

# The Role of Lipids in Determining Spaghetti Cooking Quality<sup>1</sup>

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## ABSTRACT

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Durum semolina nonpolar lipids influence surface stickiness of microprocessed cooked spaghetti. Removal of nonpolar lipids with petroleum ether increases stickiness, whereas nonpolar lipid enrichment decreases stickiness. Neither commercial coconut oil nor commercial sunflower oil had any effect on spaghetti stickiness. Commercial monoglycerides decreased stickiness and improved tolerance to overcooking. Semolina amylograph characteristics were affected by removal and addition of lipids (except sunflower oil). Reconstitution of defatted semolina with extracted lipids demonstrated that the extraction

procedure did not influence amylograph characteristics or spaghetti quality. Some effects of lipids on farinograph characteristics were found, but these changes were not related to any of the cooking quality parameters. Spaghetti processed by a laboratory-scale continuous process press and dried at high and low temperatures verified the strong improving effect of monoglycerides on spaghetti stickiness and tolerance to overcooking. A quick method for estimating surface stickiness of cooked spaghetti and cooking loss using color measurement of the iodine-amylose complex appears promising.

Numerous studies that have been reported on cereal lipids (Morrison 1978) include methods for extraction and characterization of cereal lipids, investigation of lipolytic enzymes, and determination of the functional properties of lipids in various cereals and cereal products. However, the role of lipids in pasta products has not been widely studied. Carotenoid pigments and lipoxygenase have been the topic of a number of studies (Irvine 1959, Matsuo et al 1970, Walsh et al 1970, Burov et al 1974, McDonald 1979, Hsieh 1983).

Fabriani et al (1968) studied the changes that lipids undergo during processing of pasta products. They found less extractable lipids in pasta than in semolina, suggesting that under the mechanical action of the extrusion screw, lipids undergo chemical changes or are complexed or both. Dahle and Muenchow (1968) reported that the removal of lipids or proteins increased the amount of amylose in the cooking water. Removal of lipids led primarily to greater stickiness.

Lin et al (1974) concluded that neither nonpolar nor polar lipids affected the cooking quality of spaghetti to any extent. Quality factors assessed were water absorption, color score, cooked weight, cooking loss, and firmness score; surface characteristics were not assessed.

Changes in lipid binding during commercial pasta processing were studied by Barnes et al (1981). They found that about 90% of the free lipids in semolina became bound during processing,

especially during the drying stage. Spaghetti cooking quality was not determined. Laignelet (1983) has written a review of the literature on lipids in pasta and pasta processing.

Niihara et al (1982) studied the effect of lipids on Japanese "hand-stretched" noodles. They reported that fatty acids produced in the storage process contribute to the texture of cooked noodles by inhibiting the swelling of starch granules and affecting the viscosity of gelatinized starch after cooking. Mohri (1980) studied the interaction between starch and fatty acid esters in frozen starch noodles and showed that fatty acid esters, especially the higher molecular weight esters, were effective in decreasing the adhesive force of starch.

As there appears to be little doubt that lipids, although only a minor constituent, play a role in the physical properties of cooked spaghetti, this study was undertaken to investigate that role.

## MATERIALS AND METHODS

Samples used in the preliminary study were semolinas milled from three grade-composite samples representing export cargo shipments. For subsequent studies a sufficient quantity of semolina was milled from a large grade-composite sample. Wheats were tempered overnight and milled on a Buhler laboratory mill in conjunction with a laboratory purifier (Dexter et al 1985b). The mean semolina yield was 65% on a cleaned wheat basis, corrected for moisture loss.

### Lipid Extraction

A Soxhlet extraction apparatus was used to extract nonpolar lipids with light petroleum ether (boiling range 38.7-56.5°C, extraction time 24 hr, approximately 30 cycles of solvent). The defatted semolina was air-dried. Solvent was removed from the

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extracted lipids by a rotary evaporator. Isolated lipids were weighed, then dissolved in a fixed volume of solvent and stored under nitrogen at 4°C. Mean yield of semolina nonpolar lipids was about 1%.

