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Comparative study of the content and profiles of macronutrients in spelt and wheat, a review

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Spelt (*Triticum spelta*) is a hexaploid wheat, hulled and with a brittle rachis, and it has interesting agronomic properties. It is used in feed and food, and is becoming more widely used in the growing natural foods market. Spelt differs from wheat in that it has a higher protein content (15.6% for spelt, 14.9% for wheat), higher lipid content (2.5% and 2.1%, respectively), lower insoluble fiber content (9.3% and 11.2%, respectively) and lower total fiber content (10.9% and 14.9%, respectively). There are no important differences in starch, sugar and soluble fiber content, and there is a qualitative diversity at the protein, arabinoxylan and fatty acid levels.

Keywords. *Triticum spelta*, chemical composition, lipid content, starch, fibers, proteins.

Étude comparative des teneurs et profils des macronutriments de l'épeautre et du blé. L'épeautre (*Triticum spelta*) est un blé hexaploïde, vêtu, au rachis cassant qui présente des caractéristiques agronomiques d'intérêt. Il est utilisé en alimentation animale et humaine et se développe particulièrement sur le segment des produits naturels. L'épeautre se distingue du froment par ses teneurs supérieures en protéines (15,6 % *versus* 14,9 %) et lipides (2,5 % *versus* 2,1 %) et ses teneurs inférieures en fibres insolubles (9,3 % *versus* 11,2 %) et fibres totales (10,9 *versus* 14,9 %). Les teneurs en amidon, sucres et fibres solubles ne présentent pas de différences importantes. Une diversité qualitative au niveau des protéines, des arabinoxylanes et des acides gras est observée.

Mots-clés. *Triticum spelta*, composition chimique, teneur en lipides, amidon, fibre, protéine.

1. INTRODUCTION

Spelt (*Triticum spelta*) is a hexaploid cereal belonging to the *Triticum* genus in the Gramineae family. Spelt grains are hulled and the hull represents 21-32% of the harvested product (Percival, 1921). Spelt spikes are pyramidal and the rachis is brittle (Luo et al., 2000). The relationship between spelt and wheat has been investigated extensively, with most studies postulating that they belong to the same species, but to separate gene pools. The literature continues to consider them as distinct species, more from the point of view of use rather than genetics (Abdel-Aal et al., 2005). The most recent studies on the phylogenic origin of spelt support the hypothesis that spelt results from several hybridizations between club wheat and a hulled tetraploid emmer (Yan et al., 2003; An et al., 2005). It has been established that spelt originated from the Middle-East and migrated northwards along the Black Sea and the Danube from East to West, reaching Austria, Southern Germany and Northern Switzerland (Andrews, 1964). In Europe, during a period of climatic cooling (750-15 BC), spelt replaced einkorn (*Triticum monococcum*) and emmer (*Triticum dicoccum*) and then, in turn, was replaced by free-threshing wheat almost throughout Europe during the first millennium (Nesbitt et al., 1996).

In terms of agronomic characteristics, spelt displays high resistance to environmental factors such as diseases and stress, and can produce good yields under disadvantageous growing conditions such as wet, cold soils and high altitudes (Campbell, 1997). In addition, as the hull covers the seed, chemical treatment before sowing is not always necessary and, because of its long straw, spelt cannot withstand a high level of nitrogen fertilization (Bonafaccia et al., 2000). It is suitable for organic farming and contributes to agro-biodiversity, thus meeting the objectives of the European Union with regard to growing practices. Spelt is now cultivated in Europe, Asia (Iran), North Africa, the USA and Canada (Abdel-Aal et al., 1998a; Dvoracek et al., 2002). It is used mainly in animal feed in order to provide a balanced intake for animals fed primarily on grass silage (Lecomte et al., 1996). As an ancient crop, however, spelt occupies a niche market in North America and Europe in the natural, organic, health and specialty-food markets (Abdel-Aal et al., 2005). It has the potential for a variety of uses, including bread, pasta and breakfast cereals (Abdel-Aal et al., 1998b; Bonafaccia et al., 2000). These uses are similar to those associated with wheat, although the characteristics differ. The composition of the two cereals has been investigated for several decades and over the past five years a number of studies have produced more detailed information. The renewed interest in spelt requires an update on its composition. This paper discusses the macronutrients of spelt and wheat and highlights the differences between these cereals. The focus is on non-fiber carbohydrates, fibers, proteins and lipids.

2. NON-FIBER CARBOHYDRATES

Carbohydrates provide 40-75% of total energy intake, constituting the most important energy source in human diets (Gray, 2003). They are usually classified according to their degree of polymerization: sugars, oligosaccharides and polysaccharides (FAO, 1998). For both spelt and wheat, carbohydrates are the main components (59-71%) of the grain kernel (Belitz et al., 1999). Various studies have indicated that there is no great difference in total carbohydrate, starch and sugar content between spelt and wheat whole flour (Abdel-Aal et al., 1995; Ranhotra et al., 1995; Grela, 1996; Ranhotra et al., 1996) (**Table 1**).

2.1. Starch

Starch is the main storage carbohydrate in spelt and wheat kernels, accounting for 61-68% of the grain, whereas sugars account for 2-3% (Abdel-Aal et al., 2005). According to Abdel-Aal et al. (1999a) and Abdel-Aal et al. (1999b), spelt has a lower amylose content than wheat, but Wilson et al. (2008) reported a higher amylose content (2-21%) in spelt starch than in the hard red winter wheat control. Amylose and amylopectin are two components of the starch granule, accounting for 26-28% and 72-74%, respectively; amylose is a linear glucose homopolymer of glucose, and amylopectin is a branched homopolymer of glucose (Feillet, 2000).

Table 1. Starch and sugar contents in % D.M. [mean values and (min.-max.)] of wheat and spelt whole grain — *Teneurs en amidon et en sucres en % M.S. [valeurs moyennes et (min.-max.)] du grain complet de blé et d'épeautre*.

