterparts of C_{18} monoglycerides. This implied that shorter carbon chain fatty acids in C_{16} monoglycerides were more capable of orientating themselves more compactly in crystalline monoglycerides than C_{18} monoglycerides.

6.10 Complexing with Monoglycerides

The effect of the physical state of starch on the interaction with monoglycerides was proved by low, high and consistently higher complexing indices obtained by interacting monoglycerides with ungelatinised, additionally gelatinized or solubilized lintnerised starches.

Little difference was observed between complexing indices of ungelatinised starch with α- or β-crystallinity forms of monoglycerides, implying that, although monoglycerides have been proposed to enter starch ... complex with amylose inside the starch granules

1965), their ability to do so is limited at lower temperatures, such as 45°C.

In all other cases, higher complexing indices were obtained for all starches using C_{16} instead of C_{18}. This tended to support earlier reports of the superiority of C_{16} over C_{18} in clathrate formation (Krog, 1981; and Hoover and Hadziyev, 1982). Also in all cases α- and not the β-crystallinity form was found to be more reactive with the starches. This again supported earlier claims of the superiority of the α- over the β-crystallinity forms in complexing with starch (Krog, 1970; Lagendijk and Penning, 1970; Lonkhuysen and Blankestijn, 1974, 1976; and Hoover and Hadziyev, 1982).

The finding by Osman *et al*. (1961), and Lonkhuysen and Blankestijn (1974, 1976) that different starches complexed differently with monoglycerides, the process being modified by the physical state of the starch, were also supported.

For all the starches, 0.5% monoglycerides was found to be the optimal level for starch interaction with monoglycerides

6.11 Affinity for Vital Gluten

The affinity of the starches for vital gluten was observed to rise from the dough to the highest level (2-3 times dough values) in the early baking stages before declining to lower levels in the [illegible]lly baked stages.

The rise in affinity of starch for vital gluten from the dough to early baking stages appeared to have been stimulated by the swelling of the starch granules in early and mid gelatinization stages to ensure optimum affinity development between starch and the vital gluten before the gluten became fully denatured in the fully baked stage. The above observation appeared to be supported by similar observations made by Dahle (1971), and the absence of affinity between ungelatinized starch and native gluten as reported by Dennett and Sterling (1979).

Reduced affinity of starch for vital gluten in the fully baked stage appeared to be advantageous in producing looser crumbs, a factor related to good bread keeping qualities as latter proved by compressibility, resistance to penetration and chewability tests.

Low swelling power and starch granule size distribution of about 42.6% granules <5 µm and about 57.7% granules in the range 5-25 µm, as in wheat starches, promoted affinity of starch in baked systems, resulting in firmer crumbs, as opposed to the cases where all starch granules are small (as in arrowroot and taro) or large (10>µm, as in yam), all of which had greater swelling powers than the wheat starches.

Starch solubility enhanced starch gluten affinity, but total amylose content did not provide a consistent influence on the affinity.

6.12 Flour Water Absorption

Wheat flour (CWRSW, cv. Neepawa), with a high proportion of small sized starch granules and good quality gluten, had a higher percent water absorption than flour with a higher proportion of large sized starch granules and inferior gluten (SWSW, cv. Fielder). A similar observation was made for the respective flours made of only their starches and the same quality vital gluten. This observation implied that the granule size distribution of undamaged starch had a definite influence on the level of water absorption by a flour.

More cases in support of the above observation were provided by flours of arrowroot starch/vital gluten and yam starch/vital gluten, in which the former flour had a higher water absorption than the latter, the difference between them being that arrowroot starch grains were all small (<4 μm) compared to the large yam starch granules (>10μm).

It also appeared that starch permeability to water played an important role since yam and taro composite flours had the same absorption yet the starches differed greatly in particle size. Furthermore, in support of this view, arrowroot and taro starches, both with small granules of <4μm, had composite flours of different percent water absorption, arrowroot flour having the higher absorption. That arrowroot starch granules were less compact than taro starch granules although both consisted of tiny granules, all less than 4 μm, was reflected in starch granule swelling power, solubility and enthalpy of fusion studies.

6.13 Dough Rheological Properties

Farinographic rheological data revealed that wheat starch/vital gluten composite doughs had longer development times and stabilities than their pure flour doughs. No significant differences were noticed between the consistencies of CWRSW pure flour and its starch/vital gluten dough consistencies during prolonged mixing. [illegible] differences were however observed between the consistencies of similar doughs from pure flour and starch/vital gluten composite flours from SWSW.

The above observations indicated that the usual dough strength was not only due to quantity and quality of the gluten, but that starch/gluten surface interactions [illegible] played a significant role. Large mixing tolerance [illegible] 20 min drop for SWSW starch/vital gluten tended to [illegible] the opinion that starch from poor baking quality [illegible] an inherent inability to combine well with [illegible] was in support of observations by Harris and [illegible] that different wheat starches behaved differently [illegible] formulations with the same sample of gluten. [illegible] size distribution also appeared to be an important [illegible] influencing dough behavior.

Similar dough farinographic data of [illegible] vital gluten proved that these [illegible] reach similar consistencies as [illegible] dough in shorter times, with the exception of the composite dough with arrowroot starch, which took longer to develop. Furthermore, the composite doughs with root starches had better stabilities than the CWRSW flour dough (except taro and sweet potato starch composite doughs). This behavior might be explained by the higher affinities for gluten possessed by the root starches than the wheat starches. The deviant behavior of arrowroot starch composite dough in taking longer to develop might be explained by some other reason such as its large surface area requiring more time at constant mixing rate to be fully coated with gluten. Shorter dough stabilities in sweet potato and taro composite doughs might also be explained by differences in granule sizes and morphology in relation to gluten film coating stability against rapture during mixing.

In spite of the root starch/vital gluten composite doughs being more stable, they deteriorated faster in their consistency than pure or starch/vital gluten doughs from CWRSW. This suggested that, although root starches had more affinity for gluten, they formed weaker doughs when subjected to prolonged mixing.

Yam starch/vital gluten composite dough withstood prolonged mixing better than any other root starch composite doughs. This suggested that large and oval, apparently smooth granules with small surface area to volume ratio, as in yam, promoted coherence within the dough.

Findings which [illegible] be [illegible] to [illegible] have been reported by Bayer and [illegible] Akinwale (1975), [illegible] and D'[illegible] *et al.* (1981).

6.14 Dough and Crumb Hydration Capacities

In general, higher [illegible] to have a negative effect on dough and [illegible] capacities, thus confirming [illegible] Sterling (1978). The presence of [illegible] the flour was, however, observed to [illegible] effect on dough hydration capacity) [illegible] Fielder.

Gelatinization inflated crumb hydration [illegible] several times over their corresponding [illegible] arrowroot and taro, with negative [illegible] positive crumb hydration capacities [illegible] crumbs. Starch granule swelling power [illegible] found to have directly positive influence on [illegible] capacities, which again confirmed the [illegible] soluble amylose in the crumb [illegible] reported by [illegible]

6.15 Fractional Volume [illegible]

Wheat flour [illegible] gluten bread [illegible] over [illegible]

The differences observed in fractional volume increases of the various breads could not be related to starch granule size, amylose content, starch swelling power or solubility. Relation with starch affinity for gluten was not fully conclusive, but it appeared that the ability of a dough to retain air or proofing gas might have been more influential.

6.16 Dough and Crumb Microstructure

6.16.1 Dough Microstructure

Scanning electron (SE) micrographs of fermented and proofed dough surfaces prior to placement into the oven for baking indicated that starch granules, irrespective of source, were capable of being coated with a thin film of gluten. Bolder granule outlines retained by the root starches in their doughs appeared to suggest that root starches were only thinly coated with a film of gluten in comparison to the wheat starch granules in pure or starch composite flour doughs. This was supported further by the presence of thicker gluten coatings observed around wheat starch than root starch granules in fractured dough surfaces.

Doughs from SWSW pure or starch/vital gluten flours exhibited lower fractional volume increases than corresponding doughs from CWRSW when baked to bread .This might have been due to the presence of more pores observed in the surfaces of SWSW than in CWRSW doughs, as revealed by

SE-microscopy. The same technique also revealed that the SWSW starch was less cohesively associated with the gluten matrix than the CWRSW starch. This might also have facilitated more loss of gases from the the SWSW doughs, resulting in reduced fractional volume increases for SWSW than CWRSW based dough-bread systems.

Arrowroot and taro fractured dough surface SE-micrographs showed the existence of gluten spindle bridges between starch granules. The granules were barely covered with a thin film of gluten. Aggregates of starch granules were observed to be better coated with gluten than others. This might be explained by the large surface area possessed by the small starch granules (all <4μm) in arrowroot and taro starch doughs. These could not be equally coated with gluten, thus sometimes resulting in gluten film shredding and formation of spindle bridges between some starch granules as observed.

Cassava and sweet potato starches were better coated with gluten, as revealed by SEM of fractured surfaces of their composite doughs. Although yam starch granules were evenly coated externally, the gluten inside the dough appeared to have gathered mainly in the spaces between the starch granules. This observation seemed to be a response of overstrained gluten films to predominantly large granules of yam starch, as further supported by intergranular fissures observed exteriorly in the in the gluten film coating.

As a whole, starch granules were best coated with gluten in pure wheat flour doughs. Granule coating with gluten deteriorated in wheat starch/vital gluten doughs. Coating of the root starches with gluten was quite variable, being more strained by dominance of very small or very large starch granules.

6.16.2 Crumb Microstructure

Scanning electron microscopy of the bread crumb surfaces showed that all root starches had gelatinized well in the denatured gluten matrix, forming good crumb structures comparable to wheat bread crumb.

Whereas a weak wheat flour or composite of its starch/vital gluten flour produced weakly structured doughs reflected in less desirable crumbs compared to doughs and crumbs from a strong wheat or its starch/vital gluten composite flour, as shown respectively by wheat, cvs. Fielder and Neepawa, the observation with respect to the root starch composites with vital gluten was different.

Weaknesses seen in the composite doughs of the root starches with vital gluten seemed to disappear from their bread crumbs, which were of good quality comparable to good wheat bread crumbs. In fact root starches produced better bread crumbs than bread crumbs based on wheat, cv. Fielder flour and starch/vital gluten composite. This was attributed to the higher swelling power of the root starches, which helped to strengthen the gluten matrix structures surrounding the air-cells in the crumb. The amylose provided by the higher solubility of the root starches strengthened the crumbs by a cementing action on retrogradation.

The tiny pores observed in SE-micrographs of doughs (Evans *et al*. 1981) and in crumbs (Fleming and Sosulski, 1978) were also observed in this study. The pores were more prevalent in wheat flour or starch based doughs and crumbs than in those of root starch. This confirmed the observation that the root starches were more thinly coated with gluten in the dough, hence allowing more diffusion of the gases from the doughs, while the thicker gluten coatings observed on starch granules in wheat flour or starch/vital gluten doughs encouraged higher pressure development in the air cells in the doughs. The pores must have formed as a means of equalizing the pressure within the different air cells in the dough and latter within the developing crumb during baking. This appeared to be supported by the presence of more pores in the crumb than in the dough as a response to increased pressure within the bread during baking as the temperature rose.

Higher solubility of amylose in the root starches over longer temperature ranges than observed for the wheat starches and its cementing influence on the crumb on retrogradation might explain why composite crumbs with root starches had fewer pores than crumbs from the wheat bread. Some of the root starch composite crumbs, as in arrowroot starch/vital bread crumb, had even fewer, but larger pores, indicating the presence of greater tenacity in the amylose-gluten matrix complex between the air cells, exploding only occasionally and leaving behind only a few large pores. This observation might also explain why arrowroot/vital gluten composite bread had the highest fractional volume increase amongst all the breads based on the root starches.

6.17 Transmission Electron Microscopy of Dough and Crumb

Representative transmission electron micrographs were made from arrowroot starch/vital gluten dough and crumb (Plate 5.16).

Individual starch granules, as well as aggregates, surrounded with films of gluten, were observed both in the dough and in the crumb. Observations made in the TE-micrographs corroborated those made in the SE-micrographs of the fractured dough surface, already discussed above.

In addition, the TE-micrographs showed that, although the starch granules had been previously graded as all being less than 4µm, they were of different sizes even in their gelatinized state. Sections through the air cell walls showed that they were lined with starch granules embedded in the gluten matrix, as previously observed by Burhams and Clapp (1942), Baker and Mize (1946), Sandstedt *et al.* (1954) and Hanssen (1957).

6.18 Bread Keeping Qualities

Bread keeping qualities in the presence and absence of monoglyceride, investigated through crumb compressibility, resistance to penetration and X-ray diffraction analysis of crystallinity development in starches isolated from aged crumbs, provided complementary results.

Incorporation of monoglyceride in the bread formulation increased crumb softness, resulting in increased crumb compressibility, but reduced resistance to penetration. No monoglyceride was included in the bread formulation for X-ray analysis of aged starch isolated from the bread crumbs. This was necessary in order to determine the relative crystallinity development in the different starches, followed by establishment of the role played by starch granule internal crystallinity in bread firming.

Solubility and behavior of the solubilized amylose appeared to be the main factors influencing the compressibility of the crumb and its resistance to penetration.

