Effects of Processing Conditions and Cooking Time on Riboflavin, Thiamine, and Niacin Levels in Enriched Spaghetti[1,2]

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ABSTRACT

Durum wheat semolina was enriched to two levels with a commercial vitamin enrichment mixture containing riboflavin, thiamine mononitrate, and niacin, and processed into spaghetti in a Demaco laboratory-scale continuous-extrusion press. Spaghetti processed at each enrichment level was dried by a conventional low-temperature drying cycle and by two high-temperature drying cycles. The enrichment mixture influenced spaghetti color properties but had no effect on cooking quality. Some riboflavin was lost during all three drying cycles, particularly during both high-temperature cycles. In contrast, niacin and thiamine were stable throughout all three drying cycles. All three vitamins in spaghetti were rapidly lost during cooking. Analysis of cooking water showed that loss of riboflavin and thiamine was from the combined effects of leaching into the cooking water and vitamin degradation. All niacin lost during cooking was recovered in the cooking water. The mean proportions of each vitamin retained in the spaghetti for all laboratory spaghetti samples cooked to optimum were 30% for riboflavin, 39% for thiamine, and 48% for niacin. Although vitamin retention during cooking was significantly related to enrichment levels and drying cycle, cooking time was the predominant factor determining the proportion of each vitamin retained during cooking. The trends established for vitamin retention in cooked laboratory spaghetti were confirmed for three Canadian commercial enriched spaghetti samples.

The enrichment of alimentary pastes with a wide range of nutrients lost in wheat during milling has been proposed in Canada (Health and Welfare Canada 1979). Canadian pasta manufacturers are currently permitted to add only iron and the B vitamins riboflavin, thiamine, and niacin (Health and Welfare Canada 1980). Although they are not required to do so, Canadian manufacturers commonly enrich pasta. This not only improves the marketability of the product because of superior nutritional properties, but the presence of riboflavin compensates for the decrease in yellow pigment that results when common wheat farina or flour is blended with durum wheat semolina (Dexter et al 1981c).

Numerous studies have been reported on the stability of vitamins during the preparation of baked goods (Cakirer and LaChance 1975, Tabekhia and D'Appolonia 1979). The literature contains no information concerning the stability of vitamins in enriched semolina during pasta processing and cooking. Therefore, the current study was initiated to establish the effects of drying temperature of spaghetti and cooking time on the retention of riboflavin, thiamine, and niacin.

MATERIALS AND METHODS

Enriched Semolina

A sample of No. 1 Canada Western amber durum wheat from the 1979 crop year was milled into semolina in a three-stand Allis-Chalmers laboratory mill to about 70% extraction (Matsuo and Dexter 1980). The semolina was enriched to two levels by mixing in a tumble mixer 10 mg/100 g and 30 mg/100 g, respectively, of a commercial enrichment mixture (Stauffer Chemical Company, West Port, CT) containing per gram 32 mg of thiamine mononitrate, 65 mg of riboflavin, 224 mg of niacin, and 224 mg of reduced iron. Uniformity of enrichment was verified by analyzing portions of each enriched sample from different parts of the mixture for riboflavin content. The two enrichment levels were chosen to represent the range of enrichment currently practiced by Canadian pasta manufacturers.

Spaghetti Processing

Spaghetti was processed in a Demaco S-25 laboratory continuous-extrusion press (De Francisci Machine Corporation, Brooklyn, NY) as described by Matsuo et al (1978).

Spaghetti produced at each enrichment level was dried by a conventional low-temperature (LT) procedure and by two high-temperature (HT) procedures. In the LT procedure, spaghetti was dried at 39° C over a period of 28 hr. The first HT cycle (HT-A) featured an initial temperatue of 75° C for 2 hr followed by a decrease to 39° C over the next 5 hr, and then equilibration at 39° C for a further 6 hr before termination of the cycle. The second HT cycle (HT-B) featured an initial 1-hr period at conventional temperatures (41° C–55° C) followed by 12 hr at about 70° C, and then rapid cooling to 41° C, which was maintained for 1 hr before termination of the cycle. Complete details of all three drying cycles, including relative humidity levels and pattern of moisture loss in the spaghetti during drying, were reported previously (Dexter et al 1981b).

