SCANNING ELECTRON MICROSCOPY STUDY OF SPAGHETTI PROCESSING

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ABSTRACT

Structural changes in pasta dough during spaghetti processing in a laboratory-scale continuous process press were studied by scanning electron microscopy. When water is added in the preliminary mixing stage before dough formation, the tight compact structure characteristic of semolina begins to change to a more open structure. Concomitant with dough formation in the extrusion auger, a jagged, discontinuous protein matrix becomes predominant. Starch granules definitely align along the direction of flow by the time the dough reaches the end of the extrusion auger. The protein matrix becomes more ordered as processing continues, but does not appear to achieve a continuous network of protein sheets and fibrils, suggesting that full gluten development does not occur. Further evidence for lack of gluten development at pasta dough absorptions was gained by microscopic examination of semolina-water farinograph doughs. When mixed at breadmaking absorption (60%), the protein was observed to form a continuous fibrillar structure that was not in evidence when mixed at pasta absorption (27%).

Of the numerous studies on the microstructure of flour, dough, and flour components, few have dealt with pasta products or pasta processing. Frey and Holliger (1) used light microscopy to study cooked spaghetti structure, and Banasik et al (2) used it to study pasta dough and cooked spaghetti structure. Evans et al (3) used a scanning electron microscope to study the surface of phosphated and nonphosphated spaghetti samples. We (4) recently examined the changes in structure that occurred during cooking of spaghetti by scanning electron microscopy (SEM).

So far as we are aware, no reports have been made on the microstructure of pasta doughs using SEM. Therefore, a scanning electron microscope was used in this investigation to examine structural changes in semolina-water doughs at various stages of spaghetti processing.

MATERIALS AND METHODS

A sample of Canadian amber durum wheat, graded No. 1 Canada Western amber durum (*Triticum durum,* Desf. cv. Wakooma), was used for this study. The wheat was tempered overnight to 16.5% moisture and milled in an Allis-Chalmers laboratory mill in conjunction with a laboratory purifier (5). The long-milling flow that Black (5) described was modified to yield a semolina extraction rate of 70%. Frosted reduction rolls were not used in the flow, and more purification stages were added. The semolina had a protein content of 12.4% (N × 5.7) and an ash content of 0.67% on 14% mb. Particle size of semolina was as follows:

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[2]Contribution No. 507 from the Department of Plant Science, University of Manitoba, Winnipeg, Man. R3T 2N2.

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Held on US sieve No. 40	15.5%
Held on US sieve No. 60	61.5%
Held on US sieve No. 80	13.7%
Held on US sieve No. 100	2.7%
Through No. 100	5.8%

To obtain this coarse a granulation, the second break rolls were spaced at 0.007 in. (0.178 mm) instead of 0.004 in. (0.102 mm).

Spaghetti Processing

Spaghetti processing was done in a Demaco S-25 laboratory-scale continuous-extrusion press (De Francisci Machine Corporation, Brooklyn, NY). Semolina and water were premixed at 27% absorption (14% mb) at the lowest speed for 12 min in a Hobart C-100 mixer with a flat beater mixing paddle. The pea-sized lumps of the semolina-water mixture were transferred to the mixing chamber of the Demaco press (Fig. 1). Once the auger chamber had filled with dough, vacuum (55 cm Hg) was applied. Temperature of the extrusion chamber was maintained at 50°C. Rotational speed of the auger was set at 21 rpm.

Flow Pattern of Dough

To ensure that representative test pieces of dough were removed from various points in the extrusion press, the flow pattern of dough through the Demaco press was studied by processing three 1-kg samples of semolina in succession, each colored with a different dye. The dyes used were fast green, orange I (tropeolin 000), and bromphenol blue. The use of colored doughs facilitated identification of outer and inner dough surfaces, ie, whether the dough pieces faced toward (outer surface) or away from (inner surface) the walls of the extruding chamber. The dyed samples were examined with a scanning electron microscope. To show that the dyes did not alter the structure, undyed samples also were processed and examined microscopically.

