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Spelt (*Triticum aestivum* ssp. *spelta*) as a Source of Breadmaking Flours and Bran Naturally Enriched in Oleic Acid and Minerals but Not Phytic Acid

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The nutritional value of breadmaking cereal spelt (*Triticum aestivum* ssp. *spelta*) is said to be higher than that of common wheat (*Triticum aestivum* ssp. *vulgare*), but this traditional view is not substantiated by scientific evidence. In an attempt to clarify this issue, wholemeal and milling fractions (sieved flour, fine bran, and coarse bran) from nine dehulled spelt and five soft winter wheat samples were compared with regard to their lipid, fatty acid, and mineral contents. In addition, tocopherol (a biochemical marker of germ) was measured in all wholemeals, whereas phytic acid and phosphorus levels were determined in fine bran and coarse bran samples after 1 month of storage. Results showed that, on average, spelt wholemeals and milling fractions were higher in lipids and unsaturated fatty acids as compared to wheat, whereas tocopherol content was lower in spelt, suggesting that the higher lipid content of spelt may not be related to a higher germ proportion. Although milling fractionation produced similar proportions of flour and brans in spelt and wheat, it was found that ash, copper, iron, zinc, magnesium, and phosphorus contents were higher in spelt samples, especially in aleurone-rich fine bran and in coarse bran. Even though phosphorus content was higher in spelt than in wheat brans, phytic acid content showed the opposite trend and was 40% lower in spelt versus wheat fine bran, which may suggest that spelt has either a higher endogenous phytase activity or a lower phytic acid content than wheat. The results of this study give important indications on the real nutritional value of spelt compared to wheat. Moreover, they show that the Ca/Fe ratio, combined with that of oleate/palmitate, provides a highly discriminating tool to authenticate spelt from wheat flours and to face the growing issue of spelt flour adulteration. Finally, they suggest that aleurone differences, the nature of which still needs to be investigated, may account for the differential nutrient composition of spelt and wheat.

KEYWORDS: Spelt; wheat; fatty acid; mineral; phytic acid

INTRODUCTION

Spelt (*Triticum aestivum* ssp. *spelta*) is a breadmaking cereal, alternative to widely grown common soft wheat (*Triticum aestivum* ssp. *vulgare*). Contrary to its close relative, spelt is harvested as a hulled grain and must undergo a costly dehulling procedure before being introduced into the milling process. Authentic spelt flour is therefore much more expensive to produce than wheat flour, and spelt use has long been confined to animal feeding, owing to the large amount of insoluble dietary fiber provided by such a hulled grain when not dehulled (*1*).

Still, an increased interest for "ecoalternative" cereals and organic products is at the origin of a new success story for spelt, which is an environmentally friendly, low-input crop cultivated in Europe (Belgium, Austria, Germany, Switzerland, Italy, and

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Spain) and North America (United States and Canada) (*2*−*4*). Over the past decade, folk knowledge pointing to nutritional and even therapeutic benefits prompted unconventional medicine to recommend the use of spelt (*5*) rather than wheat.

Since the 1990s, scientific investigations have tried to substantiate the supposedly nutritional advantages of spelt over wheat, with discordant results:

(i) The claimed innocuity of spelt in gluten-sensitive patients was not confirmed, in accordance with the fact that spelt samples tested positive for gluten (*6*−*11*) and that an α-type gliadin from spelt and wheat shared >95% homology (*12*).

(ii) The oil fraction of spelt wholemeal was shown to be 25% higher as compared to wheat (*13*), with a shift to more unsaturated fatty acids in spelt (*14*, *15*); the β-carotene level was also higher in spelt (*16*), whereas phytosterol contents were comparable in both cereals (*17*, *18*).

(iii) Certain minerals were found in greater amounts in spelt (*2*, *14*, *19*, *20*), but it was not always clear whether these results were obtained with dehulled or hulled grains (*20*, *21*). Moreover, these results were not supported by another study (*16*). Finally, these observations were made using only one or, at best, two wheat cultivars for comparison, making any statistical analysis unreliable.

To add to the confusion regarding spelt's health benefits, there is growing evidence that commercially available spelt flours are adulterated more often than not—up to 100% (*22*)—with nonspelt material (*22*, *23*), which is less expensive to produce. Polymerase Chain Reaction and, to a limited extent, electrophoresis of some gliadins (gluten proteins) are suitable to detect spelt flour adulteration with wheat (*22*, *23*). In contrast, capillary electrophoresis of gliadins does not allow the discrimination of hulled and unhulled "wheats" because species with the same genome composition, such as hexaploid common wheat and spelt or tetraploid durum wheat and emmer (*Triticum turgidum* ssp. *dicoccum*), exhibit a high similarity on their gliadins (*10*). On the other hand, we have found that quantitative differences in fatty acids between spelt and soft winter wheat and, more specifically, the oleate/palmitate ratio (*15*), may be useful to develop authentication tools and detect adulteration of spelt flours.

In the present study, we went deeper into the comparison of the nutritional value of dehulled spelt and soft winter wheat. For this purpose, we quantified lipids, fatty acids, and minerals not only in wholemeal but also in the various fractions obtained from the milling process of nine spelt varieties compared to five soft winter wheat cultivars, which we will designate wheat, for simplicity. The analysis of each parameter had four objectives: (i) to determine which cereal would bring the highest nutritional advantage with regard to the compounds we analyzed, that is, minerals and lipids; (ii) in this regard, to investigate which milling fraction would best account for the nutritional differences observed; (iii) to try to understand the biochemical origin of the nutritional differences observed; and (iv) to provide new tools to authenticate commercially available spelt milling and grinding products, a necessity if health claims are attributed to them.

MATERIALS AND METHODS

Plant Material. Dr. A. Dekeyser (Walloon Agricultural Research Center, Gembloux, Belgium) provided nine dehulled spelt and five soft winter wheat samples grown in the same experimental field in Gembloux during 2001−2002. Spelt varieties were the following: Belgian landraces LR 140 and LR 260.1; experimental lines 115.11 and 115.6.2; Belgian cultivars Béryl, Redouté, and Rouquin; Austrian cultivar Ebners Rotkorn; and Swiss cultivar Oberkulmer. Winter wheat material was composed of the following European cultivars: Corbeil, Eléphant, Estica, Pajero, and Rialto.

