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MICROSTRUCTURAL STUDIES OF PASTA AND STARCH PASTA

Wen-Chieh Sung* and Martha Stone**

Key words: cooked pasta, scanning electron microscopy (SEM), wheat starch.

ABSTRACT

The processing methods for mung bean starch noodles were used to form "starch pasta" from various isolated wheat starches. The objective of this research was to evaluate the changes in the surface and internal structure of pasta and "starch pasta" made from various flours and wheat starch before and after cooking. Cooked "starch pasta" revealed a honeycomb-like internal structure similar to cooked pasta when viewed by scanning electron microscopy (SEM). The honeycomb-like structure of cooked pasta is mainly due to the coagulated protein embedded in the gelatinized starch. Swelling of cooked pasta is mainly due to the hydration and coagulation of protein rather than the gelatinized starch. The diameter of cooked starch pasta does not increase as much as that of cooked pasta. A fibrillar protein network of high cooking quality pasta was enveloped in a gelatinized starch, whereas low cooking quality products contained more diffuse gelatinized starch in a less extensive protein framework. Determination of pasta cooking quality was more dependent on a continuous protein network than the physicochemical properties of the gelatinized starch. In the absence of coagulated protein "starch pasta" strands fractured into small pieces and did not swell. This was in contrast to the pasta made from flour or durum wheat semolina which became swollen after 20 minutes of cooking.

INTRODUCTION

Many scientists have reported on the microstructure of durum wheat products starting from the original wheat kernel [2], hydrated flour particles at the beginning of dough mixing, after additional dough mix [1, 14], the pasta drying process [19], and finally cooked pasta [5, 18]. Many researchers agree that protein content and gluten strength are primary factors influencing pasta quality [7, 9, 10, 15]. Limited information is available on the starch gelatinization of cooked pasta and its relation to cooking quality. Delcour *et al*. [6] reconstituted protein, starch, water-extractable and sludge fractions in order to make pasta. Their results have shown that gel properties and/or its gluten network breakdown ability in a certain gluten ultrastructure during cooking are important for pasta quality. Although gluten, an ultrastructure-forming agent, remains a very important contributor to pasta quality in this decade, the changes in starch during high temperature and very high temperature drying cycles have gained more attention concerning their effects on pasta cooking quality [11].

For this research, the processing method for mung bean starch noodles [22] was used to make "starch pasta" from isolated wheat starch. Microstructural differences between pasta and starch pasta have the potential to clarify the roles of gelatinized starch and coagulated gluten in cooked pasta.

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MATERIALS AND METHODS

1. Isolation of starches

Durum wheat semolina, hard wheat flour and soft wheat flour were obtained (General Mills, Inc., Minneapolis, MN). Durum wheat semolina starch, hard wheat starch, and soft wheat starch were isolated from flours using the procedure of Medcalf and Gilles [16].

2. Pasta and starch pasta preparation

A 200-gram sample of flour was mixed and extruded with a laboratory pasta maker (Popeil Pasta Products, Inc., Beverly Hills, CA) using a spaghetti die (1.85 mm diameter). "Starch pasta" preparation followed the method of Sung and Stone [21] for making mung bean starch noodles with a slight modification. The temperature was held constant at 25°C and relative humidity was lowered gradually from 80% at the beginning to 40% at the end of the 48 hour drying cycle. An al dente' cooking time (20 minutes) of pasta was determined when the white core of ungelatinized starch in the strand had disappeared.

Diameter of 50 individual strands of dry pasta or 50 individual strands of dry starch pasta was measured. Cooking losses were determined with the methods of van Everen *et al*. [23]. Strength of dry pasta and strength of dry starch pasta were tested by the TA.XT2 Texture Analyzer (Texture Technologies Corp., Scarsdale, NY) with a Warner Bratzler blade (Texture Technologies Corp., Scrsdale, NY). Firmness of the cooked pasta and starch pasta was measured as force in compression with the TA.XT2 Texture Analyzer and a special lexan pasta blade and plate (probe TA-47) to imitate the action of teeth was used. Test conditions were followed the method of Sung and Stone [21].

3. Scanning electron microscopy studies

The uncooked and cook pasta and starch pasta of the SEM specimens were examined both at the surface and within the transverse section. All cooked pasta or "starch pasta" were put into a small plastic test vial after 5 minutes and 20 minutes of cooking, respectively. Then, liquid nitrogen was immediately poured into test vials to cover the samples. Water was removed from specimens by vacuum dry with a Speed Vac SC 100 (Savant Instruments, Inc., Farmingdale, NY) attached to a Precision Vacuum Pump Model DDC 195 (Precision Scientific Inc., Chicago, IL) to vacuum the dehydration chamber at low drying rates for 4 hours at 0.1 microbar. The cooked specimens were sputtered with 25 nm of gold-palladium (60:40) at 13 milliamps for 5 minutes (Hummer Sputter Coater, Techincs EMS, Inc, VA). Samples were observed in a Philips Scanning Electron Microscope 505 at an acceleration voltage of 20 kev.

