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THE INFLUENCE OF INGREDIENTS AND PROCESSING VARIABLES ON THE QUALITY AND MICROSTRUCTURE OF HOKKIEN, CANTONESE AND INSTANT NOODLES

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Abstract

Light and scanning electron microscopy have been used as a part of a research program designed to study the influence of flour quality and processing variables on three of the noodle types that are popular in South East Asia. The noodles selected for study were Cantonese, Hokkien and modern instant. They represent the range of cooking and processing variables that are commonly encountered in these products. Flour particle size and the choice of alkaline ingredients influence protein development during the sheeting process. A continuous protein matrix is required in the raw noodle if it is to have good eating quality when cooked. The swelling of the starch granules during cooking disrupts the protein matrix and the extent of this disruption at the surface of the noodle is related to surface stickiness and cooking loss.

Introduction

Noodles form an important part of the diet in many of the countries of South East Asia, China and Japan. Hence, much of the wheat that is produced in the major exporting countries is used to produce flour for noodle manufacture. However, there has been relatively little published on the factors influencing noodle quality, and even less published on the microstructure of noodles. The situation is further complicated by the fact that there are a number of different kinds of noodles, each with different production requirements and quality attributes. The three types of noodles that are considered in this paper are: Cantonese noodles which are sold uncooked; Hokkien noodles which are sold partially cooked; and modern instant noodles which are steamed and fried before sale.

There are certain similarities between the microstructure of some noodles and pasta, due in part to the similarities of low dough moisture and cooking methods. Resmini and Pagani (20) have published a detailed review of the microstructure of pasta which contains an extensive bibliography. Oh et al. (15-19) have published several papers on Japanese noodles, some of which used scanning electron microscopy (SEM) techniques to elucidate the nature of various processing changes. Dexter et al. (4) have also used SEM to study the microstructure of Japanese noodles made from soft and durum wheat flours. Endo et al. (5) used SEM to study the effect of maturation on Chinese noodle quality. There do not appear to be any papers published relating microstructure to quality aspects of modern instant noodles.

Microscopy has been used, together with other techniques, in the noodle research program conducted at the Bread Research Institute of Australia and this paper attempts to relate the microstructure of Cantonese, Hokkien and modern instant noodles to processing and quality parameters.

Key Words: Cantonese noodles, Hokkien noodles, Instant noodles, Kan swi, alkaline ingredients, noodle processing, flour quality, cryosections, light microscopy, scanning electron microscopy.
on eating quality

Table 1

| Particle Damage | High Starch and a portion remilled to increase the level of protein were also used for certain trials as indicated in the text. Flours were analysed for protein content and diastatic activity by standard methods.

Noodle Preparation

There are slight differences in the formulation and processing techniques used to produce the three different kinds of noodles, and these are summarised in Tables 2 and 3. However, basically noodle doughs consisting of flour, alkaline salts (kan swi) or common salt and water (Table 2) were mixed in a Hobart N50 mixer as previously described (10). The crumbly mix was transferred to an Otake noodle machine and compressed four times, with various folds, into a coherent sheet (Table 3). The sheet was rested and then reduced in thickness by passage three times between the rollers at successively decreasing clearance. The dough was then cut into strips by passage between the cutting rolls. Instant noodles were formed into a wave pattern at this stage by the addition of a pair of rubber plates beneath the cutters.

Table 2 Noodle Formulae

<table>
<thead>
<tr>
<th>Cantonese</th>
<th>Hokkien</th>
<th>Instant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flour (%)</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Water (%)</td>
<td>32</td>
<td>32</td>
</tr>
<tr>
<td>Kan swi</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

Table 3 Noodle Processing Variables

<table>
<thead>
<tr>
<th>Cantone Se</th>
<th>Hokkien</th>
<th>Instant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compression stage</td>
<td>3(1)</td>
<td>3(1)</td>
</tr>
<tr>
<td>Rest time</td>
<td>30 min</td>
<td>0 min</td>
</tr>
<tr>
<td>Reduction stage</td>
<td>2.2</td>
<td>0.95</td>
</tr>
<tr>
<td>Final dough sheet thickness</td>
<td>1.5</td>
<td>2.0</td>
</tr>
<tr>
<td>Cut noodle size (mm)</td>
<td>1.5 x 1.5</td>
<td>2.0 x 2.5</td>
</tr>
</tbody>
</table>

(1) Roller gap in mm and numbers of folds in parenthesis.  