Sample Preparation: Milling Fractions and Wholemeal. Sieved flour and its byproducts were obtained by milling 500-g grain samples (wheat and dehulled spelt) in a Chopin-Dubois CD1 laboratory mill (Tripette & Renaud, Villeneuve-la-Garenne, France). Before milling, the samples were tempered to 16% moisture for 24 h. Flour was obtained through one breaking passage on three rolls and two reduction passages on two rolls. After milling, coarse and fine brans were ground through a 1.0 mm sieve Cyclotec mill (Tecator, Hoganas, Sweden) to homogenize both byproducts before compositional analyses. Wholemeal was obtained by grinding of whole wheat or dehulled spelt through a 1.0 mm sieve Cyclotec mill. All material (wholemeal, sieved flour, and fine- and coarse-ground brans) was stored at −20 °C immediately after it was obtained and thawed for at least 24 h before analysis.

Lipid and Fatty Acid Contents. Free, bound, and total lipid contents were determined in duplicate by the Soxhlet method, and the fatty acid profile was determined by gas chromatography with flame ionization detection, as described elsewhere (*13*, *15*). Results for free, bound, and total lipids are expressed in grams per 100 g on a fresh basis of wholemeal, and fatty acid contents are expressed in grams per 100 g on a fresh basis of total lipids.

Vitamin E Content. Total tocopherols were determined in wholemeal samples by high-performance liquid chromatography with fluorescence detection (*24*). Total tocopherol content is expressed in milligrams of α-tocopherol per 100 g on a fresh basis of wholemeal. These analyses were performed right after grinding, to avoid tocopherol degradation, due to its high sensitivity to environmental factors such as light, temperature, and O_2. Because the production of milling fractions includes many time-consuming steps, during which tocopherol may be degraded, we did not measure it in this material.

Dry Matter Content. Dry matter was determined in duplicate by desiccation of cereal samples, which were weighed and dried at 105 °C for 24 h and then weighed again. Dry matter is expressed in percent of weighed sample.

Ash and Mineral Contents. The ash content of 5-g samples was determined in duplicate after incineration at 550 °C for 16 h. For all minerals except phosphorus, analyses were performed after the ashing of 2−3 g of wholemeal or milling fractions at 550 °C. Calcium, magnesium, iron, zinc, copper, and manganese were determined by atomic absorption. Sodium and potassium were determined by flame photometry. For P, samples were previously mineralized with H_2SO_4/H_2O_2 and P was measured by colorimetry according to AOAC method 995.11. Ash and mineral levels are expressed in grams per 100 g and milligrams per 100 g on a fresh basis of wholemeal, respectively.

Phytic Acid Content. Phytic acid was measured in ground coarse and fine brans according to AOAC method 986.11. The analysis was performed with samples stored at room temperature for 1 month, to mimic as closely as possible practical conditions of cereal product marketing. Briefly, bran samples were extracted using dilute HCl. Each extract was mixed with an EDTA/NaOH solution and placed on an ion-exchange column (SepPak Accell Plus QMA, Waters, Milford, MA). Phytate was eluted with 0.7 M NaCl solution and wet-digested with a mixture of concentrated HNO_3/H_2SO_4 to release P, which was measured colorimetrically (AOAC method 995.11). Phytic acid contents of fine bran and coarse bran samples are expressed in percent of the mean colorimetric value obtained for wheat fine bran and wheat coarse bran samples, respectively. Total P was simultaneously determined in fine and coarse bran extracts before they were passed on the anion exchange column; results are again expressed in percent of the mean value of colorimetric measurements obtained in wheat samples.

Statistical Analyses. The two-sample Wilcoxon rank-sum (Mann−Whitney) test (Stata 8.0 for Windows software) was applied to study the variability of our data in wholemeal and milling fractions from spelt versus wheat: lipid, fatty acid, tocopherol, dry matter, ash, mineral, and phytic acid contents, as well as oleate/palmitate ratio and [(oleate/palmitate)/(Ca/Fe) × 1000] index.

RESULTS

Ash Content and Proportion of Sieved Flour, Fine Bran, and Coarse Bran in Spelt versus Wheat. After milling

Table 1. Wholemeal: Total Lipid, FL/TL[a] Ratio, Total Tocopherol, Dry Matter, and Fatty Acid Contents of Nine Dehulled Spelt Compared to Five Soft Winter Wheat Varieties

	total lipids, g·100 g^{-1}, fb	FL/TL ratio	total tocopherol, mg of α-tocopherol·100 g^{-1}, fb	dry matter, %	fatty acids, g·100 g^{-1}, fb[b] palmitic	oleic	linoleic	α-linolenic
			Spelt					
LR 140[c]	2.57	0.64	2.48	88.40	0.45	0.32	1.64	0.11
Béryl	2.81	0.68	2.52	88.58	0.48	0.40	1.77	0.10
Oberkulmer	3.07	0.74	2.57	88.80	0.48	0.58	1.83	0.11
Ebners Rotkorn	3.03	0.73	2.79	89.16	0.49	0.54	1.83	0.10
Redouté	2.78	0.67	2.72	88.20	0.46	0.45	1.69	0.12
Rouquin	3.03	0.70	3.04	88.65	0.49	0.48	1.87	0.12
LR 260.1	3.01	0.69	2.89	88.76	0.50	0.52	1.81	0.12
line 115.11	2.91	0.68	3.47	88.18	0.50	0.42	1.83	0.11
line 115.6.2	3.08	0.68	3.44	88.41	0.52	0.43	1.94	0.12
av	2.92	0.69	2.88	88.57	0.48	0.46	1.80	0.11
SD[d]	0.17	0.03	0.37	0.31	0.02	0.08	0.09	0.01
			Winter Wheat					
Eléphant	2.24	0.66	2.52	88.08	0.41	0.21	1.45	0.13
Estica	2.40	0.67	2.74	87.90	0.45	0.27	1.51	0.13
Pajero	2.58	0.65	3.63	88.47	0.49	0.23	1.67	0.14
Rialto	2.57	0.68	4.14	88.47	0.52	0.27	1.62	0.12
Corbeil	2.61	0.67	3.15	87.48	0.51	0.31	1.63	0.12
av	2.48	0.67	3.24	88.08	0.47	0.26	1.57	0.13
SD	0.16	0.01	0.66	0.42	0.05	0.04	0.09	0.01
signif, *P*	<0.01	ns[e]	ns	ns	ns	<0.005	<0.005	<0.01

[a] Free lipid over total lipid. [b] Fresh basis. [c] Belgian landrace. [d] Standard deviation. [e] Not significant, $P > 0.05$.