#### Lipid Addition

To reconstitute defatted semolina or to add excess lipids to the control semolina, an appropriate volume of the lipid solution was thoroughly mixed into the semolina, and the solvent was allowed to evaporate. Commercially produced coconut and sunflower oils were dissolved in petroleum ether and added to semolina in the same way. A distilled monoglyceride powder was added directly to semolina and mixed thoroughly.

#### Lipid Analysis

Lipid components were identified by thin-layer chromatography (TLC) as described by Morrison et al (1980). Plates were analyzed with a densitometer rather than the gas chromatograph method described by Morrison et al (1980). Fatty acid composition of the lipids used in this study was determined by gas-liquid chromatography (Daun et al 1983).

#### Spaghetti Processing

Spaghetti samples were prepared by the micromethod (Matsuo et al 1972). Some semolina samples were also processed by a laboratory-scale continuous-process press (De Francisci Machine Corporation, Brooklyn, NY) under conditions reported previously (Matsuo et al 1978). Samples were dried by a conventional low-temperature (LT, 39°C) drying cycle over 22 hr, as well as by a high-temperature (HT, 70°C) drying cycle. Details of the drying conditions were described by Dexter et al (1981).

#### Spaghetti Cooking Quality

Spaghetti was cooked in water made up to constant hardness to insure repeatability of stickiness values (Dexter et al 1985b). The following reagent grade chemicals were added to deionized water: Na<sub>2</sub>CO<sub>3</sub> (60 mg/L), NaHCO<sub>3</sub> (75 mg/L), K<sub>2</sub>SO<sub>4</sub> (15 mg/L), MgCl<sub>2</sub> (15 mg/L), CaCl<sub>2</sub> (45 mg/L). A small amount of precipitate that resulted was dissolved by adding 6M H<sub>2</sub>SO<sub>4</sub>. The final pH of the prepared water was adjusted to 7.5 with 1M NaOH.

Optimum spaghetti cooking time (usually about 12 min) was taken as the time required for the white core to disappear when a strand was squashed between two clear plastic plates. Textural characteristics—shear rate (tenderness index, T), compressibility (C), and resilience (R)—were determined as described by Matsuo and Irvine (1969, 1971). A cooking score was calculated from the ratio, R/C × T; the higher the value, the better the cooking quality. Surface stickiness of cooked spaghetti was determined with a Grain Research Laboratory compression tester as described by Dexter et al (1983) with some modification (Dexter et al 1985a).

For weight of cooked spaghetti, 10 g of spaghetti (14.0% moisture basis) was cooked for 12, 17, and 22 min. Cooking water volumes were 125, 150, and 175 ml, respectively, for the three cooking times. Samples were drained, covered, and after 5 min, weighed.

The loss of solids during cooking was determined by collecting the cooking water following drainage of the spaghetti for the stickiness test and freeze-drying the cooking water overnight. The freeze-dried residue was weighed and results expressed as a proportion of uncooked spaghetti on a constant moisture basis.

#### Surface Amylose

The amount of amylose that can be washed from the surface of cooked spaghetti was determined as follows: 5 g of spaghetti was cooked for 12, 17, and 22 min in 125, 150, and 175 ml (respectively) of prepared water. Five minutes after draining, the sample was placed in a centrifuge tube with 25 ml of deionized water and rotated in a wheel (Roto-Torque, heavy duty rotator, Cole-Parmer Instrument Co., Chicago) for 20 min. It was then centrifuged at 12,000 × g for 15 min and the supernatant decanted. To 1 ml of the supernatant, diluted to 15 ml with deionized water, 1 ml of iodine solution (2.0 g I<sub>2</sub>, 20 g KI/L) was added and made up to 25 ml. The

absorbance was measured after 10 min at 600 nm.

#### Amylose in the Cooking Water

Cooking water from each sample analyzed for surface amylose was made up to constant volume (100 ml) with deionized water, and centrifuged at 12,000 × g for 15 min. Then 0.5 ml of the supernatant was tested with iodine solution as described above for surface amylose.

