Oriental noodles

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Gary Hou
Wheat Marketing Center

ORIENTAL NOODLES

GUOQUAN HOU

Wheat Marketing Center, Inc.
1200 NW Naito Parkway, Suite 230,
Portland, OR 97209, USA

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ABSTRACT

Oriental noodles have been consumed for thousands of years and remain an important part in the diet of many Asians. There is a wide variety of noodles in Asia with many local variations as result of differences in culture, climate, region and a host of other factors. In this article noodle classification, formulation, processing and evaluation are reviewed, with emphasis on eight major types. Wheat quality requirements, basic flour specifications, ingredient functions, and production variables are identified for different noodles. In the evaluation of flour for noodle making, three key quality attributes are considered: processability, noodle color and texture. Noodle process behavior is particularly important in the modern industrial production. Each noodle type has its own unique color and texture characteristics. Flour color, protein content, ash content, yellow pigment and polyphenol oxidase activity are important factors responsible for noodle color. Starch characteristics, protein content and quality play major roles in governing the texture of cooked noodles. However, the relative importance of starch and proteins varies considerably with noodle type. Starch pasting quality is the primary trait determining the eating quality of Japanese and Korean noodles that are characterized by soft and elastic texture, while protein quantity and strength are very important to Chinese-type noodles that require firm bite and chewy texture. Other factors such as ingredients added in the noodle formula and processing variables used during noodle preparation also affect the cooked noodle texture as well.

I. INTRODUCTION

Oriental noodles are one of the oldest forms of processed foods consumed in Asia. For thousands of years, noodles have been considered as a major dietary component of many Asians. The history of noodles can be dated back at least to the Han Dynasty (206 BC–220 AD) in China. In the Eastern Han Dynasty (25–220 AD), Chinese noodles were introduced to Japan by the Japanese envoy to China. Gradually, noodles were spread from China to other Asian countries and beyond. During the 13th century, Marco Polo brought the Chinese noodle-making technology back to Europe, where noodles were evolved into current pasta products. Although oriental noodles and pastas look somewhat similar in shape, there are key differences between them in ingredients used, the process involved and their consumption patterns. Noodles are characterized by thin strips slit from a sheeted dough that has been mainly made from wheat (*Triticum aestivum*) flour (hard and soft wheats), water and salt – common salt or alkaline salt. Noodles are often consumed in a water-rich condition, such as soup. In contrast, pastas are usually made from durum (*Triticum durum*) semolina (coarse durum flour) and water, and extruded through a metal die under pressure. They are dried products. After cooking, pastas are often eaten in dishes containing limited water. Eggs can be added to each product to give a firmer texture.

Oriental noodles can be made from a variety of raw materials such as wheat flour, rice flour, buckwheat flour or starches derived from rice, wheat, mung bean, tapioca, sweet potato, sago and corn. In this article, only those noodles made from wheat flour will be reviewed and discussed. Therefore, noodles are hereafter referred to as wheaten noodles. With wheat flour as the main ingredient, noodles have been further diversified into many types based on composition, method of preparation, and presentation depending on regional preference.

Noodles are prepared from a crumbly dough, which is formed by mixing three parts of flour with one part of common salt (sodium chloride) and/or alkaline salt (kan sui, a mixture of sodium and potassium carbonates) solution. The pieces of dough are compressed between a series of rolls to form a dough sheet. A uniform gluten matrix is developed during the sheeting process (Moss *et al.*, 1987), contributing to the noodle texture. The sheeted dough is then slit to yield noodle strands. The noodles are now ready for sale, or are further processed to prolong shelf life, to modify eating characteristics or to facilitate preparation by the consumer. In the preparation of modern instant noodles, the steaming process causes the starch to swell and gelatinize; extra water is removed by hot blast air or by deep-frying in the oil. The addition of alkaline salts in some Chinese-type noodles gives them a yellower color, and a firmer, more elastic texture. The resultant noodles have a unique alkaline flavor, preferable to some people.

II. ORIENTAL NOODLE CLASSIFICATION

There are tremendous varieties of oriental noodles around the world and within a country. These varieties are the results of differences in culture, climate, region and a host of other factors. Table I shows major noodle types produced in each region. No systematic classification or nomenclature has

TABLE I
MAJOR TYPES OF ORIENTAL NOODLES[a]

Region	Noodle type	Type of salt	Marketing condition
China	Instant noodles (bag or cup)	Alkali	Fried, air-dried
	Chinese raw noodles	Sodium chloride	Fresh
	Cantonese noodles	Alkali	Fresh, dry
	Udon noodles	Sodium chloride	Boiled, dry
Indonesia	Instant noodles (bag or cup)	Alkali	Fried, air-dried
	Chinese wet noodles[b]	Alkali	Parboiled
Japan	Chuka-men	Alkali	Fresh, boiled, dry, steamed
	Udon noodles	Sodium chloride	Fresh, boiled, dry, steamed
	Buckwheat noodles (soba)	Sodium chloride	Fresh, dry
	Hira-men, hiya-mugi and so-men	Sodium chloride	Dry
	Instant noodles (bag or cup)	Alkali	Fried, air-dried
Korea	Instant noodles (bag or cup)	Alkali	Fried, air-dried
	Korean dry noodles	Sodium chloride	Dry
	Udon noodles	Sodium chloride	Boiled, fresh
	Buckwheat noodles (soba)	Sodium chloride	Fresh, boiled, dry
Malaysia	Chinese wet noodles[b]	Alkali	Parboiled
	Instant noodles (bag or cup)	Alkali	Fried, air-dried
	Cantonese noodles	Alkali	Fresh, dry
	Steamed and dried noodles	Alkali	Dry
Philippines	Instant noodles (bag or cup)	Alkali	Fried, air-dried
	Chinese wet noodles[b]	Alkali	Parboiled
	Cantonese noodles	Alkali	Dry
	Udon noodles	Sodium chloride	Boiled, fresh
Singapore	Chinese wet noodles[b]	Alkali	Parboiled
	Cantonese	Alkali	Fresh, dry
	Instant noodles	Alkali	Fried, air-dried
Taiwan	Chinese wet noodles[b]	Alkali	Parboiled
	Chinese raw noodles	Sodium chloride	Fresh
	Instant noodles	Alkali	Fried, air-dried
	Cantonese noodles	Alkali	Fresh, dry
	Long life (LL) noodles	Sodium chloride	Boiled and steamed
Thailand	Bamee noodles (with eggs)	Alkali	Fresh
	Instant noodles (bag or cup)	Alkali	Fried, air-dried
	Chinese wet noodles[b]	Alkali	Parboiled
North America	Instant noodles	Alkali	Fried, air-dried
	Udon noodles	Sodium chloride	Boiled, fresh
	Yakisoba	Alkali	Steamed and water rinsed
Other areas	Instant noodles (bag or cup)	Alkali	Fried, air-dried

[a] Modified from Hou and Kruk (1998, Table IV, p. 5); used by permission.
[b] Also called hokkien noodles.

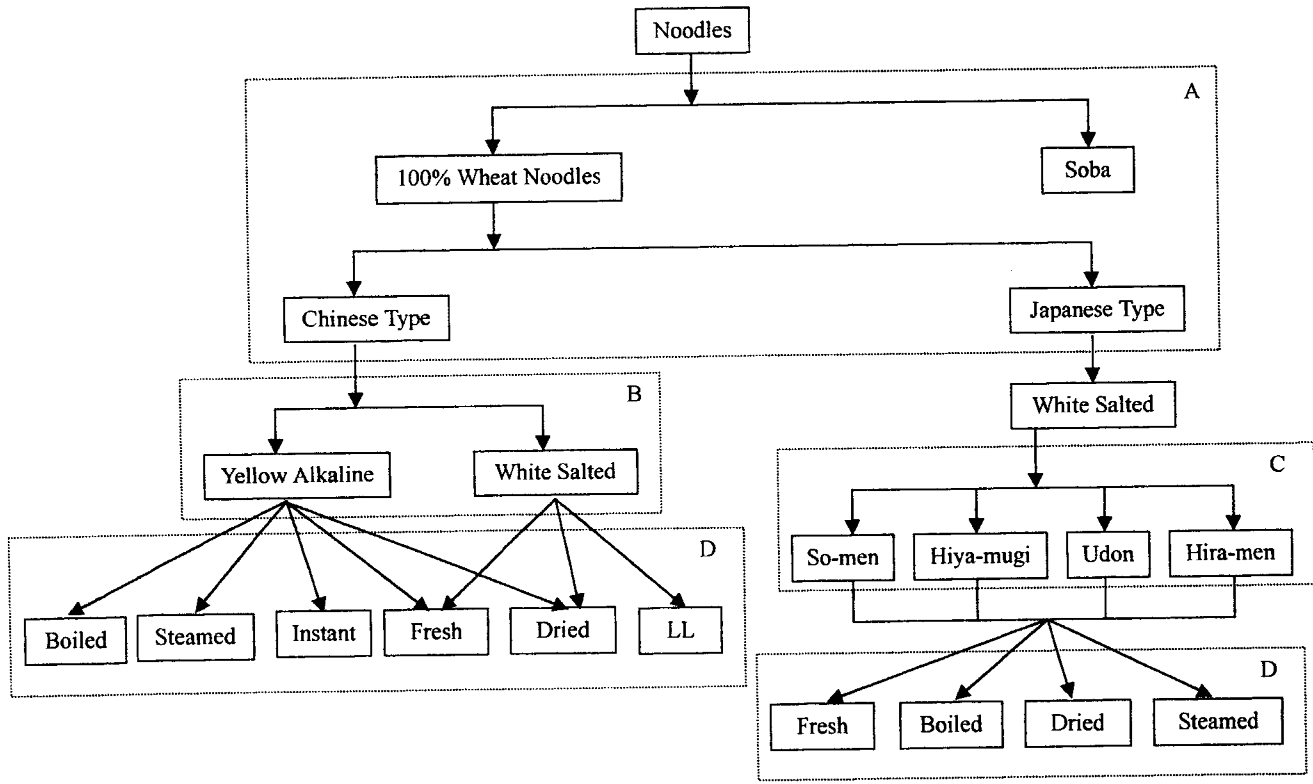

FIG. 1. Oriental noodle classification. (A) Based on raw materials; (B) based on the type of salt; (C) based on noodle strand size; and (D) based on processing (see text for details).

been made so far for noodles. There is a need to standardize noodle nomenclature using a universal classification system. Classification below (Fig. 1) is based on the current state of knowledge.

A. BASED ON RAW MATERIALS

Noodles can be made from wheat flour alone or a mixture of hard wheat with buckwheat flour. Wheat flour noodles containing a certain percentage of buckwheat flour (usually less than 40%) are called soba, meaning buckwheat noodles. Soba is widely consumed in Japan and Korea. The noodles are typically light brown or gray in color with a unique taste and flavor.

Based on the kind of wheat used, there are two major noodle types available: the Chinese type and Japanese type. Chinese-type noodles are generally made from hard wheat flours, characterized by a bright creamy white or bright yellow color and a firm texture. Japanese noodles are typically made from soft wheat flour of medium protein and are characterized by a creamy white color and a soft and elastic texture. Other noodles can be fitted into either type.

B. BASED ON SALT USED

Based on the absence or presence of alkaline salt in the formula, noodles can be classified as white salted (containing common salt) or yellow alkaline (containing alkaline salt) noodles. Alkali gives noodles their characteristic yellowness. White salted noodles comprise Chinese raw noodles or dry noodles, Japanese noodles, and Korean white salted noodles. Chinese wet noodles (hokkien), Cantonese noodles (with or without eggs), chuka-men, instant and Thailand bamee noodles fall under the yellow alkaline noodle category.

C. BASED ON SIZE

According to the width of noodle strands, Japanese noodles are classified into four noodle types (Table II). Since the smaller size noodles usually soften faster in hot water than the larger size, so-men and hiya-mugi are usually served cool in the summer and udon and hira-men are often eaten hot in the cool seasons. Other noodle types also have their own typical size.

D. BASED ON PROCESSING

The simplest way to classify noodles is based on processing: handmade versus machine-made. This is too generalized, however. Handmade

TABLE II

JAPANESE NOODLES BASED ON WIDTH[a]

Name	Size
So-men	Very thin, 0.7–1.2 mm wide
Hiya-mugi	Thin, 1.3–1.7 mm wide
Udon	Standard, 1.9–3.8 mm wide
Hira-men	Flat, 5.0–6.0 mm wide

[a] Nagao (1996).