Table 2. Wholemeal: Ash and Mineral Contents, Oleate/Palmitate Ratio, and [(Oleate/Palmitate)/(Ca/Fe) × 1000] Index for Nine Dehulled Spelt Compared to Five Soft Winter Wheat Varieties

	ash, g·100 g^{-1}, fb	mg·100 g^{-1}, fb[a] Cu	Fe	Mn	Zn	Na	K	Ca	Mg	P	oleate/palmitate ratio	(oleate/palmitate)/(Ca/Fe) × 1000
						Spelt						
LR 140[b]	1.67	<1	3.47	3.19	3.09	6.10	310	27.73	127.50	317.3	0.72	90
Béryl	1.81	<1	3.07	2.85	2.97	6.46	382	24.09	133.31	281.9	0.84	108
Oberkulmer	1.94	<1	2.84	2.68	2.97	9.22	403	31.56	132.23	244.5	1.21	109
Ebners Rotkorn	1.94	<1	3.65	2.78	3.17	8.93	391	39.31	129.86	296.9	1.11	103
Redouté	1.81	<1	2.85	2.91	3.19	10.92	368	30.06	130.32	281.3	0.98	93
Rouquin	1.85	<1	2.88	2.92	2.98	7.46	383	26.51	125.60	284.5	0.99	107
LR 260.1	1.96	<1	3.80	2.82	3.51	7.07	366	29.83	129.56	295.9	1.03	131
line 115.11	1.68	<1	2.79	2.60	2.58	8.30	358	23.55	118.81	331.7	0.84	99
line 115.6.2	1.76	<1	2.64	2.80	2.98	11.89	385	22.61	119.52	296.5	0.81	95
av	1.83	na[c]	3.11	2.84	3.05	8.48	372	28.36	127.41	292.3	0.95	104
SD[d]	0.11	na	0.42	0.17	0.25	1.97	27	5.17	5.20	24.5	0.16	12
						Winter Wheat						
Eléphant	1.38	<1	2.48	2.87	1.68	8.47	365	29.36	91.14	131.8	0.52	44
Estica	1.46	<1	2.04	2.44	1.67	6.15	372	28.82	92.31	199.1	0.61	43
Pajero	1.50	<1	1.89	3.01	2.16	14.11	356	32.58	98.26	221.5	0.47	27
Rialto	1.53	<1	2.46	2.61	1.88	9.10	394	33.93	97.62	195.9	0.53	38
Corbeil	1.56	<1	2.04	2.80	2.19	8.10	379	35.39	102.24	304.1	0.60	34
av	1.49	na	2.18	2.75	1.92	9.19	373	32.01	96.31	210.5	0.54	37
SD	0.07	na	0.27	0.22	0.25	2.96	14	2.86	4.57	62.1	0.06	7
signif, *P*	<0.005	na	<0.005	ns[e]	<0.005	ns	ns	ns	<0.005	<0.05	<0.005	<0.005

[a] Fresh basis. [b] Belgian landrace. [c] Not applicable. [d] Standard deviation. [e] Not significant, $P > 0.05$.

fractionation, dehulled spelt produced similar proportions of sieved flour (mean, 69%; range, 67−70), fine bran (mean, 11%; range, 9−13), and coarse bran (mean, 20%; range, 18−21) as did wheat: sieved flour (mean, 69%; range, 68−70), fine bran (mean, 10%; range, 7−12), and coarse bran (mean, 21%; range, 20−22).

Despite this similarity between both cereals, ash content was higher in dehulled spelt (**Table 2**): wholemeal contained 1.83% ash, as compared to 1.49% in wheat (+23%, $P < 0.005$). As shown in **Tables 4**, **6**, and **8**, respectively, the extent to which ash content was increased in spelt was highest ($P < 0.005$) in sieved flour (+30% over wheat), followed by fine bran (+25% over wheat) and then coarse bran (+18% over wheat). When individual values presented in **Tables 2**, **4**, and **6** were analyzed, it appeared that ash content allowed a full discrimination between spelt and wheat, when wholemeal, sieved flour, or fine bran was considered.

Lipid and Fatty Acid Contents in Spelt versus Wheat Wholemeal and Milling Fractions. Analysis of wholemeal samples (**Table 1**) revealed that total lipid content was, on average, 18% higher ($P < 0.01$) in spelt than in wheat, with a similar proportion of free and bound lipids in both cereals. In