In the absence of monoglyceride, yam starch/vital gluten crumb required the highest compression force and had high penetration resistance, just below that for cassava starch/vital gluten bread. Cassava starch had the highest solubility. Retrogradation of the solubilized amylose rendered the crumb firm. Compressibility and crumb resistance to penetration exhibited by its crumb were in agreement with the views of Schoch (1965). Yam had comparatively much lower solubility than cassava starch. Yam starch behavior revealed by its crumb compressibility and resistance to penetration tests implied that yam amylose retrograded more firmly, establishing a rigid network close in strength to a similar network made from a larger quantity of solubilized and retrograded amylose from cassava. This view was supported by X-ray diffraction patterns, which showed that yam starch retrograded relatively faster than cassava starch.

Yam starch bread became the softest in presence of monoglyceride, as shown by crumb compressibility (and next to the arrowroot starch bread according to the crumb penetration resitance test), suggesting that yam starch was more readily complexed by monoglyceride. Application of α-C_{18} at 0.5% tended to support this observation. Larger granule size in yam starch might also have enabled more monoglyceride to penetrate the granules and hence immobilize more amylose to a greater extent.

Arrowroot starch granules, although as small as taro starch granules were more porous and soluble. Their ability to give soft crumb in the presence of monoglyceride (but firmer than taro starch bread crumbs in the absence of monoglycerides) may be due to the higher solubility of arrowroot starch, providing more amylose, which on retrogradation resulted in firmer crumb for arrowroot than for taro bread crumbs. A similar argument for cassava and sweet potato starch bread crumbs appeared to be valid.

X-ray diffraction patterns showed that relative rate of crystallinity development in the starch granules during crumb aging was highest in yam, followed by sweet potato starches. It was slightly slower in arrowroot than in sweet potato starches, dropping for taro, and being least in cassava starch. Compressibility and crumb penetration tests proved however that crystallinity development in the starch granules within the crumbs was less significant in contributing to crumb firmness during aging than retrogradation of solubilised amylose in the intergranular gluten matrix in the crumb.

Crumb microstructure and affinity of starch for gluten in the crumb revealed that CWRSW flour and starch/vital gluten crumbs should be firmer than similar crumbs based on SWSW flour and its starch/vital gluten composite. These observations were contradicted by crumb compressibility and resistance to penetration tests. The contradiction could be explained in a similar manner as presented above for the root starch/vital gluten composite crumbs, since SWSW starch had higher solubility than CWRSW starch.

Medcalf (1968) and Kulp (1973) reported that starches high in amylose content were more resistant to gelatinization, hence had smaller swelling power. This was observed to be true for CWRSW starch, which had a higher amylose content and a lower swelling power than SWSW starch, with a lower amylose content. This might explain further the fact that crumbs from CWRSW flour and starch were more tender than bread crumbs from SWSW flour and starch.

X-ray diffraction analysis again showed that gelatinized CWRSW starch developed crystallinity faster during aging than gelatinized SWSW starch. Such crystallinity development in wheat starch granules was also found to contribute much less towards crumb firming than retrograded amylose, as revealed by extent of starch solubility and its influence on crumb compressibility and resistance to penetration.

6.19 Bread Quality Evaluation

6.19.1 Loaf Volume

Breads from CWRSW pure, and starch/vital gluten composite flours had largger volumes thansimilar breads from SWSW pure, and starch/vital gluten composite flours.This was attributed to superior gluten quality and quantity in CWRSW flour, and also due to low solubilty associated with its starch, resulting in formation of less rigid dough and crumb structures more prone to expansion by gases during fermentation and oven rise stages of bread making than in those cases involving SWSW flour and starch based breads.

It was similarly observed for root starches that starch solubility and extent of rigidity associated with soluble amylose on retrogradation had influence on loaf volumes. Starch size distribution did not appear to have any influence on loaf volume. Swelling power did not give a

It seemed that a low score for a characteritic did not indicate non-acceptability, but that the panelists viewed that characteristic in the composite bread to be different from the standard wheat bread. Composite bread internal properties were however viewed as being close to wheat bread. Since these are important properties of bread, it appeared that root starches, especiaslly from cassava, have a good potential of being used to produce composite breads similar in quality to wheat bread. This finding would probably be of greater significance where wheat availability is limited, and food products from root crops are common in the diet. Color of the crust and its character would certainly need further improvement to make the composite breads more attractive.

Further development might mean establishing the proper formulations and baking conditions for composite breads, which appear not to be identical with those established for wheat bread. Proper formulations might require spplementation of the composite starch flours with a fraction of damaged starch, a higher level of sugar or addition of α-ammylase.Fermentation period, baking temperature and time may also require proper adjustment.

Table 5.52 is provided as a final summary of all the results.

Table 5.52 Comparison of Starch Characteristics

Characteristic	CWRS Neepawa	SWSW Fielder	Cassava	Yam	Sweet Potato	Taro	Arrowroot
1.	Triticum vulgare	Triticum vulgare	Manihot utilissima	Dioscorea cayenensis	Ipomoea batatas	Colocasia esculenta	Maranta arundinacea
2.	Cereal	Cereal	Tuberous root (root cluster)	Deep tuber	Tuberous root	Corm (under-ground stem)	Rhizome (under ground stem)
3. Granule size, um	76% 10	77% 10	80%, 5-15	95%, 16-35	83% 10	all 4	all 4
4. Granule Morphology	Spherical Lenticular	Spherical Lenticular	Round Smooth Some concave Some truncated	Round Ellipsoidal Smooth	Polygonal Rounded Corners Smooth	Polygonal	Polygonal
5. % Amylose	27.3	23.0	19-21	25.0	20.0	15.0	17.0
6. % Phosphorus	0.016	0.013	0.011	0.006	0.013	0.026	0.023
7. % (Ca^{++} + Mg^{++})	0.005	0.005	0.010	0.003	0.014	0.006	0.015
8. % (Na^{+} + K^{+})	0.041	0.047	0.062	0.035	0.060	0.118	0.126
9. Water binding capacity (gH_2O/g starch - DWB) *#	0.45	0.34	0.50	0.70	0.55	0.65	0.50
10. Swelling power (g paste/g dry starch) at 95°	19.0	24.5	73.4 (Kenyan cv.)	34.0	33.5	33.0	40.02
11. % solubility at 95°C	[illegible].6	28.8	30.4	23.3	~~18.7~~	22.4	25.0

*# See appendix 37.

12.	Peak gelatinization temperature °C	55.2	50.1	58.8	65.7	58-66.5*k	78.6	67.5
13.	Viscosity at 70°C. 1% w/v slurry. 10 min of Haake rotoviscometer (cP).	0.67	0.83	2.8	3.0	1.75-2.65*	3.0	2.4
14.	Enthalpy of fusion cal/g dry starch	0.66	0.20	4.90	4.56	3.10	6.38	4.93
15.	Affinity for gluten (%)							
	Raw	31.8	24.8	48.5	40.80	40.0	41.7	50.3
	Early baking	88.6	89.6	82.1	91.50	89.10	90.0	83.6
	Baked	45.1	41.3	49.0	28.50	44.0	41.0	41.0
16.	% Moisture	9.82 8.91 (flour)	11.03 11.67 (flour)	14.23	10.35	8.96	13.51	9.23
17.	% Absorption	60.4 68.4 (flour)	54.0 56.8 (flour)	64.7	68.5	68.8	68.4	80.5
18.	Arrival time (min)	1.75 3.8 (flour)	1.0 0.8	2.0	2.3	2.5	3.0	3.25
19.	Peak time (min)	6.5 6.0 (flour)	3.5 1.20 (flour)	4.5	4.0	3.5	3.8	7.0
20.	Dough stability (min)	11.8 6.7 (flour)	7.5 0.9 (flour)	8.3	10.2	4.2	1.8	7.8
21.	MTI (BU)	25.0 26.0 (flour)	40.0 120.0 (flour)	60.0	48.0	145.0	120.0	60.0

22. 20 min drop	45.0 45.0 (flour)	60.0 150.0 (flour	130.0	80.0	190.0	190.0	120.0
23. Dough HC g H_2O/g dry solids	0.125 0.061 (flour)	0.269 0.092 (flour	0.043	0.253	0.083	- 0.10	- 0.083
24. Crumb HC g H_2O/g dry solids	5.37 3.64 (flour)	4.03 4.48 (flour)	6.6	2.65	4.12	3.14	3.29
25. Gelatinization hydration	5.25 3.58 (flour)	5.76 4.39 (flour)	6.56	2.40	4.04	3.24	3.32
26. Loaf vol. (cm^3)	1302.0 1432.0 (flour)	1122.0 1051.0 (flour)	1112.0	1022.0	1192.0	1172.0	922.0
27. Loaf mass (g)	443.0 435.0 (flour)	452.0 421.0 (flour)	426.0	435.0	426.0	426.0	419.0
28. Loaf sp. vol. cm^3/g	2.94 3.52 (flour)	2.48 2.50 (flour	2.61	2.26	2.80	2.75	2.20
29. Fractional vol. increases cm^3 (based on 50 g dough)	1.49 1.68 (flour)	1.19 1.65 (flour)	0.7	0.67	0.64	0.49	0.96
30. Crumb compressibility (kg force/mm) fresh crumbs							
+ Mg	0.04 0.03 (flour)	0.06 0.06 (flour)	0.04	0.08	0.08	0.09	0.02
- Mg	0.05 0.06 (flour)	0.07 0.011 (flour)	0.10	0.10	0.10	0.11	0.04
6 day old crumbs + Mg	0.95 0.72 (flour)	1.27 1.21 (flour)	0.97	0.66	0.90	.10	0.73
- Mg	1.02 0.75 (flour)	1.32 1.27 (flour)	1.30	1.35	1.30	1.23	1.28

31.	Crumb penetration resistance (kg force/mm)							
	Fresh crumbs							
	+ mg	0.03 0.02 (flour)	0.04 0.03 (flour)	0.03	0.03	0.02	0.04	0.02
	- mg	0.03 0.02 (flour)	0.05 0.04 (flour)	0.04	0.04	0.07	0.05	0.06
	6 day old crumbs							
	+ mg	0.20 0.08 (flour)	0.25 0.27	0.13	0.11	0.18	0.17	0.09
	- mg	0.24 0.13 (flour)	0.35 0.39 (flour)	0.36	0.34	0.30	0.25	0.21
32.	Sensory evaluation grand mean totals	64.81	64.05	52.63	44.70	43.77	39.71	32.55
33.	Preference order	1	2	3	4	5	6	7

* Depending on cultivar.

conclusive direct effect. Some available evidence indicated that decreasing amylose content was accompanied by an increase in loaf volume.

6.19.2 Sensory Panel Tasting and Statistical Evaluation

Composite breads of root starches with vital gluten appeared to be similar to those studied and reported by Kim and Ruiter (1969), Ciacco and D'Appolonia (1977), and Olatunji and Akinrele (1978).

Those considered in this study received lower sensory tasting scores than the standard wheat bread, especially in their external properties, of which the color of the crust scored the least. Their internal characteristics received more than average acceptability ratings. Cassava starch bread scored consistently higher than any other root starch breads, in both its external and internal loaf properties.

Analysis of variance showed that loaves of different breads actually differed in their characteristics. The organoleptic tests were ,however, subject to the panelists' subconscious bias , as the majority of them were foreign to edible products from root crops. It is possible that results of the same sensory tasting might be significantly differentif performed by peole to whom the composite breads might mean improvement or attractive alternatives in their usual diet.

7. CONCLUSIONS

All starch granules were found to be characteristically distinguishable in their size and morphology, amylose and mineral contents, swelling power and solubulity, viscosity and gelatinization properties, as well as in their ability to retrograde in aged gels and bread crumbs.

Retrogradation of leached out amylose was more responsible than crystallinity development in starch grains for crumb firming during aging. The presence of monoglycerides at the optimal level of 0.5% on starch dry weight basis produced a softening effect in all cases. The effect varied significantly with the type of starch.

Monoglycerides in their α- but not β-crystallinity form were found to be more reactive with the starches. Glycerol monopalmitate (C_{16}) was found to clathrate more than glycerol monostearate (C_{18}) with the starches. Solubilized starches reacted most while ungelatinized one reacted least with the monoglycerides. The reaction with gelatinized starches was intermidate under the same conditions.

Highest affinity of starch for gluten in early baking was advantageous in ensuring maximum associaton between the starch and the gluten before the gluten became fully denatured at higher temperatures during baking. Low affinity of starch for gluten in fully baked systems was found to encourage the developmemt of looser crumbs, which was found to be advantageous in bread keeping qualities.

Predominantly large or small starch granule size distribution in the flour promoted water absorption by the flour. This was found to be related to the high water binding capacities possessed by starches predominated by either large or small starch granules. Very close association between the starch granules and the gluten reduced water absorption by the flour.

Vital gluten/starch doughs reached similar consistencies as Canadian western red spring wheat flour dough, but in shorter times, and with better starbilities. This was found to be in agreement with the higher starch affinity for gluten observed for root starches than wheat starches in the dough. Root starch doughs , however, disintegrated faster on continued mixing due to root starches being only thinly coated with gluten film, and inherrent weaknesses existing at the root starch granules-gluten film interfaces.

