Effects of Physicochemical Characteristics and Lipid Distribution in Algerian Durum Wheat Semolinas on the Technological Quality of Couscous

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ABSTRACT

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Semolinas milled from 18 Algerian durum wheat cultivars cropped over a two-year period (1999-2000) were used for making couscous. This study was designed to determine the impact of lipid components of durum wheat semolina on the quality of the couscous end product. Lipids were extracted from semolina by various techniques and classified as free or bound lipids, polar or apolar lipids, and glycolipids or phospholipids. An analysis of the overall results clearly revealed that the cooking quality of couscous made from different durum wheat semolinas was partially dependent on the semolina free lipid content and composition. We have shown that this is mainly a varietal characteristic (53.4%). The surface state of the couscous, i.e., caking index ($r = -0.48$) and cooking loss ($r = -0.54$), thus depends on the apolar lipid content. Polar lipids, and especially glycolipids, affect couscous texture in terms of firmness ($r = 0.57$ and $r = 0.63$, respectively). Polar bound lipids also contribute to couscous swelling ($r = 0.53$) and caking index ($r = 0.70$). Moreover, we obtained no correlation between cooked couscous quality and the semolina total lipid content ($r < 0.3$). We also showed that couscous characteristics were not significantly related to the semolina protein and dry gluten contents or gluten index ($r < 0.3$).

Durum wheat is a staple component of the Algerian diet. It is mainly consumed as couscous, which is prepared by agglomerating durum wheat semolina with water and salt. Couscous is considered to be good quality when the particle size is uniform and there is no unusual odor. After cooking, it should be firm and unsticky, with a high water absorption capacity. Couscous quality depends on the raw materials (Guezlane 1993), the semolina particle size (Debbouz et al 1994), the manufacturing process, and the biochemical composition (Guezlane 1993; Debbouz et al 1994; Debbouz and Donnelly 1996; Hebrard et al 2003).

Lipids are key biochemical compounds of wheat and have an impact on the cooking quality of the end product (Laignelet 1983a). The proportion of lipids in the flour or semolina composition is not very high (1–2% dry matter [dm]) but their role in the final quality of cereal products has been widely confirmed, especially in breadmaking (Morrisson 1978; Pomeranz 1980; Bekes et al 1986; Chung 1986; Larsen et al 1989; McCormack et al 1991; Graybosh et al 1993; Ohm and Chung 2002).

Few studies have investigated the effects of lipids on pastification (Matsuo et al 1986). Lipids are especially involved in the color and cooking characteristics of pasta products. According to Feillet (1984), some classes of lipids, especially glycolipids, contribute to cohesion of the gluten network and to the integrity of pasta by interacting with proteins and amylose chains through hydrogen or hydrophobic bonds. Semolina free lipids interact with proteins and starch during mixing (Olcott and Mecham 1947; Chiu and Pomeranz 1966; Chung and Tsen 1975) or pasta drying (Barnes et al 1981; Laignelet 1983b). During cooking, results published to describe the impact of lipids on pasta cooking quality are sometimes contradictory. Dahle and Muenchow (1968) showed that delipidating semolina with water-saturated butanol resulted in sticky pasta, with a high proportion of amylose in the cooking water. Meanwhile, Matsuo et al (1986) demonstrated that the stickiness of spaghetti is controlled by neutral lipids. According to Lin et al (1974b), polar and apolar lipids do not affect the characteristics of cooked pasta. Kim and Robinson (1979), Eliasson and Krog (1985), and Matsuo et al (1986) showed that complexing monoglycerides with amylose leads to a marked reduction in stickiness, while boosting the resistance of pasta to overcooking. Laignelet (1983a) indicated that the cooking quality of pasta is improved by gluten lipid oxidation.

Few studies have focused on the mechanisms underlying couscous quality. The rare studies conducted have mainly assessed the effects of adding exogenous lipids on the technological and cooking quality of couscous with regard to modifications in the functional properties of the protein content. Belaïd et al (1994) showed that adding 1% monoglycerides (glycerolmonostearate and glycerolmonopalmitate) reduced stickiness and caking of precooked couscous, while increasing the firmness and resistance to overcooking. Complexing amylose to monoacylated lipids, especially during hydrothermal treatment, seems to be the main mechanism that reduces couscous caking (Guezlane et al 1998).

No studies have been made to determine the exact impact of endogenous semolina lipids on the quality of the couscous end product. Therefore, the present study was aimed at determining the extent to which lipid components of durum wheat semolina contribute to couscous quality. Eighteen Algerian durum wheat cultivars (crops from two years) produced different semolina characterized by lipid composition and were used to make couscous.

MATERIALS AND METHODS

Materials

This study focused on 18 durum wheat cultivars that are listed in the Algerian Official National Catalogue: Waha, Vitron, Mohamed Ben Bachir (Mbb), Bidi17, Hedba3, Chen's, Kebir, Oumrabi, Ofanto, Polinicum, Simeto, Ost, Sahel, Korifla, Oued Zenati, Belikh2, Duilio, and Cham3. These cultivars were crops from two years (1999 and 2000) on two locations (Constantine and Sidi Bel Abbes) by the Institut Technique des Grandes Cultures d'Alger (ITGC), which granted us access to them. The cultivars were selected to cover as broad a quality range as possible.

Wheat grain was milled into semolina using a CD2 Chopin test mill (Tripette et Renaud Chopin, France). The extraction rates were 51–66% and the milled semolinas were stored at 4°C.

Analytical Methods

The protein content (N × 5.7), dry gluten content, gluten index, and mixograph performance of the semolinas were determined using Approved Methods 46-12, 38-12A, and 54-40, respectively (AACC International 2000). An SDS analysis was conducted as described in Axford et al (1978).