RESULTS AND DISCUSSION

1. Scanning electron microscopy of dry pasta and starch pasta

Scanning electron microscopy cross sections of dry pasta made from different flours (Figure 1) revealed that the binding forces between the protein matrix and starch granules are different. The binding force between the protein and starch of durum wheat and hard wheat pasta is stronger than that of soft wheat pasta when a blade is used to prepare the cross sections. Dry "starch pasta" and pasta strength and diameter are present in Table 1. It also shows the strength of dry pasta made from durum wheat or hard wheat is stronger than soft wheat pasta. The specimens of durum wheat pasta displayed only a few starch granules with a lot of starch shadows evident on the cross section following fracturing with a razor blade (Figure 1a). These results agreed with findings of Matsuo *et al*. [14]. They found longitudinal sections of freshly extruded spaghetti with starch granules embedded in a protein matrix. Matsuo *et al*. [14] also reported numerous imprints of missing starch granules in the cross-sectioned pasta. Nevertheless, only a few starch shadows could be found in the transverse section of the soft wheat pasta (Figure 1c). Most starch granules in the soft wheat pasta were cut through without producing shadows in the cross section of the dry pasta. The binding force between starch particles in starch pasta was stronger than the binding force between starches and protein in dry pasta (Table 1).

More starch granules were surrounded by gluten in the durum wheat pasta and hard wheat pasta as compared to soft wheat pasta [Figures 2(d)-2(f)]. Resmini

Table 1. The strength and diametera of dry starch pasta and pastab made with various starches and flours

Sample	Strength (g)	Diameter (mm)	Strength (g)/Area (mm^2)
Pasta samples			
Semolina	2100.7a	1.9a	741.0b
Hard wheat flour	1965.4a	1.9a	693.3bc
Soft wheat flour	850.4b	1.8b	334.0d
Starch pasta samples			
Semolina starch	1903.4a	1.6c	947.0a
Hard wheat starch	1537.1ac	1.6c	764.7b
Soft wheat starch	1289.0bc	1.6c	641.3c

[a] All values are a mean of 4 replications with 50 sub-samples per replication.

[b] Mean values with the same grouping letter at the same grouping letter at the same column were not significantly different ($p \geq 0.05$).

and Pagani (1983) also reported that soft wheat pasta had a less extensive protein framework with more diffuse starch particles. Several authors [5, 14, 18] reported a homogeneous and porous structure where starch granules were deeply embedded in a protein matrix. A gluten fibrillar network that surrounding the starch granules after hydration has been reported in the literature [4, 5, 7, 8, 14, 18]. However, complete development of a gluten network, as would be the case in bread dough, was not found. Starch granules of durum wheat were embedded in and covered with an amorphous protein matrix. Starch granules were more visible on the surface of dry hard and soft wheat pasta (Figure 2e and 2f). Cunin *et al*. [5] and Banasik *et al*. [2] also observed numerous starch granules of varying sizes visible on the surface of the dry pasta. The tight compact structural characteristics of durum wheat semolina become a more open structure whenever water is added in the mixing stage [14].

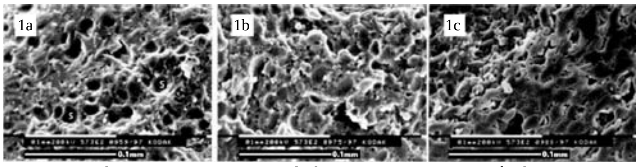
Many small holes were apparent on the surface of the dry pasta (Figure 2), which could permit the penetration of water into the interior of pasta during cooking. Cracks and holes were also observed by Cunin, *et al*. [5] and Dexter *et al*. [7]. They may have been due to shrinkage during sample preparation or tension within the pasta dough during drying. Durum wheat semolina pasta dried at an ambient temperature (22-25°C) with 30% humidity will crack and the strands broke into small pieces. The strands could not hold their shape. This indicates that the pasta drying process is as important as the factors of gluten strength and protein content in flours. In this research, durum wheat "starch pasta" dried at an ambient temperature (22-25°C) and 30% humidity held its strand shape without having cracks in the strands. Cracks in the pasta strands were due to improper dehydration of the gluten thereby causing separation from the starch. No cracks in the "starch pasta" implied that gluten was a main factor causing the formation of cracks in the pasta.