Root starch/vital gluten doughs had better mixing properties than Fielder wheat flour. Dough strength was found to depend on the nature of the gluten as well as the starch-gluten film surface interactions.

Dough and crumb microstructure were found to be significantly influenced by starch granule size, swelling power, solubility, gas formation ability and the capacity of the dough to retain the gases during mixing, fermentation, proofing and oven rise. The absence of damaged starch in the root starch/vital gluten composite flours and weaker dough structure in the presence of root starches resulted in smaller loaf volumes observed in their composites breads as compared to wheat flour or starch/vital gluten composite breads.

Dough and crumb hydration capacities were negatively influenced by increasing amylose content of the starch. Predominance of large granule size promoted dough hydration capacity. The extent of gelatinization, starch swelling power, and solubilty had positive influences on crumb hydration capacity..

CWRS wheat starch with vital gluten produced the bestcomposite bread, followed by the composite bread containg SWSW starch. This appeared to prove that starch from good bakind quality wheat had an inherrent ability to combine better with gluten and produce better quality bread than starch from poor baking quality wheat. Next to the wheat starch composites, cassava starch/vital gluten bread was judged organoleptically the best amongst the composite breads containing root starches. Following in preference were breads containing yam, sweet potato, taro and lastly arrowroot starches.

Bread loaf external properties were the most limiting factors in the organoleptic evaluation of the composite breads containing the root starches. Color of the crust and its character were the most limiting. Since conditions established for baking wheat flour bread were used in baking these composite breads, it appeared, especially for the composites with root starches, that investigations to establish proper formulations and baking conditions that would improve their sensory properties would be necessary. Nevertheless, root starches, especially casssava, yam, sweet potato and taro, have a good potential of being used as dilutants of strong wheat flours, or being used along with vital gluten to produce good quality composite breads. This development would probably be of greater significance in countries where wheat availability is limited, or food products from root crops are already popular. It would be much so especially if the availability of composite breads would lead to improvement in diet at reasonably affordable cost.

This study was concerned with model systems involving only native strarches instead of flours obtained from tropical root crops. It has provided fundamental data which can only be attributed to these starches, and vital gluten in baking. The would be interferences from the other chemical compounds such as proteins, gums, sugars, fibre, oxidants, pigments, and flavor substances native to the tropical tubers, and hence present in their flours , were thus avoided. Since the flours are predomiantly starch (75-85), their use in baking studies withfor example strong wheat flours , or with vital gluten, guided by the findings of this study would be worthwhile. Changes in dough rheological properties and bread organoleptic properties would be expected.

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9. APPENDICES

APPENDIX 1.

Gelatinization Characteristics of Cassava Starch - Fijian Cultivar

Water Volume Fraction (V_1)	Endotherms: Gelatinization (g) t°C Onset	t°C Peak	t°C End	cm^{2*}	ΔH^{**}	Crystallite (m_1) t°C Onset	t°C Peak	t°C End	cm^{2*}	ΔH^{**}
0.8	62.88±1.10	67.25±1.32	72.50±1.80	3.50±0.63	4.23±0.76	-	-	-	-	-
0.7	60.88±1.70	67.13±1.18	72.50±0.71	4.21±0.67	5.09±0.81	73.50±0.00	80.70±2.55	86.38±3.10	1.92±0.38	2.32±0.46
0.6	59.50±1.08	66.38±0.95	78.17±1.04	4.22±0.68	4.22±0.82	72.20±1.52	85.50±2.30	93.00±1.50	3.68±1.05	4.45±1.27
0.5	59.20±1.44	65.48±1.11	71.40±2.04	1.15±0.52	1.39±0.63	72.33±1.04	93.25±2.10	101.70±3.27	3.81±0.05	4.61±0.06
0.4	56.50±0.35	63.75±0.41	77.17±2.59	0.99±0.23	1.20±0.28	76.30±1.60	97.00±1.170	115.57±9.29	6.07±0.88	6.12±0.77
0.3	56.00±0.00	62.50±0.00	75.50±0.00	-	-	83.50±8.41	122.75±1.77	125.86±3.80	12.59±0.00	15.23±0.00

* Endotherm area.

** ΔH Enthalpy of Fusion, Cal/g Starch.

APPENDIX 2.

Gelatinization Characteristics of Sweet Potato Starch - Californian Centennial Cultivar

Water Volume Fraction (V_1)	Endotherms: Gelatinization (g) t°C Onset	t°C Peak	t°C End	cm^{2*}	ΔH**	Crystallite (m_1) t°C Onset	t°C Peak	t°C End	cm^{2*}	ΔH**
0.8	54.50±0.71	64.50±0.50	74.67±0.58	8.64±0.85	3.49±0.34	-	-	-	-	-
0.7	54.75±0.35	61.34±0.76	69.00±0.00	6.40±0.50	2.59±0.20	72.50±0.71	85.25±0.35	94.25±0.35	2.62±0.60	1.07±0.24
0.6	52.50±0.50	61.17±0.38	70.00±0.00	3.41±0.06	1.38±0.02	71.67±2.10	81.33±2.50	90.33±4.30	1.72±0.08	0.69±0.03
0.5	52.75±1.50	60.38±0.48	68.63±0.48	2.43±0.47	0.98±0.19	73.50±1.80	88.13±5.54	99.17±3.40	1.42±0.33	0.57±0.13
0.4	53.67±0.76	60.50±0.50	68.50±0.50	2.56±0.11	1.03±0.04	87.00±2.00	105.54±1.54	121.17±1.00	6.42±0.50	2.59±0.20
0.3	-	-	-	-	79.67±12.40	97.50±27.3	-	-	-	-

* Endotherm area.

** ΔH Enthalpy of fusion, Cal/g Starch.

APPENDIX 3.

Gelatinization Characteristics of Sweet Potato Starch - Porto Rico Cultivar

Water Volume Fraction (V_1)	Endotherms									
	Gelatinization (g)					Crystallite (m_1)				
	t°C Onset	t°C Peak	t°C End	cm^{2}**	ΔH**	t°C Onset	t°C Peak	t°C End	cm^{2}*	ΔH**
0.7	51.50±0.00	57.50±0.71	66.00±0.00	2.88±0.04	3.49±0.05	77.0±8.50	93.00±12.02	102.75±13.80	1.53±0.09	1.85±0.11
0.6	50.88±0.63	58.33±0.29	65.00±0.00	2.26±0.50	2.74±0.61	72.25±2.47	89.0±6.40	97.50±5.70	1.84±0.03	2.23±0.04
0.5	55.00±0.00	74.00±0.00	85.50±0.00	1.60±0.42	1.94±0.51	91.00±2.83	112.00±5.67	125.50±9.19	2.26±1.85	2.74±2.23
0.4	53.50±0.00	75.00±0.00	86.50±0.71	1.46±0.13	1.77±0.16	94.00±0.00	93,75±0.35	117.50± -	1.32±0.50	1.60±0.20
0.3	-	-	-	-	-	65.50±0.71	89.25±1.10	101.50±0	2.04±0.65	2.47±0.79

*Endotherm area.

**ΔH Enthalpy of Fusion, Cal/g Starch.

APPENDIX 4.

Gelatinization Characteristics of Some Canadian Wheat Starches

Type of Starch	Volume fraction	Endotherms							
		Gelatinization (g)				Crystallite (m_1)			
		t^oC Onset	t^oC Peak	t^oC End	ΔH/Cal/g*	t^oC Onset	t^oC Peak	t^oC End	ΔH/Cal/g*
cv. Fielder	0.8	50.50 ±0.72	56.00 ±1.30	62.50 ±1.80	0.89	--	--	--	--
	0.7	50.08 ±0.91	55.18 ±0.82	60.90 ±2.02	0.66 ±0.10	61.50 ±0.41	70.30 ±0.20	76.50 ±2.30	0.320 ±0.030
	0.6	49.50 ±0.65	55.50 ±0.70	62.45 ±0.90	1.20 ±0.44	62.80 ±1.10	77.50 ±0.50	92.50 ±1.40	0.920 ±0.070
	0.5	49.0 ±1.10	54.50 ±1.50	58.50 ±1.70	0.63 ±0.15	78.50 ±1.60	89.00 ±3.00	105.50 ±3.50	--
	0.4	50.00 ±1.50	53.50 ±1.30	57.00 ±2.00	--	86.50 ±1.30	--	--	--
	0.3	--	--	--	--	--	--	--	--

* Enthalpy of Fusion.

APPENDIX 5.

Complexing Indices (%) for the Interaction of the α-crystallinity Form of C_{16} and C_{18} Monoglycerides With Cassava Starch

	Cassava Starch					
	Ungelatinized		Gelatinized		Solubilized	
% MG	C_{16}	C_{18}	C_{16}	C_{18}	C_{16}	C_{18}
0.1	4.75±0.26	1.24±0.22	11.69±2.77	8.66±0.38	28.72±0.23	14.62±0.80
0.2	6.24±0.18	2.33±0.06	24.09±1.50	16.71±2.89	47.93±1.11	26.84±0.19
0.3	7.58±0.20	6.69±0.91	38.07±2.27	23.37±2.31	58.02±1.16	46.65±2.47
0.4	9.67±0.15	8.47±0.06	43.31±0.79	26.53±0.80	63.30±1.85	60.84±1.51
0.5	9.97±0.18	8.74±0.11	46.19±3.27	30.64±0.08	70.73±0.73	70.41±1.37
0.8	11.05±0.07	10.11±0.56	4.09±4.55	35.19±0.49	78.76±0.52	75.10±1.70
1.0	12.09±0.74	11.89±0.30	49.24±6.54	37.30±0.47	83.12±0.62	76.36±2.86

APPENDIX 6.

Complexing Indices (%) for the Interaction of the β-crystallinity Form of C_{16} and C_{18} Monoglycerides With Cassava Starch

	Cassava Starch					
	Ungelatinized		Gelatinized		Solubilized	
% MG	C_{16}	C_{18}	C_{16}	C_{18}	C_{16}	C_{18}
0.1	1.85±0.09	1.28±0.24	3.80±0.01	1.75±0.25	9.50±0.88	4.62±0.45
0.2	5.08±0.01	2.70±0.27	6.75±0.13	3.65±0.75	13.40±0.85	8.30±1.17
0.3	6.96±0.19	4.10±0.34	8.23±0.06	5.53±1.61	15.40±0.85	11.28±0.74
0.4	7.83±0.08	5.47±0.23	9.88±0.01	7.03±1.52	17.79±0.92	13.70±1.31
0.5	8.50±0.17	6.51±0.34	10.76±0.11	7.92±1.61	18.46±0.95	15.98±0.18
0.8	9.50±0.11	8.36±0.23	11.94±0.24	11.73±1.53	19.41±0.13	19.12±1.72
1.0	9.95±0.06	8.72±0.17	12.22±0.19	12.00±1.43	20.38±0.44	19.94±1.72

APPENDIX 7.

Complexing Indices (%) for the Interaction of the α-crystallinity Form of C_{16} and C_{18} Monoglycerides With Sweet Potato Starch

	Sweet Potato Starch					
	Ungelatinized		Gelatinized		Solubilized	
% MG	C_{16}	C_{18}	C_{16}	C_{18}	C_{16}	C_{18}
0.1	2.99±0.21	0.99±0.08	14.17±0.72	9.00±0.77	37.82±4.19	30.13±3.57
0.2	5.24±0.86	2.34±0.15	27.21±3.00	17.65±1.24	51.64±4.20	47.80±2.38
0.3	7.35±0.21	3.57±0.43	38.00±0.70	25.15±2.55	59.93±3.63	56.20±2.40
0.4	7.80±0.14	4.71±0.61	50.13±1.41	34.30±1.51	65.06±1.95	62.86±2.50
0.5	8.51±0.25	5.72±0.37	60.60±3.08	40.84±1.78	68.42±2.80	68.01±2.38
0.8	9.74±0.07	7.50±0.47	69.70±0.22	56.42±1.20	72.37±5.58	73.90±1.20
1.0	10.36±0.14	8.23±0.07	70.17±0.18	60.62±1.28	75.33±4.19	75.58±1.19

APPENDIX 8.

Complexing Indices (%) for the Interaction of the β-crystallinity Form of C_{16} and C_{18} Monoglycerides With Sweet Potato Starch

% MG	Sweet Potato Starch: Ungelatinized C_{16}	Ungelatinized C_{18}	Gelatinized C_{16}	Gelatinized C_{18}	Solubilized C_{16}	Solubilized C_{18}
0.1	0.49±0.09	0.44±0.03	10.75±0.49	7.40±1.47	13.70±2.69	10.38±1.49
0.2	0.91±0.15	0.89±0.06	23.66±0.43	18.05±1.43	25.09±1.44	22.25±5.04
0.3	1.19±0.20	1.10±0.06	29.69±0.42	25.52±1.26	32.56±0.19	30.26±6.29
0.4	1.43±0.24	1.24±0.03	32.70±0.95	29.63±0.15	35.36±1.36	35.51±7.40
0.5	1.65±0.18	1.73±0.06	36.90±0.23	33.74±0.00	38.93±0.16	38.32±8.20
0.8	2.08±0.13	1.92±0.03	42.14±0.21	37.74±0.33	47.91±0.96	40.75±8.94
1.0	2.20±0.06	2.15±0.06	44.42±0.42	38.90±1.65	52.51±0.16	43.07±8.94

APPENDIX 9.

