SCANNING ELECTRON MICROSCOPY OF COOKED SPAGHETTI[1,2]

J. E. DEXTER,[1] B. L. DRONZEK,[2] and R. R. MATSUO[1]

ABSTRACT

A scanning electron microscope was used to study changes in structure of spaghetti that occurred during cooking. The exterior of uncooked spaghetti appeared to be coated with a thin protein film that retained its integrity during cooking except for a few ruptured areas. When spaghetti was steeped in water at 22° C, the interior appearance of the spaghetti was altered from a compact amorphous structure with few visible starch granules to a more porous structure with starch granules that were loosely held within a discontinuous protein matrix. When the spaghetti was cooked in boiling tap water, the interior structure varied from an open filamentous network near the outer surface where starch gelatinization was complete to a compact amorphous structure that is characteristic of dried spaghetti where the cooking water does not penetrate. Microscopic examination of cooked spaghetti that had been incubated in 90% dimethyl sulfoxide and a combination of α- and β-amylase suggested that the filamentous network near the outer edge of the spaghetti interior was composed of a starch-coated protein network that was interconnected by starch fibrils.

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Electron microscopy has been applied widely in the study of the microstructure of the wheat kernel (1,2), flour and dough (3–6), starch (7–9), and wheat protein preparations (10–14). The amount of information currently available on the microstructure of spaghetti, however, is limited (15–17).

In this investigation, a scanning electron microscope was used to examine the microscopic structure of spaghetti, with particular emphasis on changes that occurred during the cooking process.

MATERIALS AND METHODS

The semolina used for this study was milled from a sample of 2CW amber durum wheat (cultivar Wakooma) in a Buhler laboratory mill (18) in conjunction with a laboratory purifier. Quality data for the semolina (11.8% protein on a 14%

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moisture basis) and the spaghetti processed from it were presented in a previous study (19). The spaghetti was prepared in a DEMACO (De Francisci Machine Corporation, Brooklyn, NY) semicommercial scale laboratory extruder as described previously (19).

Sample Preparation

Cooked spaghetti was prepared by placing 10 g of spaghetti in 100 ml of rapidly boiling water. At various time intervals, some spaghetti was removed, cooled with cold water, frozen in liquid nitrogen, and freeze-dried.

To study the effect of imbibition of water on spaghetti structure, dry spaghetti samples were steeped in tap water at room temperature (22° C) for various time periods. On removal from the water, the spaghetti was frozen in liquid nitrogen and freeze-dried.

To gain some information on the makeup of the filamentous network observed in cooked spaghetti, samples of spaghetti cooked for 7 min and cooled with cold water were immersed in one of the following four media for 24 hr at 40° C: 1) distilled water (control sample), 2) 0.01*M* lactic acid, 3) 90% (v/v) dimethyl sulfoxide, or 4) bacterial (bacillus subtilis) α-amylase (Calbiochem) and β-amylase (Nutritional Biochemical), 50 mg/100 ml distilled water. Each sample was frozen in liquid nitrogen and freeze-dried. To remove the dimethyl sulfoxide, those strands were thoroughly washed in distilled water prior to freezing.

SEM Specimens

Spaghetti samples were fractured to expose inner surfaces and then attached to specimen stubs with silver conducting paint. The mounted specimens were coated with a layer of gold, about 20 to 25 nm thick, in a Philips vacuum evaporator and examined in a Cambridge "Stereoscan" MK 11a SEM at 10 kv. Samples were viewed by scanning the entire surface; a representative area was photographed on 35 mm Kodak Panatomic X film.

RESULTS AND DISCUSSION

Semolina

The semolina comprised irregularly shaped particles of varying size (Fig. 1a). Close examination of the particles revealed a tight, compact structure with no air

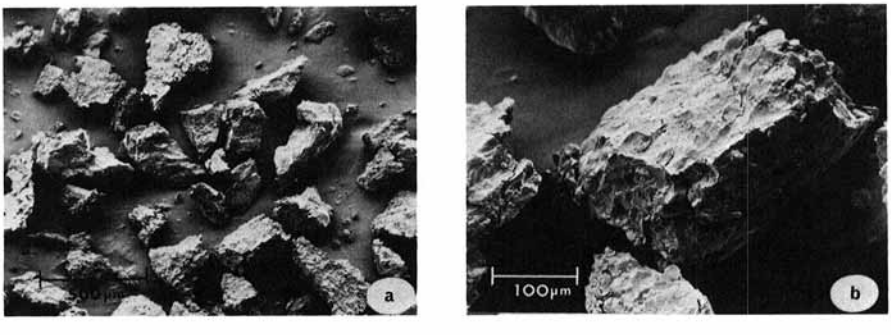

Fig. 1. a) Semolina. b) Enlarged view.

spaces (Fig. 1b). This structure is similar to that which Hoseney and Seib (20) described previously for durum wheat. The few starch granules that were visible on the surface of the semolina particles (Fig. 1b) were embedded in and covered with an amorphous protein matrix. This was in contrast to the more open structure that other workers (20) observed for soft wheat flour. Strong adherence of protein to starch granules as observed for the durum wheat in this study has been postulated as a possible explanation for grain hardness in wheat (3,20,21).