Starch granules of soft wheat or durum wheat "starch pasta" adhered to adjacent starch particles more so than hard wheat starch pasta. Numerous attached starch granules were still visible in soft wheat pasta (Figure 2f). Resmin and Pagani [19] reported that soft wheat pasta has a less extensive protein framework with there being more diffuse starch particles. The starch granules of hard wheat "starch pasta" remained intact after water addition to form slurry (Figure 2).

2. Ultrastructure of cooked pasta and starch pasta prepared by the freeze dried method

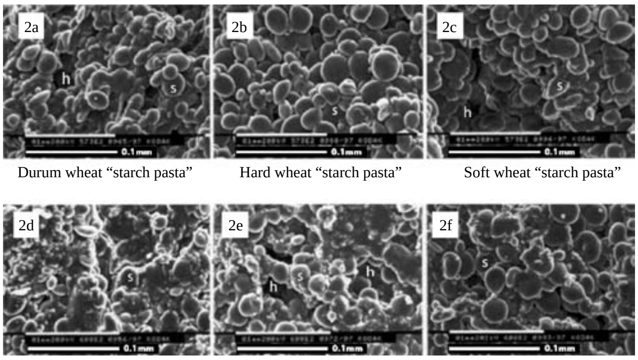
The surface of the durum wheat "starch pasta" after 5 minutes of cooking (Figure 3c) appeared as a honeycomb-like structure, but some of the gelatinized starch leached into the cooking water from the surface of the "starch pasta". Functional characteristics of 20 minutes cooking "starch pasta" and pasta are presented in Table 2. All pasta samples had significantly lower cooked weight and solid loss than "starch pasta". Continuous gluten network protein prevented the soluble starch into water better than gelatinized starch alone. Soft wheat pasta had higher cooking loss and cooked weight than semolina and hard wheat pasta, but they were not significantly different. Soft wheat "starch pasta" has significantly higher cooking loss and less cooked weight than semolina and hard wheat "starch pasta". All pasta samples except pasta made from soft wheat were significantly firmer than "starch pasta". This indicates coagulated gluten network played the role of cooked pasta firmness (Table 2).

Durum wheat pasta also formed a honeycomb-like structure 5 minutes after cooking based on SEM observations from both cross sections and surfaces (Figure 3). The different surface structure between pasta and "starch pasta" after 5 minutes cooking indicated that coagulated protein could prevent gelatinized starch leaching into the cooking water (Figure 3). Hermansson and Buchheim [12] mentioned that the freezing-drying of hydrated material containing unbound water would cause the formation of network-like artifact structures. Pagani *et al*. [18] reported that the thin section of



Durum wheat pasta   Hard wheat pasta   Soft wheat pasta

Fig. 1. Cross sections of uncooked wheat pasta made from various wheat flours. s) starch shadows.



Durum wheat pasta   Hard wheat pasta   Soft wheat pasta

Fig. 2. Surfaces of uncooked wheat pasta and starch pasta made from various wheat flours. s) starch; h) hole.

cooked spaghetti showed the development of alveoli inside the swelling starch granules, but they could not track the changes in protein. Only gelatinized starch was observed on the surface of "starch pasta" (Figure 3). The honeycomb-like gelatinized starch structure at the surface could result from remaining surface starch after some gelatinized starch was leached into the cooking water. Amend and Belitz [1] reported that a gluten network remained when the starch was removed enzymatically.

Dexter *et al*. [7] and Schreurs *et al*. [20] reported the surface of the spaghetti became smooth after 3 minutes of cooking. Figure 3a shows the surface of the pasta formed a honeycomb-like structure of gelatinized starch and some holes were apparent among the network. Cunin *et al*. [5] also claimed the surface structure of cooked pasta became rougher as cooking time increased. A porous network structure allowed easier for penetration of water into the surface of durum wheat "starch pasta" after 5 minutes of cooking (Figure 3c). Formation of a honeycomb-like network seemed to occur concomitantly with starch gelatinization [3, 13, 17].