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Lipid Extraction

Extraction of free lipids (FL) from the durum wheat semolinas (10 g) was performed in a Soxhlet extraction apparatus for 3 hr at 40°C with *n*-hexane as solvent. After solvent distillation using a rotating vacuum evaporator and elimination of any remaining traces under a flow of nitrogen, the lipid content was determined by gravimetric analysis. Extraction of bound lipids (BL) from semolinas was performed with water-saturated butanol after FL extraction under the conditions described by Bekes et al (1983). The sum of free (FL) and bound (BL) lipids contents gave the total lipid (TL) content. All measurements were obtained in duplicate.

Lipid Fractionation

Free and bound lipids were fractionated into nonpolar lipids (FL_{NP} and BL_{NP}), glycolipids (Gly), and phospholipids (Pho) by column chromatography under the conditions described by Bekes et al (1986). Samples dissolved in 5 mL of chloroform were deposited on the surface of the column (12 × 250 mm) filled with 15 g of Florisil adsorbent (magnesium silicate; 60–100 mesh; Aldrich, Germany). Three fractions were obtained after sequential elutions with chloroform (nonpolar lipids), acetone (glycolipids), and methanol (phospholipids). The different lipid fractions were weighed after solvent evaporation. The results are expressed in % dry matter of the initial semolina, and all measurements were obtained in duplicate. The sum of the glycolipid and phospholipid contents gave the polar lipid (FL_P and BL_P) content.

The different lipid fractions were separated and characterized by thin-layer chromatography. Lipids were deposited at the bottom of a ready-prepared silica gel plate (0.25-mm silica layer, Aldrich, Germany). Lipid spots were revealed with the solvent mixture recommended by Morrisson et al (1980). Apolar lipids were separated to 12 cm depth with a dietylether/toluene/ethanol/acetic acid (40/50/2/0.2, v/v) mixture, and to 18 cm depth with a dietylether/*n*-hexane (6/94, v/v) mixture.

Glycolipids were preseparated to 15 cm depth with a chloroform/acetone/acetic acid (10/90/2/3, v/v) solution, and then to 18 cm depth with a diethylether/acetic acid (99/1, v/v) solution. Finally, phospholipids were separated with a chloroform/methanol/ ammonia (33%)/water (65/35/5/2.5, v/v) solution.

Separated compounds were compared against specific standards of apolar lipids (triglycerides, diglycerides, monoglycerides, and free fatty acids), glycolipids (monogalactosyldiglyceride and digalactosyldiglyceride), and phospholipids (phosphatidylcholine, phosphatidylserine, phosphatidyletanolamine, lysophosphatidylcholine, phosphatidylglycine, phosphatidylinositol). Quantitative determinations were performed after iodine vapor revelation.

Couscous Preparation

Semolinas milled from different durum wheat cultivars were used to make couscous by a traditional procedure. Semolina (500 g) was placed in a pan. A suitable quantity of salted water (5 g of NaCl/L) was added to the semolina to obtain 33% hydration (dm basis). This mixture was then rolled for 15 min, sieved, and steam-precooked in a couscous cooker (strainer diameter = 16 cm) containing 2 L of water that was brought to a boil at 100°C, and maintained boiling for 8 min. The couscous layer in the strainer was 3 cm thick. This precooked couscous was decaked and passed through a traditional sieve. The couscous was then laid out on a clean cloth and dried for 48 hr at 25°C in an aerated room sheltered from sunlight. The final moisture content of the different couscous batches was 11.8–12.9%.

Couscous Technological Quality Assessment

The couscous particle size was determined using a Rotex Sifter (Tripette et Renaud Chopin, France) with five mobile sieves of decreasing mesh size (1,400, 1,000, 800, 710, and 500 μm). The sieves were uniformly rotated for 5 min at 200 rpm and the oversized particles remaining on each sieve were weighed. The particle-size analysis enabled us to determine the mean equivalent diameter (D_{50}) or the geometric standard deviation ($S_g = D_{84}/D_{50}$), indicating the granulometric dispersion. The results are expressed as a cumulative percentage of the total recovered mass.

Couscous Cooking Quality

Swelling. Uncooked couscous (20 g) (weighed to the nearest 0.1 g) were placed in a graduated 100-mL test tube containing 50 mL of distilled water at 100°C (Guezlane and Abecassis 1991). The test tube was sealed and rotated top-to-bottom 10 times successively to ensure that all particles were well moistened. Another 50 mL of water at 100°C were added to wash down particles sticking to the side of the test tube. The test tube was then placed in a water bath at controlled temperature and the couscous volume was recorded after 30 min. Couscous swelling was determined as

$$S_{100°C} = 100\ V/P \qquad (1)$$

where $S_{100°C}$ is the couscous swelling (mL/100 g), V is the volume (mL) of couscous measured in the test tube, and P is the weight of the test portion (20 g). Experimental values of couscous swelling can be related to the hydration capacity of cooked couscous. High values of couscous swelling can be indicative of high-quality product.

Caking index. The couscous was cooked using the method described by Guezlane (1993). Dry couscous (10 g) was placed in a crystallizer. The couscous was moistened with 16.5 mL of boiled distilled water containing 5 g/L of salt. The crystallizer was then immediately covered with a paraffin membrane and placed in an oven at 90°C for 12 min. After cooking, the product was again placed in an oven and incubated for 4 hr at 90°C to reduce the couscous moisture content to 12% (wet basis). The extent of caking of cooked couscous was assessed by sieving 10 g of cooked couscous using a Rotex sifter (Tripette et Renaud Chopin, France) through a 3,150-mm mesh sieve. The caking index was determined as

$$\text{CI} = \text{(Wt of sieved oversize particles (>3,150 mm)/Wt of test portion)} \times 100 \qquad (2)$$

where CI is the couscous caking index (%). Experimental values of couscous caking index can be related to the agglomeration degree of cooked couscous. Low values of couscous caking index can be indicative of high-quality product.