Spaghetti Quality Tests

Spaghetti color was measured by the method of Daun (1978). Brightness (standard deviation based on 10 determinations of a representative sample, SD = 0.13%) is a measure of the amount of light reflected by a sample relative to the amount of light reflected by a near-perfect white surface. Purity (SD = 0.40%) is a measure of color intensity. Dominant wavelength (SD = 0.11 nm) is the wavelength of the pure spectrum color which, in combination with a tungsten lamp source, produces the color, and thus is a measure of hue.

Textural characteristics of cooked spaghetti were evaluated on an apparatus described by Matsuo and Irvine (1969, 1971) at optimum cooking time (12 min) and after overcooking 10 min. Tenderness index (SD = 1.4 m/sec $\times 10^{-6}$) is a measure of shear rate under increasing force and is therefore a firmness indicator. Compressibility (SD = 3.5%) is a measure of deformation under constant force, and recovery (SD = 2.9%) is a measure of resilience.

Sample Preparation

Samples of laboratory-processed material were taken after extrusion and throughout each drying cycle. Spaghetti processed at each enrichment level by each drying method was cooked uncovered for various times in rapidly boiling unsalted tap water (50 g of spaghetti in 1 L of water) and drained. The spaghetti and cooking water were retained.

Three commercial brands of Canadian spaghetti were cooked in duplicate over a range of cooking times from 7.5 to 18 min. Fifty grams of spaghetti were cooked in 1 L of boiling tap water containing 0.25% salt as recommended by the manufacturers. Spaghetti was drained and the spaghetti and cooking water retained.

Samples of cooked spaghetti and cooking water were

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immediately frozen at −40° C in a freeze-drier, freeze-dried overnight, and weighed before grinding. Ground samples were stored in airtight containers at 4° C in the dark until required for analysis. Dry laboratory spaghetti was wrapped in paper and stored in the dark at room temperature (23° C) until cooked. Commercial spaghetti samples were left in their respective packages and stored in the dark at room temperature. Uncooked spaghetti was ground just before analysis.

Vitamin Analyses

Duplicate analyses for each vitamin were performed on each sample taken during spaghetti processing and for each dried spaghetti sample. Single analyses for each vitamin were performed on each cooked spaghetti sample and its corresponding cooking-water residue. At least one control sample was included each day to establish the reproducibility of the assay procedure.

Riboflavin (SD = 0.060 mg/100 g) was determined by a simplified fluorometric procedure (AACC 1962), thiamine (SD = 0.056 mg/100 g) was determined by a rapid fluorometric procedure (AOAC 1980), and niacin (SD = 0.45 mg/100 g) was determined by a colorimetric procedure (AOAC 1980).

RESULTS AND DISCUSSION

Spaghetti Quality

Addition of the enrichment mixture at 10 mg/100 g had little effect on spaghetti color properties (Table I). In contrast, addition of the enrichment mixture at 30 mg/100 g significantly altered spaghetti color properties for all three drying cycles (Table I). In particular, brightness decreased, an indication of increased surface dullness, and dominant wavelength increased, an indication of increased brownness compared to the unenriched spaghetti. These effects were likely due to the iron contained in the enrichment mixture (Matsuo and Dexter 1980). For the LT and HT-B spaghetti, purity tended to increase with addition of enrichment mixture, due to the enhanced color imparted by the riboflavin (Table I). This trend was not apparent for HT-A spaghetti. However, drying cycles such as HT-A, which feature HT during the preliminary drying stages, yield spaghetti with unusually high pigment levels due to inactivation of lipoxygenase (Dexter et al 1981a,1981b). Therefore, the unenriched HT-A spaghetti was characterized by a much greater pigment level than unenriched spaghetti dried by the other two drying cycles, as evidenced by