Wheat				**Spelt**				**Growing conditions**		**Reference**
n	**Starch**	**Sugars**	**Total**	***n***	**Starch**	**Sugars**	**Total**	**Number of locations**	**Number of years**	
1*	62.4	3.3	65.7	5	63.8 (60.9-65.8)	2.1 (1.7-2.5)	65.9 (63.4-67.6)	4 (1993) and 5 (1992)	2	Abdel-Aal et al., 1995
1	-	-	69	1	-	-	66.2	1**	1	Ranhotra et al., 1995
1	68.1	3.1	71.2	4	66.7 (65.9-67.6)	3 (2.4-3.4)	69.7 (68.4-70.9)	1	1	Grela, 1996
2	-	-	66.7 (63.6-68.3)	3	-	-	67 (59.2-69.8)	5 (spelt) and 2-3 (wheat)	1	Ranhotra et al., 1996
-	-	-	-	5	-	-	65.2 (59.5-69.4)	4**	-	Marconi et al., 1999
	63.0 (62.4-68.1)	3.3 (3.1-3.3)	66.5 (63.6-71.2)		64.0 (60.9-67.6)	2.2 (1.7-3.4)	66.1 (59.2-70.9)			Weighted mean and range

n: number of genotypes — *nombre de génotypes;* *: spring — *printemps*; **: samples cultivated in different countries — *échantillons cultivés dans divers pays*.

Gelatinization is the transformation of starch granules in four stages: loss of crystallinity (fusion of the crystalline phase, due mainly to amylopectin); water absorption (swelling); bursting of the granules; and amylose solubilization. This phenomenon is irreversible and results in increased viscosity and starch jellification when temperatures fall (Feillet, 2000). Jorgensen et al. (1997) reported that the gelatinization temperature, measured with a Brabender amylograph, was higher in spelt (87-93.2°C) than in common wheat (84.6°C) varieties. Abdel-Aal et al. (1999b) found a wide range of transition temperatures for spelt starches compared with wheat, but the difference in the enthalpy of the gelatinization of spelt starch was very similar to that of common wheat starch.

With regard to starch size distribution, Abdel-Aal et al. (1999a) observed little difference. Wilson et al. (2008) studied the relationship between the granules and technological characteristics in spelt. Negative correlations were observed between the large A-type granules and breadcrumb score, amylose level, pasting viscosity for cultivars grown in 1999 and pasting temperature for those grown in 1998. Positive correlations were found between the small B- and C-type granules and crumb score, loaf volume, amylose, Rapid Visco Analyser (RVA) final pasting viscosity for cultivars grown in 1999 and RVA pasting temperature for those grown in 1998.

Intra-species variability in starch content has been observed, which could be explained by the genotype and growing season conditions, as reported in Massaux et al. (2008) for wheat.

2.2. Sugars

Sugar content in spelt samples has been found to be more variable than in wheat samples, but the number of samples that have been investigated is limited (Abdel-Aal et al., 1995; Ranhotra et al., 1995; Grela, 1996; Ranhotra et al., 1996). With regard to free sugars, there is no difference in the total concentration between spelt and modern wheat (Zorb et al., 2007).

3. FIBERS

Dietary fiber has beneficial physiological effects, such as laxation. Specifically, insoluble dietary fiber reduces transit time and increases fecal bulk and defecation frequency (AACC, 2001). Dietary fiber fermentation results in the production of short-chain fatty acids conducive to bowel health (Moore et al., 1998). In addition, high dietary fiber intake reduces the risk of diverticular disease, hemorrhoids and colorectal cancer (AACC, 2001). Reduced blood cholesterol and/or blood glucose has also been attributed to dietary fiber, which is linked to a reduced risk of cardiac disease through reduced blood cholesterol and the prevention of the development of type 2 diabetes (AACC, 2001; Gray, 2006). Fibers help control body weight, mainly through inducing satiety (Gray, 2006).

3.1. Fibers in whole grain

According to several studies (Bognar et al., 1994[1] cited in Ruibal-Mendieta, 2004; Abdel-Aal et al., 1995; Ranhotra et al., 1995; Ranhotra et al., 1996; Bonafaccia et al., 2000; Escarnot et al., 2010), the range of total dietary fiber content is greater in spelt than in wheat. This was not the finding in one study, however, conducted by Gebruers et al. (2008), but this could have been due to the higher number of wheat genotypes (131) considered (**Table 2**). Most studies have found that common wheat is richer in dietary fiber than spelt, and the same is true for insoluble fiber (Abdel-Aal et al., 1995; Ranhotra et al., 1995; Ranhotra et al., 1996; Escarnot et al., 2010). Escarnot et al. (2010) attributed this difference to hemicellulose and cellulose. For soluble fiber, the range is similar in spelt and wheat. Uniform values have been reported by most authors, including Bonafaccia et al. (2000), Abdel-Aal et al. (1995) and Ranhotra et al. (1996); Escarnot et al. (2010) found no statistical difference between spelt and wheat for soluble fiber content. Work done by Gebruers et al. (2008) shows that the total arabinoxylan content is 1.75% (1.60-2.25) for spelt and 1.90% (1.35-2.75) for wheat, and the water-extractable arabinoxylan content is 0.35% (0.30-0.45) for spelt and 0.50% (0.30-1.40) for wheat. The large range for wheat may be due to the high number of samples analyzed (131). The average arabinose/xylose ratios for total and water-extractable arabinoxylans are identical: spelt 0.60 (0.55-0.60) and 0.50 (0.45-0.55); and wheat 0.60 (0.50-0.70) and 0.50 (0.40-0.55).

According to Marconi et al. (1999), the β-glucan content of spelt is similar to that of common wheat, with a mean value of 1.2%. Gebruers et al. (2008), however, found a higher content in wheat (0.75%) than in spelt (0.65%), with ranges of 0.55-0.70% and 0.50-0.95%, respectively, displaying a higher diversity in spelt despite the low number of genotypes (5). These values accord with those noted by Loje et al. (2003), who reported 0.7% in spelt and 0.8% in wheat (based on different years of harvest, three spelt cultivars and one wheat cultivar). The concentration of fructans, such as 1-kestose and kestotetraose, is higher in spelt than in wheat (Zorb et al., 2007).