Cooking loss. The extent of couscous disintegration during cooking was measured using the method described by Yettou (1998). This analysis was based on the measurement of loss of couscous particles during cooking under vibratory agitation for 4 min at constant velocity using an E1-Nr 14602 vibromixer. As described by Guezlane (1993), 10 g of cooked couscous was placed in 200 mL of distilled water at 25°C. After 4 min of agitation, 10 mL of supernatant was recovered and incubated in an oven for 15 hr. The extent of cooking loss (% dm) was determined as

$$\text{Cooking loss} = [100\ W_{dm}\ V\ M/10\ (100 - WC)] \qquad (3)$$

where W_{dm} is the weight of dry extract (g), V is the final volume of couscous cooking water (mL), WC is the couscous water content (%), and M is the weight of the couscous after cooking (g). Experimental values of couscous cooking loss can be related to the cooking behavior of dry couscous. Low values of couscous cooking loss can be indicative of high-quality product.

Viscoelastic properties. The viscoelastic properties of cooked couscous were determined using a Chopin viscoelastograph (Feillet et al 1977) under the conditions described in Yettou et al (1997). Couscous (10 g) was first cooked by the method described by Guezlane (1993) and then 1 g of couscous was sampled and placed under a 1,600-g weight press for 40 sec. Variations in couscous thickness were then recorded with a viscoelastogram over a time course based on three factors: e_0 (initial thickness), e_1 (thickness measured after 40 sec under the weight press), and e_2 (thickness measured 20 sec after the weight was removed). Viscoelastic properties of cooked couscous were assessed on the basis of three parameters: firmness (Eq. 4), elastic recovery (Eq. 5), and viscoelasticity index (Eq. 6).

$$\text{Firmness } (F) = e_1 \text{ (mm)} \tag{4}$$

$$\text{Elastic recovery } (ER) = e_2 - e_1 \text{ (mm)} \tag{5}$$

$$\text{Viscoelasticity } (IV) = R/C \times 10 \tag{6a}$$

$$\text{where Relative recovery } (R) = e_2 - e_1/e_0 - e_1 \tag{6b}$$

$$\text{and Compressibility } (C) = e_0 - e_1/e_0 \tag{6c}$$

Experimental values of viscoelastic properties can be related to the textural behavior of cooked couscous. Low values of firmness and viscoelasticity index are traditionally indicative of high-quality product.

Starch solubility and swelling in water was measured to assess the extent of starch grain degradation and gelatinization. The starch solubility index (I_{sol}) and swelling index (I_{swel}) were determined according to the method of Anderson et al (1969).

Experimental Design and Statistical Analysis

The plots were set up in a randomized complete block design. We determined means and standard deviations for all samples analyzed with respect to different characteristics of semolina and couscous made from durum wheat cultivars. An analysis of variance (ANOVA-MANOVA) was performed on the results, and simple correlations were determined using a software package (v. 5.0, Statistica).

RESULTS AND DISCUSSION

Semolina Physicochemical Characteristics

The physicochemical quality of durum wheat semolinas was assessed on the basis of measured total protein and dry gluten contents, the gluten index, SDS sedimentation volume, and mixograph characteristics. Table I presents the characteristics of the selected semolinas and ANOVA results. Table I shows that semolinas milled from the studied wheat cultivars had protein contents of 10.1–15.9% dm (mean 13.5% dm), which was within the normal range (8–18%) reported by Feillet (2000). ANOVA revealed that the wheat cultivar and cropping year had a highly significant effect ($P < 0.01$) on the semolina protein content. Wheat cultivar accounted for 32.1% and cropping year accounted for 51.2%. In terms of cultivar, semolina milled from Sahel had the lowest protein content (10.1% dm). Semolinas produced from Belikh2 and Cham3 had the highest protein content (>15.5% dm).

The mean dry gluten content of semolinas milled from the different durum wheat cultivars was 12.5% dm. ANOVA revealed a highly significant effect ($P < 0.05$) of the wheat cultivar (24%) and cropping year (20.8%). There were substantial differences between the selected wheat cultivars as shown by the maximum and minimum values. The semolina milled from Hedba3 had the lowest dry gluten content (9.83% dm), whereas that milled from Cham3 had the highest content (14.8% dm).

The gluten index values ranged from 43% (Vitron) to 63% (Kebir), with a mean of 51%. This indicates that the gluten in the selected semolinas was medium strength. According to Cubadda et al (1992), a strong gluten has a gluten index within the 66–85% range. ANOVA showed a highly significant effect of the wheat cultivar (46.1%) on the gluten index ($P < 0.01$) but the effect of the cropping year was not significant. The semolina gluten index thus seems to be a varietal characteristic that indicates the intrinsic quality of wheat (Garrido-Lestache et al 2005).

The experimental SDS sedimentation volume values ranged from 38 mL for Waha to 84 mL for Kebir, with a mean of 62.7 mL. These are close to the results reported by Ames et al (1999). ANOVA revealed a highly significant genotype effect (40.9%, $P < 0.01$).

The mixograph mixing development times ranged from 3 min for Waha to 6.4 min for Simeto, with a mean of 5.41 min. The maximum mixogram curve heights ranged from 43 mm for Waha to 94 mm for Polinicum, with a mean of 71 mm. ANOVA (Table I) revealed that the wheat cultivar had a highly significant effect ($P < 0.05$) on the mixing development time (56.6%) and on the mixogram curve height (49%).