TABLE I
Effect of Enriching Semolina on Some Quality Characteristics for Spaghetti Dried by Three Drying Procedures

Drying Cycle	Enrichment Level (mg/100 g)	Spaghetti Color[a] B (%)	P (%)	DWL (nm)	Cooked 12 Min[b] C (%)	R (%)	TI ($m/s \times 10^{-6}$)	Cooked 22 Min[b] C (%)	R (%)	TI ($m/s \times 10^{-6}$)
Low-temperature	Unenriched	49.7	58.5	577.6	75	31	46	74	49	61
	10	49.1	58.9	577.6	76	29	47	78	37	65
	30	47.0	60.1	577.7	77	30	46	74	42	61
High-temperature A	Unenriched	48.9	63.8	577.5	76	25	51	75	37	59
	10	47.7	62.3	577.6	78	26	50	78	38	64
	30	46.8	63.2	577.8	77	30	45	74	36	63
High-temperature B	Unenriched	48.4	60.0	577.8	73	38	44	76	33	61
	10	47.9	59.6	577.8	74	36	43	75	44	59
	30	46.0	61.3	578.0	79	30	47	74	47	60

[a] B = brightness, P = purity, DWL = dominant wavelength.
[b] C = compressibility, R = recovery, TI = tenderness index.

TABLE II
Effects of Processing on the Retention of Riboflavin, Thiamine, and Niacin for Enriched Spaghetti Dried by Three Drying Procedures[a]

Sample	Riboflavin (mg/100g) Enrichment (30 mg/100g)	Riboflavin (mg/100g) Enrichment (10 mg/100g)	Thiamine (mg/100g) Enrichment (30 mg/100g)	Thiamine (mg/100g) Enrichment (10 mg/100g)	Niacin (mg/100g) Enrichment (30 mg/100g)	Niacin (mg/100g) Enrichment (10 mg/100g)
Semolina	2.18	0.84	1.16	0.49	10.0	5.4
Following extrusion	2.27	0.78	1.12	0.47	10.3	5.1
Low-temperature						
2 hr	2.15	0.74	1.16	0.48	10.9	5.3
6 hr	ND[b]	0.67	ND[b]	0.48	ND[b]	5.1
Dry, 29 hr	1.95	0.68	1.20	0.50	9.8	5.8
Dry, stored three months	1.68	0.64	1.15	0.52	10.3	5.8
High-temperature A						
1 hr	1.89	0.67	1.10	0.48	10.3	5.7
3 hr	1.54	0.50	1.11	0.47	11.0	5.4
Dry, 13 hr	1.70	0.44	1.14	0.48	10.5	5.4
Dry, stored three months	1.67	0.42	1.01	0.48	10.3	5.6
High-temperature B						
1 hr	1.95	0.68	1.21	0.47	10.4	5.7
3 hr	1.99	0.50	1.21	0.46	10.2	5.7
Dry, 14 hr	1.73	0.50	1.19	0.45	9.7	5.7
Dry, stored three months	1.65	0.44	1.09	0.46	10.2	5.9

[a] All results expressed on a 0% moisture basis.
[b] ND = not determined.

higher purity (Table I), and this may have masked the color-enhancing effect of riboflavin in the enriched HT-A samples.

Spaghetti-cooking quality did not appear to be affected by enrichment. Although some differences were noted between samples at both optimum cooking time and after overcooking (Table I), no definite trend with enrichment level could be established for any of the drying cycles.

Spaghetti Processing

No loss of riboflavin occurred during processing for any of the spaghetti samples during extrusion (Table II). However, a significant loss of riboflavin occurred during drying, particularly for both HT drying cycles. Most of the loss occurred during the preliminary stages of each drying cycle when spaghetti moisture was highest. Further loss of riboflavin may have occurred during storage before cooking. This was particularly obvious for the heavily enriched LT dried spaghetti, in which riboflavin content during storage decreased by approximately 15%.