#### Isolation and Analysis of Surface Carbohydrate

For isolating surface carbohydrates, the method described by Dexter et al (1985a) was used. To quantitate the amount of carbohydrate in the surface material, the method reported by LaBerge et al (1973) using 0.1% orcinol in 70% H<sub>2</sub>SO<sub>4</sub> was followed.

#### Amylograms

The pasting characteristics of semolina, defatted semolina, and semolina with various lipids added were obtained with a Brabender amylograph using 65 g of semolina and 450 ml of distilled water. Pasting temperature, peak height, peak temperature, 15-min height, and setback were measured according to Medcalf and Gilles (1966).

#### Farinograms

Farinograms were obtained at 31.5% absorption as described by Irvine et al (1961). Dough development time was taken as the time to reach maximum consistency; tolerance index was measured as the decrease in consistency from the peak to 4 min past the peak; bandwidth was measured 4 min past the peak.

#### Statistical Analysis

Analysis of variance (ANOVA) was carried out using random block experimental design (Snedecor and Cochran 1967). The significance of differences between treatments was tested by the method of Duncan (1955).

## RESULTS AND DISCUSSION

Results of the preliminary study using three grade-composite samples of export cargoes, each processed three times by the microprocessing method, are presented in Table I. They show that

TABLE I  
Cooking Characteristics of Spaghetti With and Without Lipids<sup>a</sup>

Sample	Stickiness (N/m <sup>2</sup> ) <sup>b</sup>	Cooking Score	Cooking Loss (%)
Sample I, dried at 39°C			
Semolina	740	17	6.8
Defatted semolina	705	15	6.9
Semolina + 1% nonpolar lipids	675	18	6.5
Sample II, dried at 39°C			
Semolina	835	13	7.4
Defatted semolina	900	15	7.4
Semolina + 1% nonpolar lipids	795	15	6.7
Sample III, dried at 39°C			
Semolina	845	18	7.0
Defatted semolina	890	18	7.6
Semolina + 1% nonpolar lipids	805	17	6.8
Sample III, dried at 70°C			
Semolina	700	24	6.8
Defatted semolina	770	24	7.7
Semolina + 1% nonpolar lipids	680	26	6.6
Effect <sup>c</sup>			
Replicate processing	3.0*	0.4	1.4
Treatment (T)	32.6***	2.4	30.3***
Samples (S)	23.7***	9.8**	0.8
T × S	0.3	0.7	0.7

<sup>a</sup>Spaghetti processed by the micromethod and tested at optimal cooking time.

<sup>b</sup>N/m = Newtons per square meter.

\*  $P < 0.05$ ; \*\*  $P < 0.01$ ; \*\*\*  $P < 0.001$ .

nonpolar lipids significantly affected ( $P < 0.001$ ) surface stickiness. In every case the sample with added lipids showed the least stickiness, whereas the defatted sample was the stickiest. One sample was dried at 70°C to show that lipids also influence stickiness of samples dried at high temperature.

ANOVA also confirmed a strong effect ( $P < 0.001$ ) of lipids on cooking loss (Table I). However, no effect on cooking score was apparent.

The significant correlation of lipids to surface stickiness led to a more detailed study involving a large semolina sample, a portion of which was defatted. The effects of lipids from other sources—coconut oil, sunflower oil, and a sample of commercially prepared monoglycerides—on spaghetti cooking characteristics were determined.

TLC of durum semolina nonpolar lipids (results not shown) gave a lipid distribution in the range reported for wheat flour nonpolar lipids by MacMurray and Morrison (1970). Triglycerides, free fatty acids, and diglycerides were the predominant components of the semolina nonpolar lipids, constituting 45, 25, and 20%, respectively. Monoglycerides were about 5% of total semolina nonpolar lipids. As expected, TLC confirmed that monoglycerides were the principal component in commercial monoglycerides, whereas sunflower oil and coconut oil are composed primarily of triglycerides.