Dry Spaghetti

Numerous starch granules of varying size were visible on the outer surface of dry spaghetti (Fig. 2a). As others (15,16) have reported previously, the entire surface of dry spaghetti appears to be coated with a smooth protein film. Numerous small holes and cracks, which would facilitate rapid water penetration during cooking, were present on the surface.

In contrast, a cross section of dry spaghetti (Fig. 2b) exhibited a structure where few starch granules were evident, and these were completely coated with an amorphous protein matrix. This matrix bore a striking resemblance to a

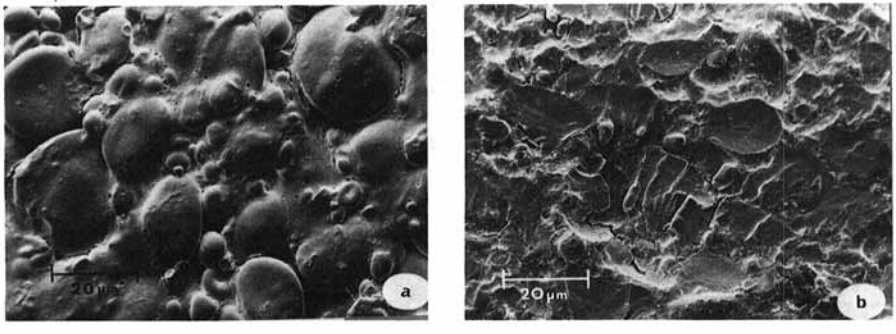

Fig. 2. Dry spaghetti. a) Exterior surface. b) Interior surface.

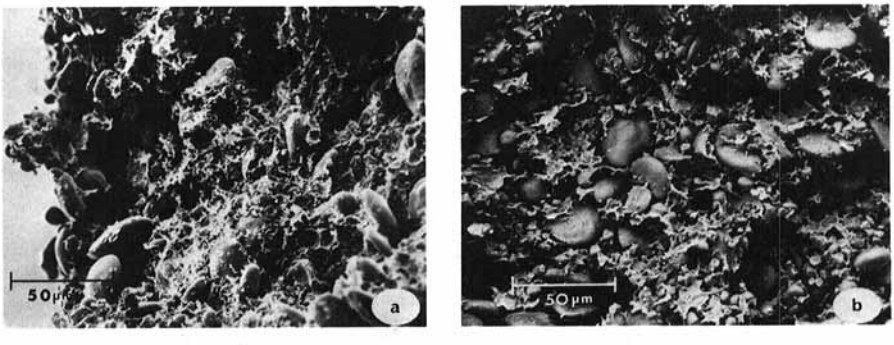

Fig. 3. Cross section of spaghetti steeped in tap water at 22°C. a) For 15 min. b) For 90 min.

previously published micrograph of gliadin (12). Despite the compact nature of the structure (Fig. 2b), many cracks and small holes were apparent in the protein matrix that would permit rapid penetration of cooking water into the interior of the spaghetti.

Steeped Spaghetti

A cross section of a strand that had been steeped in tap water at 22° C for 15 min revealed a great change near the surface in the internal appearance of the spaghetti (Fig. 3a). The structure appeared to be quite porous. Starch granules were readily apparent. The protein matrix had retracted into a discontinuous phase, although most of the starch granules still appeared to be held quite tightly. When viewed after 90 min of steeping, the internal framework of the spaghetti had undergone a further transformation (Fig. 3b). Starch granules were conspicuous and seemed to be held loosely by the protein. The protein had converted to jagged pieces that were interconnected with thin strands. These strands may be akin to the microscopic fibrils of hydrated protein that Bernardin and Kasarda (5,6) observed on wetting of wheat flour.

Cooked Spaghetti

During cooking, the surface of the spaghetti became smooth (Fig. 4a). As the strands expanded in volume, a great deal of stress was imparted on the enveloping protein film. This resulted in areas of rupture after cooking periods as short as 3 min (Fig. 4b). These ruptured areas were similar in appearance to Bernardin and Kasarda's (5,6) micrographs, which depict stretched sheets of endosperm protein in wetted wheat flour.

A continuous change in structure from the outer surface toward the core characterized the internal framework of cooked spaghetti (Fig. 5a). Just below the outer surface was a complex filamentous network consisting of numerous holes that gave a homeycomb-like appearance (Fig. 5a,b). The size of these holes decreased toward the core of the spaghetti.