TABLE III

ORIENTAL NOODLE CLASSIFICATION BASED ON PROCESSING[a]

Noodle type	Processing
Fresh	Noodle strands coming out of slitting rolls are cut into certain lengths for packaging without any further processing. Typical examples are Chinese raw noodles, Cantonese noodles, udon noodles, chuka-men, Thai bamee, and soba noodles. These noodles are often consumed within 24 hrs of manufacture due to quick discoloration. Their shelf life can be extended to 3–5 days if stored under refrigeration.
Dried	Fresh noodle strands are dried by sunlight or in a controlled chamber. Chinese raw noodles, Cantonese noodles, chuka-men, Japanese noodles, and soba noodles can be in dried form. Noodle shelf life is dramatically extended, but fragile noodles may have handling problems.
Boiled	Fresh noodle strands are either parboiled (80–90% complete cooking) or fully cooked. This type includes Chinese wet noodles, chuka-men, udon noodles, and soba noodles. After parboiling, Chinese wet noodles are rinsed in cold water, drained and coated with 1–2% vegetable oil to prevent from sticking. Boiled chuka-men, udon and soba noodles are not coated with any oil. They are recooked for another 1–2 min before serving.
Steamed	Fresh alkaline noodle strands are steamed in a steamer and softened with water through rinsing or steeping. This type is also called "Yakisoba", and it is often prepared by stir-frying for consumption.
Instant	Fresh noodle strands are waved and steamed for 2–3 min. After cutting and forming into a block, noodles are dehydrated by deep frying in hot oil (135–150°C) for 1–2 min or by hot blast air (70–80°C) for 35–45 min. Instant noodles have shelf life of 6–12 months. They can be served after cooking or soaking in hot water for 3–4 min.
LL	Fresh noodle strands are cooked, rinsed, acid soaked and packed, and are subjected to thermal processing and cooling. LL noodles can be kept for 4–6 months. Noodles are soaked in hot water for consumption.

[a] Modified from Hou and Kruk (1998, Table II, p. 2); used by permission.

noodles, still available in Asia because of their favorable texture, were prevalent before the automatic noodle machine was invented in the 1950s. In some places, stretching noodles by hand is considered an art rather than noodle making. Noodle machines are best suited to mass production.

Noodle processing operations include mixing raw materials, dough sheeting, compounding, sheeting/rolling and slitting. This series of processes remains constant among countries for all noodle types. Noodle strands are further processed to produce different varieties, and this can be a means of classification (Table III).

None of the approaches discussed above are sufficient to define each noodle type. For instance, boiled noodles contain fully cooked and parboiled types. One example of parboiled type is Chinese wet noodles (hokkien noodles), which are so called in many Asian regions except for Japan and Korea. In Japan and Korea, however, wet noodles refer to fresh, uncooked noodles. Therefore, a possible nomenclature would incorporate key aspects such as formulation and basic processing to fully describe the nature of each noodle type. For instance, Chinese wet noodles may be called "parboiled alkaline (kan sui or sodium hydroxide) noodles", and Chinese raw noodles may be called "Chinese uncooked white salted noodles".

III. FORMULATION

Oriental noodles derive much of their variety and character from differences in the way they are produced and presented to the consumer. Table IV shows the formulas of eight major types of noodles. Both Chinese raw noodles and Japanese udon noodles have the most simplified formulas containing only flour, water and salt. However, these two noodle types are made from two distinct flours: Chinese raw noodles require hard wheat flour of medium to high protein; and Japanese udon noodles are produced from soft wheat flour of medium protein. Chinese raw noodles have been shown to be very useful in screening noodle color due to their simple formulation. Additionally, the color criteria required for Chinese raw noodles also apply to Chinese steamed bread, both of which need bright and white color.

Chinese wet noodles, chuka-men, fried instant noodles and Thai bamee noodles all use alkaline salt in their formulations. Sodium hydroxide is sometimes used to replace carbonates in Malaysia to produce Chinese wet noodles. Fried instant noodles often contain the most ingredients to achieve short rehydration time and improved texture. Thai bamee noodles are characterized by having 10% eggs in the formula.

TABLE IV

FORMULAS FOR MAJOR TYPES OF ORIENTAL NOODLES[a] (BAKERS' PERCENTAGE)

	Noodle Type							
Ingredient	Chinese raw	Japanese udon	Chinese wet (Taiwan)	Chinese wet (Malaysia)	Chuka-men[b]	China fried instant[c]	Korea fried instant[d]	Thai bamee
Flour	100	100	100	100	100	100	100	100
Potato starch							11	
Water	28	34	32	32	32	34	44	28
Salt	1.2	2	2	2	1	1.5	1.9	3
Sodium hydroxide				0.5				
Sodium carbonate			0.45		0.4	0.1	0.1	1.5
Potassium carbonate			0.45		0.6	0.1	0.1	
Eggs								10
Guar Gum						0.2	0.1	
Compound phosphates[e]						0.1	0.06	
Riboflavin							0.003	
Emulsified oil[f]							1.3	

[a] Modified from Hou and Kruk (1998, Table V, p. 5); used by permission.
[b] Chuka-men is a raw Chinese alkaline noodle widely consumed in Japan.
[c] Hou et al. (1997).
[d] Anon (1995).
[e] Hou et al. (1997); sodium polyphosphate (35%) + sodium metaphosphate (40%) + sodium pyrophosphate (10%) + sodium phosphate monobasic (15%).
[f] Soybean oil + sorbitol + emulsifier.

IV. WHEAT FOR NOODLES

Since noodles were introduced from China to other Asian countries, they have evolved into diverse forms and preparations and become an essential part of local cuisine. As a result, the demand for noodle flour has largely increased over the years, now accounting for about 20–50% of total flour consumption in many countries (Table V).

TABLE V

WHEAT, FLOUR AND PRODUCTS TRADE IN ASIA IN 1997/98 MARKETING YEAR AND ESTIMATED FLOUR USAGE FOR ORIENTAL NOODLES

Region	Wheat production in 1997/98 (1000 metric tons)[a]	Wheat import in July 1997–June 1998 (1000 metric tons)[a]	% of noodle flour in total domestic flour consumption
China	123,300	1900	35
Indonesia	No commercial	3800	50
Japan	573	6200	35
Korea	Small	3917	39
Malaysia	No commercial	1150	40
Philippines	No commercial	2000	20
Singapore	No commercial	275	40
Taiwan	No commercial	1050	37
Thailand	No commercial	650	45

[a] Anon (1998).

A. SOURCE

China has been a leading wheat producer in the world with annual production ranging from 100 to 123 million tons in the past five years, but that quantity still cannot meet its own consumption. It has been one of the largest wheat importers except in recent years because of large stock carryover from the past several crop years. In the world wheat market, the United States, European Union, Canada, Australia and Argentina are currently the five major exporters. Noodle flour, however, has been milled mainly from US, Canadian and Australian wheats (Table VI).

In many cases, wheat is purchased on a class/grade basis. This ensures certain minimum specified quality criteria such as protein content, falling number and test weight. Within each class or grade, wheat is made up with mixtures of varieties of often similar or complementary quality. There is a growing demand that wheat is marketed on an identity preserved (IP) basis, especially for wheats selected for producing noodle flour. For instance, in Australia, variety *Rosella* is often segregated for export to

TABLE VI
WHEAT ORIGINS AND CLASSES USED IN ORIENTAL NOODLE PRODUCTION

Origin		Kinds of wheat
USA	HRS	Hard red spring
	HRW	Hard red winter
	HDWH	Hard white
Australia	APH	Australian prime hard
	AH	Australian hard
	APW	Australian premium white
	ASW	Australian standard white
Canada	CWRS	Canada western red spring
	CWRW	Canada western red winter
	CPSR	Canada prairie spring red
	CPSW	Canada prairie spring white

make specific noodle flour by Asian millers, but the quantity is limited. Thus, to ensure a continuous supply of high quality noodle wheat, varieties *Cadoux* and *Eradu* are blended with other selected wheat segregations of uniform and similar quality characteristics. In the US, hard white wheat varieties such as *ID 377S* (a hard white spring wheat), *Platte* (a hard white winter wheat) and *NuWest* (a hard white winter wheat) are grown through production contracts and marketed under IP programs. In other words, these varieties must not be contaminated with other varieties at harvest, so harvesting equipment must be thoroughly cleaned; they must also be segregated from other varieties during handling, storage, and transportation until they reach the end-users.

B. WHEAT QUALITY CHARACTERISTICS

In order to produce quality noodle flour, the most important step is to select correct wheat, followed by appropriate milling procedures. Wheats to be milled for noodle flour are assessed in many aspects. Each country establishes its own official standard for wheat. US Federal Grain Inspection Service grades a wheat according to the test weight, defects, wheat of other classes present and other contamination. In general, physical quality measurements of wheat and wheat test methods are similar and independent of end products made. For example, wheat should be clean and sound, free from disease, mycotoxins and other defects, high in test weight, and uniform in kernel size and hardness. These basic characteristics result in efficient milling and high flour extraction, and, possibly, optimum quality end products.

1. *Test Weight and Thousand-Kernel Weight*

One of the simplest and oldest quality criteria is the weight per unit volume of the wheat. This is expressed in terms of pounds per bushel or kilograms per hectoliter. Kernel size has little influence on test weight, but kernel shape and uniformity are important, as they affect the manner in which kernels pack in a container. Wheats of lower moisture and higher density tend to have a higher test weight. On the other hand, diseased, drought-damaged wheat or immature wheat may have an unusually low test weight. To the millers in the past, test weight was a rough guide to the amount of flour that the wheat might be expected to produce. Barmore and Bequette (1965) reported a significant linear correlation between test weight and flour yield when the test weight was in the range of 40 to 64 lb/bushel. However, Halverson and Zeleny (1988) did not correlate flour extraction with test weight when it was larger than 57 lb/bushel.

Thousand-kernel weight (TKW) is determined using semi-automatic counting instruments on sound, whole kernels. TKW provides the miller more useful information than test weight does. It may be a more useful index of potential milling yield (Halverson and Zeleny, 1988).

2. *Millable Wheat Value Index (MWVI)*

The millable wheat value index (MWVI) was first proposed by Drynan (1986) to allow wheat buyers to assess the economic potential of a wheat purchase relative to the actual price they pay for it. In this case the miller considers the content of moisture and screenings (unmillable material) in the wheat, the expected extraction of flour and by-products, and the price at which the finished products are sold. The presence of screenings and moisture (M) in wheat influences its milling performance because wheat is cleaned and tempered to a certain moisture level prior to milling. The screenings include foreign materials (FM), shrunken and broken kernels (SHBN) and dockage (D), which are expressed as percentage of the uncleaned wheat. Once screenings are removed, water must be added into wheat to a tempering moisture (TM) level (usually 14.5% for soft wheat and 16.5% for hard wheat). Thus, the percentage of cleaned, tempered wheat (CTW) from uncleaned, untempered wheat can be calculated as:

$$\text{CTW}\ (\%) = \frac{(100\% - \text{FM} - \text{SHBN} - \text{D}) \times (100\% - \text{M})}{(100\% - \text{TM})} \times 100\%$$

The result is the quantity of wheat to the first break roll of the mill. By computing the CTW, the miller can determine the quantity of wheat available for milling from a certain amount of wheat he has purchased.

The millable wheat value index (MWVI) is calculated by dividing the CTW into 100% (MWVI = 100%/CTW), the ratio of the quantity purchased to the millable wheat. The smaller the MWVI value is, the more the millable wheat will be. Multiplying the MWVI by the price that is paid for the wheat will assist the buyer to determine the real milling cost of the wheat he has purchased. However, this index does not take into account the impact of other wheat quality factors.

3. *Soundness*

A typical minimum falling number set for noodle wheat is 300 sec, because the use of flour from sprouted grain can cause problems in noodle manufacture. Rain-damaged wheats possess excessive amylase activity to break down the starch structure, and proteases that hydrolyze the proteins, thereby weakening the noodle structure and resulting in uneven stretching during drying. Amylases and proteases are reported to cause sticky doughs, soft eating texture and dark and unattractive noodle color (Simmonds, 1989).

4. *Single Kernel Characteristics*

Wheat kernel size, hardness and their distribution are important quality factors in the evaluation of milling performance and end-use quality. These kernel characteristics can be readily measured using a Single Kernel Characterization System (SKCS, Perten Instruments). Large size, uniform kernels are expected to have high flour yield. Wheat hardness deserves particular attention since it affects the tempering conditions (moisture and time), flour starch damage level, flour particle size distribution and milling yields. The uniformity of wheat kernel hardness appeared to improve the milling performance (Ohm *et al.*, 1998). Damaged starch not only absorbs more water but may also reduce noodle cooking and eating quality. Chinese-style noodles are usually produced from hard wheat flour. However, wheat suited for Chinese noodles should not be too hard, and the milling process should be controlled to avoid excess starch damage.