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[1] Bognar A. & Kellermann C., 1994. Ballaststoffgehalt von Dinkel. *Ernährungs-Umschau*, **41**, 454-455.

Table 2. Insoluble and soluble fiber contents in % D.M. [mean values and (min.-max.)] of wheat and spelt whole grain, white flour and bran — *Teneurs en fibres insolubles et solubles en % M.S. [valeurs moyennes et (min.-max.)] du grain complet, de la farine blanche et du son de blé et d'épeautre.*

Material	**Wheat**				**Spelt**				**Growing conditions**		**Reference**
	n	**Insoluble**	**Soluble**	**Total**	***n***	**Insoluble**	**Soluble**	**Total**	**Number of locations**	**Number of years**	
Whole grain	1	-	-	12.5	4	-	-	9.3 (8.8-10.3)	1	1	Bognar et al. 1994*
Whole grain	1			12.7	4	-	-	8.7 (7.7-9.3)	1	1	Bognar et al. 1994*
Whole grain	1 (spring)	10.8	1.7	12.5	5	8.22 (8.0-8.4)	1.76 (1.7-1.9)	10 (9.8-10.3)	4 (1993) and 5 (1992)	2	Abdel-Aal et al., 1995
Whole grain	1	13.2	2.2	15.4	1	10.8	1.8	12.4	2**	1	Ranhotra et al., 1995
Whole grain	2	11.7 (10.7-12.6)	1.8 (1.7-1.9)	13.5 (12.5-14.3)	3	9.1 (8.5-9.9)	1.4 (1.2-1.7)	10.5 (10.1-11.6)	5 (spelt) et 2-3 (wheat)	1	Ranhotra et al., 1996
Whole grain					5	10.7 (8.7-12.9)	2 (1.2-2.4)	12.7 (10.5-14.9)	4**	-	Marconi et al., 1999
Whole grain	1	11.4	1.4	12.8	3	11.5 (11.2-12.1)	1.7 (1.7-1.8)	13.2 (12.9-13.8)	1 (spelt) et 1** (wheat)	3 (spelt) et 1 (wheat)	Bonafaccia et al., 2000
Whole grain	131			15.2 (11.5-18.3)	5			12.0 (10.7-13.9)	1	1	Gebruers et al., 2008
Whole grain	3	10.1 (9.8-10.5)	1.6 (1.4-1.9	11.7 (11.3-11.9)	4	8.8 (7.8-10.1)	1.4 (0.8-2.0)	10.3 (8.5-11.9)	1	1	Escarnot et al., 2010
Whole grain	141	11.2 (10.7-13.2)	1.7 (1.4-2.2)	14.9 (12.3-15.4)	34	9.3 (8.0-12.9)	1.7 (1.2-2.4)	10.9 (7.7-14.9)			Weighted mean and range
White flour	1	0	2.52	2.52	1	0.58	2.07	2.65	1 et 1	1	Marques et al., 2007
Bran	3	32.1 (32.0-32.2)	1.2 (0.3-2.6)	33.3 (32.3-34.7)	4	29.4 (21.2-34.4)	2.9 (2.5-3.5)	32.6 (23.7-37.1)	1	1	Escarnot et al., 2010

n: number of genotypes — *nombre de génotypes;* *: Bognar A. & Kellermann C., 1994. Ballaststoffgehalt von Dinkel. *Ernährungs-Umschau*, **41**, 454-455, cited in Ruibal-Mendieta, 2004; **: samples cultivated in different countries — *échantillons cultivés dans divers pays.*

Table 3. Lignin, hemicellulose and cellulose contents in % D.M. [mean values and (min.-max.)] of wheat and spelt whole grain and bran, and spelt spikelet — *Teneurs en lignine, hémicellulose et cellulose en % M.S. [valeurs moyennes et (min.-max.)] du grain complet et du son de blé et d'épeautre, et de la farine d'épillets d'épeautre.*

Material	Wheat					Spelt					Growing conditions		Reference
	n	Lignin	Hemi-cellulose	Cellulose	Crude	*n*	Lignin	Hemi-cellulose	Cellulose	Crude	Number of locations	Number of years	
Whole grain	1				1.83	10				2.18 (1.71-2.76)	1	3	Moudry et al., 1999
Whole grain	1				3.3	7				2.77 (2.5-3.26)	2	1	Jorgensen et al., 1997
Whole grain	1	1.18	9.17	2.16	2.73	4	1.02 (0.88-1.08)	10.57 (7.8-18.84)	2.07 (1.93-2.29)	2.64 (2.39-2.97)		3	Grela, 1996
Whole grain	3	0.7 (0.6-0.7)	7.3 (7.0-8.1)	2.4 (2.1-2.8)		4	0.7 (0.6-0.8)	5.4 (4.6-6.4)	1.7 (1.4-1.9)		1	1	Escarnot et al., 2010
Whole grain	6	0.9 (0.6-1.2)	8.2 (7.0-9.2)	2.3 (2.1-2.8)	2.4 (1.8-3.3)	25	0.9 (0.6-1.1)	9.3 (4.6-18.8)	2.0 (1.4-2.3)	2.4 (1.7-3.3)			Weighted mean and range
Spikelet						24	2.7	13.2	12.8		1	1	Lecomte et al., 1996
Spikelet						4	1.3 (1.2-1.3)	12.3 (10.0-13.2)	10.4 (8.1-11.3)		1	1	Escarnot et al., 2010
Bran	3	2.1 (2.0-2.2)	22.6 (22.2-22.9)	7.5 (7.2-8.2)		4	2.3 (1.8-2.6)	18.6 (12.2-23.3)	5.7 (3.3-7.9)				Escarnot et al., 2010

n: number of genotypes — *nombre de génotypes*.