Co[illegible] Indices (%) for the Interaction of the α-Crystallinity Form of C_{16} and C_{18} Monoglycerides With Taro Starch

	Taro Starch					
	[illegible]ngelatinized		Gelatinized		Solubilized	
% MG	C_{16}	C_{18}	C_{16}	C_{18}	C_{16}	C_{18}
0.1	4.59±0.97	3.48±0.71	10.02±0.74	9.75±0.88	36.70±1.51	29.75±0.77
0.2	6.93[illegible]	5.97±1.41	15.29±0.75	14.38±0.53	44.40±0.81	38.82±0.62
0.3	8.2[illegible].72	8.47±1.54	20.77±1.17	18.30±0.42	47.64±0.58	45.51±0.44
0.4	10.89±1.75	10.44±2.11	26.89±0.74	21.87±0.57	51.26±0.40	49.53±0.42
0.5	11.89±1.82	10.68±2.46	29.99±2.32	25.22±0.85	54.33±0.30	52.03±0.38
0.8	14.08±1.72	11.93±2.81	41.96±0.49	31.02±1.25	56.49±0.73	55.03±0.22
1.0	14.72±1.56	12.43±2.81	44.52±0.16	35.37±2.71	55.81±0.61	55.81±0.61

APPENDIX 10.

Complexing Indices (%) for the Interaction of the β-Crystallinity Form of C_{16} and C_{18} Monoglycerides With Taro Starch

	Taro Starch					
	Ungelatinized		Gelatinized		Solubilized	
% MG	C_{16}	C_{18}	C_{16}	C_{18}	C_{16}	C_{18}
0.1	2.35±0.47	1.19±0.00	4.76±0.84	2.52±0.15	7.65±0.78	6.57±1.73
0.2	4.69±0.94	2.23±0.21	8.63±0.42	4.76±0.52	10.52±0.58	9.88±2.10
0.3	5.69±1.41	3.42±0.21	11.01±0.42	7.04±0.46	13.39±1.16	13.00±1.90
0.4	7.03±1.16	3.82±1.34	13.28±1.53	8.82±0.45	15.71±0.96	15.23±2.11
0.5	8.71±0.95	5.36±0.84	14.58±0.42	10.17±0.57	17.76±0.38	17.02±1.27
0.8	10.72±1.89	7.59±0.77	18.00±0.21	16.06±0.60	21.32±0.77	19.70±0.84
1.0	12.05±1.90	8.33±1.68	19.19±0.21	18.74±1.26	22.68±0.39	20.86±1.65

APPENDIX 11.

Complexing Indices (%) for the Interaction of the α-crystallinity Form of C_{16} and C_{18} Monoglycerides With Yam Starch

	Yam Starch					
	Ungelatinized		Gelatinized		Solubilized	
% MG	C_{16}	C_{18}	C_{16}	C_{18}	C_{16}	C_{18}
0.1	2.13±0.13	1.21±0.53	13.97±0.39	10.62±0.11	19.46±0.97	18.62±0.65
0.2	3.46±0.07	2.25±0.40	27.95±0.52	23.48±0.35	34.86±1.45	29.86±0.59
0.3	4.88±0.10	2.83±0.64	45.96±0.45	30.98±0.27	46.38±1.61	44.63±1.85
0.4	6.22±0.17	3.19±0.67	52.60±0.16	45.24±1.10	54.82±0.65	48.54±1.52
0.5	7.27±0.32	3.77±0.27	59.66±0.45	47.00±1.84	61.21±0.00	51.31±0.91
0.8	10.89±2.27	4.08±0.00	63.87±0.03	50.45±0.00	67.13±1.92	60.33±0.61
1.0	11.90±1.92	4.08±0.00	65.28±0.35	55.45±0.32	69.20±1.62	63.22±0.80

APPENDIX 12.

Complexing Indices (%) for the Interaction of the β-crystallinity Form of C_{16} and C_{18} Monoglycerides With Yam Starch

	Yam Starch					
	Ungelatinized		Gelatinized		Solubilized	
% MG	C_{16}	C_{18}	C_{16}	C_{18}	C_{16}	C_{18}
0.1	0.21±0.03	0.17±0.01	16.17±2.93	7.24±1.49	17.53±4.03	13.80±2.88
0.2	0.37±0.00	0.26±0.01	37.70±0.17	12.99±1.66	42.99±0.26	20.78±1.43
0.3	0.53±0.05	0.50±0.07	40.65±0.11	17.60±1.76	46.20±0.10	26.84±0.69
0.4	0.67±0.16	0.59±0.06	43.48±0.25	20.61±0.44	49.36±0.12	30.51±0.59
0.5	0.77±0.06	0.73±0.13	45.88±5.67	22.74±0.78	56.18±4.91	33.21±1.98
0.8	0.93±0.13	0.83±0.11	56.39±1.65	26.46±2.30	58.71±3.87	38.09±1.49
1.0	1.05±0.20	0.92±0.11	55.24±8.59	27.08±2.40	62.00±6.19	39.59±1.77

APPENDIX 13

Percent Complexing Indices of the Interaction Between Lintnerized Wheat cv. Neepawa Starch With α-C_{16} and α-C_{18} Monoglycerides

	Lintnerized Wheat cv. Neepawa Starch*					
	Ungelatinized		Gelatinized		Solubilized**	
% MG*** Added	α-C_{16}	α-C_{18}	α-C_{16}	α-C_{18}	α-C_{16}	α-C_{18}
0.1	8.47±0.36	3.75±0.82	17.80±0.54	11.32±0.55	29.66±0.23	16.56±0.77
0.2	13.55±0.46	7.26±0.74	36.00±0.00	27.78±0.11	43.24±0.88	27.66±3.25
0.3	15.37±1.17	8.59±0.73	46.21±1.07	35.17±0.06	51.32±2.85	39.06±3.23
0.4	16.09±1.75	9.32±0.77	52.27±1.06	47.22±0.55	57.46±1.55	48.97±2.09
0.5	16.33±1.93	9.56±0.84	56.06±0.00	51.39±0.71	66.35±2.32	56.80±1.17
0.8	16.70±1.70	9.94±0.91	66.50±2.12	55.56±0.40	68.62±3.16	69.37±2.35
1.0	16.94±1.73	10.05±0.44	70.46±1.07	55.56±0.36	71.23±2.94	73.49±2.41

*Starch lintnerization was done by treatment of dry starch with 7.5% HCl at 40°C for 72 hrs.

**Starch solubilization was done by dispersing the ungelatinized starch in aqueous 1 N KOH at 4°C for 30 min.

***MG, Monoglyceride.

APPENDIX 14.

Percent Complexing Indices of the Interaction Between Lintnerized Wheat cv. Neepawa Starch With β-C_{16} and β-C_{18} Monoglycerides

	Lintnerized Wheat cv. Neepawa Starch*					
	Ungelatinized		Gelatinized		Solubilized**	
% MG*** Added	β-C_{16}	β-C_{18}	β-C_{16}	β-C_{18}	β-C_{16}	β-C_{18}
0.1	4.03±0.23	2.25±0.39	8.75±0.58	5.64±0.71	12.88±0.86	7.11±1.07
0.2	8.06±1.81	3.84±1.19	13.30±1.01	8.53±0.69	19.80±2.30	14.21±2.14
0.3	12.90±0.29	5.42±1.73	17.86±0.25	11.46±1.03	26.80±2.51	22.57±2.05
0.4	13.71±0.01	6.88±2.09	21.14±0.38	12.81±2.96	30.42±0.26	29.47±1.00
0.5	15.32±0.59	7.94±1.34	23.23±0.91	12.85±0.64	33.41±0.96	31.26±0.88
0.8	16.13±2.25	9.39±0.16	26.43±0.96	19.81±0.89	45.89±0.42	36.40±2.10
1.0	16.93±2.20	9.66±0.86	29.62±0.87	20.21±0.52	54.25±0.71	39.79±0.55

*Starch lintnerization was done by treatment of dry starch with 7.5% HCl at 40°C for 72 hrs.

**Starch solubilization was done by dispersing the ungelatinized starch in aqueous 1 N KOH at 4°C for 30 min.

***MG, Monoglyceride.

APPENDIX 15.

Percent Complexing Indices of the Interaction Between Lintnerized Wheat cv. Fielder Starch With α-C_{16} and α-C_{18} Monoglycerides

% MG*** Added	Lintnerized Wheat cv. Fielder Starch*					
	Ungelatinized		Gelatinized		Solubilized**	
	α-C_{16}	α-C_{18}	α-C_{16}	α-C_{18}	α-C_{16}	α-C_{18}
0.1	12.16±0.58	11.84±0.45	12.87±0.52	13.05±1.05	13.35±0.57	11.24±1.62
0.2	19.52±2.18	15.04±0.41	26.11±0.52	27.54±0.00	26.90±1.79	24.53±0.64
0.3	22.08±0.46	17.92±0.72	38.61±1.56	39.13±2.05	38.51±1.27	38.74±0.64
0.4	23.36±0.68	19.33±0.74	47.43±0.52	47.83±4.09	49.81±2.14	48.58±1.51
0.5	24.17±0.48	20.16±1.92	53.31±0.36	50.73±4.09	55.38±3.01	54.19±2.24
0.8	25.43±0.49	20.88±2.32	62.87±0.82	50.90±3.08	64.52±3.57	63.68±1.84
1.0	25.92±0.49	21.44±0.94	65.81±0.32	54.90±3.08	70.36±3.64	68.82±1.94

*Starch lintnerization was done by treatment of dry starch with 7.5% HCl at 40°C for 72 hrs.

**Starch solubilization was done by dispersing the ungelatinized starch in aqueous 1 N KOH at 4°C for 30 min.

***MG, Monoglyceride.

APPENDIX 16.

Percent Complexing Indices of the Interaction Between Lintnerized Wheat cv. Fielder Starch With β-C_{16} and β-C_{18} Monoglycerides

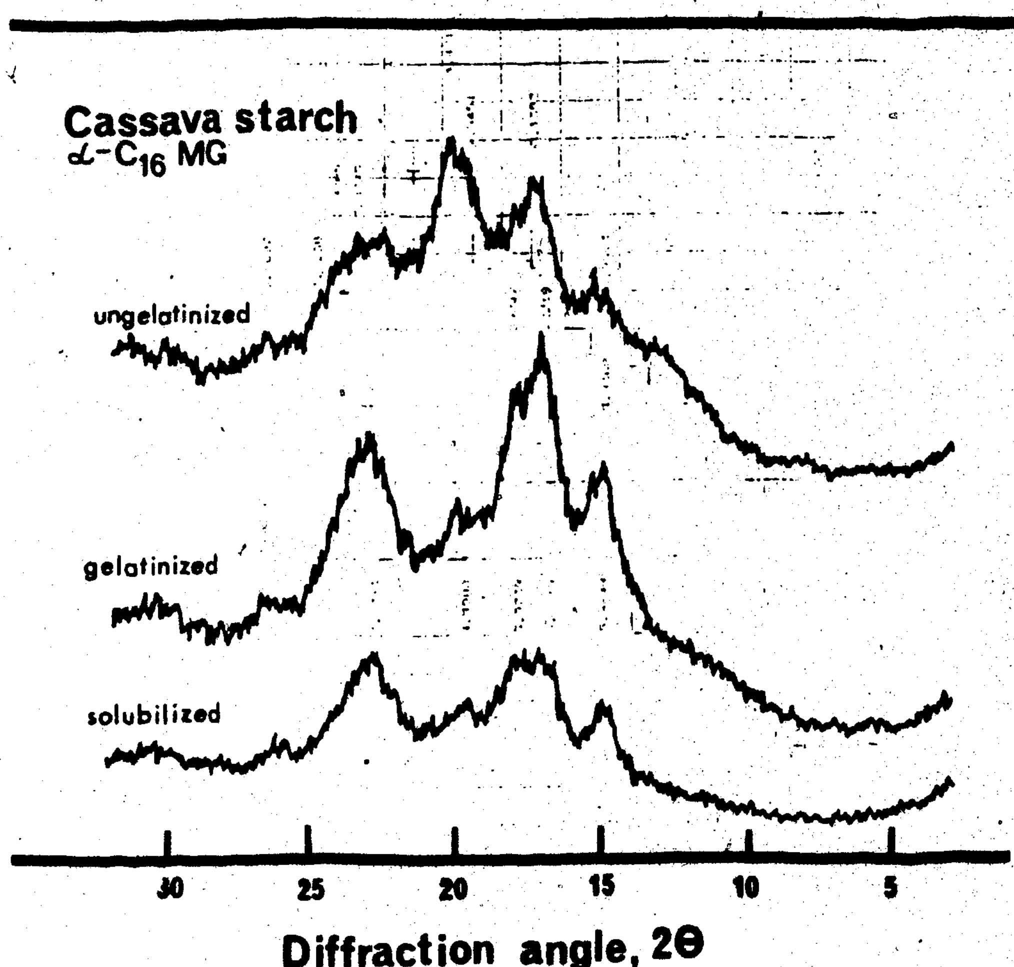
	Lintnerized Wheat cv. Fielder Starch*					
	Ungelatinized		Gelatinized		Solubilized**	
% MG*** Added	β-C_{16}	β-C_{18}	β-C_{16}	β-C_{18}	β-C_{16}	β-C_{18}
0.1	7.20±0.58	5.83±0.52	14.93±0.66	8.09±0.78	13.65±0.66	12.34±0.32
0.2	14.24±2.18	10.29±0.41	27.63±0.88	18.70±0.42	26.45±0.50	22.72±0.26
0.3	19.89±0.46	13.38±0.72	34.00±1.41	25.43	38.25±0.01	30.98±1.39
0.4	22.63±0.68	15.43±0.74	36.37±1.23	28.73±2.33	50.24±0.05	35.79±1.11
0.5	24.14±0.48	17.14±1.92	37.75±0.35	34.18±0.56	57.81±0.07	42.56±0.78
0.8	25.03±0.49	19.87±2.32	41.92±1.29	38.23±0.36	71.86±0.42	48.10±1.28
1.0	25.37±0.49	20.23±0.94	42.50±0.71	38.91±1.76	71.50±0.25	51.30±1.70

*Starch lintnerization was done by treatment of dry starch with 7.5% HCl at 40°C for 72 hrs.