Noodle Cooking

All noodles were stored in plastic bags at 22°C prior to cooking. Cantonese noodles (10) were cooked on the day of preparation by immersion in boiling water until the uncooked core had just disappeared (Table 4). Hokkien noodles (11) were pre-cooked in boiling water for 40 sec on the day of preparation. They were then oiled and on the following day they were fully cooked by boiling for 2.5 min. Instant noodles were steamed for 1 min at 55 kilopascals followed by frying in palm oil at 150°C for 45 sec. Instant noodles were sealed in a plastic bag and stored at 22°C for one month before organoleptic evaluation.

Table 4 Cantonese Noodles

| Optimum Cooking
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Flour Protein (%)</td>
<td>Time (Min)</td>
<td>Eating Quality</td>
</tr>
<tr>
<td>9.0</td>
<td>4.0</td>
<td>Soft</td>
</tr>
<tr>
<td>12.0</td>
<td>4.25</td>
<td>Firm</td>
</tr>
<tr>
<td>18.7</td>
<td>4.75</td>
<td>Rubbery</td>
</tr>
</tbody>
</table>

Noodle Evaluation

Noodle eating quality was determined by the method of Miskelly and Moss (10). Stickiness was subjectively assessed by a trained taste panel and its presence was identified by the noodles sticking to the teeth during mastication or by stickiness during handling. Noodle pH was determined by the method of Moss et al (12). Cooking loss was determined by evaporating an aliquot (70ml) of cooking water to dryness in a tared pyrex dish. The dish plus residue was then weighed, the residue ashed at 600°C for 1 h and then weighed. Cooking loss was the amount of organic material removed during ashing and was expressed as mg dry matter per 100g raw noodles. Cooking water pH was measured on a separate aliquot of cooking water.
Noodle quality and microstructure

Microscopy
The samples were prepared for light microscopy (LM) as previously described (15) and stained for protein (8, 16), starch (6), fat (7), and bran (9) or germ (9). In the case of cooked products, the samples were prepared for sectioning by rapidly freezing in iso-pentane, cooled by liquid nitrogen to just above the freezing point of the iso-pentane. Some sections of these samples were allowed to dry in the cryostat and examined, unstained and mounted in a synthetic resin (Eukitt, Carl Zeiss, West Germany) using either polarised light or phase-contrast microscopy. This was done to avoid any further swelling of the gelatinised or partially gelatinised starch granules due to contact with aqueous solutions. Samples for scanning electron microscopy were rapidly frozen in a similar manner, freeze-dried and prepared for examination in a Cambridge S600 SEM as previously described (15).

Results and Discussion
Noodle Doughs
The same general microstructural changes took place for all types of noodle doughs during processing, but the rate of development of the dough was influenced by such factors as flour quality, other ingredients and the processing variables selected for each product.

In all types of noodle doughs there is very little gluten development in the mixing stage, which is in contrast to bread dough. In the latter the protein is pulled away from the starch granules in the early stages of mixing to form a coarse, discontinuous network (Fig. 1). Further mixing is then required to develop the desired fine continuous network. In noodle doughs the protein does not pull away from the starch granules during mixing and the microstructure resembles that of compacted flour, with many endosperm particles being clearly discernible (Fig. 2). This is due to the low moisture content of noodle doughs (31-32%) and is characteristic of such products as pasta, in addition to noodles.

In noodle manufacture, the main aims of mixing are, therefore, to uniformly distribute ingredients and to hydrate the flour particles. Dough development is carried out by passage through rollers.

After mixing, all noodle doughs are then compressed into a continuous sheet by repeated passage through pairs of rollers. Examination of dough microstructure during this process indicates that adjacent endosperm particles become "fused" together so that the protein matrix within one endosperm particle becomes continuous with that of adjacent particles. There is much less protein orientation in noodle doughs than in bread doughs that are passed through rollers. Only a few, sub-aleurone, protein masses show orientation in noodle doughs. At the end of the compression stage the visual appearance of the dough sheet looks quite uniform, but microstructurally, fusion of endosperm particles is not complete. The outline of partially fused endosperm particles is still clearly recognisable (Fig. 3).

The reduction stage which follows further develops the gluten. To obtain the best quality

Legend to Figures.
All light micrographs are transverse sections. In colour micrographs of sections stained with periodic acid Schiff reagent (PAS)/Fast green the starch is stained magenta and the protein blue-green.