With regard to crude fibers, the range is wider for wheat than spelt (Grela, 1996; Jorgensen et al., 1997; Moudry et al., 1999), but no general rule can be established on content (**Table 3**). The two studies on hemicellulose (Grela, 1996; Escarnot et al., 2010) produced contradictory results.

Lignins are non-polysaccharide cell wall substances derived mainly from the three monolignols: *p*-coumaryl, coniferyl, and synapyl alcohols. The monolignols are targeted to different and distinct regions of various cell wall types, where they are polymerized to form wall-reinforcing biopolymers with distinctive biophysical properties (Davin et al., 2005). Lignin content is similar in spelt and wheat (Grela, 1996; Escarnot et al., 2010). The Klason lignin was evaluated by Gebruers et al. (2008), with similar levels being observed for spelt and wheat (2.25% and 2.20%, with ranges of 1.85-2.90% and 1.40-3.25%, respectively). Cellulose content is lower in spelt than in wheat (Grela, 1996; Escarnot et al., 2010).

These studies were based on enzymatic-gravimetric methods derived from Prosky for insoluble, soluble and total fiber and from Van Soest for cellulose, hemicellulose and lignin. A minor part of the variability can therefore be attributed to the evolution of the method over the years. Intra-species variability is not surprising as it has been demonstrated that genotype and environment (including management practices), and the interaction between them, have influenced the pentosan content of wheat (Li et al., 2002; Jiang et al., 2007).

3.2. Fibers in grain milling fractions

Escarnot et al. (2010) observed that spelt bran is richer than wheat in soluble fibers and lignin, but less rich in hemicellulose and cellulose (**Table 3**). In the bran, total-arabinoxylan content is much higher in wheat than in spelt (18% [13.2-22.1] and 12.7% [11.1-13.9], respectively), and the same is true for water-extractable arabinoxylan content (0.40% [0.30-0.85] and 0.30% [0.30-0.35]). The average arabinose/xylose ratio for total arabinoxylans is similar (spelt 0.50% [0.45-0.55] and wheat 0.60%

[0.55-0.70]), but the average arabinose/xylose ratio for water-extractable arabinoxylans is higher for spelt (1.40% [1.20-1.6]) than for wheat (1.00% [0.70-1.65]) (Gebruers et al., 2008). Escarnot et al. (2011) extracted 55% of the arabinoxylans in spelt bran; 13% were water-extractable and 87% were water-unextractable. The populations of water-extractable arabinoxylans were 7-8 kDa and 28 kDa, and of water-unextractable arabinoxylans they were 7-8 kDa and 310-415 kDa.

In hulled grain, Lecomte et al. (1996) reported absolute higher values of cellulose, hemicellulose and lignin, unlike those reported by Escarnot et al. (2010). The analysis of the whole spikelet flour displayed great diversity among the several genotypes studied (Escarnot et al., 2010).

Xylanase and xylanase-inhibitors affect grain quality, production parameters and, consequently, product quality. The only study conducted on enzymatic activity (Gebruers et al., 2010) indicates that spelt white flour and bran do not display high xylanase activity. Spelt and wheat have similar *Triticum aestivum* xylanase inhibitor activity and display high xylanase-inhibiting protein activity. In addition, inhibitor activity is much higher in spelt bran than in spelt flour (Gebruers et al., 2010).

4. PROTEINS

Proteins are a source of energy and provide essential amino acids. The wheat and spelt proteins are albumins, globulins, glutenins and gliadins. Most of the physiologically active proteins (enzymes) are albumins and globulins. They are concentrated in the cells of the aleurone layer, the pericarp and the germ, with a lower content in the endosperm. Glutenins and gliadins are storage proteins known as prolamins. They are limited to the endosperm, including the aleurone layer, and are therefore absent from the pericarp and the germ (Hoseney, 1994a).

4.1. Total content

Most literature data indicate higher protein content in spelt than in wheat (Abdel-Aal et al., 1995; Ranhotra et al., 1995; Codianni et al., 1996; Grela, 1996; Piergiovanni et al., 1996; Ranhotra et al., 1996; Jorgensen et al., 1997; Marconi et al., 1999; Moudry et al., 1999; Bonafaccia et al., 2000; Matuz et al., 2000a; Abdel-Aal et al., 2002; Marconi et al., 2002) (**Table 4**). This has been confirmed under low nitrogen fertilization: Oliveira (2001) found higher protein content in spelt than in wheat, and Dvoracek et al. (2002) observed that spelt grains had 0.5% more nitrogen than common wheat grain, but this difference was not statistically significant. For white flour, Pruska-Kedzior et al. (2008) found significantly higher protein content in spelt flour (14.7%) than in common wheat flour, and Wilson et al. (2008) reached the same conclusion about spelt and a hard winter wheat control. Wilson et al. (2008) also noted highly variable protein content in spelt white flour (from five cultivars after three years of cultivation). As the degree of nitrogen absorption from the soil and its conversion into proteins depend greatly on genotype and cultivation conditions, Gräber et al. (1992) recommended comparing samples grown under the same conditions. The general attribution of high protein content in spelt could be a consequence of the low grain yield. When comparing protein yields ($kg \cdot ha^{-1}$), the values for spelt are lower than those for conventional durum wheat, with a difference of up to 25% (Piergiovanni et al., 1996). In addition, a negative heterosis effect has been observed for spelt-common wheat crosses in terms of protein content (Schmid et al., 1994).

Intra-species protein content varies widely in the different studies. All analyses were performed using the Kjeldhal method, and therefore the variability could be explained by the growing conditions (environment and nitrogen fertilization) and genetic background that influence protein content (Dupont et al., 2003).