Thiamine and niacin levels did not appear to be reduced by any of the spaghetti-processing procedures (Table II). Similarly, the levels of both vitamins were not affected by spaghetti storage.

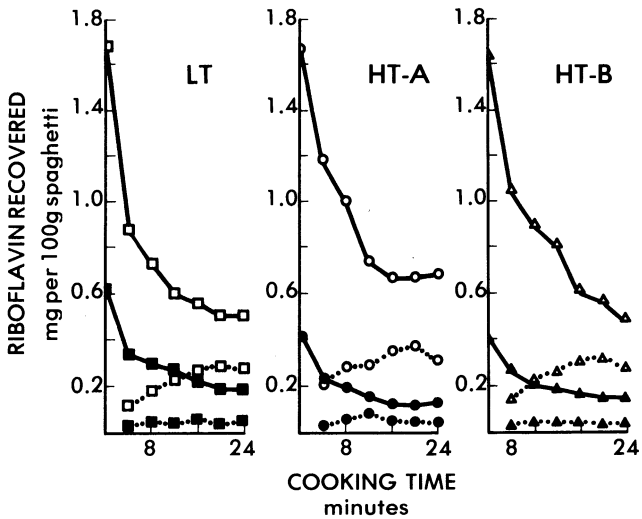

Fig. 1. Riboflavin retained in cooked spaghetti (solid curves) and cooking water (broken curves) for spaghetti enriched with commercial enrichment mixture to two different levels (□, o, Δ = 30 mg/100 g of semolina, ■, •, ▲ = 10 mg/100 g of semolina) and dried by low temperature (□, ■), high temperature A (o, •), or high temperature B (Δ, ▲).

TABLE III
Analysis of Variance for Percentage of Vitamins Retained During Cooking for Laboratory-Processed Spaghetti

Vitamin	Source of Variation	Degrees of Freedom	Mean Square	F[a,b]
Riboflavin	Enrichment level	1	171.61	8.21*
	Drying method	2	121.55	5.81*
	Cooking time	5	743.82	35.58**
	Drying method × cooking time	10	16.16	0.77
	Error	17	20.90	
Thiamine	Enrichment level	1	426.42	111.88**
	Drying method	2	18.16	4.76*
	Cooking time	5	1,480.73	388.51**
	Drying method × cooking time	10	8.31	2.18
	Error	17	3.81	
Niacin	Enrichment level	1	358.47	10.90**
	Drying method	2	26.96	0.82
	Cooking time	5	392.15	11.92**
	Drying method × cooking time	10	9.57	0.29
	Error	17	32.88	

[a] Computed F values assume a fixed-treatment effects model (Snedecor and Cochran 1967).
[b] * = significant at $P = 0.05$, ** = significant at $P = 0.01$.

Spaghetti Cooking

Riboflavin was rapidly lost from spaghetti during the early stages of cooking for all the laboratory samples (Fig. 1). With the exception of the highly enriched HT-B spaghetti, no significant loss ($P = 0.05$) of riboflavin occurred in the cooked spaghetti after 12 min of cooking. Analysis of the cooking water revealed that the loss of riboflavin during the initial stages of cooking was due to the combined effects of riboflavin leaching into the cooking water and to riboflavin degradation. After only 4 min of cooking, the mean proportion for all samples of riboflavin retained in the spaghetti was about 65% of that originally in the uncooked spaghetti, and total recovery of riboflavin, including that found in the cooking water, was about 70%. When cooked for the optimum cooking time of 12 min, 45% of the riboflavin was retained in the cooked spaghetti, and total riboflavin recovery, including that detected in the cooking water, was less than 60% of the original amount in the uncooked spaghetti. When losses during processing were considered (Table II), spaghetti cooked for 12 min contained only about 30% of the riboflavin in the enriched semolina before processing.