The different physicochemical characteristics of durum wheat semolinas were compared by a linear correlation matrix analysis (Table II). This correlation matrix analysis revealed highly significant ($P < 0.05$) positive correlations between the protein content and the dry gluten content ($r = 0.76$). No significant correlation was noted between the gluten index, the dry gluten content and the protein content. Moreover, the SDS sedimentation volumes were positively correlated with the mixograph mixing development times ($r = 0.74$) and the maximum curve heights ($r = 0.86$). These results were in line with those obtained by Dexter et al (1980), who showed that the SDS sedimentation volume can accurately predict the gluten strength, and thus the intrinsic value of durum wheat cultivars. We also obtained highly significant correlations between the mixogram curve heights and the protein content ($r = 0.47$) or dry gluten content ($r = 0.53$).

The results presented in Table II highlight two apparently independent groups. First, the protein and dry gluten contents were highly positively correlated with each other. Second, the SDS sedimentation volume and mixograph characteristics were also highly correlated with each other. The gluten index was the only parameter that was not correlated with any other semolina physicochemical characteristics.

TABLE I
Description and Analysis of Variance (ANOVA) of Physicochemical Characteristics of Semolinas Obtained from Selected Durum Wheat Cultivars[a]

Characteristics	Terms	Mean Value ± SD	Minimum	Maximum	% Variability	
					Cultivar[b]	Year[c]
Milling yield (%)	MY	61.5 ± 3.61	52.9	66.0	. . .	. . .
Protein content (% dry matter)	PC	13.5 ± 1.76	10.1	15.9	32.1**	51.2**
Dry gluten (%)	DG	12.5 ± 1.63	9.8	14.8	24.0*	20.8*
Gluten index (%)	GI	51.1 ± 5.45	43.0	63.0	46.1**	. . .
SDS-sedimentation vol (mL)	V_{SDS}	62.7 ± 13.9	38.0	84.0	40.9**	. . .
Mixograph time (min)	MT	5.4 ± 0.87	3.0	6.4	56.6**	. . .
Mixograph peak height (mm)	MPH	71.0 ± 14.3	43.0	94.0	49.0**	. . .

[a] Calculated from two replicates for the 18 cultivars from two years in Algeria. Mean values ± standard deviations. Significant at 5% (*) or 1% (**).
[b] Analysis of variance over 18 cultivars.
[c] Analysis of variance over two years.

Lipid Content of Semolinas from Different Durum Wheat Cultivars

Table III pools the main results concerning total lipid content (TL), free lipid content (FL), bound lipid content (BL), and contents of the different lipid classes, along with ANOVA results.

The semolina total lipid content ranged from 1.76% dm for Polinicum to 2.13% dm for Korifla, with a mean of 1.95% dm. ANOVA revealed that the semolina total lipid content was not influenced by the wheat cultivar or cropping year. Variations noted between the different analyzed samples could have been due to semolina contamination by wheat seed coat particles (Hargin and Morrison 1980; Morrison 1988) due to fluctuations in extraction rates during semolina milling. It is known that the semolina lipid content increases with the extraction rate (Prabhasankar and Rao 1999).

The free lipid (FL) content ranged from 0.92% for Vitron to 1.47% dm for Korifla, with a mean of 1.15% dm. On average, free lipids accounted for 59% of the semolina total lipid content. ANOVA (Table III) revealed that the wheat cultivar had a highly significant effect on the semolina free lipid content (53.4%, $P < 0.01$). The semolina free lipids included both polar (FL_P) and apolar (FL_{NP}) lipids. The mean semolina apolar free lipid (FL_{NP}) content was 0.70% dm. The wheat cultivar was responsible for 85.5% of the observed variability in apolar free lipid content ($P < 0.05$). In all analyzed samples, Vitron produced semolina with the lowest apolar free lipid content (0.52% dm), whereas that produced from Korifla had the highest content (0.87% dm). Semolina polar free lipids (FL_P) ranged from 0.34% for Bidi17 to 0.59% dm for Korifla, with a mean of 0.45% dm. Note that the semolina polar free lipid content was lower than the apolar free lipid content. On average, polar lipids represented 39% of the semolina total free lipid content. ANOVA revealed that the polar free lipid content depends on the wheat cultivar (42.6%, $P < 0.05$).

Semolina free lipids included equal quantities of glycolipids (Gly) and phospholipids (Pho). The glycolipid and phospholipid contents of the different samples are presented in Table III. The semolinas had glycolipid contents ranging from 0.25% dm for Mbb to 0.41% dm for Ofanto. The variability in the glycolipid content depended on the wheat cultivar (38.2%, $P < 0.05$). The mean phospholipid content of the different analyzed samples was 0.13% dm. ANOVA revealed that the wheat cultivar had a highly significant effect on the phospholipid content (54.9%, $P < 0.01$). The Bidi17 had the lowest semolina phospholipid content (0.07% dm), while the Korifla had the highest (0.19% dm).

Semolina bound lipids (BL) represented 41% of the total lipids on average. Semolina milled from Vitron had the highest bound lipid content (0.99% dm) and Ofanto had the lowest content (0.61% dm), with an overall mean of 0.80% dm. The cultivar had a highly significant effect on the bound lipid content (51.8%, $P < 0.05$).

Semolina bound lipids included both polar (BL_P) and apolar (BL_{NP}) lipids. The mean semolina apolar bound lipid (BL_{NP}) content for all studied cultivars was 0.34% dm. The highest semolina apolar bound lipid content was obtained for Duilio (0.56% dm), while the lowest content was noted for Polinicum (0.08% dm). Semolina polar bound lipids (BL_P) represented more than 57% of the bound lipids. We noted that, contrary to free lipids, semolina bound lipids had a lower apolar lipid content. Polinicum produced semolina with the highest polar bound lipid content (0.57% dm), while that produced by Belikh had the lowest polar bound lipid content (0.35% dm), for a mean of 0.46% dm. Table III indicates that neither the wheat cultivar nor the cropping year had a significant effect on polar (BL_P) or apolar (BL_{NP}) bound lipid contents.