5. *Wheat Protein*

Wheat protein content is one of the important quality factors affecting wheat price and the finished noodle quality (color, texture and cooking characteristics). Flour protein content is generally 1–2% lower than its parent wheat depending on the extraction level. Thus, wheat of appropriate protein level should be selected according to the resultant noodle flour protein. Wheat protein quality (strength) is often evaluated by a SDS or Zeleny sedimentation test. Different noodle types require different protein contents and dough strength (discussed later). Generally speaking, Chinese-type noodles need hard wheat of high protein content and strong gluten, and Japanese noodles require soft or semi-soft wheat of medium protein content and dough strength.

6. *Wheat Ash*

Low ash content (1.4% or lower on a 12% moisture basis) is always an advantage to noodle wheat since flour ash is mainly determined by wheat ash. One of the important noodle flour specifications is ash content because it is traditionally viewed as causing noodle discoloration. However, there are cases where low ash flour (0.4% ash or lower, 14% moisture basis) may not make desirable noodle color. Noodle color is affected by many factors (discussed later).

7. *Wheat Color*

Millers have generally favored white wheat over red wheat to produce noodle flour as evidenced by the acceptance of Australian white wheat in the Asian noodle market. In recent years, wheat breeders and researchers in the US and Canada have increasingly expanded their hard white wheat breeding programs. Hard white wheat generally has flour extraction 1–2% points higher than its counterpart hard red wheat when both are milled to similar color standards. White wheat tends to contain lower levels of polyphenol oxidase (PPO) compared with red wheat. This enzyme is mainly located in the bran layer and can pass into flour during milling. PPO activity in wheat is determined by both cultivar and growing location, and flour retains an average of 3% PPO of the activity in wheat (Baik *et al.*, 1994a). The PPO is believed to be partially responsible for noodle darkening. Thus, fresh noodles made from white wheat flour show a slower rate of discoloration.

C. NOODLE FLOUR SPECIFICATION

Flours used for noodle making are of variable quality requirements. Nevertheless, the flour shall be the fine, clean and sound product obtained in the commercial milling of sound and clean wheat under modern sanitary conditions. It shall be free from lumps, insect infestation, dirt, grit, other adulterants and all foreign matter. It shall also be free from fermented, musty or other objectionable odor or taste. These are the minimum quality attributes of flour regardless of what noodles are to be made.

The earlier discussion of noodle wheat sources and quality characteristics provides a valuable yardstick in aiming for desired flour quality. However, each noodle type requires its own specific flour quality criteria. Table VII lists some basic flour specifications for various types of noodles. Flour protein and ash content, flour pasting characteristics and, sometimes, farinograph stability are the main specifications. Protein content varies according to the noodle type to achieve the desired eating quality. Generally speaking, high flour protein imparts an elastic and strong biting effect to the finished product, but has a negative impact on noodle brightness. Thus, there is an optimum flour protein content required for each noodle type. Japanese udon noodles and Korean bag-type fried instant noodles require soft wheat flour of 8.0–9.5% and 8.0–10.0% proteins, respectively. Other noodles require hard wheat flours of high protein content (10.0–13.0%), giving firmer bite and springier texture.

Flour ash content has been rated as one of the important noodle flour specifications because it generally affects noodle color negatively (Simmonds, 1989). Most noodle flours require ash content below 0.5%, but premium quality noodles are often made from flours of 0.4% or less ash. However, ash content is not always related to noodle color. In some cases,

TABLE VII
FLOUR SPECIFICATIONS FOR ORIENTAL NOODLES[a]

	Flour specifications (14% moisture basis)			
Noodle type	Protein (%)	Ash (%)	Amylograph peak viscosity (BU)[b]	Farinograph stability (min)
Chinese Raw	10.5–12.5	0.35–0.41	650–850	≥ 10
Japanese Udon	8.0–9.5	0.35–0.40	≥ 750	–
Chinese Wet (Taiwan)	11.0–12.5	0.40–0.45	650–850	≥ 10
Chinese Wet (Malaysia)	10.0–11.0	≤ 0.48	650–850	–
Chuka-Men	10.5–11.5	0.33–0.40	650–850	–
Chinese Fried Instant (bag-type)	10.5–12.0	0.40–0.50	≥ 650	≥ 4
Korean Fried Instant (bag-type)	8.0–10.0	0.36–0.40	≥ 650	7–9
Japanese Fried Instant (bag-type)	10.0–11.5	0.40–0.45	≥ 650	–
Thailand Bamee	11.5–13.0	≤ 0.46	650–850	≥ 10

[a] Modified from Hou and Kruk (1998, Table III, p. 4); used by permission.
[b] Method: 65 g flour (14% mb) + 450 ml distilled water. Amylograph heating cycle is: heating from 30 to 95°C at 1.5°C/min; holding at 95°C for 20 min; and cooling to 50°C at 1.5°C/min.

flour color may be more related to noodle color. Flour color L* (whiteness) > 91 measured with a Minolta Chroma Meter (CR–3/0) is often required.

Starch pasting characteristics (as measured on the amylograph or Rapid Visco Analyzer) also play an important role. The ratio of amylose to amylopectin content determines a starch's pasting characteristics (Moss, 1980; Moss and Miskelly, 1984; Zeng, *et al.*, 1997). Flour amylose content between 22–24% is often required for Japanese-type noodle making. Measurement of the pasting viscosity of flour or wholemeal also relates to noodle quality, and eliminates the starch isolation step. However, the presence of excessive α-amylase activity (which breaks down starch) in the flour or wholemeal will undermine the prediction results because even a small quantity of the enzyme is likely to reduce the paste viscosity. The addition of certain α-amylase inhibitors into the test solution has been shown to improve the correlation between the viscosity of flour or wholemeal and the eating quality of Japanese noodles (Batey *et al.*, 1997).

Dough properties measured by other relevant tests (sedimentation test, and farinograph and extensigraph measurements) are often also included in noodle flour specifications because they affect noodle processing behavior and eating quality. Farinograph stability time has shown a positive relationship with cooked Chinese raw noodle texture in hot soup (Hou *et al.*, unpublished results). High sedimentation volumes indicate a strong dough, which is good for Chinese-style noodles that require a firm bite and springy texture. Extensigraph parameters measure the balance of dough extensibility versus elasticity. Too much extensibility results in a slack dough, while too much elasticity causes difficulty in controlling final noodle thickness. It should be cautioned that a noodle dough is much lower in water absorption than bread dough (28–36% vs. 58–64%). Rheological tests, initially developed to evaluate bread dough performance, may not be applicable to noodle dough evaluation. There is a need to develop new tests specifically for relating a noodle dough's rheological properties to eating quality.

V. INGREDIENTS

Water and salt (common salt or alkaline salt) are indispensable ingredients besides flour in noodle formulas. Many other ingredients are often included by noodle manufacturers in noodles to improve the quality of finished products or expand the varieties (Table VIII) (Miskelly, 1998). The selection of raw materials and the quality requirement of them are determined by the noodle types, noodle quality grades, economic factors and supply situations.

TABLE VIII
INGREDIENTS USED IN ORIENTAL NOODLE PRODUCTION[a]

Main Ingredients	Additional ingredients
Flour	Buckwheat
Water	Starch
Salt/alkaline salt	Edible oil
	Antioxidants
	Stabilizers
	Polyphosphates
	Vital gluten
	Eggs/egg powder
	Preservatives
	Emulsifiers
	Colorings

[a] Modified from Miskelly (1998, Table 1, p. 124); used by permission.

A. MAIN INGREDIENTS

1. Water

First, water used in noodle making shall be clean, without taste or odor. It shall be free from microorganisms and contains low levels of minerals. In the case of boiling, the quality of water is very important because starch, dextrins, salts and other materials are leached out or washed from the noodle surfaces during boiling, thus these materials accumulate in the bath. Noodle surface breakdown is accelerated by higher concentrations of salts and higher alkalinity in the boiling water. In normal practice, used boiling water is slowly replaced with fresh water to reduce side effects. If necessary, the pH of boiling water is adjusted to 5.5–6.0 by adding lactic acid. There is no doubt that water condition varies greatly from plant to plant.

2. Salt

Addition of 1–3% salt to noodle dough not only gives the taste to noodles but also imparts a number of other benefits to noodle quality. These include the strengthening and tightening of gluten structure to give it improved viscoelasticity, and accelerating water uptake during cooking by increasing water permeability (Dexter *et al.*, 1979). At the 2% addition level, salt appeared to strengthen the dough as shown by an increase in farinograph mixing time and a decrease in the mixing tolerance index; the internal structure of the dough exhibited a smoother and more uniform appearance than that found in the dough prepared with no added salt.

When the level of salt was increased to 5%, the dough still handled well during sheeting, although it was slightly dry. But the sheeted dough became quite dry and lacked strength when 10% salt was added. At this level of added salt, dough formation would not occur in the farinograph and the internal structure of the sheeted dough revealed a very undeveloped gluten structure. Thus, it appeared that addition of about 2% salt can have a favorable effect on dough characteristics, whereas addition of a higher level of salt causes a deterioration in dough properties in the absence of additional water.

In a study on the effect of salt on the RVA pasting characteristics of wheat starch, Bhattacharya and Corke (1996) reported that 2% NaCl dramatically increased the starch paste peak viscosity. It was believed that salt has a function of increasing and regulating the swelling of starch granules (Ganz, 1965). The integrity of starch granules is, therefore, enhanced in the presence of salt, and they remain intact for a longer period of time and swell to a greater extent, thus increasing the peak viscosity. In addition to raising starch paste peak viscosity, salt can also cause larger breakdown and lower setback (Bhattacharya and Corke, 1996), all of which are desirable starch characteristics needed for good quality Japanese noodles.

3. *Alkali*

The alkaline salt (kan sui) used for various types of noodles can be in liquid or solid forms. Most alkaline noodles use mixtures of Na_2CO_3 and K_2CO_3, Na_2CO_3 and $NaHCO_3$, Na_2CO_3 and NaOH or NaOH alone, the ratios of which are variable, but the pH of these solutions is in the range of 8.5–12. The quantity of alkaline salt added is 0.5–1% of flour weight.

An alkaline solution affects the flavor of the resulting noodles and, by detaching flavones from the polysaccharides, allows the yellow color to become manifest. It is noticed that the yellow color becomes intense as the dough pH increases. When either a hydroxide or a carbonate is used, the yellow color formed is dull and not fresh and attractive as in the case when a mixture of hydroxide and carbonate is used. At the high pH, even as high as pH 12, kan sui can slow enzymatic darkening by inhibiting much enzyme activity.

Lye water also toughens the dough. When compared to doughs prepared with water, NaOH showed a great increase in noodle dough stiffness; carbonates had an intermediate effect (Edwards *et al.*, 1996). Additionally, noodle doughs containing NaOH continued to increase in stiffness over 24 hours, indicating that the effect of pH may be time-dependent. It is assumed that increased stiffness may have been due to alkaline gelatinization and subsequent retrogradation of starch. In a recent study, however, a mixture of Na_2CO_3 and K_2CO_3 (50/50) was found to yield much harder hokkien noodles than an equivalent amount (0.8% of flour weight) of NaOH alone (Hou, unpublished results).

The RVA peak viscosities of starches at pH 11 were reported much higher than in water (Bhattacharya and Corke, 1996). The presence of Na^+ or OH^- ions and the effects of high pH might strengthen the bonding forces within the starch granules. The alkali treatment was shown to accelerate the gelatinization process of starch as indicated by the lower temperature and shorter gelatinization time on the RVA pasting profile. However, the alkaline pH could not maintain granular integrity for long, resulting in the rapid breakdown of starch granules. When both salt and alkali were present, the peak viscosity was most likely higher than in water, but not as high as when salt or an alkali condition was used alone. The cumulative effect of salt and alkaline pH seems to weaken the hydrogen bonds between starch chains, resulting in the decrease of paste viscosity.

B. ADDITIONAL INGREDIENTS

1. Buckwheat

Buckwheat flour is often blended, at 10–40% levels, into wheat flour to make buckwheat noodles (soba). Because buckwheat flour protein lacks gluten-forming ability, the high protein (12% minimum) wheat flour is needed to act as binding flour to incorporate buckwheat flour into a tight dough sheet. Thus, wheat flour protein content should increase with the percentage of buckwheat flour in the noodle formula.