Figure 4a shows a continuous change in the structural framework pasta cooked for 5 minutes from the outer surface toward the core. Starches were gelatinized on the surface of pasta cooked for 5 minutes (Figure 4c), but raw starch granules can still be seen at the core (Figure 4b). Dexter *et al*. [7] also reported a continuous change phenomenon occurring in their cooked spaghetti. Figure 5 shows cross sections of cooked durum wheat "starch pasta" after different heats for 5 minutes or 20 minutes. In the absence of coagulated protein, the "starch pasta" had already fractured into small pieces and did not swell in contrast to pasta after 20 minutes of cooking (Table 2). Five minutes cooked specimens have a larger ungelatinized area than twenty minutes cooked specimens (Figure 5). The starch of durum wheat was not a key factor related to better cooking quality of pasta compared to the starch of hard wheat. Swelling of cooked pasta was mainly due to the hydration of protein. Pasta samples swelled to twice their original diameter after 20 minutes of cooking, but the diameter of cooked "starch pasta" did not change at all [21]. A gradual transition from figure 5a to figure 5b was evident from the open gelatinized starch filamentous structure, to an ungelatinized region between

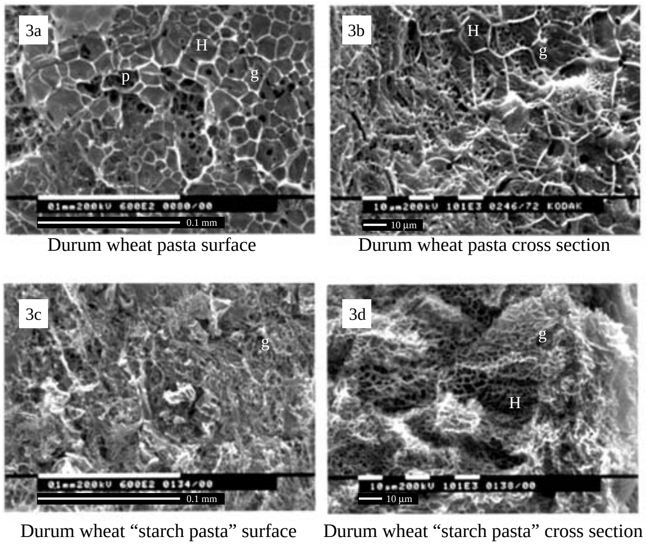


Fig. 3. Freeze dried pasta and starch pasta after 5 minutes cooking. H) Honeycomb-like structure; p) porous network; g) gelatinized starch.

Table 2. Functional characteristics[a] after 20 minutes cooking starch pasta and pasta[b]

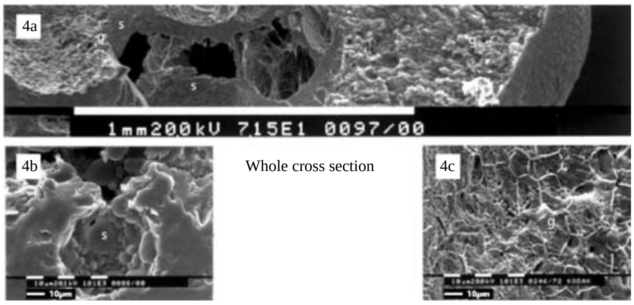
Sample	% Cooked weight	% Cooking loss	Stickiness (N/m^2)[c]	Firmness (g/mm)
Pasta samples				
Semolina	313.5a	6.2a	1150.5a	44.9a
Hard wheat flour	313.4a	8.2a	3248.9b	44.4a
Soft wheat flour	389.6a	8.8a	6108.6b	28.4b
Starch pasta samples				
Semolina starch	357.4b	26.6b	729.8a	20.8ce
Hard wheat starch	439.7b	19.3b	9558.9b	18.4cde
Soft wheat starch	310.6c	41.7c	30076.1c	14.3d

[a] All values were a mean of 4 replications with 3 sub-samples per replication.
[b] Mean values with the same grouping letter at the same column were not significantly different ($p \geq 0.05$).
[c] Data were analyzed on log10 scale, and least squares means were reported.

the outer surface and the core, to a more compact core of durum wheat "starch pasta" (Figure 5). The core might have been cooked but for the limited penetrated water and not all the starch was being gelatinized.