**Starch solubilization was done by dispersing the ungelatinized starch in aqueous 1 N KOH at 4°C for 30 min.

***MG, Monoglyceride.

APPENDIX 17.



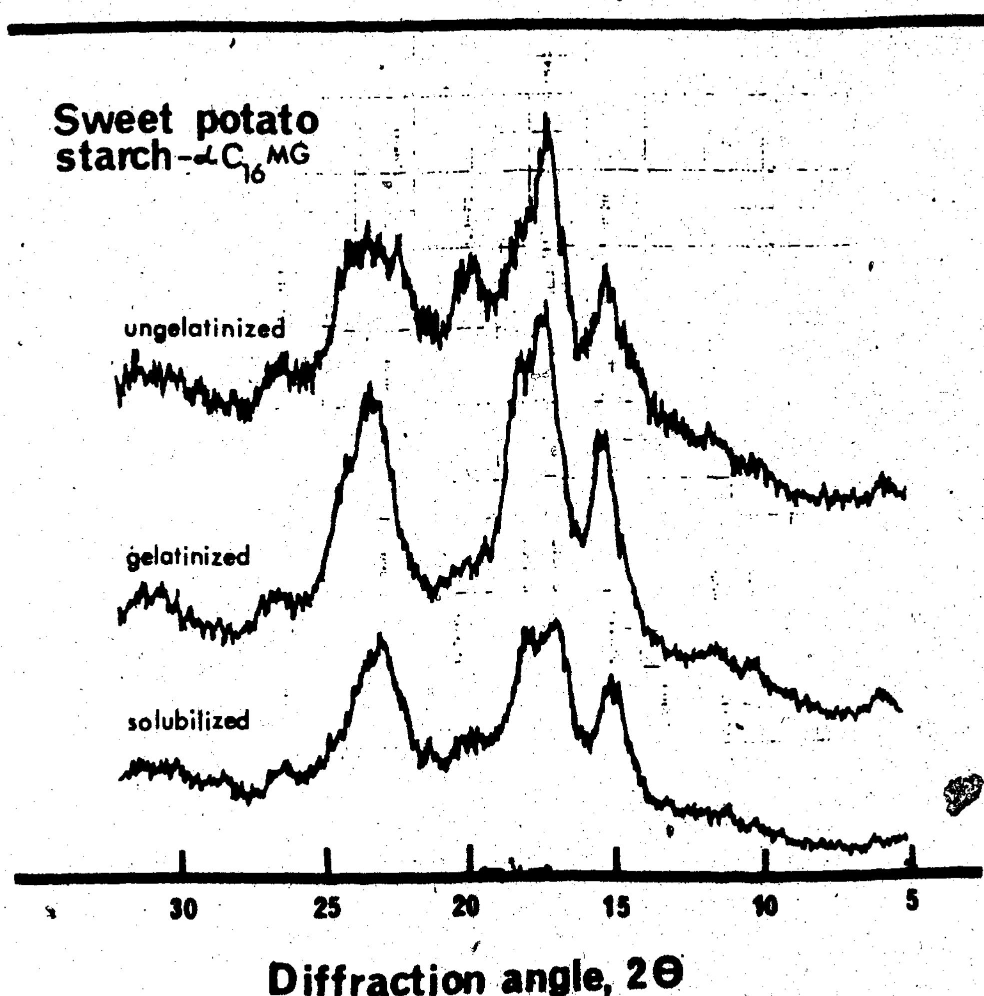
X-Ray Diffraction Patterns of Cassava Starch Clathrates With α-C_{16} Monoglyceride

APPENDIX 18.

X-Ray Diffraction Patterns of Cassava Starch Clathrates With α-C_{16} Monoglyceride

Cassava Starch								
Ungelatinized			Gelatinized			Solubilized		
°2θ	d, Å	Intensity cps	°2θ	d, Å	Intensity cps	°2θ	d, Å	Intensity cps
14.885	5.9513	281	15.055	5.8848	193	14.922	5.9368	390
17.254	5.1392	422	16.948	5.2315	245	16.982	5.2210	543
19.531	4.5451	434	17.478	5.0739	248	17.830	4.9747	490
20.081	4.4218	483	19.769	4.4908	203	19.955	4.4492	351
22.432	3.9634	360	22.955	3.8743	262	22.871	3.8883	443
23.196	3.8345	356				26.524	3.3605	237
22.680	3.9205	309				29.766	3.3605	237
24.570	3.6230	271				29.766	3.0014	237
26.450	3.3697	243						
29.953	2.9831	226						
30.928	2.8913	226						

APPENDIX 19.



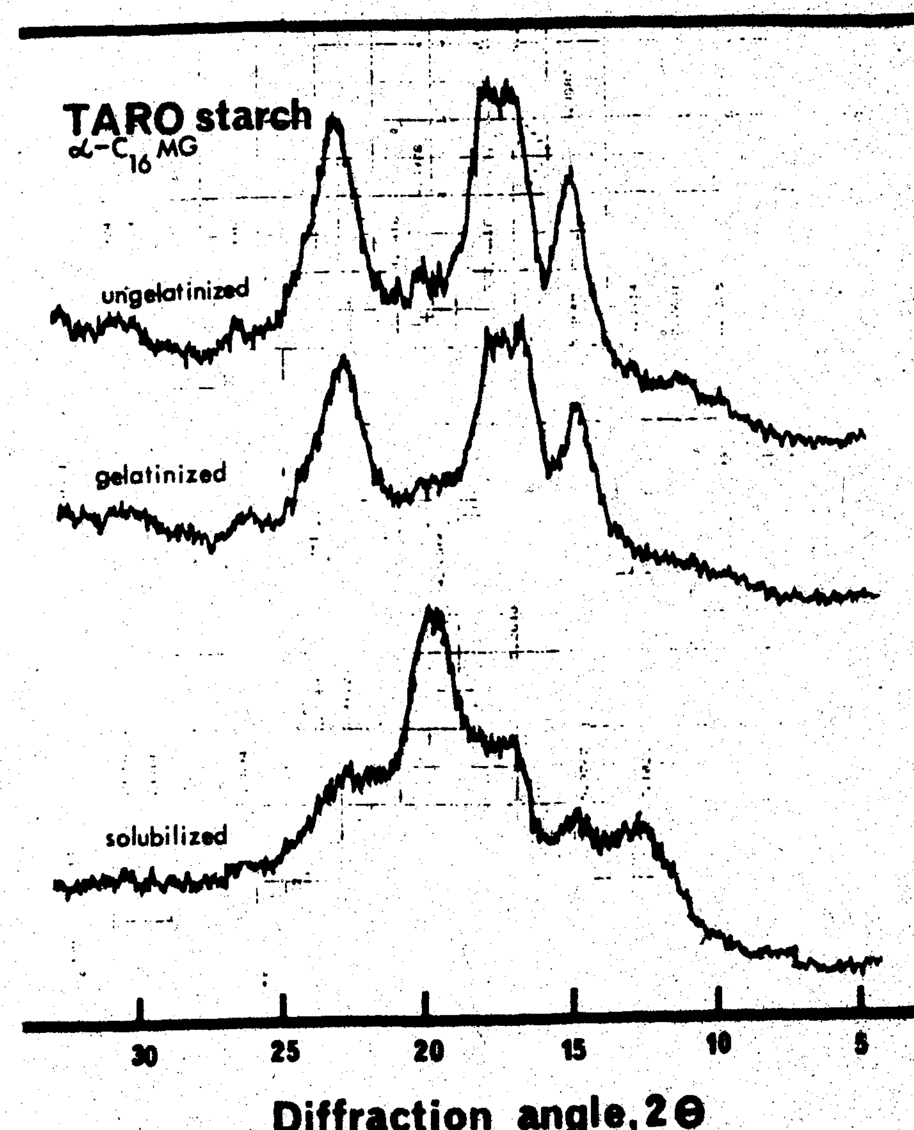
X-Ray Diffraction Patterns of Sweet Potato Clathrates with α-C_{16} Monoglyceride.

APPENDIX 20.

X-Ray Diffraction Patterns of Sweet Potato Starch Clathrates With α-C_{16} Monoglyceride

Sweet Potato Starch								
Ungelatinized			Gelatinized			Solubilized		
°2θ	d, Å	Intensity cps	°2θ	d, Å	Intensity cps	°2θ	d, Å	Intensity cps
11.669	7.5837	141	10.170	8.6978	146	11.194	7.9039	108
15.137	5.8528	346	11.196	7.9025	170	13.232	6.6909	126
17.203	5.1543	526	14.971	5.9173	432	15.159	5.8445	248
19.874	4.4673	361	17.002	5.2148	591	17.045	5.2018	341
22.454	3.9591	380	17.767	4.9919	526	17.971	4.9358	326
23.272	3.8222	385	22.789	3.9020	407	20.324	4.3695	189
26.281	3.3910	244	23.594	3.7707	391	21.391	4.1538	183
30.199	2.9594	230	26.721	3.3361	230	23.040	3.8601	326
31.085	2.8770	232	30.239	2.9555	251	26.315	3.3866	176
						28.458	3.1363	157
						30.083	2.9705	168

APPENDIX 21.



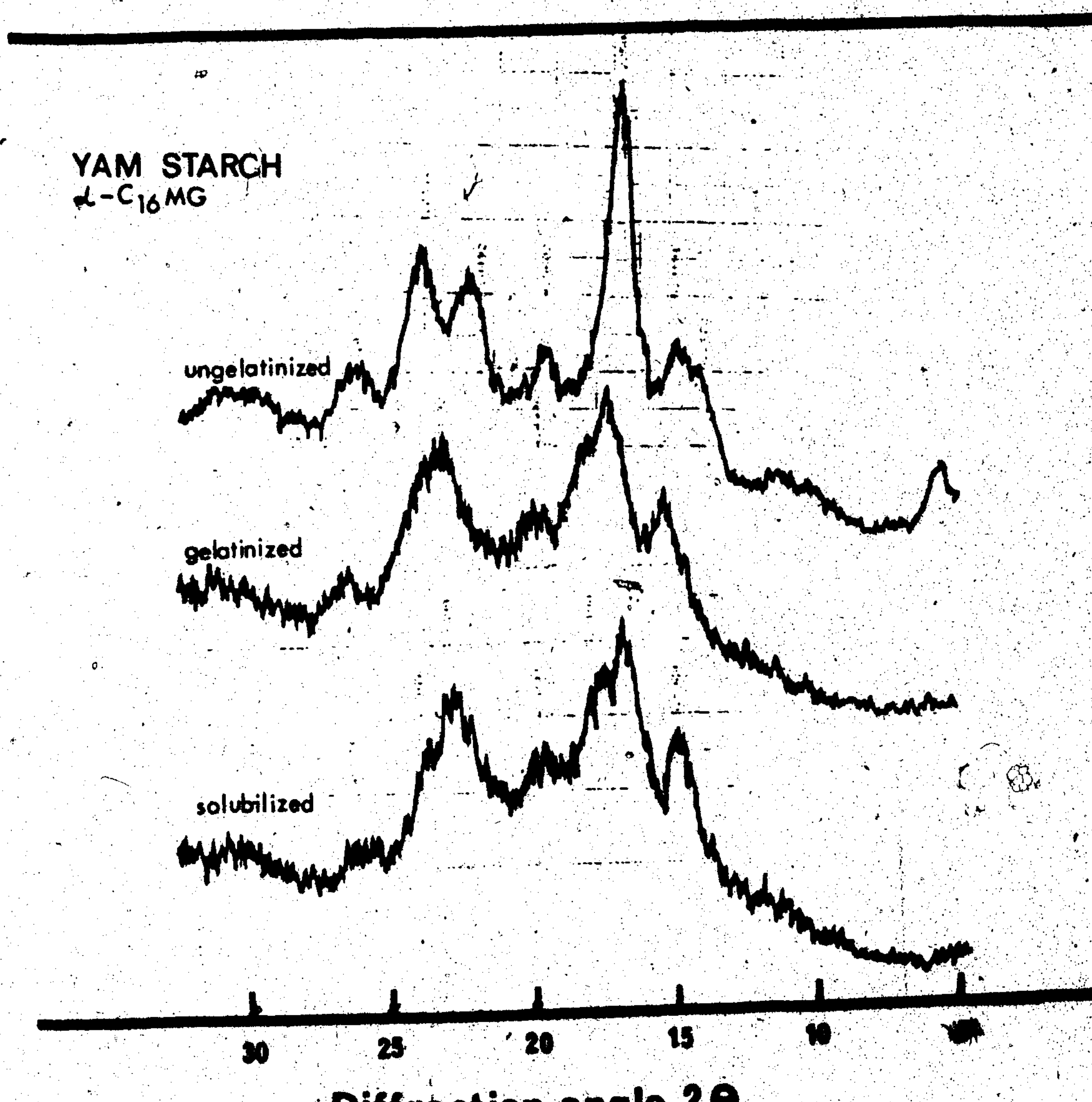
X-Ray Diffraction Patterns of Taro Starch Clathrates with α-C_{16} Monoglyceride.