A correlation matrix was used to compare the contents of the different types of lipids (Table IV). This revealed a significant positive correlation ($P < 0.05$) between the semolina total lipid (TL) content and the free lipid (FL) content ($r = 0.47$). The broad range of total lipid contents noted in the different semolinas thus seemed to depend slightly more on the free lipid (FL) content than on the bound lipid (BL) content, despite the fact that we noted a significant positive correlation between the total lipid content and the apolar bound lipid content ($r = 0.53$). It was thus logical to obtain a negative correlation ($r = -0.62$) between the semolina free lipid content and the bound lipid content. Table IV shows the highly significant positive correlations that were obtained between

TABLE II
Linear Correlation Coefficients (r) Between Different Physicochemical Characteristics of Semolinas Obtained from Selected Durum Wheat Cultivars[a]

Characteristics	Terms	PC	DG	GI	V_{SDS}	MT	MPH
Protein content	PC	1					
Dry gluten content	DG	0.76*	1				
Gluten index	GI	0.07	0.12	1			
SDS-sedimentation vol	V_{SDS}	0.43	0.49*	0.06	1		
Mixograph time	MT	0.18	0.38	0.03	0.74*	1	
Mixograph peak height	MPH	0.47*	0.53*	0.02	0.86*	0.79*	1

[a] Significant at $P < 0.05$ (*); and $n = 18$.

TABLE III
Description and ANOVA of the Contents (mg/100 g of dry matter) of Lipid Classes in Semolinas Obtained from Selected Durum Wheat Cultivars[a]

					% Variability	
Lipid Classes	Terms	Mean Value ± SD	Minimum	Maximum	Cultivar[b]	Year[c]
Total lipids	TL	1.95 ± 0.11	1.76	2.13	· · ·	· · ·
Free lipids	FL	1.15 ± 0.13	0.92	1.47	53.4**	· · ·
Nonpolar free lipids	FL_{NP}	0.70 ± 0.09	0.52	0.87	85.5*	· · ·
Polar free lipids	FL_P	0.45 ± 0.06	0.34	0.59	42.6*	· · ·
Glycolipids	Gly	0.32 ± 0.05	0.25	0.41	38.2*	· · ·
Phospholipids	Pho	0.13 ± 0.03	0.07	0.19	54.9**	· · ·
Bound lipids	BL	0.80 ± 0.13	0.61	0.99	51.8*	· · ·
Nonpolar bound lipids	BL_{NP}	0.34 ± 0.11	0.08	0.56	· · ·	· · ·
Polar bound lipids	BL_P	0.46 ± 0.06	0.35	0.57	· · ·	· · ·

[a] Calculated from two replicates for 18 cultivars at two years in Algeria. Mean values ± standard deviations. Significant at 5% (*) or 1% (**).

[b] Analysis of variance over 18 cultivars.

[c] Analysis of variance over two years.

the free lipid content and the apolar free lipid content ($r = 0.91$), the polar free lipid content ($r = 0.81$), the glycolipid content ($r = 0.65$), and the phospholipid content ($r = 0.73$). All lipid components involved in the free lipid complex (polar, apolar, glycolipids, and phospholipids) thus accounted for the diversity in the total free lipid content. In addition, we obtained significant correlations between the contents of the different components involved in the free lipid complex, e.g., between the apolar free lipid content and the polar free lipid content ($r = 0.61$) or between the polar free lipid content and the glycolipid content ($r = 0.92$) or phospholipid content ($r = 0.67$).

Table IV also presents significant positive correlations between the semolina bound lipid content and the apolar bound lipid content ($r = 0.87$) or polar bound lipid content ($r = 0.48$). The broad range of semolina bound lipid contents thus seemed to depend on the joint contribution of polar and apolar bound lipid contents. Logically, we obtained negative correlations between the bound lipid content and the free lipid content ($r = –0.62$), the apolar free lipid content ($r = –0.53$), the polar free lipid content ($r = –0.55$), and the phospholipid content ($r = –0.53$). Similar negative correlations were also noted with the polar bound lipid content. We also found that the polar bound lipid content was not correlated ($r = –0.03$) with the apolar bound lipid content but there was a significant correlation for polar and apolar free lipids ($r = –0.53$).

No positive or negative correlations were noted in Table V between the semolina physicochemical characteristics and the different lipid contents (at $P < 0.05$). This lack of correlation is in agreement with results obtained by Berger (1983) and Fennyvesi-Simon et al (1992), who demonstrated that there were no correlations between lipid fractions and other flour or semolina components (proteins or gluten). Moreover, the lack of correlation between semolina polar lipid contents and protein (or gluten) contents indicates that the lipoprotein associations do not exist in raw semolina and could only be formed during the couscous-making process.

Couscous Quality Assessment

The characteristics of uncooked couscous made with semolina milled from the different wheat cultivars studied are listed in Table VI. We were unable to conduct ANOVA of the uncooked couscous and cooked couscous characterization results because no replicate was presented on these data. The median particle size (D_{50}) of the different uncooked couscous batches ranged from 823 μm for Polinicum to 982 μm for Belikh2, with a mean of 913 μm. The granulometric dispersion (S_g) had a range of 1.11–1.18, with a mean of 1.14. The low granulometric dispersion of the couscous batches obtained indicated that the particle sizes were very homogeneous.