Fatty acid composition shows (Table II) the predominance of unsaturated acids in durum semolina lipids and in sunflower oil, contrasted to the very large percentage of saturated acids in coconut oil. The coconut oil contained a high content of low- and medium-chain-length fatty acids. The major fatty acid component in the commercial monoglyceride sample is oleic acid.

The effects of lipids on the semolina pasting properties are shown in Figures 1 and 2. Removal of nonpolar lipids decreased

amylograph viscosity throughout the heating and cooling cycle (Fig. 1). Reconstitution of the defatted semolina restored the original peak viscosity indicating that the pasting characteristics were not irreversibly affected by petroleum ether extraction. Addition of 1% nonpolar lipids, on the other hand, increased viscosity throughout the cycle. Coconut oil exerted a similar effect whereas sunflower oil had no effect (Fig. 2). Monoglycerides increased setback significantly, but not the peak viscosity or viscosity during the 95°C hold.

Similar effects of lipids on amylograph viscosity have been reported previously. Medcalf et al (1968) showed a significant increase in amylograph peak viscosity upon addition of nonpolar lipids to wheat starch. Krog (1973) reported not only a significant increase in amylograph viscosity of wheat starch with 0.5% monoglycerides, but also a significant increase in the pasting temperature. Oleic acid increased amylograph viscosity throughout the complete cycle and also decreased the swelling and solubility of wheat starch when heated (Niihara 1984).

The change in amylograph viscosity caused by lipids has been attributed to formation of a lipid-amylose complex that makes the structure more rigid by stabilizing the swollen granules against breakdown (Schoch 1969).

To determine whether lipids affected the rheological properties of pasta doughs, farinograms at pasta dough absorption (31.5%, 14% moisture basis) were obtained. Results (Table III) indicated a slight influence of lipids on the mixing characteristics. Sunflower oil had no effect on farinograph characteristics. Coconut oil increased dough development time (DDT), whereas semolina lipids decreased DDT but did not affect maximum consistency (MC), tolerance index (TI) or band width (BW). Commercial monoglycerides decreased DDT slightly and lowered MC by 100 Brabender units. Removal of lipids decreased DDT slightly and increased MC. Compared to the control semolina, reconstituted defatted semolina exhibited shorter DDT, lower MC, and

TABLE II  
Fatty Acid Composition of Lipids (% Total Fatty Acids)

Fatty Acid	Durum Wheat Semolina Nonpolar Lipids	Commercial Sunflower Oil	Commercial Coconut Oil	Commercial Monoglycerides
8:0	...	...	6.7	...
10:0	...	...	6.0	...
12:0	...	...	45.9	...
14:0	...	0.1	17.4	...
16:0	16.5	6.2	9.4	11.5
18:0	1.4	4.3	3.4	33.6
18:1	19.6	19.3	8.0	53.1
18:2	56.8	68.4	3.0	1.4
18:3	3.4	0.2	...	...
20:0	0.1	0.3	0.2	...
20:1	0.5	...	...	0.4
22:0	0.1	0.7	...	...

TABLE III  
Effect of Lipids on Farinograph Properties<sup>a</sup>

Sample	Mixing Time (min)	Maximum Consistency (BU) <sup>b</sup>	Tolerance Index (BU)	Band Width (BU)
Control semolina	5.50	690	110	80
Defatted control	5.00	730	100	80
Reconstituted control	4.00	620	120	50
Control with				
1% semolina nonpolar lipids	4.75	620	120	60
1% coconut oil	6.75	690	110	70
1% sunflower oil	5.50	660	100	80
0.5% commercial monoglycerides	5.00	590	120	60

<sup>a</sup> Farinograph absorption = 31.5%.

<sup>b</sup> BU = Brabender units.