4.2. Fractional composition and nutritional quality

Albumins and globulins account for about 20% of the protein content in spelt (Pruska-Kedzior et al., 2008). Reversed Phase-High Performance Liquid Chromatography (RP-HPLC) has revealed a much higher content of total gliadins and a lower content of total glutenins in spelt than in wheat. The gliadin/glutenin ratio is significantly higher in spelt than in wheat (Wieser, 2000): 3.5 for spelt and 2 for common wheat (Koenig et al., 2009). In spelt, α-gliadins and γ-gliadins are predominant, whereas low and high molecular weight (LMW and HMW) glutenin subunits and ω-gliadins are generally minor components (Wieser, 2000). Acetic acid soluble prolamins accounted for 94.1% of total gluten protein in spelt flours and 85-87% of the total gluten protein in wheat flours (Pruska-Kedzior et al., 2008).

Gliadins and glutenins in spelt differ in structure from those in common wheat (Abdel-Aal et al., 1996; Harsch et al., 1997; Radic et al., 1997; Von Büren et al., 2000) and spelt storage proteins form gluten in which the properties and quality differ from those of common wheat (Abdel-Aal et al., 1995; Schober et al., 2002).

The *in vitro* digestibility of spelt and wheat proteins is similar (86.7% on average), but it is 97.6% for casein (Abdel-Aal et al., 2002). Ranhotra et al. (1995) observed a protein digestibility of 80.1% for spelt, 78.9% for wheat and 91.6% for casein, and concluded that this could suggest that spelt grain is better digested than common wheat, but the differences are minor.

Table 4. Crude proteins content in % D.M. [mean values and (min.-max.)] of wheat and spelt whole grain — *Teneur en protéines en % M.S. [valeurs moyennes et (min.-max.)] du grain complet de blé et d'épeautre*.

Wheat		**Spelt**		**Growing conditions**		**Reference**
n	**Crude proteins N·5,7**	***n***	**Crude proteins N·5,7**	**Number of locations**	**Number of years**	
1 (spring)	15.3	5	15.4 (14.9-16)	4 to 5	2	Abdel-Aal et al., 1995
1	14.4	1	14	1*	1	Ranhotra et al., 1995
1	12.3	4	11.1 (9.8-13.1)	1	1	Grela, 1996
1 (durum)	15	1	16.1	1	2	Codianni et al., 1996
3 (durum)	15.3 (14.1-16.1)	37	17.1 (15-19.4)	1	1	Piergiovanni et al., 1996
2	15.4 (13.4-17.5)	3	18.5 (15.8-25.5)	2-3 wheat and 5 spelt	1	Ranhotra et al., 1996
1	10.9	7	13.3 (12.5-14.3)	1	1	Jorgensen et al., 1997
		5	15.7 (14.3-18.4)	4*	unknown	Marconi et al., 1999
1	12.9**	10	13.5** (12.2-15.2)	1	3	Moudry et al., 1999
1	13.8	3	16.4 (15.9-17.1)	1* wheat and 1 spelt	1 wheat and 3 spelt	Bonafaccia et al., 2000
4	15.8** (13-16.7)	1	20.6**	unknown	unknown	Matuz et al., 2000
1 (spring)	16.4	2	16.9 (16.5-17.4)	1	2	Abdel-Aal et al., 2002
		5	14 (12.8-16)	1	1	Marconi et al., 2002
17	14.9 (10.9-17.5)	84	15.6 (9.8-25.5)			Weighted mean and range

n: number of genotypes — *nombre de génotypes;* *: samples cultivated in different countries — *échantillons cultivés dans divers pays*; **assumption of dry matter of 90% — *en supposant une matière sèche à 90 %*.

Gliadins. Through hydration, gliadins form the gluten network that makes wheat and spelt unique bread-making cereals (Hoseney, 1994b). The MW of spelt gliadins is between 34 and 75 kDa (Abdel-Aal et al., 1996). Abdel-Aal et al. (1996) and Harsch et al. (1997) found that the gliadin profile for common wheat and spelt differed. Spelt gliadins do not have slow-moving ω-gliadin or strong-staining fast-moving ω-gliadin, but these are present in common wheat. Spring and winter spelt were characterized by a large number of slow-moving α-gliadins. A γ-gliadin band was also observed in spring spelt, but not in winter spelt or wheat, and this could be a useful point of distinction. Von Büren et al. (2000) discovered an unknown γ-gliadin gene in 18 spelt and spelt-wheat crosses and in the cultivar Chinese Spring, whereas the 16 wheat cultivars had a previously documented allele. In 2001, Von Büren et al. (2001) developed a polymerase chain reaction (PCR)-based method on the allelic difference in the γ-gliadin gene GAG56D to determine the proportion of wheat in spelt flour and products, with a minimal detection level of 5%. Piergiovanni et al. (2003) found that lines belonging to the same species could be differentiated mainly by comparing the pattern of β- and ω-gliadins. Federmann et al. (1992) reached the same conclusion and recommended slow-moving ω-gliadins for discriminating spelt flour. Using RP-HPLC and sodium dodecyl sulfate (SDS) electrophoresis, Koenig et al. (2009) observed that spelt was deficient in the so-called ω-bound gliadins (a minor portion of the ω-gliadins with a MW of 50-55 kDa) that are present in the glutenin fraction due to one cysteine residue in the amino acid sequence. This group of proteins could therefore be used to detect and quantify small amounts of common wheat in spelt and spelt products.

Glutenins. Most of the LMW-glutenin subunits of spelt seem acetic acid soluble. Spelt flour has been found to contain half as many NaOH-soluble glutenins (5.1% of total gluten protein) as common wheat flour (about 10% of total gluten proteins) (Pruska-Kedzior et al., 2008). HMW and LMW glutenins have been associated with bread and pasta-making quality in common and durum wheat, respectively (Pogna et al., 1990; Shewry et al., 1995). From a cross between *Triticum aestivum* and *Triticum speltoides*, Moonen et al. (1985) found that two HMW glutenin subunits (5 and 9) of common wheat coded by a gene locus on the arm of chromosome 1B (Glu-B1c) are associated with good baking quality and that the replacement of these subunits by two others derived from *T. speltoides* (S1 and S2) led to poorer quality in the backcrossed lines examined. Radic et al. (1997) found differences in glutenin between spelt and common wheat using SDS polyacrylamide gel on 28 spelt samples, 16 spelt-wheat crosses and 10 winter wheat samples. Radic-Miehle et al. (1998) studied SDS soluble protein with and without a pre-extraction method, where typical bands could be identified for each species. Caballero et al. (2004c) showed that variability in the LMW-glutenin subunits in spelt is higher than in other species. Alleles Glu-A3h and Glu-B3d coding LMW-glutenin subunits are present in spelt, but rare or absent in common wheat (Yan et al., 2003).