Miller *et al.* (22) found a similar filamentous network in cooked wheat starch, which they attributed to leaching out of material from the starch granules. Hill and Dronzek (9) and Chabot *et al.* (23) also found a leaching of material from

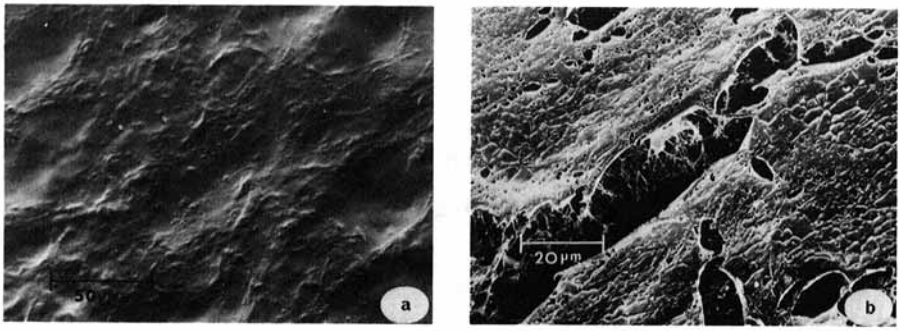

Fig. 4. Exterior surface of cooked spaghetti. a) Normal. b) Ruptured.