Riboflavin levels at each cooking time for each spaghetti sample (Fig. 1) were converted to percentage of riboflavin retained from the corresponding uncooked spaghetti samples, and the data were subjected to analysis of variance using the two enrichment levels as replicates. Table III shows the expected strong interaction between cooking time and riboflavin retention. Significant interactions also occurred between riboflavin retention and both enrichment level and drying method. In each case, this can be attributed to the generally higher retention of riboflavin in the highly enriched HT-A spaghetti relative to the other samples throughout the entire cooking range.

The levels of thiamine in all the enriched spaghetti samples decreased very rapidly during the initial stages of cooking (Fig. 2). In contrast to riboflavin, thiamine levels in the cooked spaghetti continued to decline significantly ($P = 0.05$) throughout the complete range of cooking times examined. After 12 min of cooking, the mean value of thiamine retained for all the samples was about 40% of that originally present in the uncooked spaghetti. By 24 min, the mean value had decreased to less than 25% of that in the uncooked spaghetti. Analysis of the cooking water (Fig. 2) revealed that thiamine loss in cooked spaghetti was a result of

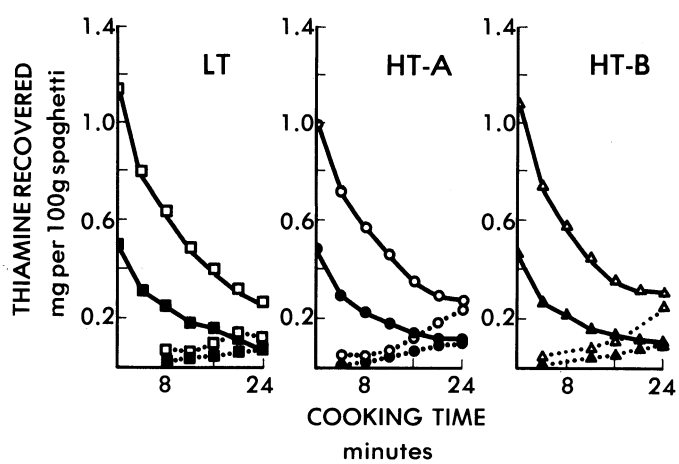

Fig. 2. Thiamine retained in cooked spaghetti (solid curves) and cooking water (broken curves) for spaghetti enriched with commercial enrichment mixture to two different levels (□, o, Δ = 30 mg/100 g of semolina, ■, •, ▲ = 10 mg/100 g of semolina) and dried by low temperature (□, ■), high temperature A (o, •), or high temperature B (Δ, ▲).

leaching into the cooking water and thiamine degradation. Total thiamine recoveries, including the cooking water contributions, progressively decreased from a mean value of 75% after 4 min of cooking, to 47% after 12 min of cooking, and less than 40% after 22 min of cooking.

In addition to the effect of cooking time on thiamine retention in cooked spaghetti, analysis of variance (Table III) revealed a strong interaction between enrichment level and thiamine retention. This was a reflection of generally greater retention of thiamine (about 10%) in all three higher-enriched spaghetti samples relative to the corresponding lower-enriched spaghetti samples throughout the complete range of cooking times. A small but significant interaction also occurred between drying method and thiamine retention during cooking. This was a result of slightly lower thiamine retention of LT spaghetti at both enrichment levels compared to the two HT-dried spaghetti samples, particularly during the latter stages of cooking. This may in part reflect the previously established tendency of LT spaghetti to lose more solids during cooking than HT spaghetti (Dexter et al 1981b), a trend confirmed in the present study (results not shown).

Niacin levels in the cooked spaghetti are shown in Fig. 3. The pattern of niacin loss during cooking was quite similar to that of riboflavin, with no significant ($P = 0.05$) loss of niacin occurring after 12 min. In contrast to both riboflavin and thiamine, niacin loss in cooked spaghetti was entirely due to leaching into the cooking water, not to niacin degradation. This was confirmed by analysis of the cooking water (Fig. 3), which, in combination with the cooked spaghetti, accounted for essentially 100% of the niacin originally present in the uncooked spaghetti throughout the range of cooking times examined. Nevertheless, the mean proportion of niacin retained in the cooked spaghetti was not much greater than for the other two vitamins, decreasing to 48% after 12 min of cooking.