APPENDIX 22.

X-Ray Diffraction Patterns of Taro Starch Clathrates With α-C_{16} Monoglyceride

Taro Starch								
Ungelatinized			Gelatinized			Solubilized		
°2θ	d, Å	Intensity cps	°2θ	d, Å	Intensity cps	°2θ	d, Å	Intensity cps
9.895	8.9385	118	9.935	8.9030	96	12.463	7.1022	258
11.391	7.7681	154	15.106	5.8649	308	14.822	5.9767	261
12.940	6.8414	167	16.974	5.2234	389	17.038	5.2040	378
15.045	5.8887	408	17.927	4.9478	338	19.592	4.5309	537
16.958	5.2282	505	22.989	3.8686	352	22.729	3.9122	331
17.932	4.9466	514	30.961	2.8882	182	23.554	3.7769	296
20.191	4.3978	283				26.294	3.3894	222
20.943	4.2416	255				29.465	3.0314	198
23.058	3.8571	472				30.449	2.9356	207
26.522	3.3607	223						
30.173	2.9619	239						
30.915	2.8924	234						

APPENDIX 23.



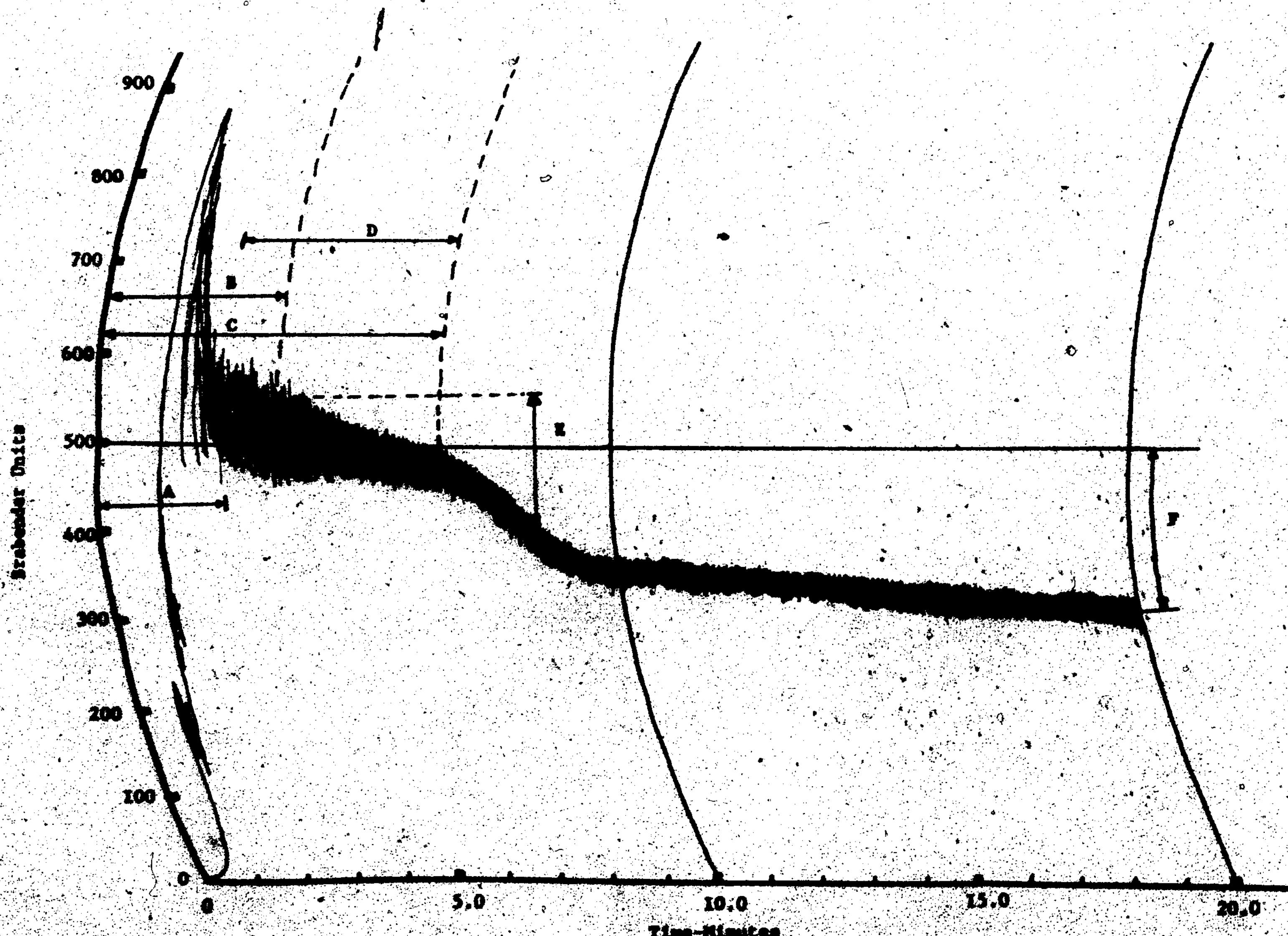
X-Ray Diffraction Patterns of Yam Starch Clathrates with
-C_{16} Monoglyceride.

APPENDIX 24.

X-Ray Diffraction Patterns of Yam Starch Clathrates With α-C_{16} Monoglyceride

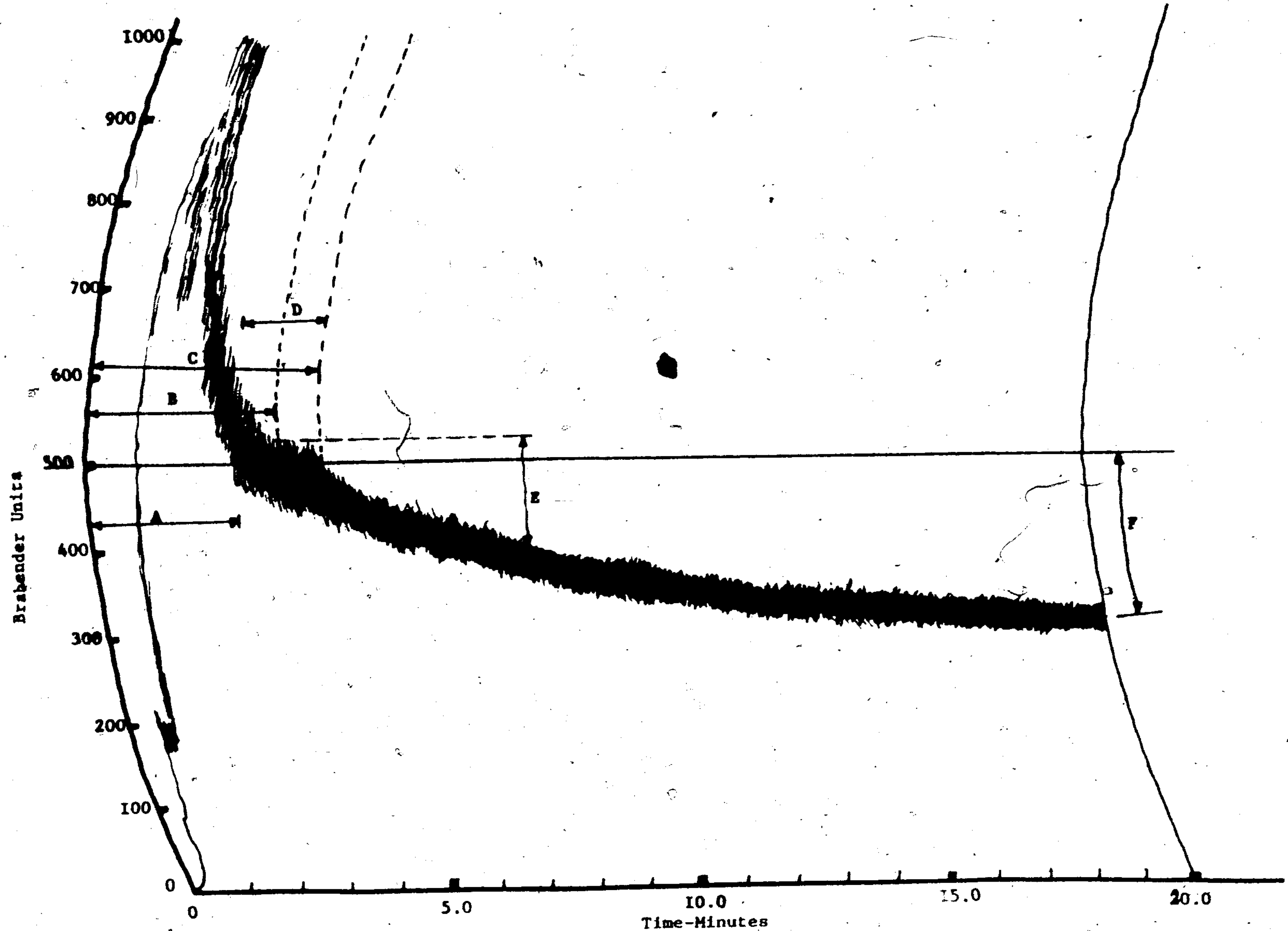
Yam Starch								
Ungelatinized			Gelatinized			Solubilized		
°2θ	d, Å	Intensity cps	°2θ	d, Å	Intensity cps	°2θ	d, Å	Intensity cps
5.482	16.1216	159	9.995	8.8491	109	15.285	5.7964	352
14.245	6.2172	273	11.412	7.7538	146	17.192	5.1576	472
14.967	5.9191	322	15.202	5.8279	400	16.988	5.2190	394
16.969	5.2250	639	17.097	5.1861	530	19.666	4.5141	321
19.465	4.5602	309	19.615	4.5257	324	23.168	3.8390	395
21.950	4.0492	362	22.940	3.8767	455	24.001	3.7076	321
23.819	3.7356	442	26.383	3.3781	220	26.377	3.3788	210
26.075	3.4172	280				30.525	2.9285	213
						31.246	2.8626	225

APPENDIX 25.