2. Starch

Native or modified potato starch, tapioca starch or other equivalents are often added in premium instant noodles and some white salted noodles. These starches are typical of high viscosity, rapid swelling characteristic, and low gelatinization temperature. As a result, they can improve the steaming and cooking quality of noodles, providing a more springy texture and quicker rehydration time. Modified starches have improved gelling properties and freeze-thaw stability, so are especially beneficial to LL (long life) noodles that require thermal processing or freezing. Because starches are very white, they can give a whiter or lighter background color to the finished noodles as well.

3. Edible Oils

Oils are used in Chinese wet noodles and fried instant noodles. In the case of Chinese wet noodles, about 1–2% of the vegetable oil is coated on the parboiled, cool-rinsed, and drained noodles to prevent stickiness.

In the selection of oils for frying instant noodles, several criteria should be met (Chen, 1994):

(a) Frying fats should be bright, white and unadulterated; and should not exhibit an unpleasant odor and taste, or unacceptable appearance (dark color, foaming, etc.).
(b) Frying oil should have good thermal stability, i.e. small thermal oxidation and polymerization; slow changes in darkening, taste, viscosity increase and acid value.
(c) Frying oils should have a high smoke point (>200°C).
(d) Frying oils should be easy to drain off from the products.

Based on these specifications, palm oil, palm olein, corn oil, peanut oil and sesame oil are suitable for frying instant noodles. Palm oil or palm olein is especially often used in Asia, while in North America, noodle frying oil is typically composed of mixtures of canola, cottonseed and palm oils.

4. Antioxidants

Fried instant noodles have a fat content of 17–22%. The oxidative rancidity is a major factor limiting shelf life. Several antioxidants have been experimented with to stabilize frying oil (Martin, 1953) or prolong the shelf life of fried noodles by retarding rancidity during storage (Rho *et al.*, 1986).

Silicones have been shown to be useful for retarding the high temperature oxidation of frying. Martin (1953) reported that methyl silicones at 0.2–0.5 ppm reduced gum formation, helped retain tocopherols, and improved the flavor stability of the fried product. Antioxidants such as butylated hydroxytoluene (BHT), butylated hydroxyanisole (BHA), mixtures of BHT and BHA, and tocopherol (vitamin E) are often added into frying oil to inhibit oxidation of fried noodles. Rho and coworkers (1986) experimented with frying noodles in plain palm oil and palm oil added with 200 ppm of one of three antioxidants, BHA, TBHQ, or Poly-A, a polymerized BHA. They discovered that the noodles fried in the untreated fat developed rancidity after storage at 63°C for 60 days. TBHQ was shown to be the most effective in extending the shelf life of fried noodles.

5. *Eggs*

Eggs may be added to the dough as fresh, frozen or dried eggs. The addition of eggs increases the flavor of the noodles and gives a more elastic and firm texture. Noodles enriched with fresh eggs seemed to darken at a faster rate when compared with plain noodles.

6. *Stabilizers*

Guar gum, locust bean gum, alginates and carboxymethyl cellulose (CMC) are common stabilizers used in noodle making to impart viscosity to the noodles when cooking in water, providing improved firmness, body, and mouthfeel. These compounds normally have a high molecular weight and so are used at low levels (0.1–0.5%). Through their ability to bind water, stabilizers can reduce the oil absorption of fried instant noodles, and also increase the rehydration rate of instant noodles upon cooking or soaking.

7. *Polyphosphates*

A typical polyphosphate salt used in noodles is usually composed of a mixture of sodium polyphosphate (35%), sodium metaphosphate (40%), sodium pyrophosphate (10%), and sodium phosphate monobasic (15%) (Hou *et al.*, 1997). This salt solution has a pH of 6.7–7.3. It is often added at 0.1–0.2% of flour weight.

The function of polyphosphate salt includes (Chen, 1994): (a) improving the viscoelasticity of noodles by accelerating the starch gelatinization, (b) reducing the cooking loss, and (c) giving better mouthfeel by allowing more water retention on the noodle surface.

8. *Vital Gluten*

For making Chinese-type noodles, high protein flour is required. If the flour protein is too low, cooked noodles will not have a desired bite texture. In this case, vital gluten powder is often added (~2%) to improve the noodle bite. However, too much gluten causes noodle darkening.

9. *Preservatives*

Noodles of high moisture content can be easily spoiled by microorganisms. Besides controlling the sanitary condition of the manufacturing line, noodle storage life can be improved by applying some preservatives. Propylene glycol, ethanol, organic acids, sodium acetate and glycine are among those preserving reagents commonly used by noodle manufacturers.

10. Emulsifier

Mono-/diglycerides, sucrose fatty acid ester, and lecithin are the three commonly used emulsifiers (0.1–0.5% of flour weight) in fried instant noodles. These additives are claimed to have the functions of reducing noodle stickiness, improving starch gelatinization, reducing cooking water cloudiness, retarding starch retrogradation and shortening noodle rehydration time (Chen, 1994; Li, 1996).

11. Colorings

Natural and synthetic yellow colorants are often added in Chinese wet noodles and fried instant noodles to enhance the attractiveness of the products. Each country sets its own regulations on the type and level of colorants to be used. Among them, riboflavin, tartrazine, sunset yellow, β-carotene, and vitamin E are commonly used.

VI. PRODUCTION

The basic processing steps for machine-made noodles are outlined in Fig. 2. These steps involve mixing raw materials, resting the crumbly dough, sheeting the dough into two dough sheets, compounding the two dough sheets into one, gradually sheeting the dough sheet into a specified thickness and slitting into noodle strands. Noodle strands are further processed according to noodle types. Table IX summarizes the types of unit operations adopted in the processes for six noodle types.

A. MIXING INGREDIENTS

Mixing formula ingredients (Table IV) is often carried out in a horizontal or vertical mixer for 10–15 min. Inside the mixer are horizontal or vertical shafts with blades vertical to them. Because the horizontal mixer seems to have better mixing results, it is more commonly used than the vertical one in commercial noodle production. Mixing results in the formation of small dough crumbs.

Protein content, protein quality, starch (especially damaged starch), flour granulation, and pentosans determine the mixing moisture level of flour. An insufficient absorption level usually causes streaky dough, and sometimes

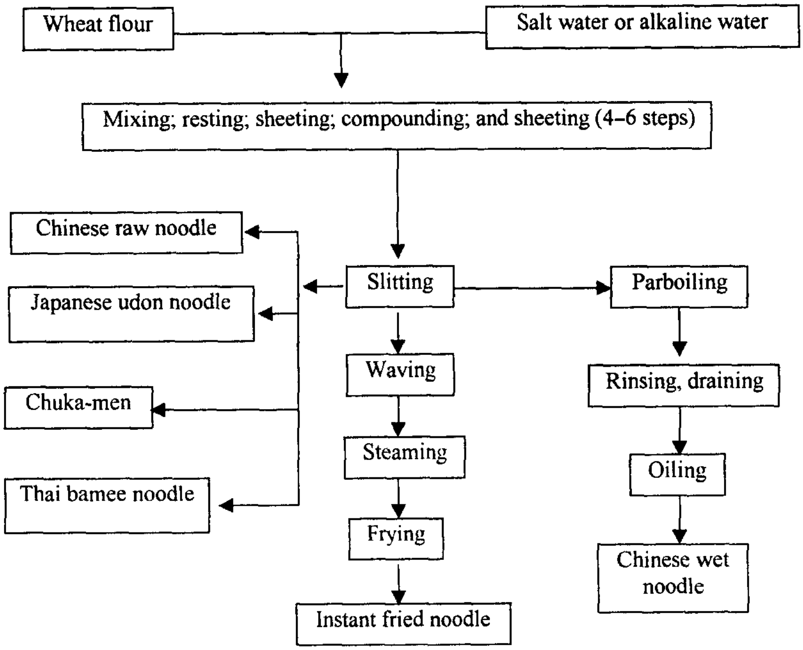

FIG. 2. Noodle-making procedures.

TABLE IX
UNIT OPERATIONS USED IN SIX NOODLE TYPES

Unit operation	Noodle type					
	Chinese raw	Japanese udon	Chinese wet	Chuka-men	Fried instant	Thailand bamee
Mixing	X	X	X	X	X	X
Compounding	X	X	X	X	X	X
Sheeting/slitting	X	X	X	X	X	X
Cutting	X	X	X	X	X	X
Shaping/forming	X	X		X		X
Waving					X	
Steaming					X	
Cooking			X			
Cooling			X		X	
Oil coating			X			
Frying					X	
Packing	X	X	X	X	X	X

flaking on the surface of the dough sheet. The resultant noodle strands are weak and easy to break during drying because of presence of noncohesive zones. On the other hand, excessive water causes problems in dough sheeting due to much gluten development during dough mixing. Even so, the water absorption level in noodle dough is not so sensitive to processing as to that in bread dough. Variation in noodle dough water absorption among different flours is generally within 2–3%, and this is usually determined by dough handling properties. A 10 g-mixograph method was proposed to predict the optimum absorption of flour for noodle preparation (Oh *et al.*, 1986). Unfortunately, this approach has not been practically used due to its inconvenience. Complicating the matter is that flour mixing moisture level strongly affects the uncooked noodle brightness (Kruger *et al.*, 1994; Baik *et al.*, 1995), thus, for noodle color comparison, the mixing moisture level should be kept constant for all flours.

The sizes of dough crumbs are affected by flour particle size and distribution, flour protein content, and starch damage level. Flour particle size and their distribution affect the time that water penetrates into the flour. Larger particle flours require a longer time for water to incorporate and tend to form larger dough lumps. It is desirable to have relatively fine and evenly distributed particle size flours to achieve optimum dough mixing. Flour of high protein content and/or high level of starch damage also tends to produce large dough crumbs that are often uneven in hydration, wet outside and dry inside (Azudin, 1998). Small crumb size is preferred to assure even formation and development of gluten during subsequent sheeting, resulting in smoothness and uniformity of sheeted dough. However, under the normal mixing condition, the mixing moisture level is relatively low (28–35%), thus gluten development in noodle dough during mixing is minimized. Lower water absorption helps to slow down noodle discoloration and reduces the amount of water to be taken out during the final drying or frying process.

When vacuum mixing is applied, higher mixing moisture (36–40%) is allowed and also needed (Wu *et al.*, 1998). The authors stated that if the mixing moisture level is lower (less than 36%), it is difficult to obtain optimal results and larger mixing energy is required. However, if the mixing moisture is too high (higher than 40%), the dough pieces tend to form large lumps, causing difficulty in subsequent sheeting and in controlling the final dough sheet thickness. The authors further summarized the advantages of using vacuum mixing with sufficient mixing moisture for four noodle types. When extra water is added during vacuum mixing, the gluten development is improved during mixing and sheeting. A well-developed gluten network gives the noodles a continuous internal structure and improves their biting texture. For making instant noodles, starch gelatinizes better and swell to a greater extent during steaming when the noodle moisture is higher. Well-gelatinized starch imparts the noodles shorter cooking time, less surface stickiness, slower retrogradation rate during refrigeration and more viscoelastic texture after cooking.

B. DOUGH RESTING

After mixing, the dough pieces are usually rested for 20–40 min before compounding. Dough resting helps water penetrate into dough particles evenly, resulting in a smoother and less streaky dough after sheeting. In commercial production, the dough is rested in a receiving container while being stirred slowly.

C. COMPOUNDING AND SHEETING

The rested, crumbly dough pieces are transferred to the hopper of a compounding unit which consists of two pairs of horizontal rolls located below the hopper, rotating inwardly in opposite directions. The dough pieces are divided into two portions, each passing through a pair of sheeting rolls to form a noodle dough sheet. The two sheets are then combined (compounded) and passed through a second set of sheeting rolls to form a single sheet. The roll gap is adjusted so that the dough thickness reduction is between 20–40%. The combined dough sheet is often carried on a multilayer conveyor belt located in a temperature and relative humidity-controlled cabinet. This stage of dough resting has at least four functions (Kogawa, 1984 and Ito, 1988 cited in Wu *et al.*, 1998): (a) to help moisture distribute more evenly, (b) to enhance disulfide bond formation, (c) to form bonds between gluten and lipids, and (d) to relax the gluten for easy reduction in the subsequent sheeting operation. The aging time takes about 30–40 min.

Whether a dough sheet is allowed to rest or not has a significant impact on the degree of starch gelatinization during steaming. According to Wu *et al.* (1998), a well-rested dough has a higher degree of starch gelatinization than an unrested dough as examined by differential scanning calorimetry. The lack of evenly distributed water may prevent starch from being fully gelatinized during steaming. Meanwhile, the unrelaxed gluten may suppress starch swelling.