TABLE IV
Linear Correlation Coefficients (*r*) Between Different Contents of Lipid Classes in Semolinas Obtained from Selected Durum Wheat Cultivars[a]

Lipid Classes	Terms	TL	FL	FL$_{NP}$	FL$_{P}$	Gly	Pho	BL	BL$_{NP}$	BL$_{P}$
Total lipids	TL	1								
Free lipids	FL	0.47*	1							
Nonpolar free lipids	FL$_{NP}$	0.47	0.91*	1						
Polar free lipids	FL$_{P}$	0.32	0.81*	0.49*	1					
Glycolipids	Gly	0.28	0.65*	0.31	0.92*	1				
Phospholipids	Pho	0.25	0.73*	0.61*	0.67*	0.34	1			
Bound lipids	BL	0.41	–0.62*	–0.53*	–0.55*	–0.42	–0.53*	1		
Nonpolar bound lipids	BL$_{NP}$	0.53*	–0.38	–0.25	–0.44	–0.41	–0.29	0.87*	1	
Polar bound lipids	BL$_{P}$	–0.12	–0.57*	–0.61*	–0.32	–0.11	–0.57*	0.48*	–0.03	1

[a] Significant at $P < 0.05$ (*); $n = 18$.

TABLE V
Linear Correlation Coefficients (*r*) Between Contents of Lipid Classes in Semolinas and Physicochemical Characteristics of Semolinas Obtained from Selected Durum Wheat Cultivars[a]

Characteristics	Terms	TL	FL	FL$_{NP}$	FL$_{P}$	Gly	Pho	BL	BL$_{NP}$	BL$_{P}$
Protein content	PC	–0.10	–0.06	0.12	–0.29	–0.31	–0.13	–0.03	0.03	–0.03
Dry gluten	DG	0.06	0.14	0.26	–0.08	–0.08	–0.10	–0.09	–0.02	–0.09
Gluten index	GI	0.30	0.22	0.19	0.19	0.28	–0.08	0.04	0.03	0.15
SDS-sed vol	V$_{SDS}$	0.06	0.22	–0.34	–0.03	–0.10	0.11	–0.05	–0.20	0.14
Mixo time	MT	0.22	0.25	0.32	0.06	0.06	0.02	–0.06	–0.19	0.08
Mixo peak height	MPH	–0.06	0.02	0.13	–0.13	–0.06	–0.22	–0.08	–0.18	0.03

[a] Significant at $P < 0.05$ (*); $n = 18$. Lipid terms as defined in Table IV.

TABLE VI
Technological Characteristics of Homemade Couscous Made from Selected Durum Wheat Cultivars[a]

Characteristics	Terms	Mean Value ± SD	Minimum	Maximum
Average diameter (μm)	D_{50}	913 ± 46	823	982
Granulometry scattering (d_{80}/d_{50})	S_g	1.14 ± 0.02	1.11	1.18
Swelling (mL/100g)	$S_{100^\circ C}$	414 ± 20.3	375	437
Caking index (%)	CI	23.9 ± 6.14	8.25	32.6
Cooking loss (% dm)	CL	12.5 ± 0.52	11.4	16.3
Starch solubility index (%)	I_{sol}	5.11 ± 1.20	3.16	7.34
Starch swelling index (g/g)	I_{swel}	4.65 ± 0.45	3.94	5.39
Couscous firmness (mm)	F	6.61 ± 0.54	5.79	7.53
Couscous elastic recovery (mm)	ER	0.54 ± 0.09	0.33	0.79
Viscoelasticity index	IV	1.33 (± 0.36)	0.72	1.91

[a] Calculated from two replicates for the 18 cultivars at two years in Algeria. Mean values ± standard deviations.

Couscous cooking quality was assessed on the basis of swelling at 100°C ($S_{100^\circ C}$), the caking index (CI), the extent of cooking loss (CL), firmness (F), elastic recovery (ER), viscoelasticity index (IV), and starch performance solubility (I_{sol}) and swelling index (I_{swel}). The different cooked couscous characteristic values are presented in Table VI. The extent of couscous swelling ($S_{100^\circ C}$) varied between semolinas. The highest values were recorded for semolina milled from Vitron (437 mL/100 g), while the lowest values were obtained for semolina derived from Sahel (375 mL/ 100 g), with an overall mean of 414 mL/100 g. The couscous caking index (CI) had a range of 8.25% for Belikh2 to 32.6% dm for Simeto, with a mean of 23.9% dm. The couscous cooking loss (CL) values ranged from 11.4% for Oued Zenati to 16.3% dm for Oumrabi, with an overall mean of 12.5% dm. Differences were also noted between couscous batches in terms of the solubility (I_{sol}) and swelling (I_{swel}) index. The lowest solubility index values were obtained for Oumrabi (3.16% dm) and Bidi17 (3.72% dm). The highest swelling index values were obtained for Oued Zenati (5.39 g/g) and Oumrabi (5.27 g/g). The cooked couscous cooking quality was also assessed on the basis of textural properties. In all couscous batches studied, firmness (F) ranged from 5.79 mm for couscous made from Belikh to 7.53 mm for couscous produced from Chen, with a mean of 6.61 mm. The Oumrabi produced couscous with the highest elastic recovery (ER) (0.79 mm) and Kebir produced couscous with the lowest value (0.33 mm), with a mean of 0.54 mm. Kebir showed the lowest viscoelasticity index (IV) while Ost produced couscous with the highest index (1.91), with an overall mean of 1.33.

We calculated correlation coefficients ($P < 0.05$) between the different couscous batches (Table VII). The results analysis revealed correlations ($r = -0.59$) between the uncooked couscous particle size (D_{50}) and the cooked couscous caking index (CI). Indeed, the cooked couscous caking index (CI) decreased as the uncooked couscous particle size (D_{50}) increased. Couscous swelling ($S_{100^\circ C}$) was not correlated with the other couscous characteristic parameters, except with cooking loss ($r = 0,55$) and starch solubility index ($r = -0.49$). We noted that the different parameters concerning couscous texture were closely correlated. The cooked couscous elastic recovery (ER) was thus positively correlated with firmness ($r = 0.55$) and viscoelasticity index ($r = 0.64$).