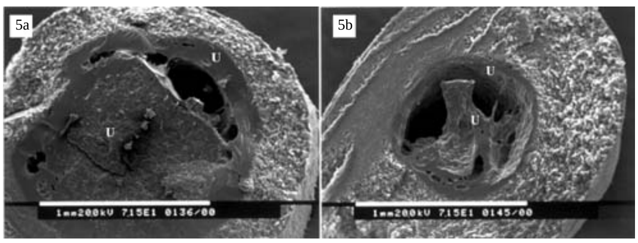
Unswollen starch granules can still be found inside the durum wheat "starch pasta" and pasta after 5 minutes of cooking. Cross sections of pasta (Figure 4b) and starch pasta (Figure 5a) showed that boiling water was prevented by the barrier of gelatinized starch 5 minutes of heating. All cooked pasta and "starch pasta" have similar honeycomb-like structures in the cross sections after 20 minutes of cooking (Figure 6). This honeycomb-like structure is formed from the gelatinized starch; however, coagulated protein cannot be identified in the SEM samples (Figure 6). Although durum wheat "starch pasta" appeared translucent after 20 minutes of cooking, its central core was still not yet completely gelatinized (Figure 7a). This may have been due to the barrier of gelatinized starch that prevented the entry of water into the central part of the starch pasta. Figure 7b also shows the starch particles in the central core after 20 minutes of cooking of the durum wheat pasta. Continuous gluten network protein prevented the heating into the core of pasta being better than gelatinized starch alone. All "starch pasta" and pasta have a uncooked core, even after the optimum cooking time of 20 minutes. Dexter *et al*. [7] also reported finding small uncooked central cores even after 10 minutes beyond optimum the cooking time (12 minutes additional). Following observations after cooking for 13 minutes (al dente' time) Cunin *et al*. [5] also indicated a limited degree of gelatinization with the protein network in the center of the strand still being continuous and dense. These researchers assumed that the intermediate zone might have acted as a barrier to the diffusion of amylose out of the granule during implosion [5].

The surfaces of the durum wheat, hard wheat and soft wheat "starch pasta" and pasta have many pores (Figure 8) after 20 minutes of cooking. The surface of the hard wheat "starch pasta" was small porous. Various wheat pastas had some similar structures at their surface after 20 minutes of cooking, as shown in Figure 8. Some gelatinized starch of cooked durum wheat pasta was leached into the water after 20 minutes heating and was seen on the surface (Figure 8). The honeycomb-like structure was invisible on the surface of cooked pasta made from various flours after 20 minutes of cooking. This phenomenon might prove that the honeycomb-like structure is not a product of the freeze dried method.



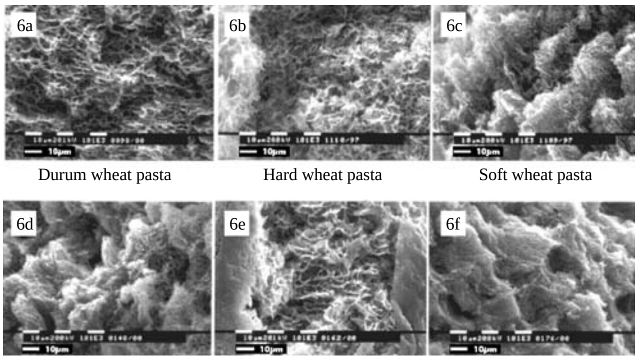
Core part of cross section — Outer surface part of cross section

Fig. 4. Continuous change in the framwork of 5 minutes cooked pasta from the outer surface toward the core. s) starch; g) gelatinized starch.



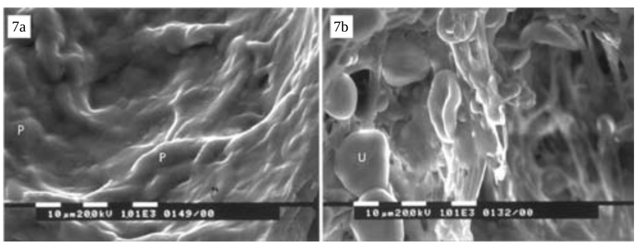
5 minutes cooking — 20 minutes coking

Fig. 5. Cross sections of cooked starch pasta. U) Ungelatinized region.



Durum wheat "starch pasta" — Hard wheat "starch pasta" — Soft wheat "starch pasta"

Fig. 6. Cross sections of 20 minutes cooked samples prepared by freeze dried method.



Uncooked part of starch pasta — Uncooked part of pasta

Fig. 7. Ungelatinized starch in proportion of cooked pasta and starch pasta after 20 minutes heated treatment. P) Partial gelatinized starch; U) Ungelatinized starch.

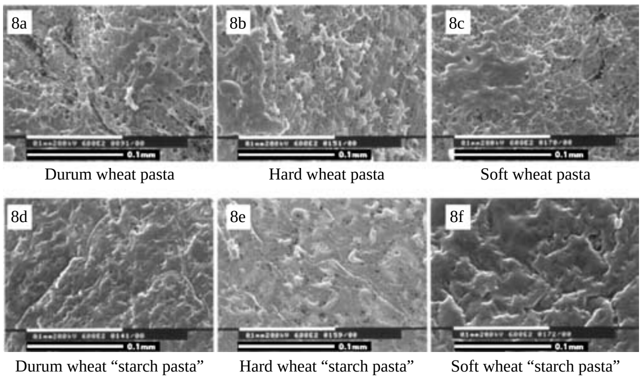


Fig. 8. Surfaces of 20 minutes cooked pasta and starch pasta.

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