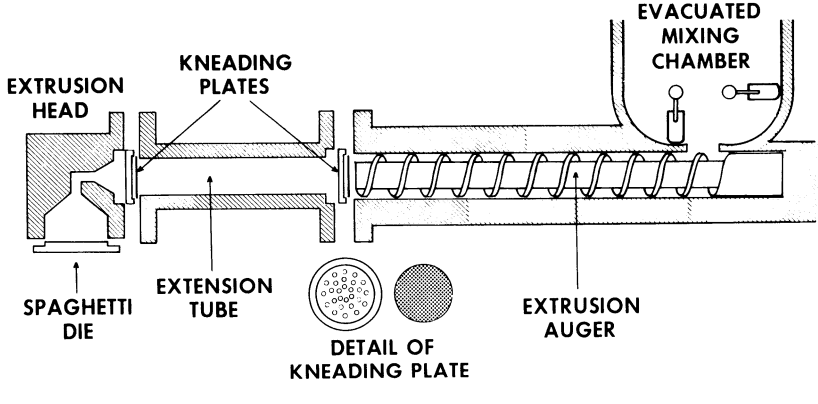

Fig. 1. Schematic representation of Demaco semicommercial laboratory-scale continuous extrusion press.

Dough Samples Examined

A schematic diagram of the Demaco press is shown in Fig. 1. Samples were taken in the mixing chamber after premixing in the Hobart mixer, in the extrusion auger about a third of the way down from the mixing chamber, in the middle of the extrusion auger, in the end of the extrusion auger, in the extension tube immediately after the kneading plate, in the end of the extension tube, in the extrusion head above the spaghetti die, and from freshly extruded spaghetti.

Test pieces were frozen immediately in liquid nitrogen and freeze-dried.

Farinograms

To determine the effect of absorption on dough structure, semolina was mixed in a farinograph at two absorption levels, 27 and 60%. The lower absorption dough was mixed according to the method that Irvine et al (6) described, while the higher absorption dough was mixed with the normal linkage setting (1:1).

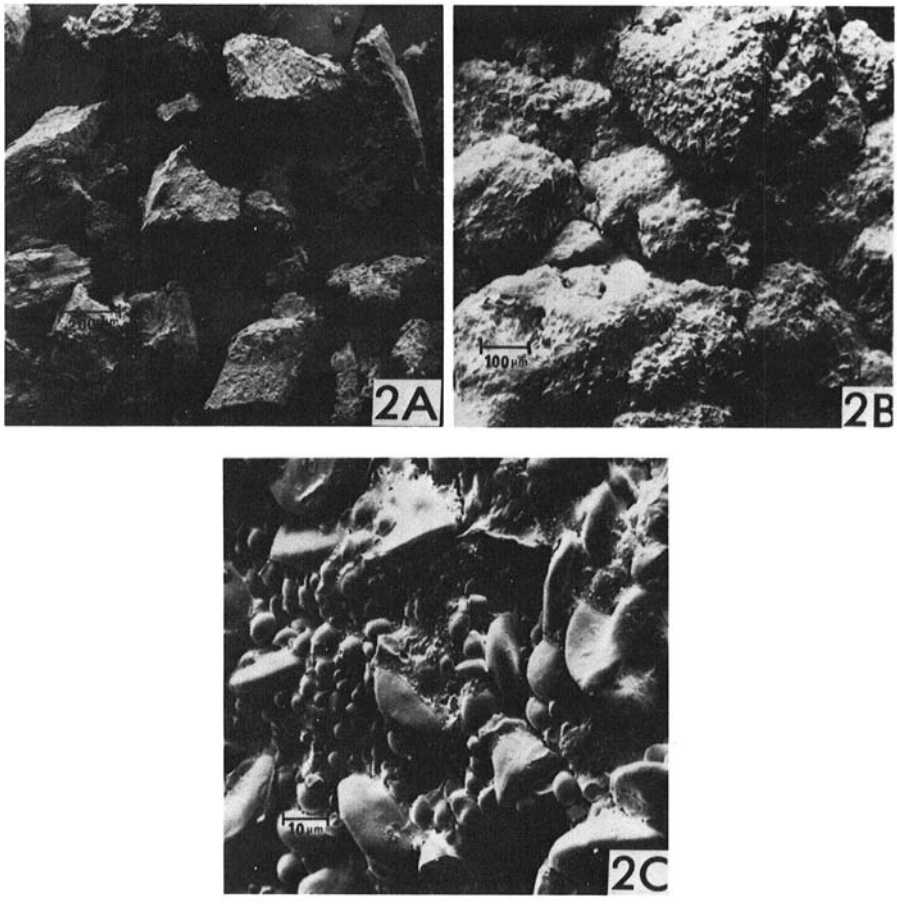

Fig. 2. Scanning electron micrographs of A) semolina, B) sample from mixing chamber, C) enlarged view of sample from mixing chamber.