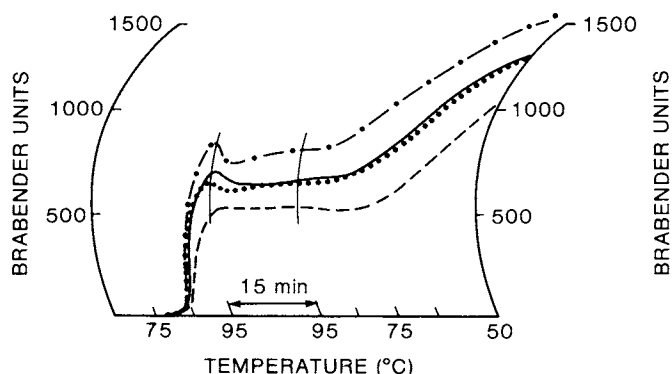


Fig. 1. Amylograph pasting curves for a durum wheat semolina (control —) and after defatting (---), reconstitution (●●●), and enrichment with nonpolar lipids (●-●-●).

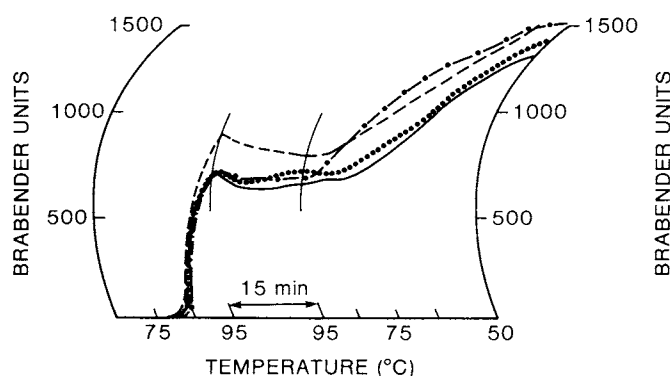


Fig. 2. Amylograph pasting curves for a durum wheat semolina control (—) and after enrichment with coconut oil (---), sunflower oil (●●●), and monoglyceride (●-●-●).

narrower BW, indicating an effect of solvent extraction on rheological properties.

Cooking characteristics of spaghetti processed from defatted, reconstituted, and enriched semolina are presented in Table IV. Reconstitution did not affect the cooking characteristics even though farinograph characteristics (DDT and MC) were affected. It has been shown (Dexter and Matsuo 1980) that of the farinograph characteristics only BW is strongly related to the cooking score. The slight change in BW is not sufficient to affect cooking quality.

Generally, at optimum cooking time lipids appear to be unrelated to cooking score (Table IV), as reported by Lin et al (1974). However, stickiness results of these samples confirmed the preliminary results. Removal of lipids heightened stickiness, whereas addition of semolina lipids or commercial monoglycerides lessened it. To a lesser extent cooking loss was also influenced by lipids. Removal of nonpolar semolina lipids increased cooking loss, whereas addition of monoglycerides reduced cooking loss. Coconut oil and sunflower oil have no effect on any of the cooking quality parameters.

The amount of surface carbohydrates rinsed from cooked spaghetti mirrored the change in stickiness brought about by various treatments (Table IV). This concurs with the results of D'Egidio et al (1982), who proposed a method to estimate spaghetti stickiness by isolation and determination of total organic matter.

The presence of lipids leads to less exudation of amylose during gelatinization because of lipid-amylose complexing. Dexter et al (1985a) implicated amylose on the surface of cooked spaghetti as a contributing factor to surface stickiness. Complexation of amylose with lipids, particularly monoglycerides, could lead to less amylose on the surface of cooked spaghetti resulting in reduced stickiness. In addition, if lipids decrease swelling and solubility of starch (Niihara 1984) then a decrease in cooking loss should be expected.

The determination of surface carbohydrate is time-consuming, so a simpler and quicker method was sought. Because spaghetti stickiness has been related to amylose on the surface of cooked spaghetti, the possibility of assessing stickiness by measuring the absorbance of rinsable surface material from cooked spaghetti with an iodine-amylose complex was tried on sticky and nonsticky spaghetti samples (Fig. 3). Results indicated a strong relationship ( $P < 0.01$ ) between the absorbance of the iodine-amylose complex and stickiness. The spaghetti samples were processed by the micromethod from a number of durum wheat semolinas and hard red spring wheat farina. Farina enriched with durum semolina nonpolar lipids and dried at both low and high temperatures was also analyzed for surface amylose and stickiness. Some of the scatter might be attributed to variability in free fatty acids or other lipid components that interfered with color development of the iodine-amylose complex. Nevertheless, the high correlation between the iodine-amylose absorption and stickiness shows great promise as a quick, simple method that could be used to predict stickiness.