E - edge of noodle;
EP - endosperm particle;
GS - grossly swollen starch granules;
M - protein mass;
P - protein;
S - starch.

Fig. 1. Light micrograph of a section of bread dough during the early stages of mixing. Note the isolated protein masses formed by the pulling away of the protein from the flour endosperm particles. Stain Ponceau 2R. Bar = 70 μm.

Fig. 2. Light micrograph of a Hokkien noodle dough at the end of mixing. The protein has not pulled away from the starch in the endosperm masses. Stain Ponceau 2R. Bar = 70 μm.

Fig. 3. Light micrograph of a Hokkien noodle dough at the end of the compression stage. Dough development is not complete as the outline of some of the endosperm particles is still clearly recognisable. Stain Ponceau 2R. Bar = 70 μm.
noodles, an extremely uniform protein matrix must be obtained, with no traces of endosperm particles being discernible. However, the upper and lower surfaces of the noodle sheet have a slightly less continuous protein matrix than that seen in the centre of the noodle. After the final reduction stage the noodles are cut, but this does not have any appreciable effect on the microstructure.

Cooked Noodles

The cooking process varies considerably for the 3 types of noodle under consideration. It is therefore difficult to generalise details of microstructural changes and more specific information will be given later. However, in boiled noodles softness is related either to the occurrence of voids in the noodle or the presence of highly swollen starch granules. It has been reported (5) that in Chinese noodles a 24 h maturation period prior to cooking improves eating quality and produces voids in the noodle. However, the improvement may be due to the effect of other factors that play a role during the maturation, rather than the production of voids per se. Surface stickiness is related to a breakdown of the protein matrix at the surface and to a wide outer core of grossly swollen starch granules. Cooking loss is also usually related to surface stickiness, as the disruption of the protein matrix at the periphery of the noodle allows particles to become detached from the bulk of the noodles due to the vigorous action of the boiling water.

Hokkien Noodles

General

All Hokkien noodles were prepared from the commercially milled flour of 11.0% protein content. Some of the major changes that take place during cooking can be illustrated considering the case of Hokkien noodles. After only 20 sec immersion in boiling water all the starch had started to swell and lose some birefringence (compare Fig. 4A, 4B, & 5). There was an outer zone of total gelatinisation that was 400 µm wide. The grossly swollen starch in this zone was held in place by a diffuse protein matrix and also probably by starch molecules that had leached out of the gelatinised starch granules (Fig. 5). The starch in the central region of the noodle had also started to swell and lose some birefringence (Fig. 4B). The protein was still quite compact and there were some very small voids (20-50 µm wide). Pre-cooking for an additional 20 or 40 sec caused only a slight increase in width of the outer zone (max. width 600 µm) but internally, with longer cooking, the starch granule swelling was more apparent and the number and size of the voids increased (max. diameter 100 µm). In the final cooking stage the pre-cooked noodles were reheated in boiling water until there was no longer a white core in the centre of the noodle. In the case of the 40 sec pre-cooked noodle this occurred after 2.5 min cooking. However, after 1 min of final cooking there was only the slightest trace of birefringence in the centre of the noodle. Yet, the noodle still looked opaque, presumably due to the limited swelling and water uptake of the starch. There was only a very gradual transition in the appearance of the starch from the edge to the centre of the noodle. After 2.5 min final cooking there were no birefringent starch granules in the centre of the noodle, but an increase in size of the starch granules was not apparent. At the outer edge of the noodle, the surface was

Fig. 4a. Light micrograph of the centre of an uncooked Hokkien noodle, taken with polarised light and a 1/4 wave plate. Note the majority of the starch granules are strongly birefringent. Stain Ponceau 2R. Bar = 70 µm.

Fig. 4b. Light micrograph of the centre of a 20 sec pre-cooked Hokkien noodle, taken with polarised light and a 1/4 wave plate. Note that small voids have been formed (arrows) and that all the starch granules have started to lose some birefringence indicating that they are starting to gelatinise. Stain Ponceau 2R. Bar = 70 µm.

Fig. 5. Light micrograph of the edge of a 20 sec pre-cooked Hokkien noodle, taken with polarised light and a 1/4 wave plate. Note the non-birefringent, grossly swollen starch granules at the edge of the noodle and the diffuse protein matrix. This zone is approximately 400 µm wide, and the more central starch granules still show some degree of birefringence. Stain Ponceau 2R. Bar = 70 µm.