Further dough sheeting is done on a series of 4–6 pairs of rolls with decreasing roll gaps. At this stage, roll diameter, sheeting speed and reduction ratio should be considered to give an optimum dough reduction. A reduction ratio of 30% is preferred, so the gluten can maintain its intact structure. Repeated sheeting can increase the density of the noodles by pressing out gas, thus, improving the physical integrity of raw and dry noodles. But if the sheeting speed is too fast, gluten underneath the dough surface may shear.

Most noodle machines are equipped with smooth rolls, noodles produced from them having relatively poorer biting texture than hand-made noodles. This shortcoming of machine-made noodles can be overcome by the use of waved rolls in multi-roll sheeting to simulate the motions of manual sheeting. Because the dough is sheeted multi-directionally, the gluten network is well developed and more uniform, resulting in an improved biting quality and a lower cooking loss (Zhou and Guo, 1996).

D. SLITTING AND WAVING

Noodle slitting is done by a cutting machine, which is equipped with a pair of calibration rolls, a slitter, and a cutter or a waver. The final dough sheet thickness is set on the calibration rolls according to the noodle type (Tables II and X) and measured using a thickness dial gauge. Noodle width determines the size of noodle slitter to be used (noodle width, mm = 30/slitter number). The sheet is cut into noodle strands of desired width with a slitter. Noodles can be either square or round in shape by using various slitters. Noodle strands are cut into a desirable length by a cutter. At this stage, Chinese raw noodle, Japanese udon noodle, chuka-men and Thai bamee noodle making are complete. For making instant noodles, noodle strands emerging from the slitter are hindered by metal blocks (weights), resulting in the noodle waves. The waved noodles are subjected to steaming, cutting, molding, frying or air-drying and packaging.

TABLE X
DIMENSIONS OF ORIENTAL NOODLE STRANDS[a]

Noodle type	Thickness (mm)	Width (mm)	Slitter number
Chinese raw	1.2	2.5	12
Japanese udon	2.5	3.0	10
Chinese wet (Taiwan)	1.5	1.5	20
Chinese wet (Malaysia)	1.7	1.7	18
Chuka-men	1.4	1.5	20
Fried instant (Bag)	1.2	1.5	20
Fried (Cup)	0.9	1.3	22
Thailand bamee	1.5	1.5	20

[a] Modified from Hou and Kruk (1998, Table VI, p. 7); used by permission.

E. COOKING

Cooking processes include parboiling, full boiling and steaming. Chinese wet noodles are usually parboiled for 45–90 sec to achieve 80–90% gelatinization in starch. These noodles are then coated with about 1–2% of edible vegetable oil to prevent the strands from sticking together. Parboiled noodles have extended shelf life (2–3 days) and high weight gain (60–70%). They are quickly recooked by boiling or stir-frying prior to consumption.

For making LL noodles, fresh noodles are cooked for 10–15 min, rinsed and cooled in running water, steeped in a dilute acidic water before packing, and further steamed for more than 30 min in a pressurized steamer. This type of noodle usually has a shelf life of 4–6 months. After steeping in boiling water, the noodles are ready for consumption.

Several steps can be taken to assure optimal cooking: (a) the weight of cooking water is at least 10 times that of the uncooked noodles; (b) the size of boiling pot is properly chosen; (c) the pH of boiling water is 5.5–6.0; (d) the cooking time is precisely controlled to give optimal results to the product; and (e) the cooking water temperature is carefully maintained at 98–100°C throughout the boiling process.

In making instant noodles, the wavy noodle strands are conveyed to a steaming tunnel to cook at 98–100°C for 2–3 min. The steaming time varies according to the noodle size, but can be estimated by squeezing a noodle strand between two pieces of clear glass plates. If the white noodle core disappears, the noodle strands are likely well cooked. Steam temperature, steam pressure, and steaming time are the key process factors affecting the product quality. After steaming, instant noodles are cut into blocks by a rotating blade and molded into a molder, either in bag or cup/bowl type.

As mentioned earlier, the purpose of steaming is to allow starch to swell and gelatinize to a greater extent, which is needed for a fast rehydration rate of the finished product before serving. Steaming also denatures the protein and helps to fix the noodle waves. The protein denaturation process usually occurs prior to starch gelatinization because of a relatively low moisture in noodles (40–45%, d.b.). Starch does not begin to gelatinize until at 84°C even when the moisture is more than 70% (Wu *et al.*, 1998). The starch gelatinization temperature of noodles is therefore even higher than 84°C. These suggest that noodles are only partially gelatinized under normal steaming conditions. Because the gelatinized starch plays a key role in determining the rehydration rate and viscoelastic texture of the finished noodles, it is a challenge to promote the degree of starch gelatinization during steaming.

F. DRYING

Noodle drying can be carried out by air drying (low temperature or hot blast air), deep frying or vacuum drying. The air drying process has been applied to many noodle types, such as Chinese raw noodles, Japanese udon noodles, non-fried instant noodles, and others. Air drying usually takes 5–8 hr to dry regular noodles (long and straight) and 30–40 min to dry non-fried instant noodles. Drying by frying takes only a few minutes. Vacuum drying of frozen noodles is a newer technology making it possible to produce premium quality products.

1. Air Drying

For the manufacture of regular dry noodles, fresh noodle strands of a certain length are hung on rods in a drying chamber with controlled temperature and relative humidity. Air drying usually involves multistage processes since too rapid drying causes noodle checking, similar to spaghetti drying. In the first stage, low temperature (15–20°C) and dry air is applied to reduce the noodle moisture content from 40–45% to 25–27%. In the second stage, air of 40°C and 70–75% relative humidity is used to ensure moisture migration from the interior of noodle strands to outside surfaces. In the final stage, the product is further dried using cool air.

For the manufacture of non-fried instant noodles, wavy noodle strands are first steamed for 2–3 min at 100°C, then dried for 35–45 min using hot blast air at 70–80°C. The degree of starch gelatinization for this type of noodle is usually between 80–85%, lower than that of fried instant noodles (85–90%). Prolonging steaming time can increase starch gelatinization, thus shortening the rehydration time and improving noodle eating quality. The dried noodles are cooled prior to packaging. This type of non-fried instant noodle is also called "non-expanded type" (Fig. 3), because the noodles have a tight structure and rehydrate slowly in hot water. Because the starch is not fully gelatinized during steaming, the noodles will have a better texture if cooked in boiling water, rather than soaked in hot water.

One of the key technical challenges in making non-fried instant noodles is to prevent noodle strands from sticking to each other, resulting in uneven drying. In severe cases, the dried noodle strands may not separate easily during cooking, causing uneven rehydration and giving poor texture. It has been attempted to solve this problem by spraying oil on the surface of the noodles after steaming, but it slows down the drying process by interfering with the water evaporation. Other approaches include (Wu *et al.*, 1998): (a) making round noodles to minimize the surface area, (b) forming a

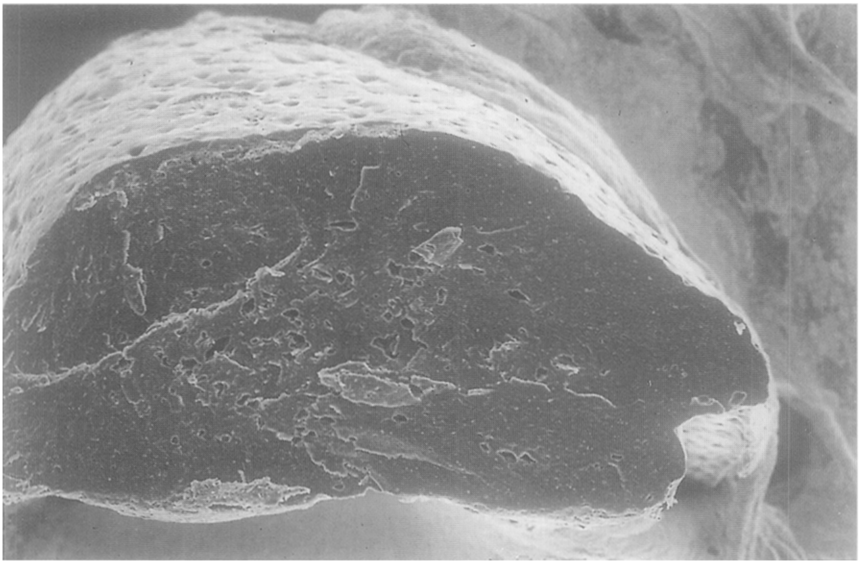

FIG. 3. Microscopic structure of non-expanded non-fried instant noodles (reprinted, with permission, from Wu *et al.*, 1998, Fig. 14, p. 62).

non-sticky film on noodle surface by adding an emulsifier or a small amount of mung bean starch, (c) applying two-stage steaming (initial steaming; spraying an emulsifier to prevent the starch from swelling excessively during the second steaming stage; and re-steaming), (d) cooling steamed noodles quickly to remove excessive water and cause soluble starch on the surface to form a film, and (e) cooling the steamed noodles quickly (10°C or below) and washing away soluble starchy material from the noodle surface.

The basic quality requirement for instant noodles is short rehydration time (less than 3–4 min) in hot water. However, the non-expanded non-fried noodles discussed above require longer rehydration time because of lack of porous structure. The "expanded" type of non-fried instant noodles (Fig. 4), however, can overcome this shortcoming. The major characteristic of expanded non-fried noodles is their porous, honeycomb-like internal structure created by high temperature expansion, which allows the rapid entry of water and shortens the rehydration time (Wu *et al.*, 1998). In principle, only noodles with a dense and well-developed gluten network structure will have a good chewy texture. Therefore, creation of a porous internal structure could undermine the noodle texture. It is necessary to control the manufacturing process to achieve this balance. The mechanism and controlling steps in making this type of product are well described by Wu and coworkers (1998).

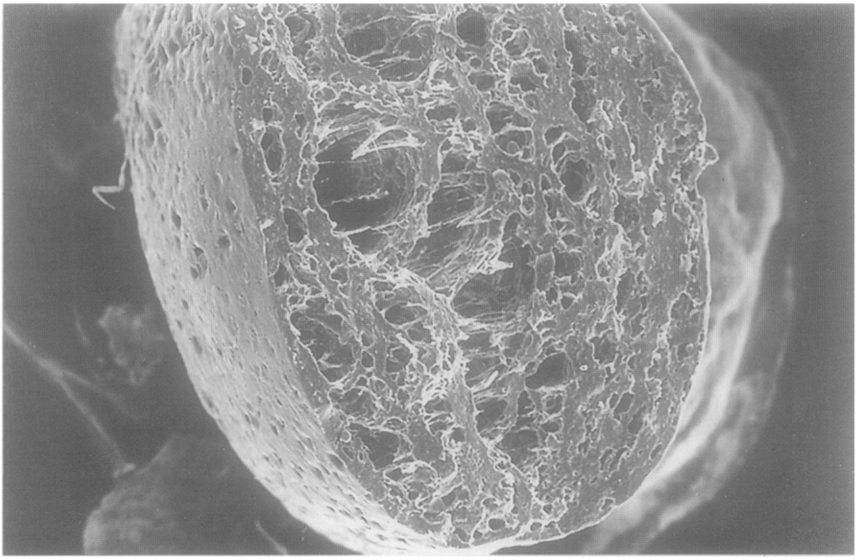

FIG. 4. Microscopic structure of expanded non-fried instant noodles (reprinted, with permission, from Wu *et al.*, 1998, Fig. 14, p. 62).

Non-fried instant noodles have a low fat content so some people prefer them. They also have a longer shelf life because little fat rancidity is involved. In Western countries, non-fried instant noodles are gradually gaining popularity because of consumers' greater awareness of healthy foods. However, the slow output of the process and lack of pleasant shortening taste and mouthfeel make the products less popular in Asia compared with fried instant noodles.

2. *Deep Frying*

Drying by frying is a very fast process. Water vaporizes quickly from the surface of the noodles upon dipping into hot oil (135–145°C). Dehydration of the exterior surface drives water to migrate from the interior to the exterior of the noodle strands, resulting in a porous spongy structure by steam (Fig. 5). Eventually, some of the water in noodles is replaced by oil. Many tiny holes created in the frying process serve as channels for water to get in upon rehydration in hot water. Because the surfaces of fried noodle strands absorb oil during frying, they can easily be separated from each other in hot water. It usually takes 3–4 min to cook or soak fried instant noodles in hot water before consumption.