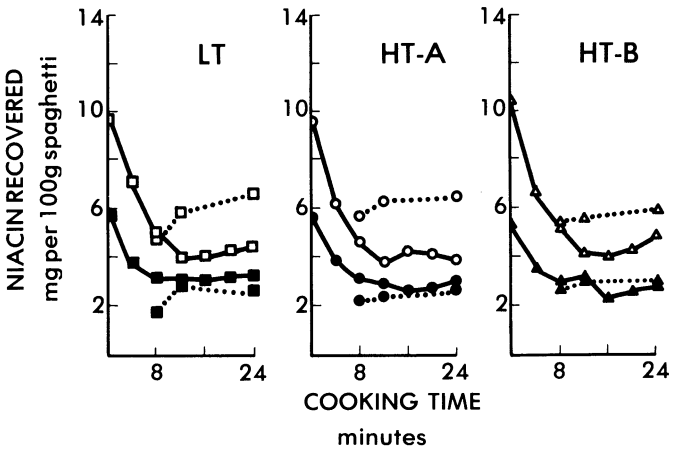

Fig. 3. Niacin retained in cooked spaghetti (solid curves) and cooking water (broken curves) for spaghetti enriched with commercial enrichment mixture to two different levels (□, o, Δ = 30 mg/100 g of semolina, ■, •, ▲ = 10 mg/100 g of semolina) and dried by low temperature (□, ■), high temperature A (o, •), or high temperature B (Δ, ▲).

Analysis of variance (Table III) revealed no effect of drying cycle on niacin loss during cooking. However, a significant interaction occurred between enrichment level and niacin loss, a reflection of the general tendency for all three higher-enriched spaghetti samples to lose a greater proportion of niacin than the lower-enriched spaghetti samples. As expected, a strong interaction occurred between cooking time and niacin loss.

Commercial Spaghetti

Three Canadian commercial enriched spaghetti samples were cooked to confirm the laboratory spaghetti results. Preliminary experiments with the laboratory spaghetti showed that the presence or absence of salt had a negligible effect on the rate of loss for all three vitamins during cooking (results not shown). However, for all the commercial products, salt was added to the cooking water to conform exactly to the directions on the respective packages. As the results of Fig. 4 show, the commercial products exhibited very similar trends for all three vitamins when compared to the laboratory spaghetti (Figs. 1–3). Because of variations in strand diameter between commercial samples, the minimum recommended cooking times ranged from eight to 12 min. When the proportions of each vitamin retained at the minimum recommended cooking time for each sample were compared, riboflavin ranged from 45 to 52%, thiamine from 45 to 52%, and niacin from 46 to 56%. Analysis of cooking water (Fig. 4) accounted for essentially all the remaining niacin originally present in the uncooked spaghetti but revealed that degradation of riboflavin and thiamine had occurred to an extent similar to that found previously in the laboratory samples.

Results (Fig. 4) for the cooked spaghetti were converted to percentage of vitamin retained from the uncooked product, and the data were subjected to analysis of variance (Table IV). For all three vitamins, significant interactions occurred between vitamin retention and the different samples. This was because the samples