Fig. 6. Light micrograph of a Hokkien noodle (40 sec pre-cook) cooked for 2.5 min (optimum). Although the swollen starch granules in the outer zone have partially disrupted the protein matrix, the outer edge of the section is smooth. Stain PAS/Fast green. Bar = 60 µm.

Fig. 7. Light micrograph of a Hokkien noodle (40 sec pre-cook) cooked for 4.0 min (overcooked). Note the extensive disruption of the noodle surface due to the vigorous action of the boiling water and the excessive swelling of the starch granules. Stain PAS/Fast green. Bar = 60 µm.

Fig. 8. Light micrograph of a Cantonese noodle made from the high protein (18.7%) flour. Note the thicker, more intensely stained protein matrix and the trapped air cells. Stain PAS/Fast green. Bar = 60 µm.

Fig. 11. Light micrograph of a Cantonese noodle, after the compression stage, made from the flour of coarse particle size (265-355 µm). Stain PAS/Fast Green. Bar = 60 µm.

Fig. 12. Light micrograph of a Cantonese noodle, after the compression stage, made from the flour of fine particle size (<85 µm). Stain PAS/Fast Green. Bar = 60 µm.

Fig. 18. Light micrograph of an Instant noodle, made from the 9.0% protein flour, after the frying process. There is no layer of fat at the surface of the noodle, and the fat is distributed uniformly throughout in the form of coarse globules which are stained red. Stain Sudan IV/Oil Red 0. Bar = 50 µm.
relatively smooth and not showing any sign of disruption (Fig. 61). The swelling of the starch, however, had stretched and partially disrupted the protein matrix in the outer zone. In the centre of the noodle the protein matrix was still continuous. After 4 min final cooking there was extensive disruption of the noodle surface due to excessive swelling of the starch granules (Fig. 71).

Effect of cooking water pH

Transverse sections of pre-cooked noodles containing either sodium hydroxide or kan swi were examined using phase contrast and polarisation microscopy. Cooking details and final pH of the pre-cooking water are given in Table 5.

Table 5 Hokkien Noodles

<table>
<thead>
<tr>
<th>Alkali</th>
<th>Pre-Cooking Water Initial pH</th>
<th>Final pH</th>
<th>Cooking Loss (g dry matter/100g raw noodles) Initial Final</th>
</tr>
</thead>
<tbody>
<tr>
<td>1% NaOH</td>
<td>8.5</td>
<td>11.0</td>
<td>2.67                                                   3.00</td>
</tr>
<tr>
<td>1% Kan swi</td>
<td>8.8</td>
<td>9.5</td>
<td>2.62                                                   2.70</td>
</tr>
</tbody>
</table>

It was apparent that both the size and general appearance of the central core was not influenced by the increase in pH of the pre-cooking water. However, the overall cross-sectional area of the partly cooked noodles increased with alkali build-up, being greatest in the case of sodium hydroxide, which was probably due to the higher pH of the latter. Thus it is only the periphery of the noodles that is affected by the build-up of alkali in the pre-cooking water. The more extensive swelling in the outer region of the noodle is associated with increased cooking loss (Table 5) and stickiness of the partly cooked noodle. The latter can be a problem in high volume, automated noodle plants if the flow of fresh water into the cooking bath is not adequate.

Cantonese Noodles

Effect of flour protein content

The three experimentally milled flours, of protein content 9.0%, 12.0% and 18.7% were chosen for this study. In all three samples the protein network in the raw, cut noodle strings surrounded all the starch. However, sections of the low protein noodles were more fragile than those from the other two samples, indicating that the protein network in the former was weaker. The protein matrix in the 18.7% protein noodles was noticeably thicker than that of the other two samples, and more air was trapped in the dough when compared to the other two samples (Fig. 8). In transverse sections all doughs showed disruption of the starch-protein matrix at the edge of the section, but the high protein sample showed the least contraction, suggesting that the protein matrix is more robust.

On cooking to optimum time (Table 4), the low protein sample had the smallest outer zone of gelatinization (300-400 μm wide) due to the shorter cooking time. However within this zone there was considerable surface disruption, due to the weaker protein network (Fig. 9). The starch granules in the central region of the noodle displayed a greater overall degree of swelling than was seen in the other two samples. The more extensive swelling was confirmed by the extremely pale colour of the starch granules when stained using the PAS reaction. The medium and high protein samples had similar, slightly wider outer zones of gelatinization (400-500 μm). The medium protein sample had a smooth outer surface indicating that the protein network was better able to hold the structure together (Fig. 10).