Contribution of Semolina Lipid and Characteristics in Couscous Properties

The results of the linear regression between the couscous quality characteristic parameters and the semolina lipid composition or the semolina physicochemical characteristics are presented in Tables VIII and IX, respectively.

No correlations were obtained between the uncooked couscous particle size (D_{50}) and the total lipid content ($r = 0.25$). The correlation analysis only highlighted one significant correlation

TABLE VII
Linear Correlation Coefficients (r) for Couscous Technological Characteristics Made from Selected Durum Wheat Cultivars[a]

Characteristics	Terms	D_{50}	$S_{100^\circ C}$	CI	CL	I_{sol}	I_{swel}	F	ER	IV
Average diameter	D_{50}	1								
Swelling	$S_{100^\circ C}$	–0.21	1							
Caking index	CI	–0.59*	0.36	1						
Cooking loss	CL	–0.10	0.36	0.22	1					
Starch solubility index	I_{sol}	0.20	–0.06	–0.20	–0.49*	1				
Starch swelling index	I_{swel}	0.22	0.35	–0.05	0.55*	–0.38	1			
Couscous firmness	F	–0.30	0.30	0.31	0.21	–0.30	0.15	1		
Couscous elastic recovery	ER	–0.29	0.45	0.14	0.29	–0.33	–0.05	0.55*	1	
Viscoelasticity index	IV	–0.34	0.15	0.34	0.05	0.05	–0.38	0.29	0.64*	1

[a] Significant at $P < 0.05$ (*); n =18.

TABLE VIII
Linear Correlation Coefficients (r) Between Couscous Technological Characteristics and the Contents of Different Classes of Lipids in Semolinas Obtained from Selected Durum Wheat Cultivars[a]

Lipid Classes	Terms	D_{50}	$S_{100^\circ C}$	CI	CL	I_{sol}	I_{swel}	F	ER	IV
Total lipids	TL	0.25	–0.43	0.03	–0.19	–0.01	0.02	0.07	–0.30	–0.09
Free lipids	FL	0.15	–0.62*	–0.27	–0.49*	–0.02	–0.26	0.14	–0.15	–0.13
Nonpolar free lipids	FL_{NP}	0.18	–0.68*	–0.44	–0.48*	0.14	–0.27	–0.19	–0.37	–0.17
Polar free lipids	FL_P	0.05	–0.32	–0.09	–0.27	–0.25	–0.17	0.57*	0.46	–0.04
Glycolipids	Gly	–0.07	–0.25	–0.42	–0.05	–0.44	–0.05	0.63*	0.14	–0.10
Phospholipids	Pho	0.26	–0.30	–0.48*	–0.54*	0.24	–0.33	0.19	0.26	0.09
Bound lipids	BL	0.08	0.26	0.31	0.30	0.02	0.38	–0.09	–0.12	0.06
Nonpolar bound lipids	BL_{NP}	0.46	–0.01	–0.05	0.23	0.08	0.43	–0.24	–0.29	–0.18
Polar bound lipids	BL_P	–0.65*	0.53*	0.70*	0.20	–0.11	0.01	0.25	0.26	0.44

[a] Significant at $P < 0.05$ (*); n =18. Terms for technological characteristics as defined in Table VII.

TABLE IX
Determination of Linear Correlation Coefficients (r) Between Couscous Technological Characteristics and the Physicochemical Characteristics of Semolinas Obtained from Selected Durum Wheat Cultivars[a]

Characteristics	Terms	D_{50}	$S_{100^\circ C}$	CI	CL	I_{sol}	I_{swel}	F	ER	IV
Protein content	PC	–0.30	0.24	–0.05	–0.06	0.31	–0.10	–0.29	–0.16	–0.04
Dry gluten	DG	–0.08	–0.05	–0.26	–0.13	0.19	–0.13	–0.28	–0.22	–0.13
Gluten index	GI	0.13	–0.08	0.20	–0.20	0.22	0.22	0.07	–0.46	–0.38
SDS-sed volume	V_{SDS}	–0.23	–0.36	–0.10	–0.47	0.57*	–0.50*	–0.34	–0.54*	–0.17
Mixo time	MT	0	–0.54*	–0.23	–0.43	0.32	–0.30	–0.29	–0.56*	–0.11
Mixo peak height	MPH	0.34	–0.29	0.06	–0.33	0.27	–0.44	–0.41	–0.44	–0.01

[a] Significant at $P < 0.05$ (*); n =18. Terms for technological characteristics as defined in Table VII.

($P < 0.05$) between the couscous particle size (D_{50}) and the semolina polar bound lipid content. D_{50} increased as the polar bound lipid content decreased (r = –0.65). However, no significant effects of the free lipid, polar and apolar free lipid, and glycolipid or phospholipid contents were recorded. Nor were correlations between the uncooked couscous D_{50} and the semolina physicochemical characteristics noted.

In cooked couscous, there were no correlations between couscous swelling ($S_{100°C}$) and the total lipid content (r = –0.43). In contrast, negative significant correlations were noted between couscous swelling and the semolina free lipid content (r = –0.62), especially the apolar free lipid content (r = –0.68). Couscous swelling ($S_{100°C}$) was also correlated with the polar bound lipid content (r = 0.53). In addition, the results showed a lack of correlation between couscous swelling ($S_{100°C}$) and semolina physicochemical characteristics, except for mixograph mixing development time (r = –0.54). These results are in agreement with the studies of Addo and Pomeranz (1992), who showed that free lipids have a negative impact on dough swelling by masking the sites of hydrophilic groups involved in water molecule fixation. The reduction in the hot swelling capacity of monoglyceride-supplemented couscous was also reported by Belaïd et al (1994).