Temperature for both absorptions was controlled at 50°C to correspond to the spaghetti processing temperature. After a total mixing time of 10 min, dough pieces were frozen in liquid nitrogen and freeze-dried.

SEM Specimens

Dough and spaghetti samples were fractured to expose inner surfaces. Specimens were attached to stubs using silver conducting paint and were coated with a layer of gold about 20–25 nm thick in a Philips vacuum evaporator. The entire surface of each sample was scanned with a Cambridge Stereoscan MK 11a scanning electron microscope at 10 kV, and a representative area was photographed on 35 mm Kodak Panatomic X film.

RESULTS AND DISCUSSION

Flow Pattern of Dough During Processing

Under the operating conditions of the Demaco press in our laboratory, the time required for the dough to pass from the mixing chamber to the

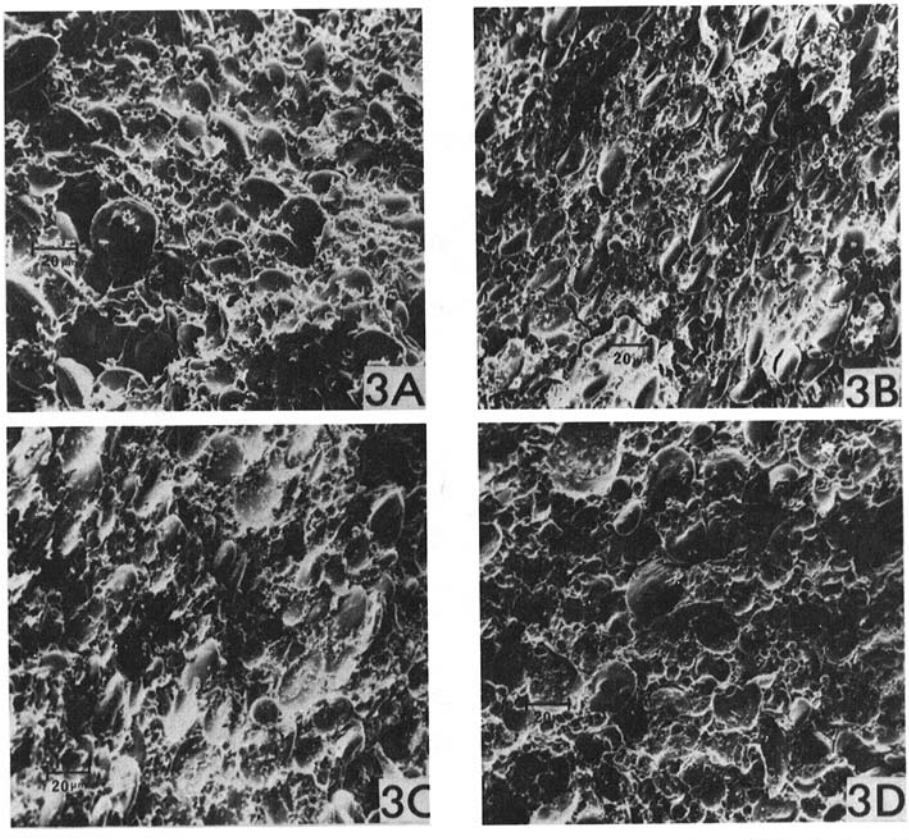

Fig. 3. Scanning electron micrographs of cross-sectioned doughs from A) beginning of extrusion auger, B) end of extrusion auger, C) beginning of extension, D) end of extension.

spaghetti dye was about 3 min. The movement of the dough in the auger was rapid, but as the color pattern from the dyes showed, the dough next to the wall of the extrusion chamber moves faster than that at the surface of the barrel of the auger. At both the leading and trailing edges of the helix were stationary deposits of compacted dough. Thus, instead of a 90-degree angle between the face of the helix and the barrel of the auger, the surface was rounded.

In both the extension tube and the extrusion head, laminar flow was quite pronounced as observed by a blend of all three colors in concentric rings.

Internal Structure of Pasta Dough and Spaghetti

As we (4) described previously, semolina particles were irregularly shaped and variable in size. The structure was compact, with few visible starch granules (Fig. 2A).

The pea-sized lumps formed in the Hobart mixer during the preliminary mixing stage were heterogeneous (Fig. 2B). Some areas were similar in appearance to semolina (presumably nonhydrated), while in other areas starch granules had become distinctly visible but still firmly held within a protein matrix (Fig. 2C). At this stage, where dough formation has not yet taken place, little, if any, indication of gluten development is apparent.