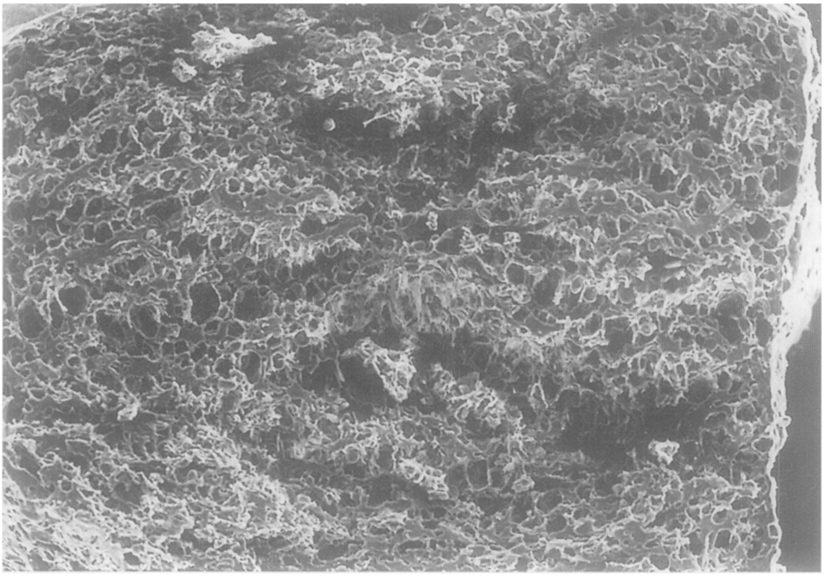

FIG. 5. Microscopic structure of fried instant noodles (reprinted, with permission, from Wu *et al.*, 1998, Fig. 13, p. 61).

VII. QUALITY EVALUATION

Quantifying the quality of flour for noodle making has been a challenge to researchers. Three primary sensory characteristics, i.e. process performance (machining), noodle color and texture, are usually evaluated. Table XI shows the score allocation of each noodle attribute for different noodle types. The process effect is generally weighted higher for instant noodles due to there being more steps involved and high-speed production. Noodle color and color stability is particularly important for Chinese raw, Japanese udon, chuka-men and Thailand bamee because of the lack of heat treatment, which allows more rapid darkening. As for Chinese wet noodles, color is also very important because it is evaluated on both parboiled and uncooked noodles. Chinese wet noodles have a typical shelf life of 2–3 days. Although good noodle color is required, especially for premium quality noodles, desirable texture is essential in all the markets. Other quality characteristics are weighted lower, but they can be very critical to overall noodle performance. For example, Chinese wet noodles are sold in a parboiled form, so the cooking weight gain (%) is a very important noodle quality attribute for noodle manufacturers. If noodles can take up more water within a fixed cooking time

TABLE XI
SCORING FACTORS FOR ORIENTAL NOODLES[a]

	Characteristics and scores (%)			
Noodle type	Noodle process	Noodle color	Noodle texture	Others
Chinese raw	25	30	45	0
Japanese udon	Not applicable[b]	25	45	30[c]
Chinese wet (Taiwan)	15	20	40	25[d]
Chinese wet (Malaysia)	25	40	20	15[e]
Chuka-men	Not applicable[b]	30	40	30[f]
China fried instant	35	10	55	0
Korea fried instant	25	9	30	36[g]
Thailand bamee	10	45	20	25[h]

[a] Modified from Hou and Kruk (1998, Table VII, p. 8); used by permission.
[b] Noodle process evaluation is not included in scoring.
[c] Surface appearance, 20%; taste, 10%.
[d] Cooking weight gain.
[e] Cooking weight gain, 10%; shelf life after 48 hr, 5%.
[f] Specks of raw noodle, 20%; taste, 10%.
[g] Noodle cooking property, 30%; taste, 6%.
[h] Dryness, 10%; cooking quality, 10%; cooked noodle surface smoothness, 5%.

and still maintain their texture characteristics, they will be more desirable and profitable products.

Each noodle type has its own evaluation sheet due to a different focus on the noodle quality preferences (Tables XII –XIX). Within the categories of processing, noodle color or noodle texture, there are a number of evaluation items.

A. PROCESSING

The performance of flour in the process of noodle production is of great importance to noodle manufacturers because it has an impact on end product quality. The ease of handling and the consistency of processing behavior of flour in a high-automated processing environment determine the acceptance of particular flour in the manufacture of noodles. Evaluation criteria for each processing step are described in Table XX. Evaluation should be done at each stage of processing. It should be emphasized that steaming is one of the critical control points in instant noodle processing. The degree of starch gelatinization in instant noodles determines the noodle rehydration rate, firmness and visco-elasticity, and is most controlled by the steaming process. During frying, because the moisture content in noodles drops rapidly, starch gelatinization is very limited.

TABLE XII
CHINESE RAW NOODLE SCORING SHEET[a]

Date ____________ **Name** ______________ **Sample Lab No.** ______________

Points	Quality factor	Evaluation item	Score (1–10)[b]	Subscore[c]
20	Machining	Mixing (10) Sheeting (6) Slitting (4)		
5	Dough sheet appearance			
30	Noodle color stability	2 hr (10) 24 hr (20)		
20	Texture after cooking for 5 min	Bite (10) Springiness (6) Mouthfeel (4)		
25	Texture after cooking for 5 min and holding for 5 min in hot water	Bite (12) Springiness (5) Mouthfeel (3) Tolerance (5)		
100	Total score			

[a] From Hou and Kruk (1998, Table VIII, p. 9); used by permission.
[b] On a scale of 1–10; the control sample is scored 7 for each item.
[c] Subscore is the product of (score × maximum point)/10. Example: if a sample's sheeting is scored 8 (scale: 1–10), and its maximum point is 6, the subscore is (8 × 6)/10 = 4.8.

B. COLOR

Noodle color is one of the most important quality characteristics, because it is the first to be perceived by the consumers. Whether the noodle color is attractive or not determines to a large extent the customer's purchase decision. Table XXI summarizes the noodle color requirements for various types. All noodles require good brightness. Color can be either white or yellow depending on the absence or presence of alkalin salts. Minimal noodle darkening within 48 hours is desirable. This may not be a problem for noodles that are subjected to boiling, steaming, frying, drying or retort pouch packaging because these processes can largely inhibit the enzyme action causing noodle darkening.

The ultimate judgement of noodle color acceptability has to be done by eye. However, when a subjective evaluation is not possible, instrumental measurement of noodle color can be a reliable alternative tool. It has been

TABLE XIII
BOILED JAPANESE NOODLE SCORING SHEET[a]

Date ____________ **Name** _____________ **Sample Lab No.** _____________

Points	Quality factor	Evaluation item	Score range and control[b]	Score[c]
25	Color		10–25 (17.5)	
20	Surface appearance		8–20 (14)	
45	Texture	Softness/hardness (10)	4–10 (7)	
		Elasticity (25)	10–25 (17.5)	
		Smoothness (10)	4–10 (7)	
10	Taste		4–10 (7)	
100	Total score		40–100 (70)	

[a] Modified from Nagao (1996, Table II, p. 190); used by permission.
[b] The lowest possible score for each item assessed is 40% of the maximum score. Score for the control sample is shown in parentheses and is given 70% of the maximum score allocated to each evaluation item.
[c] Scoring is done in increments of 10% of the maximum score.

reported that several instrumental color parameters of noodle dough sheets are highly correlated with sensory noodle color scores. Miskelly (1984) measured the dough sheet brightness (L) using a Hunterlab Color Difference Meter and correlated it with sensory color scores of both uncooked and boiled udon noodles. Using the same instrument, Lee and coworkers (1987) found that brightness (L) and yellow index (YI) of uncooked noodles and dry noodles had significant positive and negative correlations, respectively, with the appearance preference scores of cooked Korean dry noodles. They also noticed that yellowness in raw and dry noodles carried through to the cooked products, but cooked noodle brightness was not affected by the color of raw or dry noodles. These suggest that measuring raw noodle sheet color may not always predict the color preference of the finished product. At the author's laboratory, one of our research objectives was to identify instrumental measures of noodle color and texture that can be correlated with sensory evaluation results done by Asian noodle experts. We use a Minolta Chroma Meter (model CR-310) to measure the L*, a* and b* values (CIE L*a*b* color space) of flour, uncooked and cooked noodle sheets and read the color at different time intervals, typically 0 hr, 24 hr and, sometimes, 48 hr after noodles are made. It was discovered that the L* value of uncooked noodle sheet positively correlated

TABLE XIV
CHINESE WET NOODLE (TAIWAN) SCORING SHEET[a]

Date ____________ **Name** ______________ **Sample Lab No.** ______________

Points	Quality factor	Evaluation item	Score (1–10)[b]	Subscore[c]
15	Machining	Mixing (7) Sheeting (6) Slitting (2)		
20	Parboiled noodle color stability	2 hr (10) 24 hr (10)		
25	Cooking yield (1.5 min cooking)			
20	Texture after cooking parboiled noodles for 2 min	Bite (10) Springiness (6) Mouthfeel (4)		
20	Texture after cooking parboiled noodles for 2 min and holding for 5 min in hot water	Bite (10) Springiness (4) Mouthfeel (3) Tolerance (3)		
100	Total score			

[a] From Hou (1998).
[b] On a scale of 1–10; the control sample is scored 7 for each item.
[c] Subscore is the product of (score × maximum point)/10. Example: if a sample's sheeting is scored 8 (scale: 1–10), and its maximum point is 6, the subscore is (8 × 6)/10 = 4.8.

in each case with sensory noodle color score of Chinese raw, Chinese wet and Thai bamee noodles (Kruk *et al.*, 1996).

C. TEXTURE

In contrast to color, texture characteristics of noodles are more complicated and less understood. Table XXI also describes the general texture attributes for various noodle types. There is a distinction in noodle texture between Japanese noodles and other types in that Japanese noodles are softer and more elastic, while others have harder bite. The texture of Korean fried instant noodles and dry noodles are somewhat similar to the Japanese noodles.

Sensory evaluation of noodle eating quality is a direct and ultimate method for evaluating the final product. Nevertheless, sensory evaluation is very subjective, laborious and expensive and, therefore, quicker and more accurate methods to identify wheat flour suitable for noodles are required.

TABLE XV

CHINESE WET NOODLE (MALAYSIA) SCORING SHEET[a]

Date ____________ **Name** ____________ **Sample Lab No.** ____________

Points	Quality factor	Evaluation item	Score (1–10)[b]	Subscore[c]
20	Machining	Mixing (5)		
		Sheeting (10)		
		Slitting (5)		
5	Dough sheet appearance			
10	Cooking yield	45 s (7.5)		
		2 min (2.5)		
20	Uncooked noodle color			
		Brightness		
		0 hr (5)		
		24 hr (2.5)		
		48 hr (2.5)		
		Yellowness		
		0 hr (5)		
		24 hr (2.5)		
		48 hr (2.5)		
20	Parboiled noodle color			
		Brightness		
		0 hr (5)		
		24 hr (2.5)		
		48 hr (2.5)		
		Yellowness		
		0 hr (5)		
		24 hr (2.5)		
		48 hr (2.5)		
20	Texture	Bite (10)		
		Springiness (5)		
		Mouthfeel (2.5)		
		Integrity (2.5)		
5	Shelf life after 48 hr (moldiness, taste, aroma)			
100	Total score			

[a] From Hou (1998).

[b] On a scale of 1–10; the control sample is scored 7 for each item.

[c] Subscore is the product of (score × maximum point)/10. Example: if a sample's sheeting is scored 8 (scale: 1–10), and its maximum point is 10, the subscore is (8 × 10)/10 = 8.0.

TABLE XVI
CHUKA-MEN NOODLE SCORING SHEET[a]

Date ____________ **Name** ______________ **Sample Lab No.** ______________

Points	Quality factor	Evaluation item	Score range and control[b]	Subscore[c]
30	Uncooked noodle color	0 hr (10) 24 hr (20)	4–10 (7) 8–20 (14)	
20	Uncooked noodle specks	24 hr (20)	8–20 (14)	
40	Boiled noodle texture	0 hr (20) 7 min (20)	8–20 (14) 8–20 (14)	
10	Boiled noodle taste	0 hr (10)	4–10 (7)	
100	Total score		40–100 (70)	

[a] Modified from Nagao (1996, Table III, p. 193); used by permission.
[b] The lowest possible score for each item assessed is 40% of the maximum score. Score for the control sample is shown in parentheses and is given 70% of the maximum score allocated to each evaluation item.
[c] Scoring is done in increments of 10% of the maximum score.