No correlations were obtained between the caking index (*CI*) and the total lipid, free lipid and bound lipid contents (Table VIII). However, there were correlations between the caking index (*CI*) and the polar bound lipid content (r = 0.70) or the phospholipid content (r = –0.48). The semolina phospholipid content seemed to promote a reduction in the couscous *CI*, whereas the polar bound lipid content promotes an increase (r = 0.70). Phospholipids reportedly decrease couscous stickiness through interactions with glutenins (Chiu and Pomeranz 1966; Chung and Tsen 1975) or through the formation of multilayer films at the water/starch interface (Feillet 2000). Couscous caking has thus been further decreased through the addition of monoglycerides (Belaïd et al 1994) or neutral oil (Aboubacar and Hamaker 1999, 2000). The positive impact of lipids on decreasing the caking index (*CI*) is in line with traditional couscous preparation practices, whereby the product is cooked twice successively and fat is added between these two operations. Similar results have been reported for cooked pasta. Adding a spoonful of oil reduced spaghetti stickiness during cooking (Feillet 2000).

We obtained a significant negative correlation ($P < 0.05$) between couscous cooking loss (*CL*) and the semolina free lipid content (r = –0.49), especially the semolina phospholipid content (r = –0.54) or apolar free lipid content (r = –0.48). In contrast, couscous cooking loss (*CL*) was not correlated with the total lipid content or the bound lipid content. According to Guezlane et al (1998), amylose diffusion on the couscous particle surface during cooking, which is responsible for particle disintegration, can be limited by the action of fatty acids and monoglycerides. Our results revealed that apolar lipids on the particle surface could complex with amylose during cooking, thus reducing its diffusion and disintegration. Kim and Robinson (1979) showed that starch-monoglyceride interactions occur at the onset of starch gelatinization. Monoglycerides bind weakly at temperatures <30°C. The extent of linkage increases as the temperature rises, to peak at 90°C. Monoglycerides complex with amylose after a conformational change in the amylolytic chain, which then becomes helicoidal. High semolina apolar free lipid contents could result in decreased starch loss during the cooking of certain couscous batches (Guezlane et al 1998).

The correlation matrix did not reveal any significant effects of the contents of the different classes of lipids on the starch solubility (I_{sol}) or swelling (I_{swel}). These parameters were not affected by the flour lipid composition. According to Ming et al (1997), observed variations in the degree of starch gelatinization are due mainly to the wheat cultivar and the starch amylose content. Starch swelling increases as the amylopectin content increases (Seib 1997). Note in Table IX also that there was a significant positive correlation (r = 0.57) between the SDS sedimentation volume (V_{SDS}) and the starch solubility index (I_{sol}) and a significant negative correlation (r = –0.50) with the swelling index (I_{swel}). Indeed, wheat gluten swelling index decreases as gluten strength increases. This contrasts with the results obtained by Debbouz et al (1994), who found that couscous made with semolina milled from firm-gluten wheat cultivars had high starch swelling indices in comparison to couscous made with semolina milled from wheat cultivars containing relatively unfirm gluten.

The correlation matrix analysis revealed no correlations between the couscous textural properties (*F*, *ER*, and *IV*) and the total lipid content (Table VIII). We only observed a positive effect of the polar free lipid content on the cooked couscous firmness, (*F*) especially on the basis of the glycolipid content (r = 0.63). The couscous firmness increased as the semolina polar free lipid content increased (r = 0.57). However, the couscous elastic recovery (*ER*) and viscoelasticity index (*IV*) were not correlated with the semolina lipid composition. In contrast to pasta, apolar lipids did not seem to have a positive impact on cooked couscous firmness and elastic recovery. For Matsuo et al (1986), pasta elasticity is controlled by neutral lipids. Monoglycerides are responsible for the resistance of spaghetti to overcooking. We also noted negative correlations between the cooked couscous elastic recovery (*ER*) and semolina SDS sedimentation volume (r = –0.54) and mixograph mixing development time (r = –0.56).

The analysis of all the results thus clearly showed that the cooking quality of couscous made from the different durum wheat semolinas was partially dependent on the semolina free lipid composition. We demonstrated that this was mainly a varietal characteristic. The couscous surface state (caking index and cooking loss) thus depended on the apolar lipid and phospholipid contents. Polar lipids contributed to the couscous texture in terms of firmness. Our results also showed that the cooked couscous quality criteria were independent of the semolina total lipid content.

We have also shown that the couscous characteristics were not significantly related to the semolina protein and dry gluten contents or the gluten index (Table IX), contrary to the results generally reported for pasta (Matveef 1966; Damidaux and Feillet 1978; Feillet 1984; Cubbada et al 1992). No high correlation was noted between the mixograph dough properties of semolinas and the couscous technological quality but this could be explained by the fact that these tests provide more information on flour performance during bread dough mixing than on couscous performance. This can be explained by the specific process conditions applied during couscous technology (low water content and low mechanical energy input during mixing), compared with bread processing that could induced specific physicochemical mechanisms.

Further details on the technological value of wheat cultivars in relation to their couscous-making quality could be obtained through more in-depth studies involving a greater number of wheat cultivars from several cropping sites and spanning several harvest years. Although some correlation coefficients have been found statistically significant, their relative low values (r = 0.4–0.7) restrict their use to demonstrate some relationships between couscous quality parameters and lipid characteristics of semolina. Because lipid composition seems to be primarily a varietal characteristic and couscous cooking quality is at least partially dependant on lipid composition, our results could be taken into consideration by breeders to improve durum wheat cultivars for production of couscous. Additional experimental data will be necessary to propose a relevant model for predictive purposes.

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