Some Properties of Starches Derived from Wheat of Varied Maturity[1]

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ABSTRACT

Physicochemical and baking characteristics of starch from hard winter wheat (Gage variety) harvested at the time of full maturity and at 1, 2, and 3 weeks prior to this stage were investigated. Determinations of iodine affinity indicated a progressive increase of apparent amylose content with maturity. Viscographic measurements showed that hot paste consistencies increased with maturity. The gelatinization temperature ranges were depressed with progressing maturity. While starch solubilities did not change appreciably, swelling powers and hydration capacities decreased with the maturity of the wheat. The starch from mature wheat was more susceptible to the action of amylases than that from immature wheat. Starch from fully matured wheat produced breads of higher loaf volumes than that isolated from immature wheat.

It is generally recognized that the composition of starch during the course of its biogenesis does not remain constant, but changes as plants mature. This is well documented by reports indicating gradual increases in iodine affinity values with

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maturity of starches derived from wheat (1,2,3), barley (4), corn (4), pea seeds (5), potato (6), and tobacco leaves (7). These data are considered to indicate either a gradual increase of the amylose content in the granules, or a basic structural transformation of the starch polymers during maturing. The latter possibility was studied by Matheson (3) who observed some structural differences attributable to maturity in amyloses prepared according to the classical procedure of Muetgeert (8), but failed to detect them in the amyloses isolated by other methods.

Although it is obvious that the changes in starch during maturation may have profound effects on the physicochemical behavior and the functionality of starch in general, only starch from sweet corn has been studied from this point of view (9). The present investigation was therefore undertaken to evaluate the effects of molecular changes of starch during maturing of wheat on the physicochemical characteristics and breadmaking properties of wheat starch.

MATERIALS AND METHODS

Wheat and Starch

A hard winter wheat (Gage) was grown in an experimental plot at the University of Nebraska (Lincoln). The spikes were marked at the time of anthesis and harvested at various stages of maturity. The wheat collected 5 weeks subsequent to anthesis was fully mature. That of 4, 3, and 2 weeks after anthesis was 1, 2, and 3 weeks immature, respectively. The starch was isolated from these wheat samples by a wet-milling process as detailed previously (10). This procedure involves steeping the wheat in water under toluene at 50°C. for 12 hr., breaking up the grain in a Waring Blendor, and recovering the starch from the mash by filtration and centrifugation.

Viscography

Viscograms were prepared as previously (10) by means of Brabender Viscoamylograph. A suspension of nine parts of starch solids in 100 parts (420 ml.) of water was heated to 95°C., kept at this temperature 60 min., then cooled to 35°C. and held at 35°C. for an additional 60 min.

Determinations

The amylose content of starch was estimated by a potentiometric procedure (11) and also amperometrically by the method of Larson et al. (12). Moistures were determined by a vacuum method (13). The intrinsic viscosity of the starch solution in 1N potassium hydroxide at 35°C. was measured according to Leach (14) using a size 50 Cannon-Fenske capillary viscometer. Gelatinization temperature ranges were followed, using a polarizing microscope equipped with a Kofler hot stage (15). The method of Leach, McCowen, and Schoch (16) was used to determine swelling power and solubility; that of Leach and Schoch (17) was used to estimate enzyme susceptibility of starch granules; and that of Medcalf and Gilles (18) was used to determine starch water-binding capacity.

Baking Tests

The remix procedure of Irvine et al., as modified for preparation of pup-loaves from a gluten-starch system (10), was used to test the baking potential of starches of different maturity. Gluten from a single preparation was added to starch to produce 12.5% protein (N × 5.7, dry basis) in the mixture.