Table 3. Sieved Flour: Total Lipid, FL/TL[a] Ratio, Dry Matter, and Fatty Acid Contents of Nine Dehulled Spelt Compared to Five Soft Winter Wheat Varieties

	total lipids, g.100 g^{-1}, fb	FL/TL ratio	dry matter, %	fatty acids, g.100 g^{-1}, fb[b] palmitic	oleic	linoleic	α-linolenic
			Spelt				
LR 140[c]	1.52	0.61	84.57	0.29	0.15	1.00	0.05
Béryl	1.64	0.65	85.06	0.30	0.22	1.03	0.04
Oberkulmer	1.81	0.67	85.36	0.30	0.31	1.11	0.05
Ebners Rotkorn	1.85	0.67	84.70	0.32	0.30	1.14	0.05
Redouté	1.61	0.61	85.08	0.28	0.22	1.01	0.06
Rouquin	1.81	0.69	85.15	0.31	0.25	1.16	0.05
LR 260.1	1.74	0.68	84.84	0.30	0.26	1.09	0.05
line 115.11	1.65	0.63	85.02	0.30	0.21	1.07	0.05
line 115.6.2	1.73	0.65	84.75	0.31	0.22	1.11	0.05
av	1.71	0.65	84.95	0.30	0.24	1.08	0.05
SD[d]	0.11	0.03	0.25	0.01	0.05	0.05	0.00
			Winter Wheat				
Eléphant	1.21	0.59	84.64	0.22	0.09	0.82	0.05
Estica	1.42	0.65	85.36	0.26	0.13	0.94	0.06
Pajero	1.36	0.60	84.46	0.26	0.11	0.91	0.06
Rialto	1.40	0.62	84.57	0.29	0.13	0.90	0.05
Corbeil	1.55	0.63	84.54	0.29	0.16	1.01	0.06
av	1.39	0.62	84.71	0.27	0.13	0.92	0.05
SD	0.12	0.02	0.37	0.03	0.03	0.07	0.00
signif, *P*	<0.005	ns[e]	ns	<0.01	<0.005	=0.005	ns

[a] Free lipid over total lipid. [b] Fresh basis. [c] Belgian landrace. [d] Standard deviation. [e] Not significant, $P > 0.05$.

Table 4. Sieved Flour: Ash and Mineral Contents, Oleate/Palmitate Ratio, and [(Oleate/Palmitate)/(Ca/Fe) × 1000] Index for Nine Dehulled Spelt Compared to Five Soft Winter Wheat Varieties

	ash, g•100 g^{-1}, fb	mg•100 g^{-1}, fb[a] Cu	Fe	Mn	Zn	Na	K	Ca	Mg	P	oleate/palmitate ratio	(oleate/palmitate)/(Ca/Fe) × 1000
						Spelt						
LR 140[b]	0.49	<1	0.93	0.41	0.93	5.38	46	16.75	13.37	115.0	0.72	40
Béryl	0.46	<1	1.05	0.36	1.88	7.07	109	15.62	19.51	123.8	0.84	57
Oberkulmer	0.63	<1	1.05	0.49	1.11	8.35	123	21.42	31.36	128.5	1.21	60
Ebners Rotkorn	0.66	<1	1.01	0.48	3.44	6.71	117	20.62	31.20	114.8	1.11	54
Redouté	0.56	<1	1.40	0.38	3.65	5.70	91	15.64	26.23	100.6	0.98	88
Rouquin	0.58	<1	1.02	0.43	1.44	5.81	110	18.63	29.24	103.9	0.99	54
LR 260.1	0.57	<1	1.04	0.53	1.08	13.87	92	19.79	30.99	106.3	1.03	54
line 115.11	0.50	<1	0.75	0.40	0.58	6.24	105	17.19	26.82	58.5	0.84	37
line 115.6.2	0.46	<1	0.77	0.46	0.50	5.16	95	17.20	23.07	68.6	0.81	36
av	0.54	na[c]	1.00	0.44	1.62	7.14	99	18.09	25.75	102.2	0.95	53
SD[d]	0.07	na	0.19	0.06	1.17	2.71	23	2.13	6.14	23.8	0.16	16
						Winter Wheat						
Eléphant	0.36	<1	0.72	0.50	0.48	8.72	107	19.30	12.36	54.7	0.42	15
Estica	0.44	<1	0.69	0.46	0.80	11.84	118	17.28	18.82	34.1	0.49	20
Pajero	0.40	<1	0.46	0.54	0.41	5.40	99	18.81	21.79	93.5	0.41	10
Rialto	0.45	<1	0.70	0.44	0.37	10.36	122	20.42	18.24	81.8	0.47	16
Corbeil	0.44	<1	0.58	0.50	0.98	7.70	101	19.13	18.81	100.6	0.55	17
av	0.42	na	0.63	0.49	0.61	8.80	109	18.99	18.00	72.9	0.53	23
SD	0.04	na	0.11	0.04	0.27	2.47	10	1.13	3.45	27.9	0.25	14
signif, *P*	<0.005	na	<0.005	ns[e]	<0.05	ns	ns	ns	<0.05	<0.05	<0.005	<0.005

[a] Fresh basis. [b] Belgian landrace. [c] Not applicable. [d] Standard deviation. [e] Not significant, $P > 0.05$.

contrast, the germ-specific tocopherol level displayed an opposite trend, being 13% lower (ns) in spelt when compared to wheat (**Table 1**). Data on wholemeal fatty acids showed that the concentrations of palmitic acid were similar in both cereals, whereas mean oleic and linoleic acid contents in spelt versus wheat were 78% ($P < 0.005$) and 14% higher ($P < 0.005$), respectively. In contrast, α-linolenic acid content was significantly lower in spelt compared to wheat (−18%, $P < 0.01$).

Analysis of milling fractions (**Tables 3**, **5**, and **7**) revealed that the highest concentrations of oleic and linoleic acids were found in coarse bran and fine bran, at a level 3−4 times that observed in sieved flour with, in certain spelt varieties, >1 g of oleic acid per 100 g of fine bran or coarse bran. When individual values were analyzed, it appeared that oleic acid content also allows a full discrimination between spelt and wheat wholemeal (**Table 1**) or fine bran samples (**Table 5**).