TABLE IV  
Effect of Lipids on the Cooking Characteristics  
of Spaghetti Processed by the Micromethod<sup>a</sup>

Sample <sup>b</sup>	Stickiness (N/m <sup>2</sup> ) <sup>c</sup>	Surface Carbohydrate (%)	Cooking Score	Cooking Loss (%)
Control semolina	875 b	0.98 bc	15 a	7.4 bc
Defatted control	980 a	1.30 a	14 a	8.1 a
Reconstituted control	860 bc	0.94 bc	16 a	7.8 ab
Control enriched with 1% semolina				
nonpolar lipids	775 d	0.90 bc	14 a	7.5 bc
1% coconut oil	805 bcd	0.98 bc	14 a	7.4 bc
1% sunflower oil	820 bcd	0.84 bc	14 a	7.8 ab
0.5% commercial monoglycerides	660 e	0.75 c	15 a	7.2 c

<sup>a</sup> Means of duplicate processings.

<sup>b</sup> Spaghetti samples dried at 39°C and cooked to optimal time. Values followed by the same letter are not significantly different  $P < 0.05$ .

<sup>c</sup> N/m<sup>2</sup> = Newtons per square meter.

To determine whether processing methods influenced the effect of lipids on surface stickiness, spaghetti samples were processed from semolina with and without added lipids and from defatted semolina on a laboratory-scale continuous process press. Results of cooking tests are given in Tables V and VI. Although results were obtained for three cooking times, the 17-min results are omitted as the values were intermediate between the 12- and 22-min results. The repeatability of stickiness values for the overcooked samples was more variable than those for the optimally cooked samples. This may be attributed to the poor condition of the surface and more inconsistency in water drainage. The extent of surface dryness has a profound effect on stickiness values (Dexter et al 1983). The surface amylose values indicated

TABLE V  
Surface Characteristics and Cooking Score of Macroprocessed  
Spaghetti Dried at 39°C (LT) and 70°C (HT) Cooked for 12 or 22 min

Sample	Stickiness <sup>a</sup> (N/m <sup>2</sup> )		Surface Amylose <sup>b</sup> (600 nm)		Cooking Score <sup>b</sup>	
	12 min	22 min	12 min	22 min	12 min	22 min
Control semolina						
LT	940	920	0.411	0.720	14	4
HT	595	715	0.270	0.244	22	0
Defatted semolina						
LT	1,270	1,200	0.860	1.191	14	0
HT	690	1,220	0.358	0.502	20	2
Control + 1% nonpolar lipids						
LT	945	1,150	0.256	0.351	15	8
HT	605	750	0.199	0.202	24	17
Control + 0.5% monoglycerides						
LT	850	655	0.100	0.074	14	11
HT	530	610	0.058	0.051	23	19
Effect <sup>c</sup>						
Samples (S)	67.1***		320.6***		28.6***	
Drying temperature (D)	177.8***		298.7***		89.5***	
Cooking time (C)	5.7**		20.4***		82.9***	
S × D	5.2**		73.1***		3.4*	
S × C	3.3*		5.0**		6.5***	
D × C	12.0***		8.1**		7.4**	
S × D × C	4.4***		2.1		1.7	

<sup>a</sup> Means of duplicated results. N/m<sup>2</sup> = newtons per square meter.

<sup>b</sup> Means of triplicated results.

<sup>c</sup> \*  $P < 0.05$ , \*\*  $P < 0.01$ , \*\*\*  $P < 0.001$ .