RESULTS AND DISCUSSION

Amylose Content vs. Maturity

As evident from the data given in Table I, the iodine affinity of starch increases progressively with its maturity. The respective apparent amylose levels were estimated from the iodine affinity values by assuming the iodine absorption of pure wheat amylose to be 19.24 (19). Although, as expected, the potentiometric method gave lower values than the amperometric one, both indicated a similar trend. These results are in agreement with reports of literature, showing that the iodine affinity of starches from various sources increases with maturity. As pointed out by Maywald et al. (9), these changes do not necessarily indicate an increase in amylose levels, but may be caused by an increase in the degree of polymerization or other molecular changes. In his recent studies of amyloses derived by preparative ultracentrifugation and exclusion chromatography from starches of wheats of varied maturity, Matheson (3) concluded that the observed changes were a result of simple increases in amylose content, although his previous studies using a butanol-complexing procedure indicated otherwise. It appears that a further investigation of amylopectin and the intermediate components should be conducted before this interpretation is accepted.

The intrinsic viscosities of these starches are also shown in Table I. They increased gradually with maturity, suggesting increases in size of the starch molecules. Analogous results were reported by Maywald et al. (9) in a study of sweet corn.

Viscographic Results

The viscograms in Fig. 1 demonstrate the effects of maturity on the pasting properties of wheat starch. As evident from the respective peak consistencies and from changes in the viscogram portions representing the cooking phase (60 min. at 95°C.), the hot pastes from mature starch were lower in consistency but more stable to heat and shear than those from immature ones. On subsequent cooling to 35°C., the pastes from mature starch had higher consistencies than those from immature ones. All of these changes were gradual and were proportional to the degree of maturity.

This pasting behavior indicated that the intragranular associative forces of immature starch were weaker than those of mature ones, relaxing more readily upon heating and causing the granules to swell to a greater degree than the mature ones. On additional heating, the swollen granules of immature starch became

TABLE I. AMYLOSE CONTENT AND INTRINSIC VISCOSITIES ([η]) OF STARCH FROM WHEAT OF DIFFERENT MATURITY

Starch Isolated from[a]	Potentiometric Method		Amperometric Method		
	I_2 Affinity %	Amylose %	I_2 Affinity %	Amylose %	[η] ml./g.
Mature wheat	4.14	21.5	4.49	23.31	1.96
1 week immature	4.11	21.4	4.49	23.36	1.93
2 weeks immature	3.72	19.4	4.15	21.60	1.81
3 weeks immature	3.16	16.4	3.59	18.61	1.78

[a]Results of duplicate determinations.

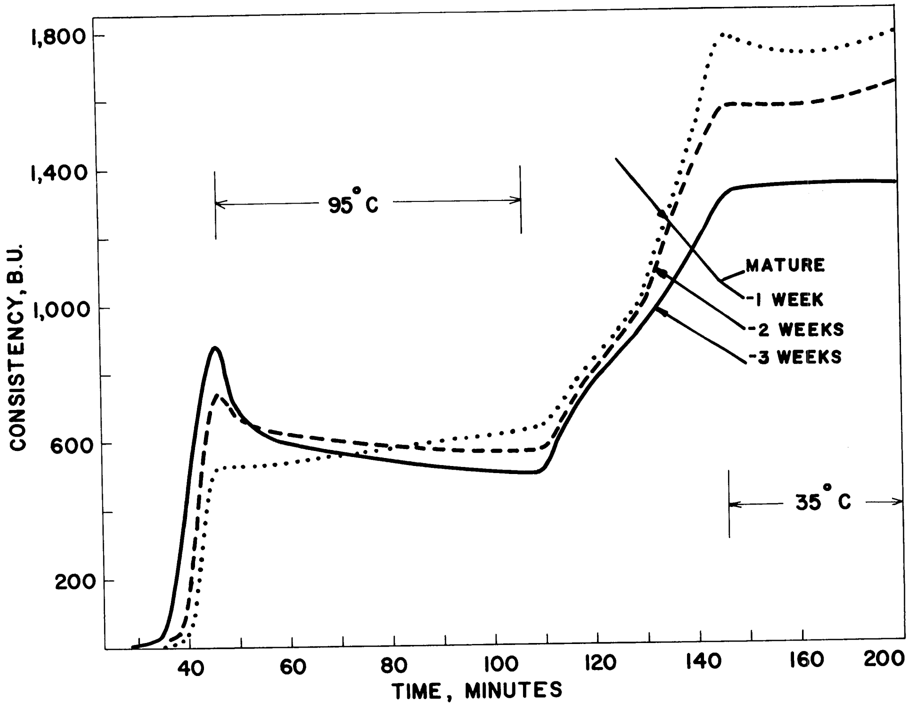

Fig. 1. Effect of starch maturity on the viscographic properties of wheat starch.