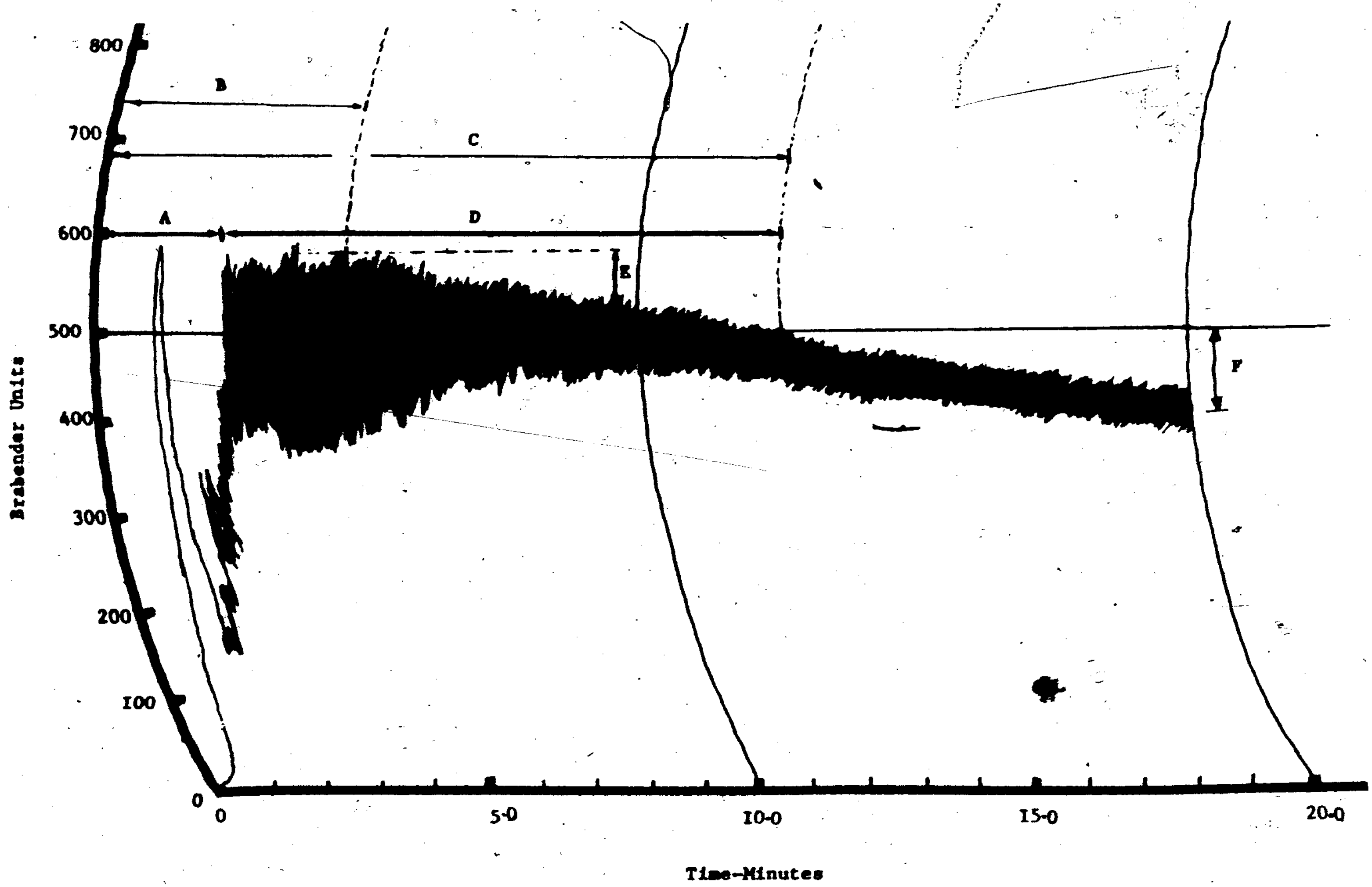
Sweet Potato Starch (85%)/Vital Gluten (15%) Composite Flour Farinogram

APPENDIX 26.



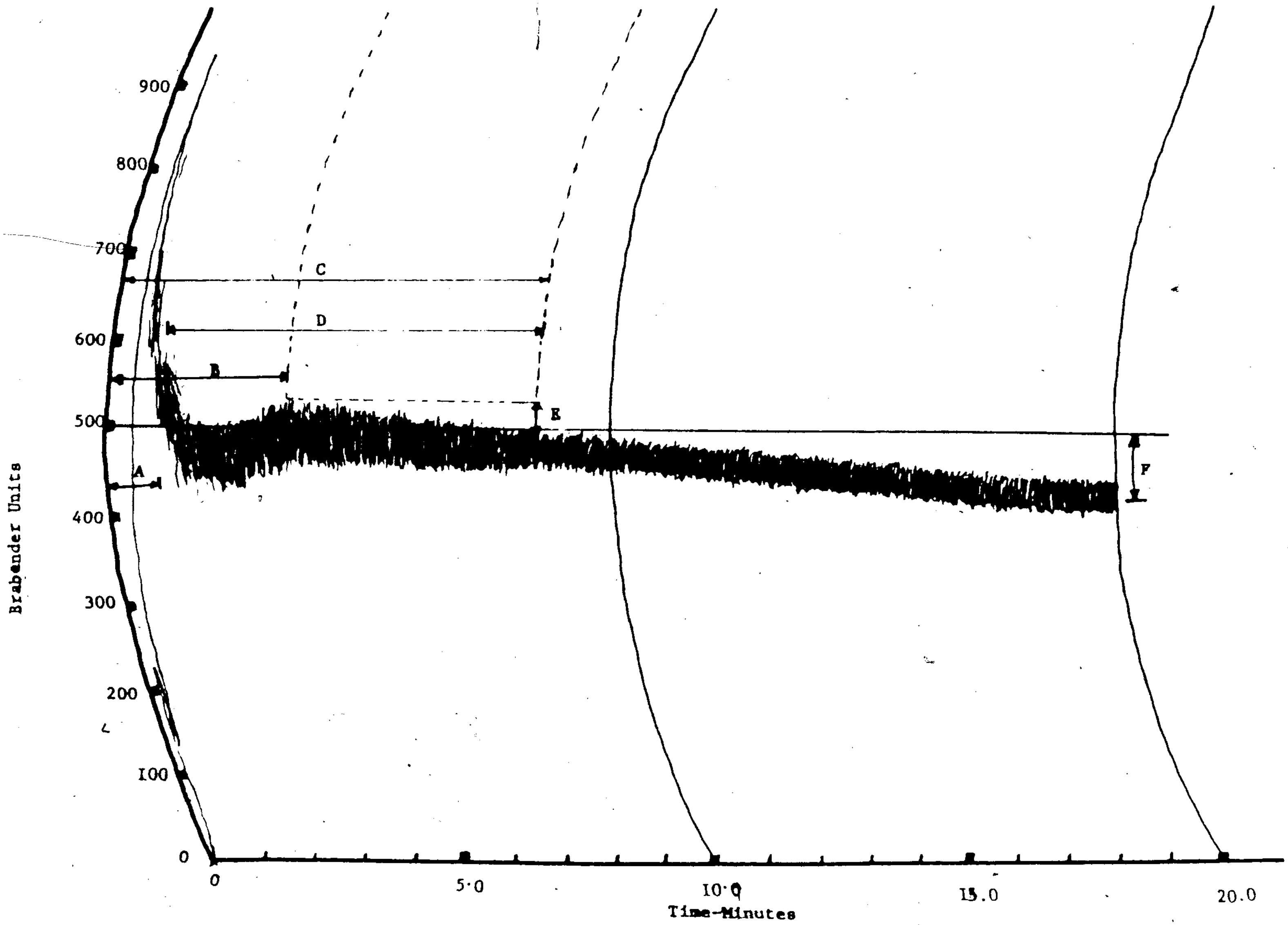
Taro Starch (85%)/Vital Gluten (15%) Composite Flour Farinogram

APPENDIX 27.



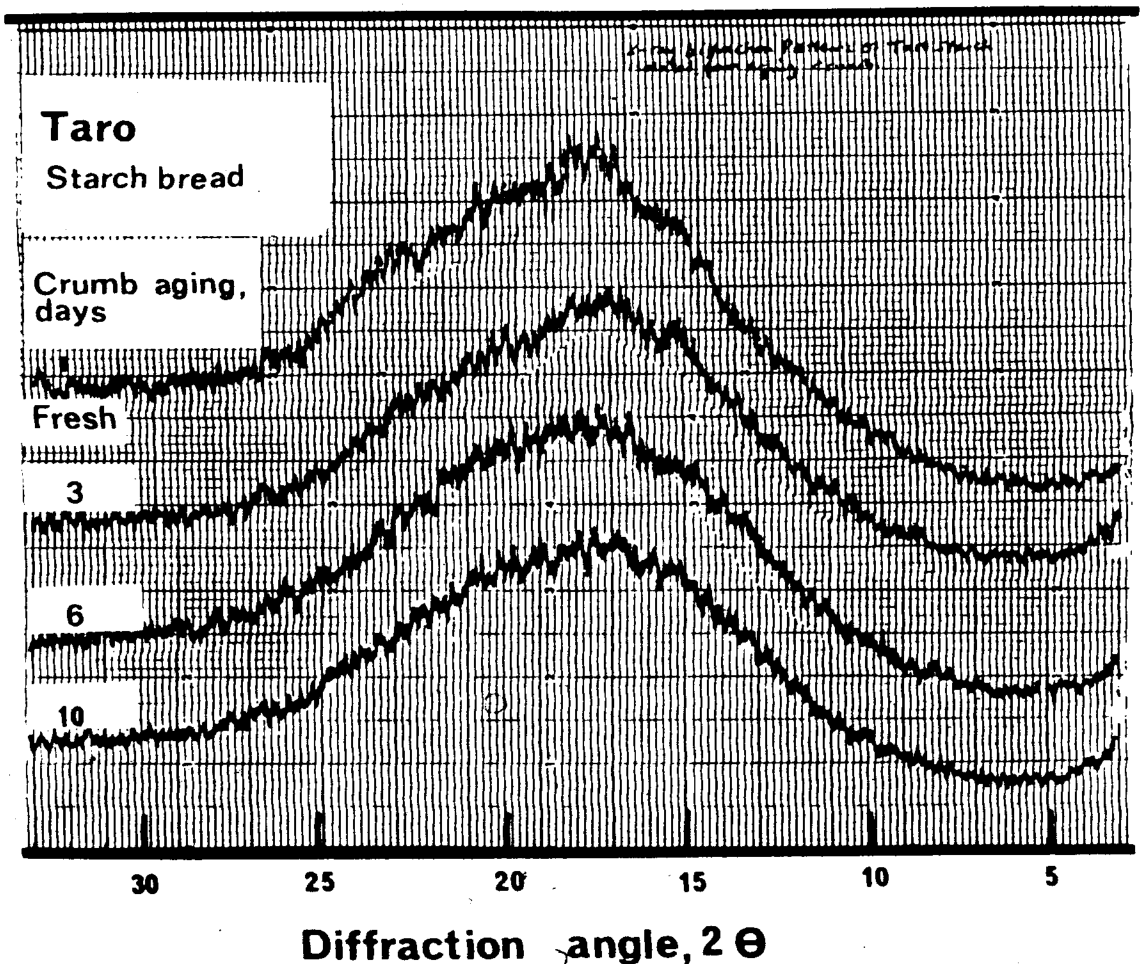
Yam Starch (85%)/Vital Gluten (15%) Composite Flour Farinogram

APPENDIX 28.



Wheat,cv.Fielder, Starch(85%)/Vital Gluten(15%) Composite Flour Farinogram

APPENDIX 29.



X-Ray Diffraction Patterns of Starch Isolated From Aging Taro Bread Crumbs.

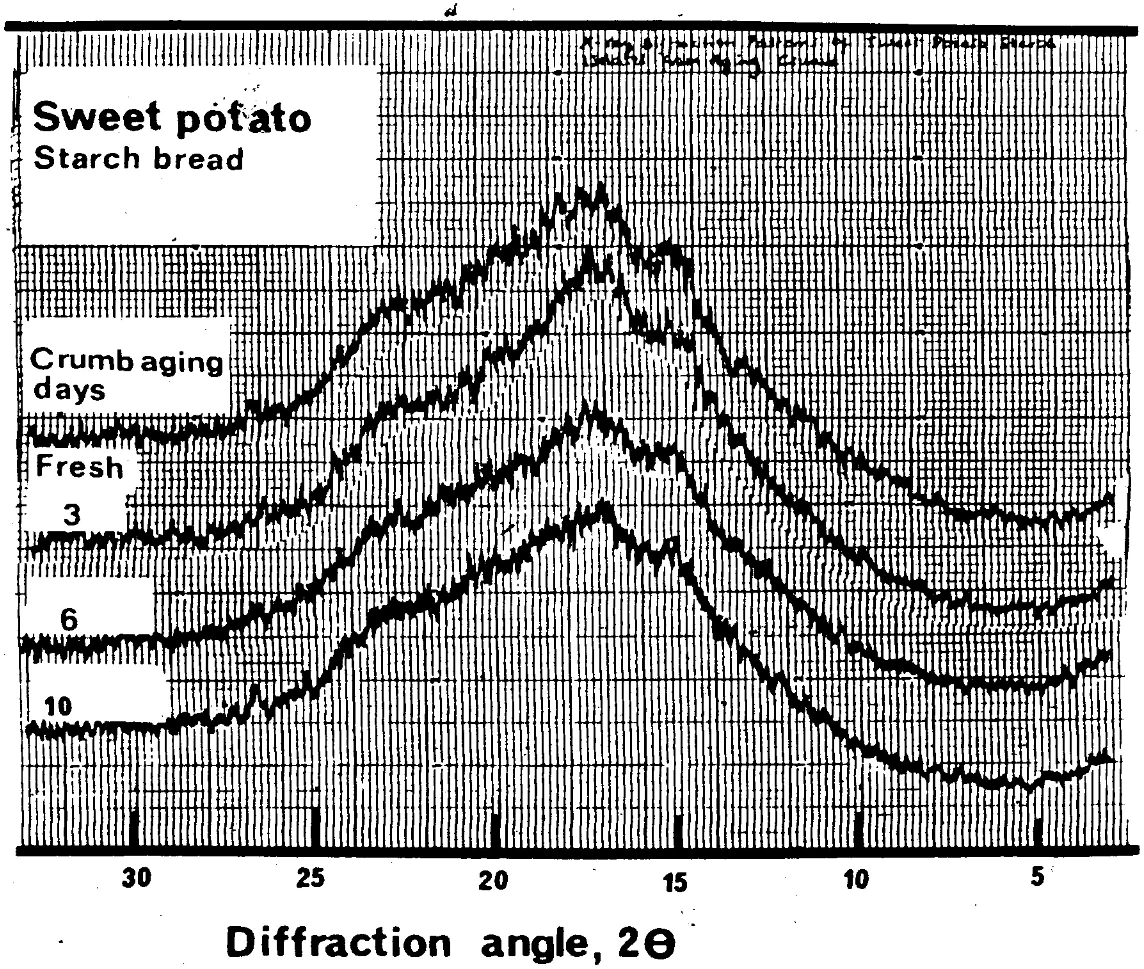
APPENDIX 30.