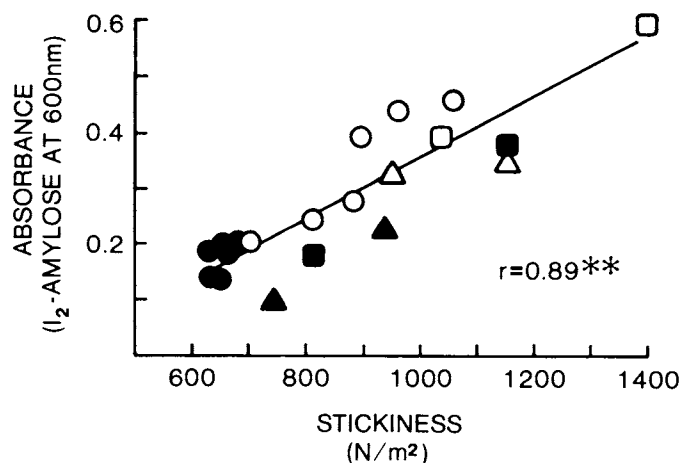


Fig. 3. Relationship between absorbance of iodine-amylose complex rinsable cooked spaghetti surface material and the instrumental assessment of cooked spaghetti stickiness. Spaghetti samples were processed from durum wheat semolina (O, ●), hard red spring wheat farina (□, ■) and hard red spring wheat farina enriched in nonpolar lipids (Δ, ▲). Samples were dried by low-temperature (O, □, Δ) and high-temperature (●, ■, ▲) procedures.

that stickiness values should be higher, particularly for the overcooked, LT defatted sample. As in the case of the microprocessed samples, defatting significantly increased stickiness and surface amylose ( $P < 0.001$ ). However, unlike results for samples prepared by the micromethod (Table IV), enrichment with semolina nonpolar lipids had no significant effect on stickiness. Commercial monoglycerides, on the other hand, decreased stickiness significantly ( $P < 0.001$ ).

One limitation with the iodine method for estimating amylose is the interference by some lipid components. That fatty acids and surfactants decrease the color intensity of the iodine-amylose complex is well established (Kim and Robinson 1979, Osman et al 1961); thus, the decrease in absorption after adding durum semolina nonpolar lipids may be the combined effect of less amylose on the surface and the increased level of lipid components interfering with iodine color development. Because about 90% of the free lipids are bound during pasta processing, especially during drying (Barnes et al 1981), some may be complexed to amylose, thereby leading to deceptively lower iodine-amylose absorbance readings, especially for those samples enriched with lipids (Table V). The absorbance values for samples with monoglycerides were lower than stickiness would indicate, again indicating unavailability of amylose likely resulting from formation of monoglyceride-amylose complexes.

The cooking score at normal cooking time was not affected by lipids, confirming the results of the preliminary study. However, significant improvement in the overcooked sample was noted with both nonpolar semolina lipids and monoglycerides.

There was very little difference in cooked weight of spaghetti (Table VI) whether the samples were dried at low or high temperature. Increasing the cooking time increased the cooked weight by about 25%. The cooking loss values give an indication of the state of the cooked product. For the overcooked, defatted LT sample, the cooked weight appeared normal but cooking loss was highest (20.9%), indicating the presence of about 8% more absorbed water in the cooked spaghetti on a dry matter basis. The overcooked monoglyceride-enriched LT sample was lowest in cooked weight.

Determination of amylose in the cooking water by the iodine-

amylose absorption method was very closely related ( $P < 0.01$ ) to cooking loss. The extent that amylose leached into the cooking water appeared not to be affected by fatty acids or other lipids. The iodine-amylose absorption method of determining cooking loss was much faster and can replace the freeze-drying method.

## DISCUSSION

Of the lipids that exert a marked influence on spaghetti cooking quality, monoglycerides exert the greatest effect, not only decreasing surface stickiness but also improving tolerance to overcooking. It is well established that lipids, especially monoglycerides, form water-insoluble complexes with amylose (Kim and Robinson 1979, Larson 1982, Eliason and Krog 1985), and this reduction of free amylose is thought to result in reduced stickiness of starch foods, such as pasta products. Monoglycerides with saturated fatty acids are very effective in complexing amylose in aqueous solutions at 60°C (Eliason and Krog 1985). Unsaturated monoglycerides, like monoolein and monolinolein, are ineffective in forming complexes in water at 60°C but more effective at 30–40°C. Therefore, if complex formation can be assumed to follow similar temperature dependence in dough, the temperature at which dough development occurs during processing may be the deciding factor as to the effect of various lipids. The involvement of oleic acid in decreasing starch solubility and swelling is reported by Niihara (1984). Thus, lipids other than monoglycerides are involved in the amylose reaction.