Amino acids. Generally, cereal proteins are known for their low essential amino acid content, especially lysine (the first most deficient amino acid) (Kies et al., 1970) and threonine (the second most deficient amino acid), but they are rich in glutamic acid and proline, the major functional amino acid in dough formation (Abdel-Aal et al., 2005). Spelt contains 38.2% of essential amino acids, as does wheat (Grela, 1996); the percentage of essential amino acids over total amino acids in protein is similar for wheat and spelt, indicating equivalent protein quality (Grela, 1996; Jorgensen et al., 1997; Abdel-Aal et al., 2002; Ruibal-Mendieta, 2004) (**Table 5**) and equivalent biological value of proteins (indicated by the ratio of amino acid over protein) (Matuz et al., 2000a).

The spelt amino acid composition of proteins differs slightly from that of wheat (Ranhotra et al., 1995; Cubadda et al., 1996; Grela, 1996; Bonafaccia et al., 2000; Abdel-Aal et al., 2002). Even if there is no statistical difference between spelt and common wheat in terms of amino acid content, there is evidence of higher values (except for isoleucine, leucine and glycine) in spelt than in common wheat (Dvoracek et al., 2002). This was confirmed by Matuz et al. (2000a), who observed that wholemeal and flour from spelt had a higher content of most amino acids than some recently developed common wheat.

According to Grela (1996), the average lysine content is considerably higher in spelt (3.19 g per 16 gN) than in wheat (2.91 g per 16 gN), but most studies show that lysine content is lower in spelt than in wheat (Matuz et al., 2000a; Abdel-Aal et al., 2002), with a difference of up to 28% (Ranhotra et al., 1995). Jorgensen et al. (1997) reported that lysine content was 2.72 g per 16 gN (2.58-2.89) in spelt and 2.97 g per 16 gN in wheat. Clamot (1984) found considerable genetic differences in protein and lysine content among 164 spelt samples, including 77 breeding lines from old Belgian landraces, 72 introductions from various countries and 15 induced mutants over a 3-year period.

Two studies found a higher methionine content in spelt than in common wheat (Ranhotra et al., 1995; Bonafaccia et al., 2000), but Matuz et al. (2000a) found the opposite. Jorgensen et al. (1997) found no significant differences for methionine content among the spelt varieties.

Within the group of essential amino acids, no significant differences were found for isoleucine, leucine, phenylalanine and valine content among the spelt varieties. In the group of non-essential amino acids, spelt had significantly more proline and less alanine and arginine than wheat (Jorgensen et al., 1997). Spelt had also significantly more glutamic acid, significantly and negatively correlated with lysine (Jorgensen et al., 1997; Abdel-Aal et al., 2002) and more tyrosine than wheat (Ranhotra et al., 1995; Jorgensen et al., 1997). Aspartic acid was higher in spelt than in wheat (Ranhotra et al., 1995).

5. LIPIDS

5.1. Fatty acid content and profiles

Lipids are minor grain constituents, accounting for about 3% of the wheat kernel. They are more concentrated in

Table 5. Percentage of essential amino acids within total amino acids in wheat and spelt whole grain [mean values and (min.-max.)] — *Pourcentage des acides aminés essentiels par rapport aux acides aminés totaux du grain complet de blé et d'épeautre [valeurs moyennes et (min.-max.)]*

Wheat		Spelt		Growing conditions		Reference
n	**% essential amino acids/total amino acids**	***n***	**% essential amino acids/total amino acids**	**Number of locations**	**Number of years**	
1	39	4	40 (39-41)	1	1	Grela, 1996
1	37	7	36 (35-37)	1	2	Jorgensen et al., 1997
2 (spring and durum)	34	2	34	1	2	Abdel-Aal et al., 2002
4	35.6 (34-39)	13	36.4 (34-41)			Weighted mean and range

n: number of genotypes — *nombre de génotypes*.

the germ (which contains 28.5% of lipids) and in the aleurone layer (8.0%) than in the endosperm (1.5%) (Delcour et al., 2010). Whole-wheat lipids are made up of about 70% non-polar lipids, 20% glycolipids and 10% phospholipids (Delcour et al., 2010), to which small percentages of sterols, tocopherols and other fat-soluble vitamins are added (Abdel-Aal et al., 2005). In flour from the starchy endosperm, some lipids are associated with starch granules (1.0%), but others are not (1.4%). Among the non-starch lipids, free lipids (with non-polar and polar lipids) and bound lipids are distinct, and among the starch lipids the non-polar and polar lipids are separated (Chung et al., 2009). Starch lipids are made up of 9% non-polar lipids, 5% glycolipids and 86% phospholipids (Delcour et al., 2010). Starch lipids are contained within starch granules as inclusion complexes and located between amylose and monoacyl lipids, such as lysophosphatidylcholines (Feillet, 2000). Non-starch lipids are made up of 60% non-polar lipids, 25% glycolipids and 15% phospholipids (Delcour et al., 2010). Non-starch lipids are dispersed inside the albumen and can react with other flour constituents. In the germ and the aleurone layer, lipids are assembled into spherosomes that are triglycerides surrounded by polar lipids and proteins (Feillet, 2000). In cereals, lipid content is usually determined by extraction with non-polar solvents. Bound lipids (to starch) are not taken into account because their extraction requires the use of polar solvents. Free lipid content is a practical estimate of total content and allows the comparison of data from different laboratories (Chung et al., 2000).