Minerals in Spelt versus Wheat Wholemeal and Milling Fractions. The individual concentrations measured for nine minerals in wholemeal of dehulled spelt and wheat varieties are shown in **Table 2**. The content of the following four minerals was, on average, significantly higher in spelt as compared to wheat: Zn (+60%, $P < 0.005$), Fe (+43%, $P < 0.005$), P

Table 5. Fine Bran: Total Lipid, FL/TL[a] Ratio, Dry Matter, and Fatty Acid Contents of Nine Dehulled Spelt Compared to Five Soft Winter Wheat Varieties

	total lipids, g·100 g^{-1}, fb	FL/TL ratio	dry matter, %	fatty acids, g.100 g^{-1}, fb[b]			
				palmitic	oleic	linoleic	α-linolenic
			Spelt				
LR 140[c]	5.36	0.87	88.11	0.92	0.75	3.30	0.26
Béryl	4.87	0.83	89.02	0.79	0.81	2.96	0.20
Oberkulmer	5.29	0.84	89.20	0.81	1.11	3.03	0.22
Ebners Rotkorn	4.81	0.84	88.11	0.74	1.01	2.79	0.18
Redouté	4.42	0.82	88.70	0.69	0.82	2.61	0.20
Rouquin	4.98	0.86	88.84	0.77	0.91	2.97	0.21
LR 260.1	4.92	0.87	88.99	0.79	0.98	2.84	0.20
line 115.11	5.10	0.86	88.22	0.84	0.83	3.11	0.20
line 115.6.2	5.56	0.88	89.21	0.89	0.91	3.38	0.25
av	5.04	0.85	88.71	0.80	0.90	3.00	0.21
SD[d]	0.34	0.02	0.45	0.07	0.11	0.24	0.02
			Winter Wheat				
Eléphant	4.05	0.83	89.69	0.70	0.43	2.55	0.28
Estica	4.55	0.85	88.71	0.80	0.57	2.82	0.26
Pajero	4.17	0.84	87.75	0.76	0.41	2.65	0.25
Rialto	4.54	0.86	88.55	0.84	0.54	2.79	0.25
Corbeil	4.15	0.83	88.59	0.72	0.55	2.56	0.22
av	4.29	0.84	88.66	0.77	0.50	2.67	0.25
SD	0.24	0.01	0.69	0.05	0.07	0.13	0.02
signif, *P*	<0.01	ns[e]	ns	ns	<0.005	<0.05	<0.05

[a] Free lipid over total lipid. [b] Fresh basis. [c] Belgian landrace. [d] Standard deviation. [e] Not significant, *P* > 0.05

Table 6. Fine Bran: Ash and Mineral Contents, Oleate/Palmitate Ratio, and [(Oleate/Palmitate)/(Ca/Fe) × 1000] Index for Nine Dehulled Spelt Compared to Five Soft Winter Wheat Varieties

	ash, g·100 g^{-1}, fb	mg·100 g^{-1}, fb[a]								% of mean wheat values		oleate/ palmitate ratio	(oleate/palmitate)/ (Ca/Fe) × 1000
		Cu	Fe	Mn	Zn	Na	K	Ca	Mg	P	phytic acid		
						Spelt							
LR 140[b]	3.39	1.80	6.39	7.33	7.38	14.39	597	43.82	273.16	nd[c]	nd	0.81	118
Béryl	3.70	1.57	7.58	7.71	8.30	16.57	749	44.30	297.74	121	67	1.03	176
Oberkulmer	4.04	1.45	7.73	7.79	8.30	16.47	818	47.92	293.23	143	3	1.37	221
Ebners Rotkorn	4.17	1.53	8.85	7.73	8.77	17.47	839	51.81	312.18	133	3	1.36	231
Redouté	4.05	1.52	8.04	8.30	8.61	20.03	823	46.37	336.16	102	3	1.20	208
Rouquin	3.78	1.56	7.44	7.56	7.09	19.08	776	42.96	290.57	128	54	1.18	203
LR 260.1	3.79	1.59	8.30	6.77	8.11	14.92	731	46.33	301.45	nd	nd	1.24	222
line 115.11	3.35	1.28	6.58	6.37	6.22	22.49	690	38.30	284.57	126	81	0.99	170
line 115.6.2	3.49	1.26	6.90	7.21	7.39	19.69	752	41.53	281.69	79	46	1.02	169
av	3.75	1.51	7.53	7.42	7.80	17.90	753	44.82	296.75	119	37	1.13	191
SD[d]	0.30	0.16	0.81	0.58	0.83	2.63	76	3.89	18.70	22	33	0.19	36
						Winter Wheat							
Eléphant	3.04	1.50	5.29	10.15	5.14	16.20	743	56.66	230.00	93	14	0.61	57
Estica	3.25	1.28	5.11	7.60	6.11	20.36	782	54.81	259.97	113	32	0.71	66
Pajero	2.92	1.04	4.28	7.64	5.49	10.26	685	52.17	230.62	71	99	0.54	44
Rialto	2.98	1.14	4.77	7.41	5.33	13.78	751	54.97	205.49	114	161	0.65	56
Corbeil	2.77	1.17	4.16	7.74	5.85	21.92	623	57.17	205.81	109	194	0.76	55
av	2.99	1.23	4.72	8.11	5.58	16.50	717	55.16	226.38	100	100	0.65	56
SD	0.17	0.18	0.50	1.15	0.40	4.76	63	1.96	22.47	19	78	0.09	8
signif, *P*	<0.005	<0.05	<0.005	ns[e]	<0.005	ns	ns	<0.005	<0.005	ns	ns	<0.005	<0.005

[a] Fresh basis. [b] Belgian landrace. [c] Not determined. [d] Standard deviation. [e] Not significant, *P* > 0.05.

(+40%, ***P* < 0.05**), and Mg (+32%, *P* < 0.005). These contents allow a nearly complete discrimination of all of our spelt samples from wheat samples. In contrast, Na, K, and Mn concentrations were comparable in both cereals, whereas Ca content tended to be lower, but not significantly, in spelt (−13%, *P* > 0.05) as compared to wheat. The lack of sensitivity of our assay method below 1 mg·100 g^{-1} of wholemeal did not allow us to detect any difference in Cu concentration in wholemeals.

In milling fractions, analysis of minerals (**Tables 4**, **6**, and **8**) revealed that the highest concentrations of Zn, Fe, and Mg were found in coarse bran (7 times as high as those observed in sieved flour), except for P, for which the highest concentration was found in fine bran. A higher Cu content in spelt compared to wheat was this time clearly detected in coarse bran (+67%, *P* < 0.01) and fine bran (+23%, *P* < 0.05) but not in sieved flour.