Dough formation began soon after the semolina-water mixture passed into the extrusion auger. At this stage (Fig. 3A), proteinaceous particles were clearly visible, more in the form of platelets and jagged edges than in the form of sheets and fibrils. At the end of the auger (Fig. 3B), the protein matrix was still irregular but appeared to be more interconnected. Some indication of alignment of starch granules appeared along the direction of flow.

In the extension tube immediately after the first kneading plate, the protein matrix had become quite continuous (Fig. 3C), although some jagged edges were still in evidence. Starch granules clearly were aligned. At the end of the extension tube before the second kneading plate, the dough had become translucent and

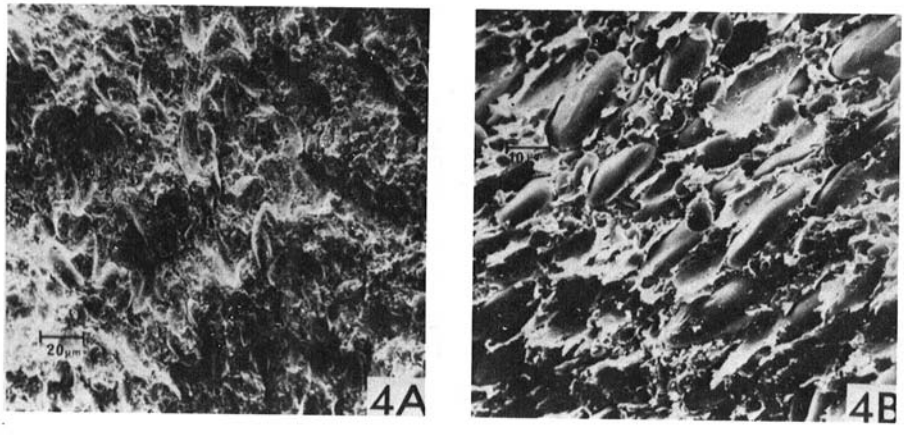

Fig. 4. Scanning electron micrographs of A) cross section of freshly extruded spaghetti, B) longitudinal section of freshly extruded spaghetti.

cohesive and would be considered "fully developed." Microscopic examination of a cross section revealed that the protein matrix had become much smoother (Fig. 3D). Numerous imprints of missing starch granules indicated a continuous protein structure. Alignment of starch granules was not obvious, because the fracture plane of this specimen was 90 degrees out of phase compared with previous specimens (Fig. 3A–C). All of the granules, however, were observed to be lying flat (Fig. 3D) so that if this dough specimen were rotated 90 degrees, granules would appear aligned as in the previous dough micrographs (Fig. 3A–C).

Microscopic examination of a cross section of freshly extruded spaghetti (Fig. 4A) revealed a compact structure, with starch granules deeply imbedded in a protein matrix. A longitudinal section (Fig. 4B) clearly showed the aligned starch granules surrounded by a laminar protein network.