Similar to noodle color, instrumental measurement of cooked noodle texture can be a reliable and convenient alternative evaluation to the sensory method (Oh *et al.*, 1983; Lee *et al.*, 1987; Hou *et al.*, 1997). This is especially useful in screening large numbers of plant breeders' lines or when subjective evaluation is not possible.

By using an Instron Universal Testing instrument, Oh and coworkers (1983) found that the maximum cutting stress and the resistance to compression of cooked dry noodles were highly correlated with noodle firmness and chewiness, respectively. On the other hand, Lee and coworkers (1987) measured cooked Korean dry noodles using a shear-extrusion test in a specially designed Rheometer adaptor. They discovered that the texture preference of cooked noodles was inversely correlated with initial force, maximum force and work from the shear-extrusion test. Thus, the shear extrusion test was seen as a very useful, objective measure of the texture preference of cooked noodles. In a study on the relationship of Chinese fried instant noodle quality with flour properties, Hou and coworkers (1997) performed texture profile analysis (TPA) on cooked noodles using a TA.XT2 Texture Analyzer (Texture Technologies Corp., Scarsdale, NY/Stable Micro Systems, Haslemere, Surrey, UK). They reported that cohesiveness, hardness, and chewiness of TPA were significantly correlated

TABLE XVII
CHINESE FRIED INSTANT NOODLE SCORING SHEET[a]

Date ____________ **Name** ____________ **Sample Lab No.** ____________

Points	Quality factor	Evaluation item	Score (1–10)[b]	Subscore[c]
35	Machining	Mixing (10) Sheeting, slitting and waving (10) Steaming (10) Frying (5)		
10	Fried noodle color			
25	Texture after cooking for 4 min	Bite (10) Springiness (10) Mouthfeel (5)		
30	Texture after cooking for 4 min and holding for 6 min in hot water	Bite (15) Springiness (10) Mouthfeel (5)		
100	Total score			

[a] From Hou (1998).
[b] On a scale of 1–10; the control sample is scored 7 for each item.
[c] Subscore is the product of (score × maximum point)/10. Example: if a sample's mixing is scored 8 (scale: 1–10), and its maximum point is 10, the subscore is (8 × 10)/10 = 8.

with the eating quality of cooked noodles. Of the three instrumental parameters, cohesiveness was shown to be the most useful instrumental measure for the evaluation of fried instant noodle eating quality.

VIII. FACTORS AFFECTING NOODLE COLOR

Factors that can affect noodle color can be categorized as three main groups: flour based, ingredient based and process based (Table XXII). There are many variables in each category, however, flour-based variables are primary causes and deserve particular attention.

A. FLOUR COLOR

Flour color is a major determinant of noodle color. Flour color is affected by numerous variables: wheat variety, growing location, milling effect

TABLE XVIII
KOREA FRIED INSTANT NOODLE SCORING SHEET[a]

Date ____________ **Name** ______________ **Sample Lab No.** ______________

Points	Quality factor	Evaluation item	Score[b]
25	Machining	Mixing (5) Sheeting, slitting and waving (5) Steaming (10) Frying (5)	
5	Dough sheet color		
30	Cooking property	Cooking water cloudiness, noodle breakage (10) Swelling tolerance in soup (20)	
40	Sensory evaluation of cooked noodles	Appearance (brightness and shininess) (4) Mouthfeel (smoothness and tenderness) (10) Bite texture (hardness and viscoelasticity) (20) Taste (6)	
100	Total Score		

[a] Modified from Anon (1995).
[b] Scoring is done compared with a control sample for each item.

(extraction rate, particle size and starch damage level), protein content, and the effect of bleaching treatments (Miskelly, 1984). The whiteness of flour is governed by two independent factors: brightness and yellowness. Brightness is influenced largely by the milling process through bran inclusion effects and particle size, whereas yellowness is due principally to the carotenoid pigments of wheat (Fortmann and Joiner, 1977). Miskelly (1984) indicated that protein content was the single most important determinant of dry flour brightness, but when flour was measured for wet paste brightness, brown pigment became the single most important component. Flour carotenoids, principally xanthophyll, together with flavone compounds, are responsible for flour yellow color. Bleaching with benzoyl peroxide has been a commercial practice to destroy yellow pigments.

Oliver *et al.* (1993) reported that CIE L* was correlated with flour ash content, b* with yellow pigment, and L*-b* with both ash and yellow pigment. Tristimulus color measurement of dry flour is easy, speedy, with simple sample preparation, and is non-destructive; it also provides information simultaneously about both the brightness and yellowness

TABLE XIX

THAILAND BAMEE NOODLE SCORING SHEET[a]

Date ____________ Name ____________ Sample Lab No. ____________

Points	Quality factor	Evaluation item		Score[b]
10	Machining	Mixing (5)		
		Sheeting and slitting (5)		
30	Uncooked noodle color	Brightness	0 hr (10)	
			24 hr (10)	
		Yellowness	0 hr (5)	
			24 hr (5)	
10	Uncooked noodle dryness	0 hr (5)		
		24 hr (5)		
15	Cooked noodle color	Brightness (10)		
		Yellowness (5)		
5	Cooked noodle surface appearance			
10	Cooking property at 3 min			
20	Texture	Bite (10)		
		Springiness (5)		
		Smoothness (5)		
100	Total score			

[a] From Hou (1998).

[b] Scoring is done compared with a control sample for each item; the control sample score is given 80% of the maximum score allocated to each evaluation item.

components. The main disadvantage of dry flour measurement is that differences in particle size limit the extent to which results can be compared. Particle size of dry flour affects reflectance. Coarser flour appears darker because of the shadow cast by the larger particles. A flour with finer particle size is brighter and whiter. This limitation can be overcome by measuring flour-water slurries. Flour color grade measured using the Kent Jones on a flour/water paste is strongly associated with protein and is correlated more closely with protein than with ash (Bushuk *et al.*, 1969).

The fact that starch damage also affects the flour brightness (Miskelly, 1984) suggests that wheat hardness may be important. Whole starch granules reflect more light, and this reflectance decreases with increasing starch damage in the milling process.

TABLE XX
ORIENTAL NOODLE PROCESSING EVALUATION[a]

Process	Evaluation criteria
Mixing	Optimal water absorption; small and uniform crumb size; no big sticky lumps
Sheeting	No tearing and folding; non-sticky and smooth surface; free of streakiness; correct thickness reduction
Slitting	Clean cut; sharp edges; correct noodle size; no breakage; no loose crumbs
Waving	Uniform and continuous waves
Steaming	High degree of starch gelatinization; not sticky; glossy surface; good wave integrity
Frying	Uniform noodle appearance; good shape; not oily; characteristic fried noodle aroma
Regular air drying	Free from checking and breakage; no "hair" splitting
Hot blast air drying	Free from checking; not sticking to each other
Parboiling	High cooking yield; low cooking loss; good cooking tolerance
Cooking in water	Short cooking time; good texture tolerance to overcooking

[a] Modified from Hou and Kruk (1998, Table IX, p. 10); used by permission.

B. NOODLE COLOR FACTORS

Flour Color Grade, protein content and yellowness were found to be the most useful predictive parameters for noodle color (Miskelly, 1984). Japanese noodles and Chinese raw noodles are both made from flour, salt and water, and products with satisfactory brightness and whiteness are preferred by consumers. Thus, the color of the product is determined primarily by the color of the flour used (Yasunaga and Uemura, 1962). Miskelly (1984) confirmed that the sensory color score of fresh Japanese noodles was highly correlated with Flour Color Grade.

After examining 56 wheat samples grown in several locations and multiple years for Japanese udon noodle making, Miskelly (1984) concluded that flour protein content, other than color, was the single most important factor affecting the brightness (L, measured by a Hunter Color Difference Meter) of the fresh Japanese noodle sheets. Flours of lower protein content gave the whiter noodles. High brown pigment levels were also found to be associated with the discoloration of fresh noodles. Brown pigments are dark-colored melanins resulting from the oxidation of phenols to quinones by PPO that subsequently reacted with proteins. Once the noodles were boiled in water, noodle color did not correlate significantly with either protein content or brown pigments, presumably because the melanins dissolved in the cooking water. However, the boiled noodle color was negatively affected by the yellowness pigment of the flour.

TABLE XXI

ORIENTAL NOODLE COLOR AND TEXTURE EVALUATION[a]

Noodle type	Color requirement	Texture requirement
Chinese raw	Bright and white color; little discoloration within 24 hr	Firm bite and elastic; good mouthfeel; less texture deterioration in hot water
Japanese udon	Bright and creamy white color; little discoloration within 24 hr	Soft and elastic; smooth surface; good mouthfeel
Chinese wet	Bright yellow color; little discoloration within 48 hr	Firm bite, chewy and elastic; less sticky; stable texture in hot water
Chuka-men	Clear bright yellow color; little discoloration and specks within 24 hr	Good balance of softness and hardness; elastic; smooth; less texture deterioration in hot water
Chinese fried instant	Bright yellow color	Firm bite and chewy texture; smooth surface; stable texture in hot water
Korean fried instant	Bright yellow color	Optimum firm; visco-elastic; good mouthfeel
Thailand bamee	Bright, intense yellow color; little discoloration within 24 hr	Strong bite, springy and smooth texture

[a] Modified from Hou and Kruk (1998, Tables X and XI, p. 10); used by permission.

TABLE XXII

FACTORS AFFECTING NOODLE COLOR[a]

Flour source	Other ingredient source	Process source
Flour color	Salt/alkaline salt	Number of sheeting passes
Flour ash	Added water level	Cooking
Proteins	Eggs	Drying
Enzymes	Added colorings	Frying oil quality
Flour particle size	Added gluten	Frying oil temperature
Starch damage	Added starch	Packaging
Pigments	Hydrocolloids	
	Preservatives	

[a] Modified from Miskelly (1998, Table 4, p. 131); used by permission.

The brightness of the raw Chinese alkaline noodles also had an inverse relationship with the flour protein and brown pigment level (Miskelly, 1984). In the evaluation of Chinese instant noodles, where flours of extraction rates of 60 to 72% were included, Miskelly (1984) found that the brightness and yellowness of the noodle sheet showed respective negative and positive correlations with extraction yield. By increasing flour extraction, more flavone compounds are available for reaction with the kan sui to produce a yellower color, but increased contamination by bran and other components high in minerals leads to noodle discoloration. Oh *et al.* (1985c) reported that the color of white dry noodles darkened as protein content increased or when flour extraction was high.

The PPO is located largely in the bran and tends to increase exponentially with increasing mill extraction rate (Hatcher and Kruger, 1993; Baik *et al.*, 1994a). The presence of high levels of PPO was found to be detrimental to the color of raw Cantonese noodles because PPO produced a deleterious dull brown color rather than the desired pale yellow color (Kruger *et al.*, 1992). In a study investigating the cause of noodle sheet discoloration for udon, Cantonese and instant noodles, Baik *et al.* (1995) noticed that discoloration (as measured by CIE L* values) was highly correlated with protein and PPO activity. Within a cultivar, protein is a dominant factor, and across cultivars that are wide in protein content, PPO activity plays a major role in the discoloration of noodle sheet. It was noted that the greatest discoloration happened shortly after dough mixing, when water activity in the crumbly dough was highest.

IX. FACTORS AFFECTING NOODLE TEXTURE

Factors affecting the texture of cooked noodles include starch characteristics, protein content and quality, ingredients added and processing variables. Of these factors, starch and protein play a major role in governing textural properties. But requirements for these two components differ for different types of noodles. Generally speaking, starch characteristics are more important to Japanese noodles and some Korean noodles that require soft wheat flour of low to medium protein content. Other types of noodles are made from 10–12.5% protein flour, thus, protein would be expected to play a greater role in determining end product quality than for lower protein products.

A. STARCH

The Australian Standard White (ASW) has been the preferred wheat class for the production of Japanese noodles. The quality of this wheat has been characterized as soft wheat having moderately high dough strength and good starch characteristics that have been reported to be responsible for superior Japanese noodle quality. The importance of starch characteristics to the eating quality of Chinese yellow alkaline noodles has also been recognized. Starch properties that have been investigated and related to the eating quality of cooked noodles include starch paste peak viscosity, gelatinization temperature, time to peak viscosity, breakdown, amylose content, swelling power and swelling volume.