Phytic Acid and Phosphorus Levels in Spelt versus Wheat Fine Bran and Coarse Bran. As shown in **Tables 6** and **8**,

Table 7. Coarse Bran: Total Lipid, FL/TL[a] Ratio, Dry Matter, and Fatty Acid Contents of Nine Dehulled Spelt Compared to Five Soft Winter Wheat Varieties

	total lipids, g•100 g^{-1}, fb	FL/TL ratio	dry matter. %	fatty acids, g•100 g^{-1}, fb[b] palmitic	oleic	linoleic	α-linolenic
			Spelt				
LR 140[c]	4.79	0.76	88.13	0.81	0.67	2.98	0.23
Béryl	5.30	0.72	88.56	0.86	0.87	3.25	0.21
Oberkulmer	6.02	0.75	88.69	0.90	1.29	3.47	0.24
Ebners Rotkorn	5.25	0.76	88.18	0.80	1.08	3.03	0.21
Redouté	5.27	0.76	87.68	0.81	0.96	3.11	0.27
Rouquin	5.79	0.76	88.07	1.04	1.20	3.07	0.32
LR 260.1	5.63	0.76	87.63	0.89	1.13	3.21	0.25
line 115.11	6.08	0.75	88.19	1.01	0.97	3.72	0.26
line 115.6.2	5.99	0.72	89.20	0.96	0.94	3.67	0.28
av	5.57	0.75	88.26	0.90	1.01	3.28	0.25
SD[d]	0.44	0.02	0.49	0.09	0.19	0.28	0.03
			Winter Wheat				
Eléphant	3.85	0.59	88.79	0.67	0.43	2.42	0.25
Estica	4.52	0.70	88.19	0.79	0.58	2.79	0.26
Pajero	4.52	0.69	88.22	0.81	0.45	2.88	0.28
Rialto	4.68	0.66	88.53	0.87	0.59	2.87	0.24
Corbeil	4.98	0.66	88.40	0.87	0.72	3.03	0.25
av	4.51	0.66	88.43	0.80	0.55	2.80	0.26
SD	0.41	0.04	0.25	0.08	0.12	0.23	0.01
signif, *P*	<0.005	<0.005	ns[e]	ns	<0.005	<0.01	ns

[a] Free lipid over total lipid. [b] Fresh basis. [c] Belgian landrace. [d] Standard deviation. [e] Not significant, $P > 0.05$.

Table 8. Coarse Bran: Ash and Mineral Contents, Oleate/Palmitate Ratio, and [(Oleate/Palmitate)/(Ca/Fe) × 1000] Index for Nine Dehulled Spelt Compared to Five Soft Winter Wheat Varieties

	ash, g•100 g^{-1}, fb	mg•100 g^{-1}, fb[a] Cu	Fe	Mn	Zn	Na	K	Ca	Mg	% of mean wheat value P	phytic acid	oleate/palmitate ratio	(oleate/palmitate)/ Ca/Fe) × 1000
							Spelt						
LR 140[b]	5.04	3.59	8.96	9.86	9.35	45.4	982	63.50	381.19	nd[c]	nd	0.83	117
Béryl	5.45	3.23	10.28	9.63	8.47	69.0	1083	102.19	425.53	91	64	1.01	101
Oberkulmer	5.60	3.14	8.96	9.27	7.91	61.0	1202	68.24	396.79	92	35	1.43	188
Ebners Rotkorn	5.68	2.40	8.67	8.79	9.04	57.0	1070	78.15	350.31	56	78	1.34	149
Redouté	4.81	2.96	9.02	9.35	13.41	52.0	1089	142.02	376.01	142	196	1.17	75
Rouquin	5.20	2.81	9.87	9.23	7.62	74.0	1087	124.25	383.50	78	7	1.15	92
LR 260.1	5.11	3.26	8.44	8.28	9.78	49.3	1000	108.37	341.54	nd	nd	1.27	99
line 115.11	5.04	5.21	9.28	8.89	7.71	131.0	1082	53.46	378.40	122	3	0.96	167
line 115.6.2	5.13	3.27	12.17	8.94	7.58	99.0	1118	48.86	379.24	102	116	0.97	242
av	5.23	3.32	9.52	9.14	8.99	70.9	1079	87.67	379.17	98	71	1.13	137
SD[d]	0.29	0.79	1.15	0.47	1.84	27.8	64	32.90	24.35	28	68	0.20	55
							Winter Wheat						
Eléphant	4.12	1.62	8.96	8.50	5.32	15.4	1074	61.46	321.50	98	99	0.64	93
Estica	4.22	1.87	8.10	7.70	7.55	30.8	1064	65.59	312.62	99	136	0.73	91
Pajero	4.50	3.07	7.83	10.35	6.43	81.0	1181	73.57	349.51	103	45	0.55	59
Rialto	4.39	1.88	7.29	7.40	5.28	31.6	1176	77.58	317.93	86	45	0.68	64
Corbeil	4.85	1.97	6.92	9.13	6.33	38.2	1211	77.33	369.16	114	174	0.83	75
av	4.42	2.08	7.82	8.62	6.18	39.4	1141	71.11	334.14	100	100	0.69	76
SD	0.28	0.57	0.79	1.18	0.94	24.7	67	7.25	24.23	10	57	0.11	15
signif, *P*	<0.005	<0.01	<0.01	ns[e]	<0.005	<0.05	ns	ns	<0.01	ns	ns	<0.01	<0.01

[a] Fresh basis. [b] Belgian landrace. [c] Not determined. [d] Standard deviation. [e] Not significant, $P > 0.05$.

and contrary to what could be expected, although total P content tended to be higher in spelt brans than in wheat brans, phytic acid content showed exactly the opposite trend, being lower in spelt than in wheat fine bran and coarse bran. Even though the differences observed were not significant ($P > 0.05$), probably due to the restricted number of samples analyzed, only $n = 7$ for spelt and $n = 5$ for wheat, this phenomenon was most marked in fine bran, with the phytic acid value ~40% lower in spelt versus wheat, contrasting with total P, ~20% higher in spelt. In coarse bran samples, mean P contents of spelt and wheat were comparable, but the mean phytic acid proportion of spelt was ~30% lower compared to wheat.