tenuous and fragile toward shear, resulting in a general weakening of the paste. The viscogram patterns of immature starches were reminiscent of those of weakly bonded tuber starches. One may speculate that, during the growth period, as in tubers, the initially high moisture environment in the wheat kernel favors the formation of a weak association of starch molecules within the granules, which then become more closely associated as moisture level diminishes during maturing. The increasing level of amylose during ripening is also likely to contribute to a closer molecular association in the granules, with concomitant restriction of granular swelling.

Gelatinization Temperature Ranges

A gradual decrease of these temperature ranges with maturation was observed (Table II). This suggests a change in the nature of the starch crystallites and could be caused by a change in the composition or the molecular structure of the granules.

Swelling Power and Solubility

The swelling power values (Fig. 2) decreased with increasing maturity of the starch, and the swelling became more restricted, gradually approaching the typical cereal starch pattern. A two-stage swelling, characteristic for wheat starch, was apparent at all stages of maturity, indicating that both types of bonding forces responsible for this behavior existed throughout the starch synthesis. As a general

TABLE II. GELATINIZATION TEMPERATURE RANGES OF STARCHES ISOLATED FROM WHEATS OF DIFFERENT MATURITY

Starch Isolated from	Gelatinization Range, °C. Initiation	Midpoint	Final
Mature wheat	52.0	54.0	60.0
1 week immature	52.0	57.0	60.5
2 weeks immature	53.0	58.0	61.5
3 weeks immature	56.0	61.0	63.5

rule, the higher the swelling power at 95°C., the lower the hot paste stability as indicated by viscograms (20). This was found to hold true for this series of starches.

The solubility values given in Table III were affected only slightly by maturity, except at 95°C., at which temperature higher values for the immature starches were observed. This reflects the fragility of the swollen, immature starch granules, as was also indicated by the respective viscograms.

Water-Binding Capacity and Enzymolysis

Figure 3 represents changes of these properties as affected by maturity. The water-binding capacity decreased with maturing, indicating a progressively closer association of the starch molecules in the granules, which reduced the accessibility

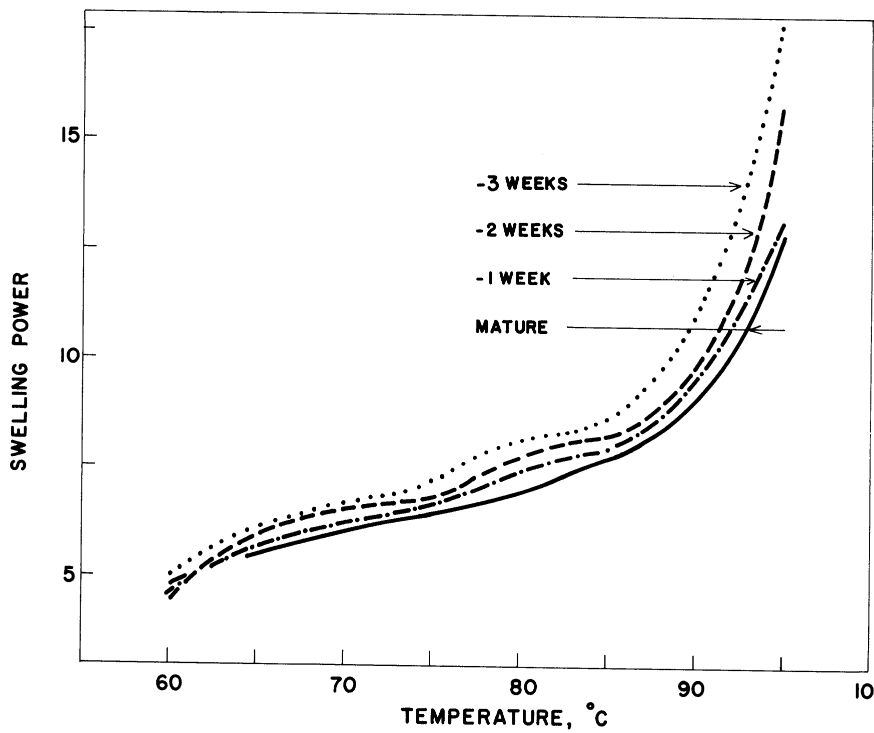

Fig. 2. Effect of maturity on swelling powers of wheat starch.