Most studies on free lipids show that spelt is richer in lipids than wheat (Abdel-Aal et al., 1995; Ranhotra et al., 1995; Grela, 1996; Piergiovanni et al., 1996; Ranhotra et al., 1996; Moudry et al., 1999; Ruibal-Mendieta et al., 2002; Ruibal-Mendieta et al., 2005) (**Table 6**). Ruibal-Mendieta et al. (2002) found that total lipid content was also higher for spelt than wheat and true spelt might contain more lipids than hybrid spelt, although this difference was significant in two out of three harvest years. These observations suggest that germ is present in higher proportions in spelt kernels than in common wheat kernels (Marconi et al., 1999).

With regard to fatty acids, studies show that the major fatty acids in spelt and wheat wholemeal are linoleic, palmitic, oleic and linolenic acids (Grela, 1996; Ruibal-Mendieta et al., 2004b; Ruibal-Mendieta et al., 2005). The proportion of oleic acid in fatty acids is higher in spelt than in common wheat, but the proportion of linoleic and linolenic acids are lower in spelt than in common wheat. More saturated fatty acids have been observed in wheat than in spelt (averages of 19.8% and 18.9%, respectively; **table 7**).

Most results have been obtained using extraction with ether or petrolether, so the variation in content can be attributed partly to the change of method. However, it is known that lipid content and composition are influenced by genetic variation (including wheat class and cultivar), environmental effects during growth (including location, year, weather and soils) and the effects of the genetic x environment interaction (Chung et al., 2009). For fatty acids, Ruibal-Mendieta et al. (2004b), Ruibal-Mendieta et al. (2005) and Grela (1996) used different methods, respectively from Stoldt (1952) and from Folch et al. (1957) but there was variability among studies that used the same method. Method, environment, genotype and their interaction therefore all contribute to the variability.

Table 6. Free lipid contents in % D.M. [mean values and (min.-max.)] of wheat and spelt whole grain — *Teneurs en lipides libres en % M.S. [valeurs moyennes et (min.-max.)] du grain complet de blé et d'épeautre*.

Wheat		**Spelt**		**Growing conditions**		**Reference**
n	**Free lipids**	***n***	**Free lipids**	**Number of locations**	**Number of years**	
1 (spring)	2.1	5	2.4 (2.2-2.5)	4 to 5	2	Abdel-Aal et al., 1995
1	2.2	1	2.8	1*	1	Ranhotra et al., 1995
1	2.3	4	3.9 (3.8-4.0)	1	1	Grela et al., 1996
2	3.2 (2.8-3.7)	3	2.4 (1.6-2.7)	5 spelt and 2-3 wheat	1	Ranhotra et al., 1996
3 (durum)	1.5 (1.1-2.1)	37	2 (1.4-2.8)	1	1	Piergiovanni et al., 1996
		5	4.4 (3.8-5.2)	4*	unknown	Marconi et al., 1999
1	1.6	10	1.9 (1.6-2.2)	1	3	Moudry et al., 1999
5	1.9 (1.7-2.0)	9	2.3 (1.9-2.6)	1	1	Ruibal-Mendieta et al., 2005
14	2.1 (1.1-3.7)	74	2.5 (1.4-5.2)			Weighted mean and range

n: number of genotypes — *nombre de génotypes*; *: samples cultivated in different countries — *échantillons cultivés dans divers pays*.

Table 7. Fatty acid content in % D.M. [mean values and (min.-max.)] of wheat and spelt whole grain — *Teneur en acides gras en % M.S. [valeurs moyennes et (min.-max.)] du grain complet de blé et d'épeautre.*

n	Myristic acid C14:0	Palmitic acid C16:0	Palmitoleic acid C16:1	Stearic acid C18:0	Oleic acid C18:1	Linoleic acid C18:2	α-Linolenic acid C18:3	Eikosenoic acid C20:1	Growing conditions: Number of locations	Growing conditions: Number of years	Reference
Wheat											
1	0.5	16.7	0.2	0.8	11.3	62.8	7.1	0.6	1	3	Grela, 1996
11		19.2		0.9	11.6	62.5	5.6		-	1	Ruibal-Mendieta et al., 2004b
5		19.1		0.5	11.6	63.5	5.1		-	1	
5		19.3			10.7	64.6	5.3		1	1	Ruibal-Mendieta et al., 2005
22	0.5	18.9 (16.7-19.3)	0.2	0.8 (0.5-0.9)	11.4 (10.7-11.6)	63.2 (62.5-64.6)	5.6 (5.1-7.1)	0.6			Weighted mean and range
Spelt											
4	0.55	18.5	0.3	1.4	20.4	55.0	3.0	0.7	1	3	Grela, 1996
11		16.8		1.0	18.2	59.4	4.5		-	1	Ruibal-Mendieta et al., 2004b
16		16.7		0.7	17.3	61	4		-	1	
9		16.8			16.1	63.2	3.9		1	1	Ruibal-Mendieta et al., 2005
40	0.6	17.2 (16.7-18.5)	0.3	1.0 (0.7-1.4)	18.1 (16.1-20.4)	59.6 (55.0-63.2)	3.8 (3.0-4.5)	0.7			Weighted mean and range

n: number of genotypes — *nombre de génotypes*; percentage of total identified fatty acids — *pourcentage des acides gras identifiés.*