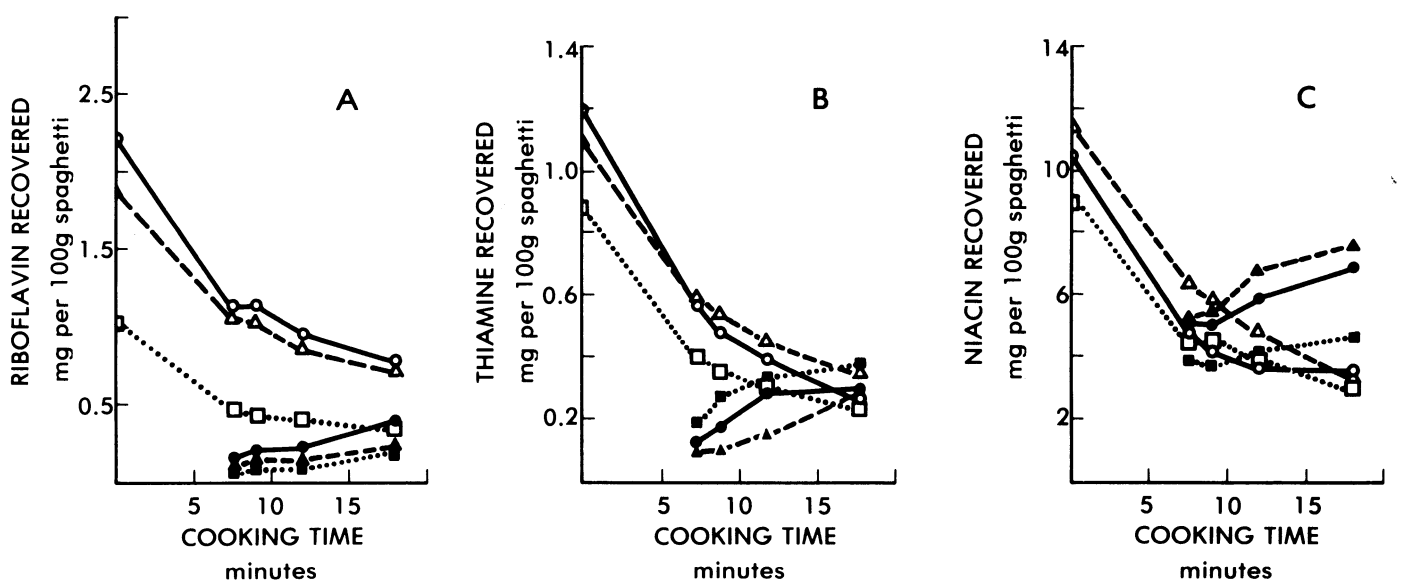

Fig. 4. Vitamins retained in cooked spaghetti (□, o, Δ) and cooking water (■, •, ▲) for three Canadian commercial enriched spaghetti samples (Δ = strand diameter, 1.72 mm, recommended cooking time 12–15 min; □ = strand diameter 1.59 mm, recommended cooking time 8–10 min; o = strand diameter 1.55 mm, recommended cooking time 9–12 min).

TABLE IV
Analysis of Variance for Percentage of Vitamins Retained During Cooking for Commercial Enriched Spaghetti

Vitamin	Source of Variation	Degrees of Freedom	Mean Square	F[a,b]
Riboflavin	Replicate cookings	1	82.35	4.00
	Samples	2	207.03	10.06**
	Cooking time	3	321.42	15.63**
	Samples × cooking time	6	11.70	0.57
	Error	11	20.57	
Thiamine	Replicate cookings	1	0.43	0.80
	Samples	2	73.52	137.23**
	Cooking time	3	498.57	930.60**
	Samples × cooking time	6	1.20	2.25
	Error	11	0.54	
Niacin	Replicate cookings	1	5.04	1.37
	Samples	2	146.78	39.84**
	Cooking time	3	281.75	76.47**
	Samples × cooking time	6	32.51	8.82**
	Error	11	3.68	

[a] Computed F values assume a fixed-treatment effects model (Snedecor and Cochran 1967).
[b] ** = significant at $P = 0.01$.

cooked at different rates because of their different strand diameters and were overcooked or undercooked relative to each other at each cooking time. This factor was also responsible for the niacin-retention interaction between significant samples and cooking time. The interactions observed between cooking time and retention of each vitamin (Table IV) were very similar to those observed for the laboratory spaghetti (Table III). A particularly strong interaction occurred between cooking time and thiamine retention compared to the other two vitamins for both the laboratory and the commercial samples (Tables III, IV), reflecting the tendency of thiamine to decrease in the cooked spaghetti beyond optimum cooking time to a much greater extent than the other two vitamins.

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