Fig. 9, Light micrograph of an optimally cooked (4.0 min.) Cantonese noodle made from the low protein (9.0%) flour. There has been considerable surface disruption due to the weaker protein network. Stain Ponceau 2R. Bar = 70 μm.

Fig. 10, Light micrograph of an optimally cooked (4.25 min.) Cantonese noodle made from the medium protein (12.0%) flour. There has been relatively little surface disruption due to the stronger protein network. Stain Ponceau 2R. Bar = 70 μm.

However, the high protein sample showed surface disruption equivalent to that of the low protein sample. This is partly due to the increased cooking time, but could also indicate some abnormality in the protein, since the protein content of the original wheat was abnormally high (19.6%). The eating quality of the noodles is shown in Table 4 and the differences in texture would appear to be related more to the protein network than the starch as the low protein sample had a larger central zone of less swollen starch than the other two samples. Cooking always
created voids in the central zone of the noodles, but for good, firm eating quality, the voids should be small (<50 μm diam). The voids are predominantly created by forces imparted by the expanding, gelatinizing starch partially disrupting the structure. The more substantial protein matrix of the high protein sample was responsible for the rubbery texture and slowed down water penetration to such an extent that surface breakdown occurred if the centre of the noodle was to be adequately cooked.

When the three samples were cooked to the optimum time established for the high protein sample, the major difference was in the appearance of the starch in the centre of the noodle. The starch in the low protein sample was more swollen and less intensely stained by the PAS reaction than that in the other two samples, suggesting that the protein matrix in the low protein sample had allowed the water to penetrate into the noodle more rapidly and thus allowed the starch to absorb more water. In the centre of the other two samples the appearance of the starch was similar, being more intensely stained by the PAS reaction. This conflict in cooking requirements at the high protein content meant that the flour was “out of balance” in terms of optimising quality. The protein matrix should be such that it allows the water to penetrate into the noodle so that the central starch granules are optimally gelatinised before surface breakdown occurs. However, the matrix must be sufficiently strong to hold the noodle together. The best “balance” was shown by the medium protein noodle.

Effect of flour particle size and starch damage on noodle quality.

The microstructure of dough sheets made from flours of different particle size and starch damage (Table 1) was examined after the compression and reduction stages of processing. After the compression stage it was apparent that the larger the particle size, the slower was the rate of gluten development and fusion of endosperm particles (compare Figs. 11 and 12). However, the dough microstructure of the extremely fine, high starch damage sample was not as uniform as either the <85 μm or the 85-180 μm sample. This suggests that the extra milling had altered the properties of the gluten as well as the starch. It was also interesting to note that the high starch damage sample did not require any more water than the other samples. This again emphasises the different nature of gluten development of noodles compared to bread doughs. However Oh et al. [18] found that an increase in starch damage did increase water absorption of Japanese dried noodles. This anomaly may be due to different ingredients or processing techniques.

After the final reduction pass the microstructure of both the <85μm and the 85-180 μm samples was identical and totally uniform. The 2 coarser samples had progressively less uniform microstructure and this indicates that in noodle doughs, for optimum gluten development the flour should be of relatively fine particle size, but below 180 μm particle size is not critical. The rollers used in noodle processing are therefore not as effective as a pasta press in developing the protein present in coarse endosperm particles.

The protein structure in the high starch damage sample is more uniform than the two coarser samples, but less uniform than the two finer samples. These differences in gluten development are reflected in terms of both eating quality and cooking loss (Table 1). Oh et al. [18] reported that decreasing particle size did not increase the firmness of cooked noodles, but they used pin-milled flour of fine particle size. The very poor eating quality and large cooking loss of the high starch damage sample would be mainly due to the starch damage, rather than the slightly impaired protein development. It would also appear that the high starch damage had slowed the rate of water penetration into the noodle, as indicated by the long cooking time.

Effect of alkali.