5.2. Sterols

Phytosterols are known to reduce serum cholesterol and could offer protection against several cancer types (Nurmi et al., 2008). The range in phytosterol content in 16 spelt genotypes (9 cultivars and 7 landraces) was broader in a study conducted by Ruibal-Mendieta et al. (2004a) than for 5 cultivars in a study by Nurmi et al. (2008). Ruibal-Mendieta et al. (2004a) observed no difference in sterol content in spelt and winter wheat, but Nurmi et al. (2008) found higher average content in spelt than in wheat (928 [893-963] $\mu g \cdot g^{-1}$ [D.M.] and 841 [670-959] $\mu g \cdot g^{-1}$ [D.M.]). This latter finding was confirmed by Iafelice et al. (2009), who reported 717 (628-819) $\mu g \cdot g^{-1}$ (D.M.) total sterol, on average, for spelt, and 634 (600-677) $\mu g \cdot g^{-1}$ (D.M.) for wheat. The free sterol content, however, was higher in wheat 324 (288-387) $\mu g \cdot g^{-1}$ (D.M.) than in spelt 252 (191-294) $\mu g \cdot g^{-1}$ (D.M.), and esterified sterol content was slightly higher in spelt 267 (251-291) $\mu g \cdot g^{-1}$ (D.M.) than in wheat 258 (219-330) $\mu g \cdot g^{-1}$ (D.M.) (Iafelice et al., 2009). This accords with the amount of free and esterified sterols measured by Ruibal-Mendieta et al. (2004a) of 527 $\mu g \cdot g^{-1}$ (D.M.) in spelt and of 528 $\mu g \cdot g^{-1}$ (D.M.) in wheat.

Ruibal-Mendieta et al. (2004a) found that spelt and wheat display a similar sterol profile and content. The Δ7- avenasterol content is an exception; it is 45% higher in spelt than in wheat (Ruibal-Mendieta et al., 2004a). For spelt, Ruibal-Mendieta et al. (2004a) reported that sitosterol and campesterol accounted for about 70 and 20% of the total sterols, respectively, and stanols for 5%, which differed from the results reported by Nurmi et al. (2008) where sitosterol, campesterol and stanols accounted for 49%, 14% and 26%, respectively.

In the Nurmi et al. (2008) study, the proportions for wheat were sitosterol 52%, campesterol 15% and stanols 24%. These differences in sterol profiles appear to have resulted from analytical differences (Nurmi et al., 2008). The results reported by Iafelice et al. (2009) confirmed the earlier ones, with 59% sitosterol, 18% campesterol and 17% stanols in wheat and 56%, 16% and 19% in spelt, respectively, among the total sterols. For the free sterols, the proportions were similar in spelt and wheat, with slightly more sitosterol (by 2%) in wheat. For the esterified sterols, the proportion of sitosterol was higher in spelt than in wheat (59% and 56%, respectively), but that of campesterol and sitostanol was lower in spelt (16% and 15%, respectively) than in wheat (18% and 17%, respectively) (Iafelice et al., 2009).

6. CONCLUSION

This paper has highlighted differences in the macronutrient content and profiles of spelt and wheat. It has shown that spelt has a higher protein and lipid content and a lower insoluble and total fiber content than wheat, and that there is no significant difference between them in starch, sugar and soluble fiber content (**Table 8**). The differences can affect the techno-functional properties of spelt. Bread-making and pasta making from spelt requires adapted techniques, and the evaluation procedures used for wheat and wheat products should not be directly applied to spelt and spelt products (Abdel-Aal et al., 2005). This study should be followed by one on micronutrient content – ashes, minerals, vitamins and bioactive

Table 8. Macronutrient contents in % D.M [weighted mean and (min.-max.)] (**A**) and fatty acid distribution (%) (**B**) of wheat and spelt whole grain reported by different studies — *Teneurs [moyenne pondérée et (min.-max.)] en macronutriments (% M.S.) (**A**) et répartition des acides gras (%) (**B**) du grain complet de blé et d'épeautre de différentes études*.

Species	**Wheat**		**Spelt**	
Component	***n***	**Weighted mean and range**	***n***	**Weighted mean and range**
A				
Starch	2	63.0 (62.4-68.1)	9	64.0 (60.9-67.6)
Sugar	2	3.3 (3.1-3.3)	9	2.2 (1.7-3.4)
Carbohydrate	5	66.5 (63.6-71.2)	18	66.1 (59.2-70.9)
Insoluble Fiber	8	11.2 (10.7-13.2)	21	9.3 (8.0-12.9)
Soluble Fiber	8	1.7 (1.4-2.2)	21	1.7 (1.2-2.4)
Total Fiber	141	14.9 (12.3-15.4)	34	10.9 (7.7-14.9)
Lignin	4	0.9 (0.6-1.2)	8	0.9 (0.6-1.1)
Hemicellulose	4	8.2 (7.0-9.2)	8	9.3 (4.6-18.8)
Cellulose	4	2.3 (2.1-2.8)	8	2.0 (1.4-2.3)
Crude fiber	3	2.4 (1.8-3.3)	21	2.4 (1.7-3.3)
Crude protein	17	14.9 (10.9-17.5)	84	15.6 (9.8-25.5)
% Essential amino acid/Total amino acid	4	35.6 (34-39)	13	36.4 (34-41)
Free Lipid	14	2.1 (1.1-3.7)	74	2.5 (1.4-5.2)
B				
Myristic acid	1	0.5	4	0.6
Palmitic acid	22	18.9 (16.7-19.3)	40	17.2 (16.7-18.5)
Palmitoleic acid	1	0.2	4	0.3
Stearic acid	17	0.8 (0.5-0.9)	31	1.0 (0.7-1.4)
Oleic acid	22	11.4 (10.7-11.6)	40	18.1 (16.1-20.4)
Linoleic acid	22	63.2 (62.5-64.6)	40	59.6 (55.0-63.2)
α-Linolenic acid	22	5.6 (5.1-7.1)	40	3.8 (3.0-4.5)
Eikosenoic acid	1	0.6	4	0.7

n: number of genotypes — *nombre de génotypes*.

compounds – for which differences between spelt and wheat have also been reported. In addition, research on the applications of spelt should continue to look for new ways of using this crop in order to sustain its development. Exhaustive biochemical, nutritional and clinical research should be undertaken to assess claims for the pro-health properties of spelt grain and products that have not yet been scientifically proved.

Abbreviations

HMW: High Molecular Weight
LMW: Low Molecular Weight
PCR: Polymerase Chain Reaction
RP-HPLC: Reversed Phase-High Performance Liquid Chromatography
RVA: Rapid Visco Analyser
SDS: Sodium Dodecyl Sulfate

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