Authentication of Spelt by Combining Fatty Acid and Mineral Concentrations. Tables 2, **4**, **6**, and **8** show the spelt over wheat discriminating power of the already proposed oleate/palmitate ratio (*15*) in wholemeal, sieved flour, fine bran, and coarse bran and compare it to a new index, which integrates the data obtained in the present study: (oleate/palmitate)/(Ca/

Table 9. Nutritional Contributions[a] to the Daily Need in Lipids, Oleic Acid, and Essential Minerals of Spelt and Wheat[b] Breads (150 g) or Nutrition Bars (75 g)

nutrient	nutritional contribution	cereal	brown bread	wholemeal bread	fine bran bar	coarse bran bar
	AMDR,[c] %		g•100 g^{-1}, fb[d] (contribution to AMDR in %)			
lipids	30	spelt	1.9 (0.7)	3.3 (1.2)	2.5 (0.9)	2.8 (1.0)
		wheat	1.6 (0.6)	2.8 (1.0)	2.3 (0.8)	2.3 (0.8)
	AI,[e] g•day^{-1}		g•100 g^{-1}, fb (contribution to AI in %)			
linoleic acid	14	spelt	1.2 (8.5)	2.0 (14.5)	1.5 (11)	1.6 (12)
		wheat	1.0 (7.5)	1.8 (12.5)	1.3 (9.5)	1.4 (10)
	RDA,[f] mg•day^{-1}		mg•100 g^{-1}, fb (contribution to RDA in %)			
Zn	♀ 8-11 ♂	spelt	1.8 (23–17)	3.4 (43–31)	3.9 (49–35)	4.5 (56–41)
		wheat	0.7 (9–6)	2.2 (27–20)	2.8 (35–25)	3.1 (39–28)
Fe	♀ 18-8 ♂	spelt	1.1 (6–14)	3.5 (19–44)	3.8 (21–47)	4.8 (26–60)
		wheat	0.7 (4–9)	2.5 (14–31)	2.4 (13–30)	3.9 (22–49)
Cu	♀ 0.9 ♂	spelt	<1	<1	0.80 (90)	1.66 (184)
		wheat	<1	<1	0.60 (67)	1.04 (116)
Mn	♀ 1.8-2.3 ♂	spelt	0.5 (28–22)	3.2 (178–139)	3.7 (205–160)	4.6 (250–200)
		wheat	0.6 (30–24)	3.1 (172–135)	4.1 (228–178)	4.3 (240–190)
Ca	♀ 1000 ♂	spelt	18.1 (2)	28.4 (2.8)	44.8 (5)	87.7 (7)
		wheat	19.0 (2)	32.0 (3)	55.2 (6)	71.1 (9)
Mg	♀ 320-420 ♂	spelt	29.0 (9–7)	143.3 (45–34)	148.4 (46–35)	189.6 (60–45)
		wheat	20.3 (6–5)	108.4 (34–26)	113.2 (35–27)	167.1 (52–40)
P	♀ 700 ♂	spelt	115.0 (16)	328.8 (47)	380.6 (54)	229.1 (33)
		wheat	82.1 (12)	236.8 (34)	320.7 (46)	184.2 (26)

[a] From USDA (*25*, *26*). [b] Data for spelt ($n = 9$) and wheat ($n = 5$) were calculated using mean values from **Tables 1**–**8**. [c] Acceptable macronutrient distribution range. Values given here were calculated by taking into account a 2000 kcal ingestion per day, where lipid contribution reaches a maximum of 30%, corresponding to 70 g of lipids. [d] Fresh basis. [e] Adequate Intake. [f] Recommended dietary allowance is the same for both women (♀) and men (♂) when a single value is indicated. When the RDA values are different for nonpregnant, nonlactating adult women (first value) and adult men (second value), both are indicated and the cereal contribution for each is given.

Fe) × 1000. We can see that this index, integrating fatty acid and mineral contents, appears to be much more powerful to discriminate spelt from wheat samples, especially when milling and grinding products are confronted with authentication problems.

Nutritional Contribution of Spelt versus Wheat Food Products. Table 9 compares the nutritional value of spelt versus wheat as ingredients of 150 g of brown bread (made with sieved flour), 150 g of wholemeal bread, or 75 g of fine bran-based or coarse bran-based nutrition bars. These data are theoretical because no baking or processing was done, neither in the case of breads nor in that of nutrition bars. Both types of bread contain 112.5 g of flour, and bars contain an estimated 50 g of fine bran or coarse bran. The serving sizes of the different product types are based on reference amounts customarily consumed by adult subjects in the United States (*27*). It can be seen that the lipid content of spelt and wheat products bring a negligible contribution to the acceptable macronutrient distribution range (AMDR), as expected for cereal products with no added fat. However, 150 g of wholemeal spelt bread and 75-g bran bars may cover, on average, up to 14.5% (in women) of adequate intake (AI) of linoleic acid daily needs.

Mean values obtained for the following minerals, Cu, Fe, Mn, Zn, Mg, and P, confirm that spelt wholemeal bread, fine bran, and coarse bran bars cover much more appreciable proportions of the recommended dietary allowances (RDA) than wheat wholemeal or bran products.

DISCUSSION

Due to their high starch content, cultivated cereals (including spelt and wheat) are first of all valuable energy sources in the human diet (*28*, *29*). However, the nutritional contribution of cereals is not limited to calories; indeed, cereals also contain other nutrients, such as proteins, soluble and insoluble fiber, fatty acids, minerals, vitamins, and antioxidant molecules. In this perspective, our present comparative analysis of spelt and wheat indicates that the use of spelt for human consumption provides substantial nutritional advantages over wheat's use:

(i) Spelt has a higher lipid content and also a higher unsaturated fatty acid/palmitic acid ratio than wheat, which results from a nearly double level of oleic acid.