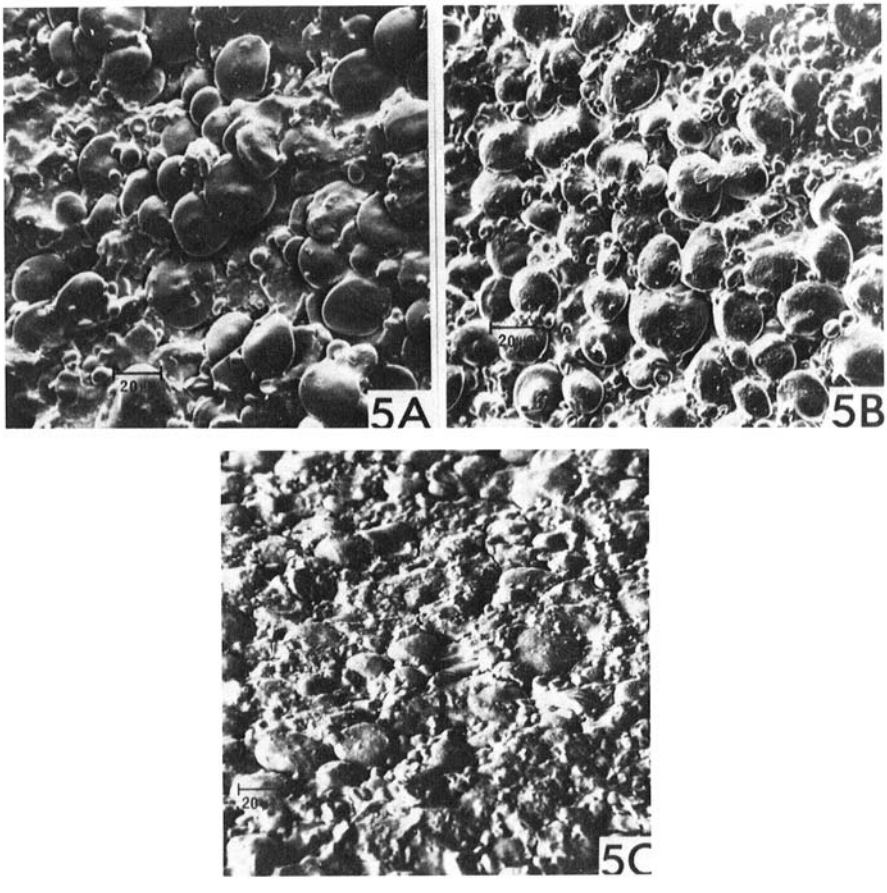

Fig. 5. Scanning electron micrographs of outer surfaces from A) dough near beginning of extrusion auger, B) dough from extrusion head, C) freshly extruded spaghetti.

Outer Surface of Pasta Dough and Spaghetti

A discontinuous protein film appeared to coat partially the outer surface of dough facing the wall of the extrusion chamber just after a cohesive dough started to form in the auger (Fig. 5A). The dough was still porous, as numerous openings occurred in the structure. The surface of dough against the wall of the extrusion head had become more compact and orderly (Fig. 5B). Starch granules appeared to be coated uniformly with a protein film and seemed to be aligned in neat rows. The outer surface of freshly extruded spaghetti (Fig. 5C) was dense and compact, with starch granules less distinct compared with the previous two surfaces. The surface was coated with a continuous protein film, with few openings.

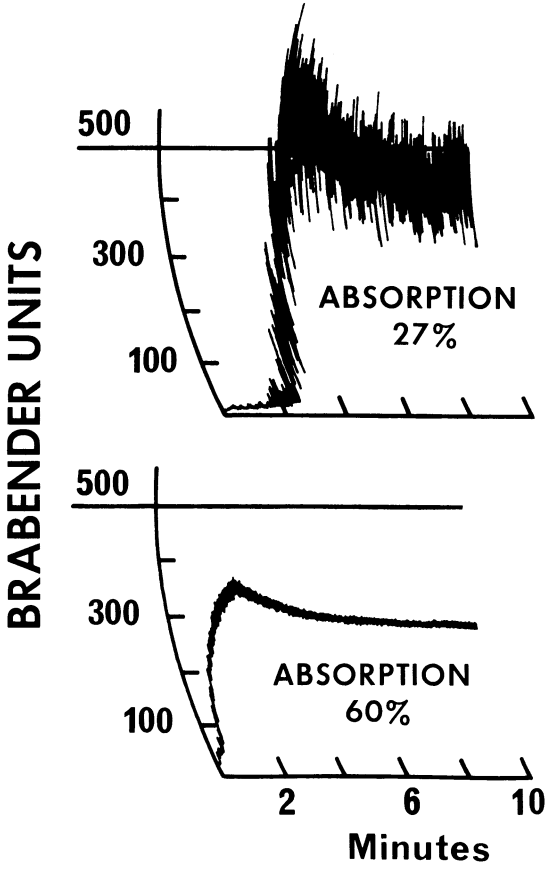

Fig. 6. Farinograph mixing curves (50-g bowl at 59 rpm) for semolina-water mixtures at pasta absorption (27%) and breadmaking absorption (60%). Temperature was regulated at 50°C for both absorptions, the temperature used for pasta processing. Lower absorption curve was obtained using rear sensitivity setting, while higher absorption curve was obtained using normal linkage setting (1:1).

Farinograms

The question of whether dough development occurs in low absorption doughs, ie, whether a continuous fibrillar protein network is formed as found under high-moisture conditions (7–9), was investigated by mixing doughs at two absorption levels in a farinograph. Differences in dough characteristics were obvious as the farinograms in Fig. 6 show. Maximum consistency was about nine times greater for the low absorption dough (about 3,000 BU compared with about 340 BU). At 60% absorption, water was sufficient to hydrate all the components in the semolina so that the band width was much narrower.