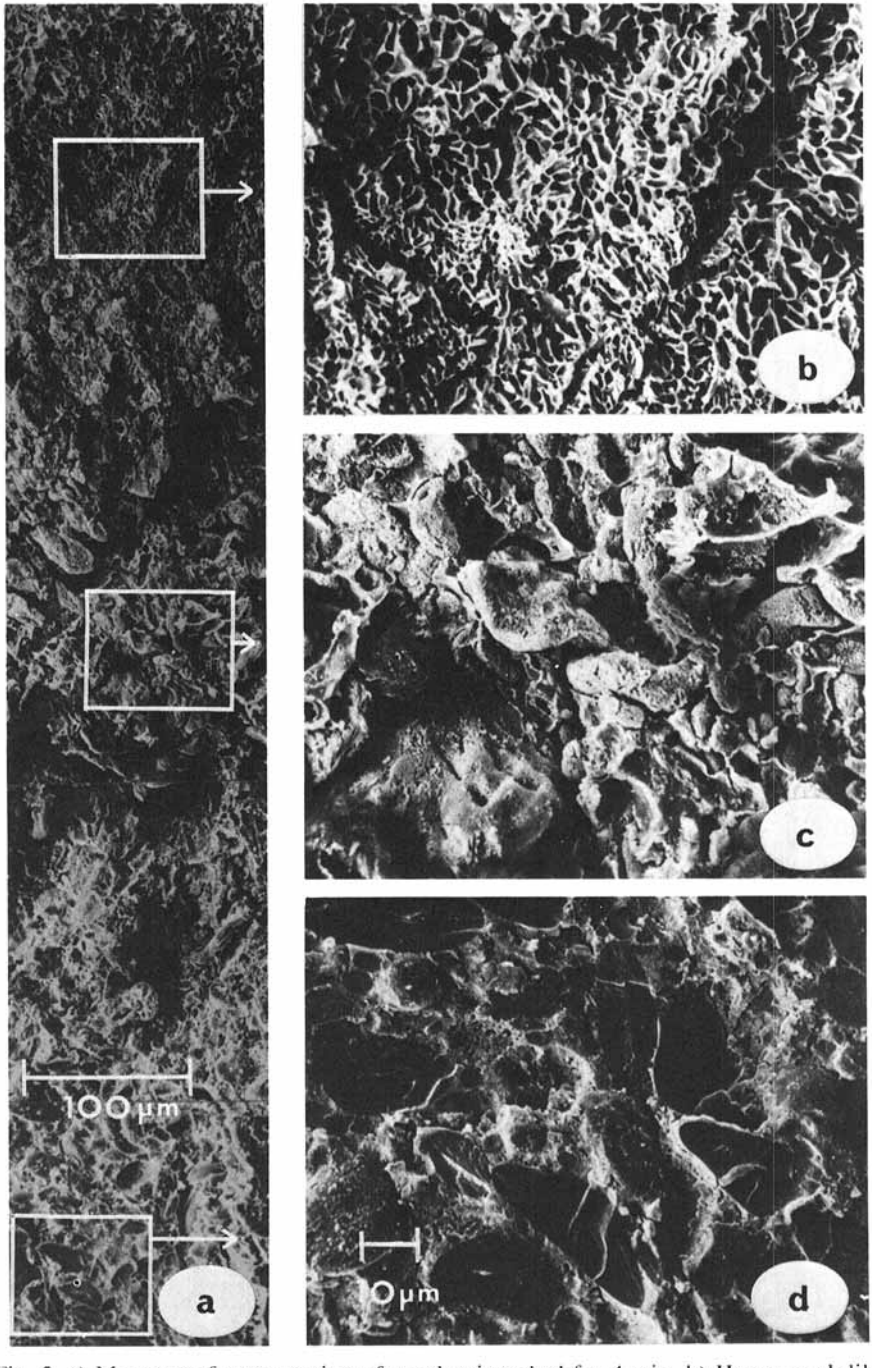

Fig. 5. a) Montage of cross section of spaghetti cooked for 4 min. b) Honeycomb-like network. c) Ungelatinized region near core. d) Core.

various types of starch granules near their gelatinization temperature. Thus, formation of this structure appears to be a phenomenon that occurs concomitantly with starch gelatinization.

Marshall and Wasik (24) reported that spaghetti that was cooked for 5 min had visible zones of cooking under polarized light. The zones comprised an outer area that exhibited almost total loss of birefringence and an inner core that showed little evidence of gelatinization. This is corroborated by the montage of spaghetti that was cooked for 4 min (Fig. 5a). It showed a gradual transition from the open filamentous structure (characteristic of gelatinized starch near the outer surface) (Fig. 5b), to an ungelatinized region near the core (Fig. 5c), to a compact amorphous structure at the core (characteristic of dried spaghetti) (Fig. 5d) where the cooking water had not yet penetrated.

The inner core, to which the cooking water did not penetrate, decreased in size with increasing cooking time. Even after 22 min of cooking (10 min beyond optimum cooking time), a small core could still be observed under the microscope. With increased cooking time, the filamentous network near the outer surface became more open (probably due to further swelling of the strand and because of leaching of starch into the cooking water) and also approached the core more closely.

Cooked Spaghetti Steeped in Extracting Media

When cooked spaghetti was incubated in water at 40° C, no change occurred in the appearance of the honeycomb-like filamentous network. Dilute lactic acid also had no discernible effect on the network structure. This was not surprising, since the boiling water would probably denature the protein present in the network sufficiently to render it insoluble.

Incubation in 90% dimethyl sulfoxide resulted in the disappearance of starch granules in the center core of the cooked spaghetti. (These granules were still visible in both the control sample and the lactic acid-incubated sample.) Noticeable modification of the filamentous network did not occur near the outer edge of the strands (Fig. 6a), however, suggesting that the network may consist of a protein network that is covered with a thin starch film. Further information

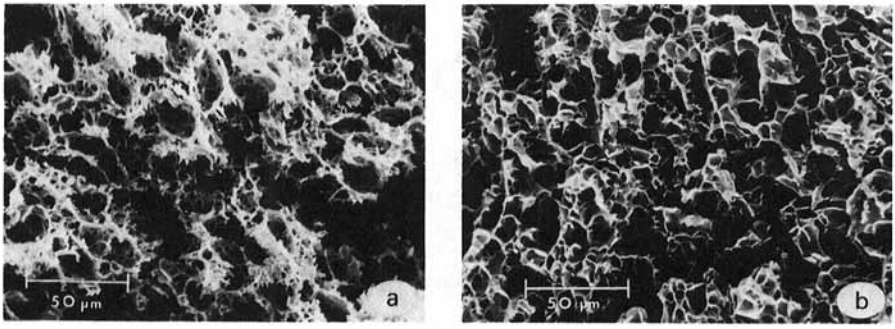

Fig. 6. Cross section of spaghetti cooked for 7 min. a) Steeped in dimethyl sulfoxide. b) Steeped in amylase.

was gained from incubation in α- and β-amylase. As was the case for dimethyl sulfoxide-incubated strands, starch granules were no longer visible near the core. The filamentous network near the surface, however, had been slightly modified (Fig. 6b). Some continuity of the structure had been lost. The pattern of holes was less regular and the network more open. This could be the result of digestion of the covering starch film and of starch fibrils (akin to those observed by Miller *et al.* [22]) that expose the underlying protein network.

CONCLUSIONS

The two most important factors relating to spaghetti cooking quality are protein content (25,26) and gluten quality (26,27). The results of this study provide two possible explanations for the importance of protein in determining spaghetti cooking quality: First, a thin protein film enveloped the spaghetti strands. The extent to which this film retains its integrity during cooking could affect cooking quality. Secondly, in the cooked region (complete starch gelatinization) the interior structure was composed of a starch-coated protein network. The extent (quantity) and strength (quality) of the protein network may be important in determining spaghetti cooking quality. In view of these observations, it would be of interest to ascertain whether quality differences can be related to cooked spaghetti structure for a series of cooked spaghetti possessing a wide range of cooking quality.

Acknowledgments

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