(ii) Compared to wheat, spelt has, on average, 30−60% higher concentrations of Fe, Zn, Cu, Mg, and P, which is most pronounced in fine bran and coarse bran, where cereal minerals are naturally concentrated (*28*).

(iii) In contrast to minerals, and especially P, the phytic acid content tends to be 40% lower in spelt than in wheat, as indicated by our data obtained in fine brans, where aleurone cells, which naturally contain phytic acid (*29*, *30*), are the most concentrated.

Our data also indicate that these nutritional advantages of spelt over wheat would be best expressed in wholemeal bread or bran nutrition bars, rather than in bread from sieved or refined flours. In our opinion, spelt fine bran is a particularly suitable raw material for nutrition bars because it combines high mineral and unsaturated fatty acid contents, a low proportion of P in the form of phytic acid, a slightly sweet taste, and a composition still rich enough in starch to manufacture biscuit-like bars. In addition, it is possible that spelt coarse bran could be more suited than wheat coarse bran in the manufacture of cereal nutrition bars, given that a recent study has evidenced that spelt's pericarp is higher in polysaccharides and lower in lignin than wheat pericarp (*31*).

When the contribution to the daily needs of each of the nutrients analyzed in this study is considered, it is clear that spelt's high mineral level is probably one of its main nutritional advantages when compared to wheat. Among minerals, Zn has been shown to be essential for intracellular metabolism and cellular growth and differentiation; it is also involved in gene expression regulation; Cu is an essential catalytic cofactor for selective oxidoreductases; Fe participates in oxygen and energy metabolism; and Mg is involved in the stabilization of ATP and other molecules and is also a cofactor of enzymatic systems (*32*−*35*). The fact that 150-g spelt wholemeal bread or 75-g spelt nutrition bars bring a higher contribution than wheat to daily requirements of Zn, Fe, and Mg, and also Cu in the case of bran-based spelt bars, should prompt nutritionists to recommend spelt's consumption.

The presence of phytic acid in cereals is an important issue because mineral intestinal bioavailability may be impaired due to phytic acid chelation. Even though the practical relevance of this phenomenon remains controversial (*30*), sourdough may be regarded as a convenient substitute for yeast in breadmaking. Indeed, bacterial phytase activity in sourdough is high (*36*), which should result in improved bread mineral bioavailability due to efficient phytic acid breakdown. Likewise, it is noteworthy that upon 4 weeks of storage of fine bran, phytic acid content was ∼40% lower in spelt than in wheat, whereas P content was 20% higher in spelt versus wheat samples. As a consequence, spelt may differ from wheat by an improved mineral bioavailability of its products, which could represent a major nutritional advantage. This difference between both cereals could reflect either an actual lower phytate level of spelt aleurone cells, where phytin crystals (complexes of phytic acid, particularly with Mg and K) are concentrated (*30*), or a higher aleurone phytase activity in spelt. In this second hypothesis, spelt milling or grinding and subsequent storage of the resulting products at room temperature for a few weeks would result in a more active and rapid degradation of phytic acid than in wheat products. As previously noted, when phytic acid is analyzed in seeds, including cereal grains, the aleurone layer is taken into account. Indeed, in this botanical part of the kernel, hydrolytic enzymes such as phytases and lipases, are synthesized and secreted. During germination, hydrolysis of storage molecules supplies nutrients for embryo development (*37*). In another study, we found that triacylglycerol degradation into free fatty acids during wholemeal storage was ∼10% faster in spelt versus wheat, suggesting a 10% higher lipase activity in spelt than in wheat (unpublished results). This observation is in favor of the enzymatic hypothesis we propose to explain the lower phytic acid content observed in spelt than in wheat bran samples (**Tables 6** and **8**). Moreover, Lopez et al. (*38*) found that in wheat wholemeal from four different varieties, improved mineral bioavailability (in rats) was related to the variety's genetic background and could be explained, to some extent, by differences in phytase activity. Further studies are thus deemed to be necessary to clarify this issue regarding a possible higher enzyme content/activity in spelt versus wheat aleurone cells.

The potential key role of the aleurone layer in explaining the differences observed between spelt and wheat is another possible conclusion of the present study. Aleurone, which ends up in different proportions in the various milling products, is most concentrated in fine bran. The higher levels of P, Zn, Fe, Mg, and Cu in spelt versus wheat, the possibly higher phytase activity, in line with that of lipase, and the higher amount of lipids without a higher level of germ-specific tocopherol, all point to substantial structural, functional, or compositional differences between spelt and wheat aleurone layers.

Finally, the present study brings new tools to help in the authentication of spelt milling products. First, it confirms our previous observation that the higher oleic acid content in spelt versus wheat, if not contributing much to daily needs of unsaturated fatty acids, could play an essential role in the authentication of spelt flours (*15*). Furthermore, a parameter as simple as ash content allows the discrimination of spelt from wheat milling products. Our present data show that the higher ash content, already noted in spelt during previous studies (*7*, *16*, *39*, *40*), does not relate to kernel macrostructural differences, as we found similar proportions of flour and bran milling fractions in spelt and wheat. Thus, the higher ash level directly reflects microstructural or biochemical differences relating to higher mineral content in spelt cells. Among these minerals, the Ca/Fe ratio (but the Ca/Zn ratio works nearly as well), combined with the oleate/palmitate ratio, as (oleate/palmitate)/(Ca/Fe) × 1000, was found to bring a highly discriminating tool to authenticate spelt wholemeal and milling products (**Tables 2**, **4**, and **6**), except coarse bran (**Table 8**). This simple technological tool should help to fight the growing phenomenon of commercial spelt flour adulteration.

ABBREVIATIONS USED

AI, adequate intake; AMDR, acceptable macronutrient distribution range; fb, fresh basis; FL, free lipid; LR, landrace; na, not applicable; nd, not determined; ns, not significant; RDA, recommended dietary allowances; SD, standard deviation; TL, total lipid.

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