X-Ray Diffraction Patterns of Starch Isolated From Aging Taro Bread Crumbs*

Bread Storage, Days											
1			3			6			10		
		Intensity			Intensity			Intensity			Intensity
°2θ	d, Å	cps	°2θ	d, Å	cps	°2θ	d, Å	cps	°2θ	d, Å	cps
14.569	6.0800	629	15.193	5.8313	688	14.724	6.0163	647	13.985	6.3324	625
15.244	5.8120	721	16.979	5.2220	730	16.365	5.4163	739	15.849	5.5916	648
17.923	4.9489	838	19.951	4.4502	644	18.361	4.8319	749	16.725	5.3000	702
17.999	4.9283	903	22.917	3.8806	517	19.783	4.4876	709	18.861	4.7050	682
19.965	4.4472	784	26.524	3.3604	324	21.208	4.1891	643	20.551	4.3216	620
20.709	4.2890	777				25.835	3.4485	400	24.277	3.6661	406
21.690	4.0973	696				27.811	3.2078	347	26.588	3.3526	324
22.588	3.9363	657				28.766	3.1035	307			

*Taro starch composite flours had 15% vital gluten.

APPENDIX 31.



X-Ray Diffraction Patterns of Starch Isolated From Aging Sweet Potato Bread Crumbs.

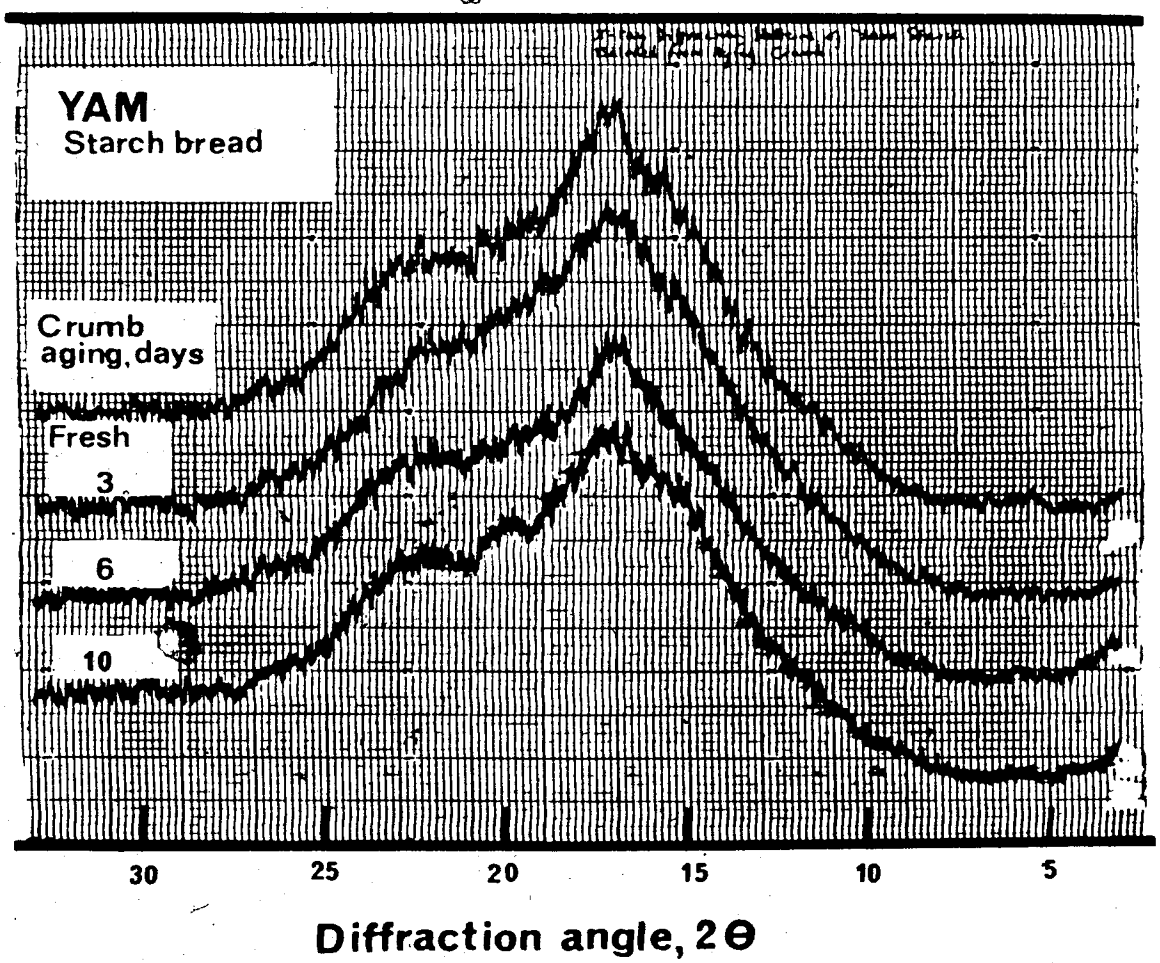
APPENDIX 32.

X-Ray Diffraction Patterns of Starch Isolated From Aging Sweet Potato Bread Crumbs*

Bread Storage, Days											
1			3			6			10		
		Intensity			Intensity			Intensity			Intensity
°2θ	d, Å	cps	°2θ	d, Å	cps	°2θ	d, Å	cps	°2θ	d, Å	cps
10.233	8.6439	289	14.889	5.9497	768	15.009	5.9027	715	12.037	7.3522	386
10.886	8.1270	473	17.380	5.1022	881	17.253	5.1395	787	15.088	5.8719	694
15.244	5.8121	760	20.078	4.4223	727	19.102	4.6461	683	16.963	5.2267	762
16.720	5.3023	852	23.089	3.8521	574	20.143	4.4082	639	23.813	3.7365	466
18.117	4.8965	832	23.834	3.7333	468	22.466	3.9574	556	26.502	3.3632	367
19.956	4.4492	787				23.201	3.8337	534			
21.545	4.1244	686									
23.131	3.8451	623									

*Sweet potato starch composite flours had 15% vital gluten.

APPENDIX 33.



X-Ray Diffraction Patterns of Starch Isolated From Aging Yam Bread Crumbs.

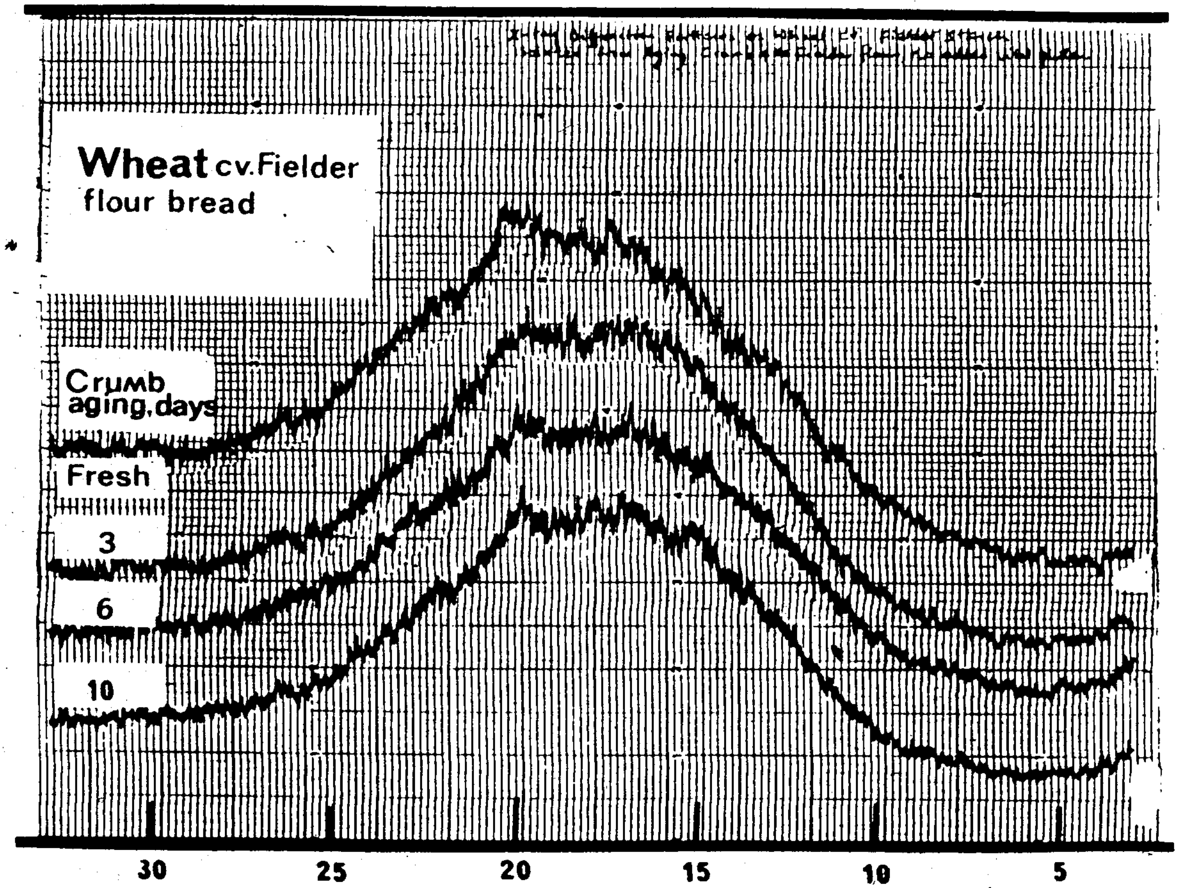
APPENDIX 34.

X-Ray Diffraction Patterns of Starch Isolated From Aging Yam Bread Crumbs*

Bread Storage, Days											
1			3			6			10		
		Intensity			Intensity			Intensity			Intensity
$^{o}2\theta$	d, Å	cps	$^{o}2\theta$	d, Å	cps	$^{o}2\theta$	d, Å	cps	$^{o}2\theta$	d, Å	cps
13.264	6.6750	538	15.352	5.7716	865	16.822	5.2702	919	11.519	7.6821	343
14.811	5.9811	793	16.735	5.2975	986	19.674	4.5124	730	15.067	5.8799	795
15.642	5.6651	938	17.942	4.9436	953	22.856	3.8907	656	16.565	5.3514	874
16.957	5.2287	1081	18.777	4.7258	880				19.799	4.4841	733
19.221	4.6175	800	22.319	3.9831	729				29.789	2.9991	361
20.316	4.3711	781	23.385	3.8039	647						
			26.586	3.3527	443						
			32.213	2.7788	380						

*Yam starch composite flours had 15% vital gluten.

APPENDIX 35.



Diffraction angle, 2Θ

X-Ray Diffraction Patterns of Starch Isolated From Aging Bread Crumbs made Wheat Flour, cv. Fielder.

APPENDIX 36.

X-Ray Diffraction Patterns of Starch Isolated From Aging Bread Crumbs Made From Wheat Flour cv. Fielder

Bread Storage, Days											
1			3			6			10		
		Intensity			Intensity			Intensity			Intensity
°2θ	d, Å	cps	°2θ	d, Å	cps	°2θ	d, Å	cps	°2θ	d, Å	cps
11.171	7.9207	391	15.880	5.5807	838	14.940	5.9296	661	13.120	6.7478	495
12.334	7.1760	498	16.880	5.2523	872	16.289	5.4414	696	15.122	5.8588	704
13.185	6.7147	581	17.503	5.0667	853	16.988	5.2193	730	16.989	5.2188	742
14.906	5.9430	723	19.707	4.5047	875	19.857	4.4712	751	17.906	4.9536	760
15.804	5.6076	769	26.503	3.3631	387	21.775	4.0813	602	19.783	4.4876	747
16.823	5.2700	849				22.873	3.8879	522	20.114	4.4144	555
17.398	5.0971	871							26.451	3.3695	348
18.382	4.8265	875									
21.487	4.1355	718									
26.471	3.3671	467									
30.234	2.9560	402									
31.101	2.8755	390									

Appendix 37

Water Binding Capacities of Some Wheat and Tropical Root Starches

Type of Starch	Water Binding Capacity g H_2O/g Starch DMB
Yam	0.70
Taro	0.65
Sweet Potato	0.55
Arrowroot	0.50
Cassava	0.50
Wheat	
cv. Neepawa	0.45
cv. Fielder	0.35

10. VITAE

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PUBLICATONS

1. Keya, E.L. and Hadziyev, D. Physico-chemical properties of some tropical root starches. Presented at the 27th Annual conference of Canadian Institute of Food Science and Technologists - Vancouver, B.C. 1984.

2. Keya, E.L. and Hadziyev, D. The use of tropical root starches in bread making. Presented at the 27th Annual Conference of Canadian Institute of Food Science and Technologists. Vancouver, B.C. 1984.
(The two papers are currently pending publication).