The effect of alkali on the quality of Cantonese noodles was examined using the commercially milled flour of 12.5% protein. Alkali (sodium hydroxide or kan swi) is an essential ingredient in Cantonese noodles and the effect of alkali on gluten development and quality of noodles has been discussed elsewhere in relation to Hokkien noodles [11]. Cantonese noodles showed a similar trend in the dough stages. Sodium hydroxide slowed down the rate of gluten development when compared to equivalent doughs containing either kan swi or sodium chloride. This effect was particularly noticeable at the upper and lower surfaces of the dough sheet. Even after the final reduction pass, the protein matrix in the sodium hydroxide noodle was not uniform and traces of endosperm particles could be discerned. However, the most obvious differences between the three samples after the final reduction stage were: firstly, that there were more voids in the sodium hydroxide dough sheet, and secondly, that the discontinuity of the protein matrix at the upper and lower surfaces of the noodle sheet was more apparent in the presence of sodium hydroxide.

The high pH of the sodium hydroxide noodle (pH 11.5) did not alter the microscopic appearance of the majority of the starch granules, probably because of the low moisture content of noodle doughs.

| Table 6 Cantonese Noodles Effect of alkali on optimum cooking time and cooking loss. |
|-----------------|-----------------|-----------------|-----------------|
| Treatment      | Optimum cooking time (min) | Cooking Loss (g dry matter/100g raw product) |
| 1% NaCl        | 4.5             | 5.32            |
| 1% Kan swi     | 5.5             | 7.45            |
| 1% NaOH        | 6.0             | 13.43           |

After cooking (Table 6), the voids were more plentiful in the sodium hydroxide noodle, partly due to the lack of continuity seen in the dough sheet. However, the toughening of the gluten in the dough by the sodium hydroxide, may have prevented the gluten from expanding during cooking, thus increasing the lack of continuity.
The noodles containing either kan swi or sodium chloride had a more delicate, continuous protein matrix, but this was always slightly more disrupted. This could be related to the firmer "bite" associated with the use of kan swi.

After optimum cooking, the starch granules in the centre of the sodium hydroxide noodles were more swollen than those in the other two samples. The surface continuity of the sodium hydroxide noodles was also less than that of the other two samples. The combination of more voids, greater swelling of the starch in the central zone, and more surface disruption resulted in the sodium hydroxide noodle having softer eating quality and surface stickiness. This could be due in part to the longer cooking time required by the sodium hydroxide noodles.

To gain a better understanding of the role of alkali during cooking, samples of sodium hydroxide and kan swi noodles were taken at intervals during the cooking process. It was apparent that the voids present at the dough stage in the sodium hydroxide noodle enlarged as the cooking proceeded, but did not appear to increase in number during cooking. In the sodium hydroxide noodles the size of the central core of less swollen starch granules was larger than that of the kan swi noodle at equivalent cooking times. This suggests that the water penetrates more slowly into the sodium hydroxide noodle, despite the lack of continuity of the protein matrix.

The increase in cooking time required to eliminate the uncooked core in the centre of the noodles meant that the outer surface of the noodle was subjected to the action of the boiling water for too long and it failed to maintain its integrity.

Effect of resting prior to reduction stage

Traditionally the noodle sheet is allowed to rest between the compression and reduction stages. This produces a smoother dough sheet and results in firmer eating noodles. However, a large number of Cantonese noodles are now produced in a continuous process with no provision for a rest period. Hence it was decided to compare the microstructure of noodles produced from both systems using the commercially milled 12.5% protein flour.

After the first reduction pass, the sample that had been rested had a more uniform protein matrix as the endosperm masses had started to fuse together more effectively. As a consequence, the rested sample also had fewer air spaces. The protein contraction at the upper and lower surfaces of the rested noodle sheet was also less than that in the unrested sample (compare Figs. 13 & 14). All these observations indicate that the protein becomes more extensible after resting. Further reduction passes lessened these differences in microstructure, but they were still apparent in the cut noodle strings.

There was no difference in cooking requirement between the two treatments, and after cooking, the internal appearance of both noodles was very similar. However there was a difference in the width and appearance of upper and lower outer zones of the noodles. In the non-rested sample the outer zone was wider (500 µm) and more clearly defined due to the gross swelling of the starch granules. This gross swelling had been allowed to take place because of the increased protein contraction seen in this zone of the raw noodles. In the cooked rested noodle the outer zone was narrower (200-300 µm) and there was a more gradual transition from the gross swelling seen at the surface to the more limited swelling in the central region. The improved eating quality which resulted from resting the noodles after the compression stage was thus due to the presence of a more continuous protein matrix in the raw, cut noodle string. Internally, the changes in microstructure that occurred due to cooking obscure these subtle differences, but at the outer surface they were magnified.