TABLE III. EFFECT OF THE STATE OF MATURITY OF WHEAT ON SOLUBILITIES OF STARCH

Temperature °C.	Solubility			
	Mature	1 Week Immature	2 Weeks Immature	3 Weeks Immature
60	0.88	1.08	0.96	0.76
70	2.28	2.48	2.28	2.60
80	3.72	3.92	3.80	3.80
90	7.24	7.48	6.20	6.60
95	14.68	15.24	16.36	16.60

of hydroxyl groups for hydrogen binding, and possibly the granular porosity. On the other hand, the mature starches were less readily attacked by amylases than the immature ones.

An indirect correlation between swelling power and enzyme susceptibility was observed by Leach and Schoch (17). They found that the weakly bonded starches (e.g., potato, tapioca) are high in swelling and low in enzyme susceptibility, and that the strongly bonded corn starch, which has a restricted swelling, is readily degraded. These properties are similarly related in the present starches: the higher swelling, immature starches are less susceptible to enzymolysis than the mature, restricted swelling starches. The explanation of this behavior may be that the close association of granules results in formation of imperfections in the crystalline structure, rendering them more sensitive to the action of enzymes.

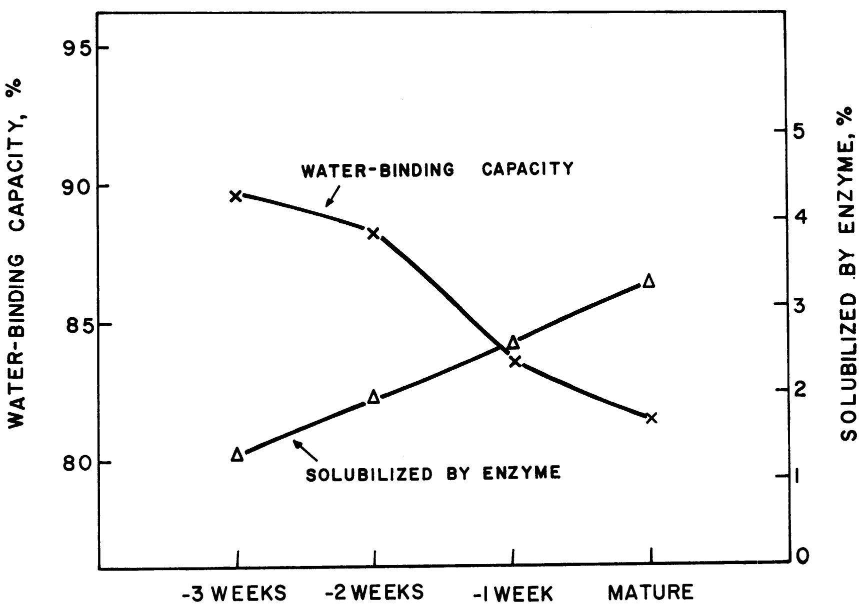

Fig. 3. Effect of maturity on water-binding capacity and enzyme susceptibility of wheat starch.

Baking Properties

The results of the baking tests are given in Table IV. All starches produced satisfactory doughs, but the starches from immature wheat required longer mixing times than the control; no additional water of absorption was necessary for the immature starches in spite of their higher water-binding capacities (Fig. 3). Bread

TABLE IV. BAKING TESTS WITH STARCHES ISOLATED FROM WHEATS OF DIFFERENT MATURITY

Starch Isolated from	Mixing Time [a] min.	Bread Volume[b] ml.	General Quality
Mature wheat	6.5	725	very good
1 week immature	6.5	715	very good
2 weeks immature	7.0	705	very good
3 weeks immature	12.5	650	very good

[a]National mixer, at remix stage.
[b]Linear correlation coefficient between wheat maturity and bread volume r=0.91, N=4.