The difference in stickiness response to nonpolar semolina lipids by microprocessing and semicommercial processing may be attributable to the lower dough processing temperature of the microprocess (39°C) compared to the semicommercial process (50°C).

The differences in stickiness values between the LT and HT samples in Table V may be due to other factors, e.g., onset of gelatinization and bound lipids. According to Olkku and Rha (1978), initial gelatinization temperature for wheat starch is 58°C, midpoint 61°C, and end-point 64°C. Although the low water activity of spaghetti dough will retard the onset of starch gelatinization at 70°C, the temperature at which HT samples are dried, some gelatinization may occur. With gelatinization, bound lipids or internal starch lipids, those inside starch granules (Morrison 1981), may be released or exposed to interact with amylose.

Kim and Robinson (1979) studied monoglyceride-starch interaction in suspension at temperatures from 30 to 90°C and found that at 30°C amylose with an extended conformation (as opposed to a helical form) bound small amounts of monoglycerides. With the initiation of gelatinization near 60°C and the concomitant conformational change to a helical form, the amount of monoglycerides bound to starch increased, reaching a maximum at 90°C.

If such a mechanism were possible even in a dough system, it would explain the significant decrease in stickiness with added monoglycerides. The stickiness value for the HT sample with monoglyceride (Table V) was the lowest of all samples studied.

The estimation of stickiness by color measurement of the iodine-amylose complex is a quick alternative method provided the lipid content and composition are comparable among samples. For screening purposes in a plant breeding program, this method is very promising. Color measurement of amylose in the cooking water offers a rapid simple test for cooking loss. In samples of variable lipid content and composition, the interference of lipids in the iodine-amylose binding might be a problem. The presence of lipid decreases the iodine binding capacity by 20 to 30% (Galliard 1983). Further study on a large number of samples for determining the usefulness of the iodine-binding method for estimating stickiness and cooking loss is planned.

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TABLE VI  
Other Cooking Quality Characteristics of Macroprocessed  
Spaghetti Dried at 39°C (LT) and 70°C (HT) Cooked for 12 or 22 min

Sample	Cooked Weight <sup>a</sup> (g)		Cooking Loss <sup>b</sup> (%)		Cooking Water <sup>b</sup> Amylose (600 nm)	
	12 min	22 min	12 min	22 min	12 min	22 min
Control semolina						
LT	26.0	33.1	7.9	11.8	0.351	0.595
HT	26.5	33.6	6.6	8.3	0.325	0.460
Defatted semolina						
LT	26.4	32.6	9.8	20.9	0.412	1.002
HT	26.3	33.4	6.5	9.2	0.282	0.462
Control + 1% nonpolar lipids						
LT	25.7	32.6	8.2	12.1	0.379	0.554
HT	26.0	33.3	6.4	9.1	0.306	0.418
Control + 0.5% monoglycerides						
LT	25.3	30.7	8.7	13.6	0.382	0.645
HT	25.4	31.4	6.2	8.3	0.283	0.409
Effect <sup>c</sup>						
Samples (S)	37.0***		86.1***		21.0***	
Drying						
temperature (D)	4.2*		748.3***		180.1***	
Cooking time (C)	1,160.3***		269.6***		135.2***	
S × D	0.3		64.8***		19.1***	
S × C	3.2*		14.1***		7.8***	
D × C	2.9		54.3***		22.9***	
S × D × C	0.7		10.8***		4.5**	

<sup>a</sup> Means of triplicated results.

<sup>b</sup> Means of duplicated results.

<sup>c</sup>  $P < 0.05$ , \*\*  $P < 0.01$ , \*\*\*  $P < 0.001$ .

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