Instant Noodles

Instant (steamed and fried) noodles were made from the three flours of differing protein content (9.0%, 12.0% and 18.7%) and the structural differences at the dough stage were similar to those reported previously for Cantonese noodles.

After steaming, the proteins were fully gelatinised, but even the 9.0% protein noodle had no appreciable surface disruption and the starch granules had not ruptured or fused together (Fig. 15). This is in contrast to the cooking behaviour of the same flour when used for the production of Cantonese noodles. The lack of surface disruption was presumably due to the reduced water uptake during the steaming process compared to being placed in boiling water (the yield after steaming was 110%, compared to over 200% for the corresponding (Cantonese noodles). The surface continuity of the 9.0% noodle was such that it was able to form large bubbles on the surface (Fig. 16). There were fewer such bubbles on the surface of the 12.0% protein noodle and none on the surface of the 18.7% noodle.

SEM examination showed that during frying, large voids were created inside all the noodles, but the internal structure of the low protein noodle was more uniformly open (Fig. 17). As the protein content increased, the voids became larger and the porosity less uniform. However, the use of aqueous reagents that are essential to the LM technique resulted in an expansion of the matrix and a marked reduction in the size of the voids. The surface of the low protein noodle showed some slight disruption after frying but this disruption decreased as the protein content increased. The shape of the starch granules was still much more clearly discernible than in boiled noodles, due to the low water content of the steamed instant noodles.

Fat up-take during frying is an important factor, as high up-take increases the cost of the finished product and may adversely affect shelf life. In the low protein noodle the fat was distributed as coarse globules and had penetrated uniformly throughout the noodle (Fig. 18). In the high protein noodle there was much less fat uptake, some areas had virtually no fat and there was less fat in the centre of the noodle. However the intermediate protein noodle had a similar fat up-take to the low-protein noodle. Thus protein content is not the sole factor influencing fat up-take. It was also surprising to observe that
Fig. 13. Light micrograph of a Cantonese noodle after the first reduction pass. This sample has been rested for 30 min. after the compression stage. There is very little contraction of the darkly stained protein network at the surface of the noodle sheet. Stain Ponceau 2R. Bar = 70 μm.

Fig. 14. Light micrograph of a Cantonese noodle after the first reduction pass. This sample has not been rested for 30 min. after the compression stage. There is some contraction of the protein network at the surface of the noodle sheet. Stain Ponceau 2R. Bar = 70 μm.

Fig. 15. SEM of the surface of an Instant noodle, made from the 9.0% protein flour, after the steaming process. The starch granules have not ruptured and fused together. Bar = 40 μm.

Fig. 16. SEM of a fracture surface of an Instant noodle, made from the 9.0% protein flour, after the frying process. The large blister on the surface was formed during steaming, and the internal voids were formed by steam generation during frying. Bar = 400 μm.

Fig. 17. SEM of a fracture surface of an Instant noodle, made from the 9.0% protein flour, before final cooking. Note the internal voids formed during frying. Bar = 100 μm.

Fig. 19. SEM of a fracture surface of an Instant noodle, made from the 9.0% protein flour, after final cooking. The internal voids seen in the sample examined after frying have disappeared due to swelling of the starch granules on boiling. Bar = 100 μm.
Noodle quality and microstructure

There was no localised concentration of fat at the outer surface of the noodles. When the noodles were re-cooked there was an increase in the area of the sections (32%) due to imbibition of water, but the most obvious change was in the condition of the voids. The starch-protein matrix had swollen to such an extent that the voids had virtually disappeared when examined using SEM (compare Figs. 17 and 19). However, light micrographs indicated that the internal cell walls that separated the voids had not fully fused together after the final cooking. The lipid in the central region appeared to have migrated from the body of the starch-protein matrix to line the walls of the former voids. However, the amount of lipid in this region was similar to that seen after frying, but the outer zone (250 μm wide) was relatively free from lipid, presumably due to migration into the cooking water.

The sponge-like structure of the noodles after frying would be expected to facilitate water penetration and assist rapid reconstitution of the noodles in the final cooking process. However, if large voids remained in the noodles after reconstitution they would have an adverse effect on texture.