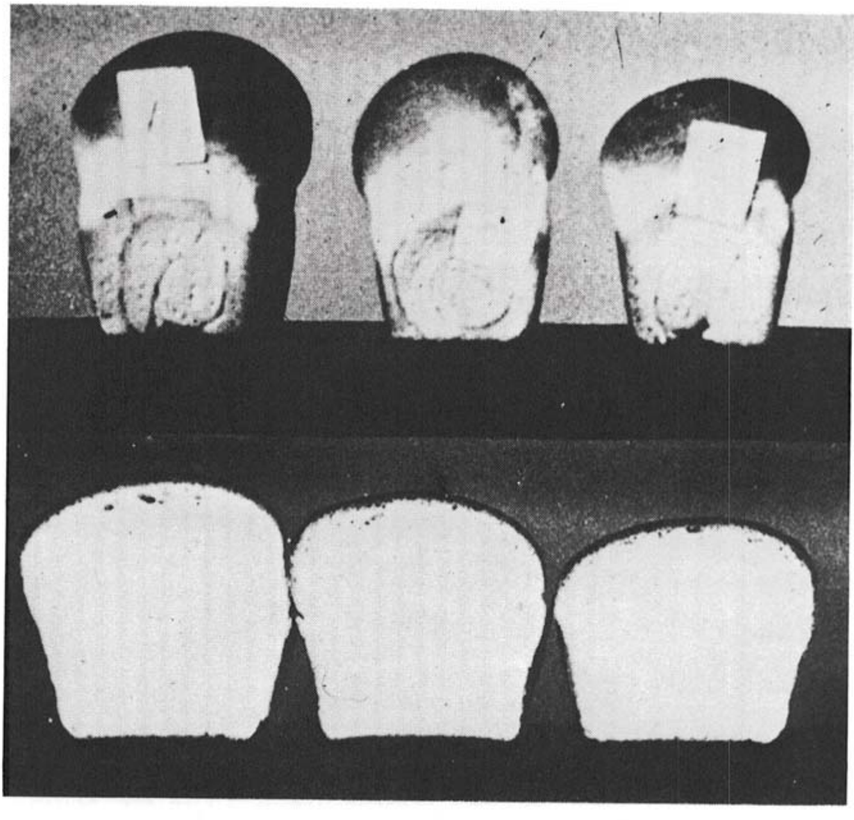

Fig. 4. External (upper frame) and internal (lower frame) characteristics of bread from fully matured, 2 weeks and 3 weeks in mature starch (left to right).

volume, which was highest with the starch isolated from fully matured wheat, decreased gradually with progressing immaturity of starch, based on the four maturity levels tested. The degree of maturity of wheat was significantly related (r=0.91**, N=4) to bread volume. The other bread characteristics were not affected by the maturity of starch, as is evident from Fig. 4, representing the breads produced using starches of different degree of maturity (1-week immature starch omitted).

CONCLUSIONS

The experimental evidence presented in this study indicates that the baking performance of starch depends on the degree of maturity of the wheat from which it was derived. A number of changes related to the chemical and physicochemical structure of starch granules demonstrated that the starch granules are not static entities, but are in a dynamic state of development during the plant growth period.

In the immature stages the starch granules are weakly associated, but become more strongly bonded as ripening progresses. An increase in iodine affinity suggested increases in amylose content and possibly other chemical transformations. Symptomatic of these changes that occur with increasing maturity were: increased paste stability, more restricted swelling, reduction of water-binding capacity, and increased enzyme susceptiblity. The baking quality of starch also improved with maturity. These data seem to point to a correlation between the baking potential of starch and its granular structure. It is impossible, however, to propose a comprehensive theory for this relationship, until properties of starch behavior, e.g. swelling and pasting, can be fully understood and explained in terms of the fundamental factors involved–such as crystalline:amorphous ratio of granules, type of crystalline structure, amylose:amylopectin ratio, and molecular size and distribution of starch polymers.

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