1. Pasting Characteristics

In early studies, measurement of starch pasting properties was done using a Brabender Amylograph/Viscograph and the results were strongly correlated with the eating quality of Japanese noodles. These pasting properties include high starch paste peak viscosity (Moss, 1980, Crosbie, 1991; Konik *et al.*, 1992), low gelatinization temperature (Nagao *et al.*, 1977), short time to peak viscosity and high breakdown (Oda *et al.*, 1980). For yellow alkaline noodles, it was reported that noodle firmness was negatively correlated with both starch peak viscosity and breakdown (Moss, 1982; Miskelly and Moss, 1985). It appears that lower starch paste viscosity is associated with the preferred firmness for alkaline noodles. However, this is not desirable when high α-amylase is responsible for the lower viscosity. On the other hand, noodle elasticity was found to be positively correlated with both starch peak viscosity and breakdown (Moss, 1982).

Using the Amylograph/Viscograph to measure starch pasting properties can be very restrictive because it requires a large sample size (45 g starch) and a long analysis time (over 1 hr). Thus, the Rapid Visco Analyzer (RVA) was later used as a replacement for the measurement of pasting properties of starch or flour (Deffenbaugh and Walker, 1989). The main advantages of the RVA are that only a small sample size is required (3–4 g) for the test and the analysis takes a short time (10–20 min). By running a 20-min profile, Panozzo and McCormick (1993) reported that the RVA results were significantly correlated with flour and starch peak viscosity obtained using the Viscoamylograph. Their results also indicated that the RVA peak paste viscosity of starch, flour or wholemeal correlated highly with the sensory eating quality of Japanese noodles and Korean white salted noodles. Using an optimized heating and cooling profile, Batey *et al.* (1997) reported that in the presence of α-amylase inhibitor ($AgNO_3$), RVA peak viscosity and breakdown of wholemeal also correlated positively with the eating quality of Japanese noodles. This would provide a quick method for screening Japanese noodle wheat without milling wheat into flour.

Some relationships between textural aspects of yellow alkaline noodles and RVA pasting properties of starch, flour or wholemeal have also been documented. In their study, Konik *et al.* (1994) reported that cooked alkaline noodle smoothness correlated positively with RVA breakdown and negatively with the final viscosity and setback of starch, flour or wholemeal. Meanwhile, cooked noodle firmness had a negative correlation with

RVA breakdown and a positive correlation with the final viscosity and setback of starch, flour or wholemeal. It appears that there is an optimum starch quality range for a balanced noodle eating quality, just as there is an optimum protein content range (10–12%). Additionally, the negative and positive correlations found for alkaline noodles were usually reverse to those found between starch properties and the eating quality characteristics of udon noodles.

2. *Amylose Content*

The wheat endosperm starch comprises amylose and amylopectin, and the ratio of the two determines the intrinsic starch property (Moss, 1980; Moss and Miskelly, 1984; Zeng *et al.*, 1997). These studies indicated that there is genetic variation in both peak paste viscosity and amylose in wheat, and that lower amylose corresponds to higher peak paste viscosity. Flour of low amylose content has been preferred for Japanese noodle manufacture (Oda *et al.*, 1980). Miura and Tanii (1994) further identified that low amylose content was a common property in cultivars suited to Japanese noodles, whereas a high flour peak viscosity was not always the case, though a high peak viscosity is another important determinant for Japanese noodle production. When the flour is sprout damaged, its peak viscosity will be affected more by α-amylase activity than by amylose content.

3. *Swelling Power or Swelling Volume*

Starch swelling power was defined as the weight of sedimented starch gel recovered per gram dry starch after gelatinizing a starch sample in water at a specified temperature for a set time, followed by centrifuging and correcting for soluble dry matter (Leach, 1965). The test offers an alternative measurement to starch paste peak viscosity for predicting noodle eating quality. It has several advantages over conventional paste viscosity measurements in terms of analysis time and sample size (Crosbie, 1991). It utilizes only one gram of starch, is relatively easy to carry out with simple laboratory equipment and can be performed on large numbers of samples simultaneously. Starch swelling power was found to be affected by the cultivar, growth location and growth season of the wheat (Konik *et al.*, 1993).

The potential of using swelling power test for predicting Japanese noodles was first suggested by Crosbie (1989) and Toyokawa *et al.* (1989). Starch swelling power was found to be highly correlated with the eating quality of boiled Japanese noodles (Crosbie, 1991, Konik *et al.*, 1993). Konik *et al.* (1993) suggested incorporating wheat protein content and wheat softness (PSI) with measures of starch swelling power to improve the overall prediction model of noodle quality. Swelling power values measured using a micro test using 0.25 g flour, 0.35 g wholemeal, 0.2 g starch or 0.2 g Quadrumat Junior flour also correlated significantly with peak paste viscosity by RVA and with Japanese noodle eating quality (McCormick *et al.*, 1991).

Although the swelling power test is much less time consuming than paste viscosity measurements, it still needs to separate the sedimented gel and supernatant layers after centrifuging, to weigh the gel and to determine the soluble dry matter in the supernatant by an evaporative or colorimetric method. This limitation led to the development of the faster swelling volume test, which has been applied to starch and a range of flour types from both soft- and hard-grained wheats (Crosbie, 1989, 1991; Crosbie *et al.*, 1992). Swelling volume is a measure of the height of resultant sedimented gel in the constant bore tube (Crosbie, 1991). The author reported that both starch swelling power and swelling volume were positively correlated with starch paste peak viscosity, and with the total texture score of the boiled Japanese noodles. The flour swelling volume accounted for 48% of the variation in total texture score, though was not as highly correlated as starch swelling volume. The flour swelling volume test is favored because there are no starch separation steps. In a subsequent study, Crosbie *et al.* (1992) further suggested that the swelling volume of each type of flour (Buhler, Quadrumat Junior micromill and wholemeal flour) could be used to predict the eating quality of Japanese noodles. This was because the swelling volume of each flour type was significantly and positively correlated with total noodle texture score and its components (balance of softness and hardness, elasticity and smoothness).

The flour swelling volume test can also be applied to slightly sprouted grain (falling number: 175–200 s) without special inactivation treatment (Crosbie and Lambe, 1993). With more severely sprouted grain (falling number: 62–63 s), flour swelling volumes declined substantially and an inactivation treatment was required (0.5 mM $AgNO_3$) to inhibit α-amylase activity. When the inactivation treatment was applied to severely sprouted grain, swelling volumes of wholemeal were highly correlated with the eating quality of boiled noodles derived from sound grain.

Much of the variation in starch paste viscosity is genetically controlled (Loney and Meredith, 1974; Loney *et al.*, 1975), therefore careful selection of wheat will enable the appropriate starch properties to be obtained for specific noodle types. Amylograph, RVA and swelling power/volume tests have been extensively used in breeding programs to screen for optimum starch properties.

B. PROTEIN

Protein quantity and quality are the primary traits responsible for the eating quality of all noodles other than Japanese and Korean types. No flour with protein below 9.5% gave Cantonese noodles of satisfactory eating quality, and strong flours as shown by high resistance and extensibility in the extensigraph yielded desirable firmness and elasticity (Miskelly and Moss, 1985).

The internal firmness of cooked, hard wheat noodles increased linearly with protein content, but the surface firmness of cooked noodles was not influenced significantly by protein content (Oh *et al.*, 1985c), but by protein quality as shown by a fractionation and reconstitution study (Oh *et al.*, 1985d). However, the findings of Oh *et al.* (1985d) were not supported by another study where gluten from soft and hard wheats was equally detrimental to surface firmness (Rho *et al.*, 1989). Additional information is needed to determine how protein in soft and hard wheat affects the surface firmness of cooked noodles.

Huang and Morrison (1988) reported, after analyzing Chinese and British wheats, that SDS sedimentation values were significantly correlated with maximum cutting stress and maximum compression stress of cooked Chinese white and yellow noodles, and might be used to predict noodle firmness and chewiness. The presence of γ-gliadin bands 44.5 and 45.0 separated by acid electrophoresis was associated with strong gluten and good noodle eating quality, and the presence of band 41.0 was associated with weak gluten and poor noodle eating quality.

It is clear that both protein content and quality are both positively correlated with the eating quality (bite) of certain Chinese noodles, but protein content is negatively correlated with noodle color and brightness (Miskelly, 1984; Miskelly and Moss, 1985; Oh *et al.*, 1985c). Consequently there is an optimum protein content range for good quality noodles.

C. INGREDIENTS

Many ingredients besides flour are used in noodle production and are functional in cooked noodle texture. Sodium carbonate, a common alkaline salt used in many Chinese-type noodles, is reported to affect the firmness of parboiled Chinese wet noodles (Shelke *et al.*, 1990). At high levels, starches can improve the noodle whiteness, but weaken the breaking stress of dry noodles (Rho *et al.*, 1989). It was noticed that all starches at the 10–15% level increased the surface firmness of cooked dry noodles, with waxy corn starch being the most effective among all. However, various starches affected the cutting stress of the cooked noodles differently. For instance, addition of 10% modified wheat starch or waxy maize starch to the hard wheat flour increased the cutting stress and surface firmness of cooked noodles, while potato, corn and wheat starches decreased the cutting stress, especially when the usage level was increased to 15%. Lecithin was found to increase the strength of the hard wheat noodles when used at 0.5% level of the flour, whereas sodium stearoyl-2-lactylate and monoglycerides improved the surface firmness of cooked dry noodles (Rho *et al.*, 1989).

D. PROCESSING VARIABLES

The texture of cooked noodles depends largely on flour characteristics and on conditions used during noodle preparation. By using a response-surface methodology, Oh and coworkers (1985a) examined the effects of five variables (water absorption, dough pH, mixing time, roll speed, and reduction percentage in roll gap) on the texture and color of uncooked and cooked dry noodles. Their results showed that cooked noodle texture parameters (cutting stress, surface firmness and resistance to compression) increased with increasing dough water absorption (32–35%) and dough pH (4–10). Dough gluten development is improved at higher water absorption (Dexter *et al.*, 1979) and/or at alkaline pH (Edwards *et al.*, 1996). The surface firmness of cooked noodles was improved when the dough passed between the rolls at a slower speed but with a quicker reduction in dough thickness with fewer sheeting steps (Oh *et al.*, 1985a). It should be cautioned that a rapid reduction of thick dough sheets might cause enough stress to damage the roll bearings. Extending dough rest time from 0 to 60 min prior to sheeting was shown to dramatically improve the surface firmness of cooked noodles (Oh *et al.*, 1985b). The length of time after preparation of raw alkaline noodles had a noticeable impact on the texture of cooked noodles (Kruger *et al.*, 1994). The maximum cutting stress (firmness) progressively decreased, where the resistance to compression (chewiness) and the surface firmness increased slightly in a period of 0–24 hr.

X. SUMMARY

Oriental noodles have been in existence for thousands of years. Several types, mostly machine-made, are produced and consumed worldwide. In the evaluation of flour for noodle making, processability, noodle color and texture are the three key quality attributes to be considered. Noodle process performance is particularly important in modern industrial production. In terms of noodle color, brightness is required, and whiteness or yellowness is essential depending on the noodle type. Noodle texture, however, is more complicated in the characterization of each noodle type, and progress can only be made to understand this property by involving Asian flour and noodle industrial representatives.

In the scientific literature, there are abundant studies on Japanese udon noodles. Research into other noodle types, however, has lagged behind by far. There are a number of areas that require further study for all noodles, but the following three deserve immediate attention. First, the functionality of biochemical components such as gluten, starch, enzyme, lipids and pentosans in noodle processing, color and texture needs to be fully investigated. Some of these components have been related to certain noodle quality, but findings have been neither conclusive nor comprehensive. Such knowledge is also needed to provide guidelines for plant breeders in developing wheat varieties of improved quality for noodle products. Second, simple and objective measurement tools need to be developed to quantify and monitor product quality at each processing stage. The noodle qualities to be measured include the rheological property of noodle dough sheet, degree of starch gelatinization, noodle color and texture. These instrumental measures are useful only when they can be correlated with sensory evaluation results. Third, it is necessary to continuously find ways to improve product quality. For example, adopting vacuum mixing can be a mean of improving Chinese-type noodle texture that requires firm bite by facilitating gluten development. Reducing the fat absorption of fried instant noodles is another interesting research topic.

Considering the fact that it has taken cereal scientists nearly a century to understand the breadmaking process, it is certainly not an easy task to research noodle products, not to mention that the variety of noodles is so tremendous. However, a certain amount of information generated from breadmaking study does have some relevance to noodlemaking. For instance, some instruments developed for measuring breadmaking quality have been used by millers and noodle makers for testing noodle flour quality. How to effectively apply some of the breadmaking knowledge to noodlemaking and build upon it remains a challenge to cereal scientists in the many years to come.

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