Conclusion

The eating quality of boiled noodles is influenced by the continuity of the protein matrix, the degree of starch swelling and the extent of surface disruption. Modern instant noodle quality is also influenced by these factors and by the formation of voids created by steam generation during the frying process. Microscopy provides a useful way of studying the manner in which ingredients and processing variables influence these quality parameters.

Acknowledgments

The authors wish to thank Miss S. Stiles for assistance with the SEM, and the Fuel Geoscience Unit of the Institute of Earth Resources, CSIRO, for the use of the SEM.

References


Discussions with Reviewers

D.D. Christianson: Could the authors elaborate on the production of the void spaces in noodles? Do the gliadin and glutenin contents influence void formation?

Authors: The gliadin and glutenin contents of the flours used in these trials were not measured and although this factor is known to influence extensibility in bread doughs it is not certain whether it plays the same role in noodle doughs where the moisture content is much lower. The protein does not necessarily have to be extensible to form a continuous matrix in noodle doughs as the matrix is formed by the fusion of the matrices already existing in the flour particles. However, on cooking, the expansion of the starch granules as they gelatinise puts a strain on the protein network. Voids are created when the protein network is torn apart at its weakest points by these forces.

D.D. Christianson: Does some chemical gelatinisation of the starch take place in the alkaline media? Barriers that reduce water penetration in NaOH noodles could be solubilised starch and/or degraded protein.

Authors: In isolated cases, some sections taken from sodium hydroxide doughs in the early stages of sheeting did occasionally contain streaks where the starch granules appeared to have suffered some chemical gelatinisation. However this fact was not emphasised in the text as it was not always observed. It would seem most likely that any chemically gelatinised starch would have arisen from the initial contact of the starch with the highly alkaline water at the start of the mixing.

P.A. Seib: In the Chinese style noodles, how does one determine the optimum moisture and alkaline agents to use?

Authors: For most trials water addition was not "optimised" but rather added at a standard level as determined through surveys carried out by the Bread Research Institute of noodle manufacturers and flour millers in the southeast Asian region. The type and amount of "kan swi" was also determined in this manner. Additional trials were carried out with the high starch damage flour to see if it required any extra water. However an additional 0.5% water caused the dough to become sticky and difficult to handle during sheeting.

R.R. Matsuo: Could the authors indicate whether the flours used for the trials were considered to be strong, medium or weak in terms of Farinograph characteristics?

Authors: The three Buhler milled flours of 9.0, 12.0 and 18.7% protein were milled from the hard grained, medium strength, Australian wheat variety Osprey. However, as descriptive interpretations of strength can be misleading, the authors have included Farinograph and Extensograph data for the three flours (Table 7).

Table 7

<table>
<thead>
<tr>
<th>Flour Pr (%)</th>
<th>Farinograph</th>
<th>Extensograph</th>
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<tbody>
<tr>
<td></td>
<td>Water Abs</td>
<td>Dev. Time</td>
</tr>
<tr>
<td></td>
<td>(%)</td>
<td>(min)</td>
</tr>
<tr>
<td>9.0</td>
<td>63.0</td>
<td>3.1</td>
</tr>
<tr>
<td>12.0</td>
<td>63.6</td>
<td>4.5</td>
</tr>
<tr>
<td>18.7</td>
<td>70.1</td>
<td>8.4</td>
</tr>
</tbody>
</table>

R.R. Matsuo: It is surprising that stickiness is noted in Hokkien noodles where the surface is coated with oil. Do the authors have a method for assessing surface stickiness?

Authors: As the reviewer has indicated, stickiness can be overcome in Hokkien noodle manufacture by the addition of oil. The stickiness referred to by the authors was observed in the un-oiled noodles. However application of extra oil to overcome excess stickiness imposes a cost penalty on the manufacturer. The authors are currently evaluating two objective methods of measuring stickiness (2,3) but our estimates of stickiness in this work were subjective, being either stickiness as observed during mastication or handling.

R.R. Matsuo: The authors state that the less uniform microstructure of the high starch damage sample suggests that the extra milling had altered the properties of the gluten as well as the starch. Is it not possible that differences noted may be due to the preferential water uptake by damaged starch rather than a change in gluten properties?

Authors: The authors wished to emphasise that both factors are important and did not intend to imply that starch damage was not an important factor. However the gluten damage which can occur as a consequence of the deliberate creation of starch damage in roller milling is often overlooked, and this can also influence dough properties as discussed elsewhere (13).