Micrographs of dough cross sections clearly showed differences in structure (Fig. 7A and B). The protein structure in the low absorption dough (Fig. 7A) was not nearly so regular or continuous as that of the higher absorption dough (Fig. 7B). At higher absorption, the network was fibrillar compared with the jagged

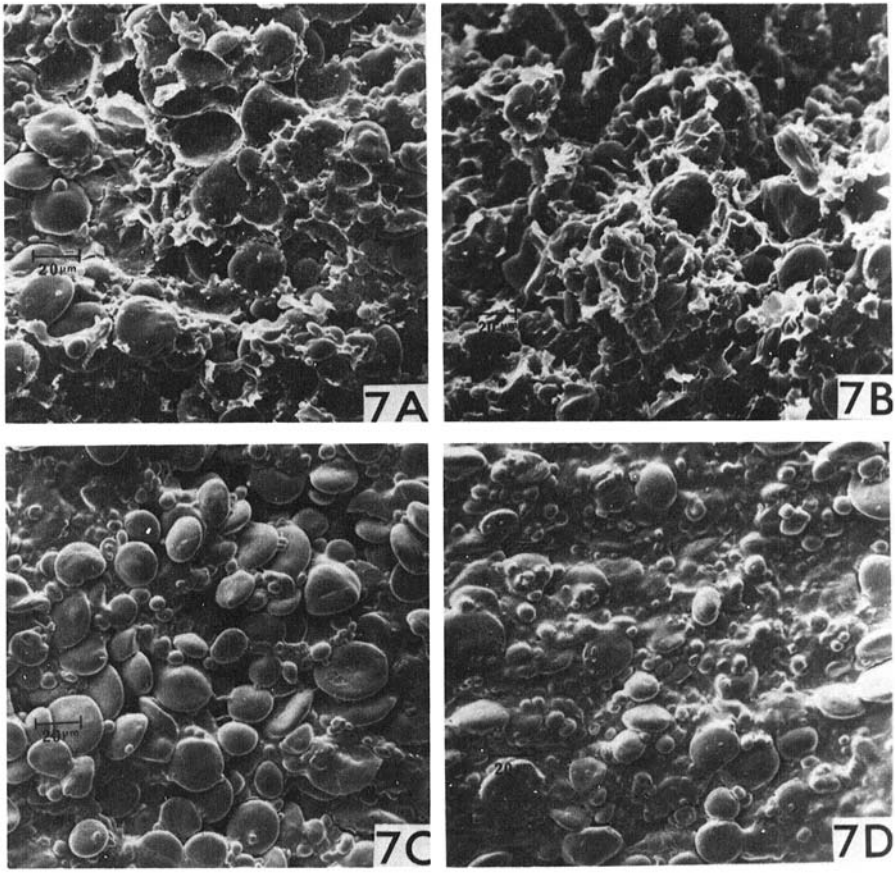

Fig. 7. Scanning electron micrographs of farinograph doughs. A) cross section at 27% absorption, B) cross section at 60% absorption, C) outer surface at 27% absorption, D) outer surface at 60% absorption.

pieces found at low absorption. The outer surface of the low absorption dough (Fig. 7C) had numerous openings and the distinctly visible starch granules were loosely held within a discontinuous protein matrix. The surface of the high absorption dough (Fig. 7D) was smooth, with few, if any, openings. A smooth protein film appeared to coat the entire surface.

GENERAL DISCUSSION

The amount of water used in pasta doughs would appear to be insufficient to hydrate gluten proteins fully and thus insufficient to form the kind of developed gluten network found in bread doughs. At no stage during pasta processing was the protein matrix found to be as smooth and continuous as that in the higher moisture farinograph dough (Fig. 7B). If dough development is defined in terms of formation of a continuous network of protein sheets and fibrils, then full dough development apparently does not take place at pasta absorptions. In a recent study, we (10) suggested that the absence of complete gluten development during pasta processing may well explain why no significant differences were detected in solubility changes of semolina proteins during spaghetti processing for wheats of widely differing spaghetti-making quality. Even when differences in gluten properties are readily detectable for a series of wheats, these differences are not necessarily reflected by the rheological properties of their pasta doughs (11). Differences in spaghetti-making quality are likely due to the manner in which the proteins withstand boiling water during cooking (4).

In the present study, only changes in dough structure that occurred during processing for one Canadian durum wheat variety have been investigated. Determining if differences in pasta dough structure exist between varieties of differing spaghetti-making quality will be the subject of a future investigation.

Acknowledgments

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