

# Composition of Functional Lipids in Hulled and Hulless Barley in Fractions Obtained by Scarification and in Barley Oil

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## ABSTRACT

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Two cultivars of hulled barley (Thoroughbred and Nomini) and two cultivars of hulless barley (Doyce and Merlin) were scarified to abrade the outer layers of hull and pericarp. The resulting scarification fines fractions were evaluated as potential sources of functional lipids (phytosterols, tocopherols, and tocotrienols). The levels of total phytosterols and total tocotrienols in the barley scarification fine fractions were probably not high enough to justify their use as functional foods. However, the levels of total phytosterols and total tocotrienols in the oils extracted from

both whole kernels and scarified fines were both sufficiently high to make it reasonable to consider their potential use as new functional oils. Indeed, the levels of total tocotrienols in barley oils (2,911–6,126 mg/kg of oil) are several-fold higher than those reported in two other oils that are being marketed as high in tocotrienols: palm oil (530 mg/kg) and rice bran oil (770 mg/kg). The levels of total phytosterols in barley oils range from 1.20 to 9.60 g/100 g of oil.

Barley is commonly pearled before use in foods to remove (abrade) the hull, which contains high levels of fiber. Pearling has also been investigated as a pretreatment for barley before its fermentation to produce ethanol as a way to remove some of the nonstarch material before fermentation (Wang et al 1993; Sosluski et al 1997; Wang et al 1997; Yeung and Vasanthan 2001). Previously we reported the results obtained by pearling Doyce hulless barley, and examining the phytosterol levels in the pearling fines fraction (Lampi et al 2003). Pearling for 90 sec removed  $\approx 15\%$  of the mass of the kernels. We concluded that the pearling fines contained  $\approx 2$  mg of total phytosterols/g, fresh weight (fw). In the previous study, we noted that pearling caused extensive breakage of the pearled barley, so in the current study we used a scarifier, a different milling device that also abrades the surface of grain kernels, instead of a pearler. In the current study, two cultivars of hulled barley (Thoroughbred and Nomini) and two cultivars of hulless barley (Doyce and Merlin) were scarified for 60 sec and the mass of resulting fines was similar to that in our previous study (11–15%). The levels of functional lipids (phytosterols, tocopherols, and tocotrienols) were quantitatively analyzed in both the kernels and scarified fine fractions and in the oils extracted from them. The potential of these barley products as sources of functional lipids was evaluated.

## MATERIALS AND METHODS

### Materials

The hulled barley cultivars used in the scarification study were Thoroughbred and Nomini, harvested in 2004 in Mt. Holly, Virginia. The hulless cultivars were a 6-row winter Doyce hulless barley cultivar harvested in 2004 from Mt. Holly, Virginia; Merlin, a 2-row spring barley cultivar, harvested in 2002 from Three Forks, Montana. Samples of Sustagrain barley kernels were obtained from ConAgra Foods, Omaha, NE.

### Scarification

Scarification was conducted using an electric laboratory seed scarifier (Forsberg, Thief River Falls, MN) with four propellers and a 40-grit abrasive surface. Samples of barley (150 g) were processed for 60 sec. The resulting material was fractionated into fines (<1.4 mm) and coarse (>1.4 mm) fractions using a US standard #14 sieve (1.4-mm sieve opening) in a Ro-Tap shaker for 1 min. The throughs were defined as the fines while the overs were the coarses

### Extraction

Extractions were performed with an accelerated solvent extractor (model ASE 200, Dionex, Sunnyvale, CA) using hexane as previously described (Moreau et al 2003). The ground sample (2 g of scarified fines or 4 g of kernels ground to 20 mesh (0.85-mm sieve opening) with a Wiley mill, Thomas Scientific, Philadelphia, PA) was placed in an 11-mL stainless steel extraction vessel and the remaining volume was filled with sea sand. The extractor was programmed to extract at a pressure of 1,000 psi (69 bar), and a temperature of 50°C, extracting each sample with a total of 22 mL of solvent, delivered in three 10-min extractions (3  $\times$  7.3 mL). Three separate extractions were performed for each sample and two HPLC injections were made from each extract.

### Nonpolar Lipid HPLC Analyses

Nonpolar lipids (including phytosterol fatty acyl esters, retention time (rt) = 1.7 min; hydroxycinnamate phytosterol esters, rt = 26 min; triacylglycerols, rt = 3–5 min; and free fatty acids, rt = 7–10 min) were quantitatively analyzed by an updated version of a normal phase HPLC method with evaporative light-scattering detection (Moreau et al 1996). These nonpolar lipid components were identified by comparison with the retention times of commercial standards. Quantitative analysis of each component was achieved by injecting multiple samples of each standard (1–50  $\mu$ g/injection) and constructing a standard curve. These analyses were performed on a HPLC with autosampler (Hewlett Packard model 1050) and detection by both an diode-array UV-visible detector (HP model 1050, Agilent Technologies, Avondale, PA) and an evaporative light scattering detector (Alltech-Varex MKII, Alltech Associates, Deerfield, IL), operated at 40°C and a nitrogen gas flow rate of 1.7 standard L/min. The column (LiChrosorb 7 micron DIOL) was 3  $\times$  100 mm (packed by Chrompack, Raritan, NJ). The binary gradient had a constant flow rate of 0.5 mL/min, with Solvent A = hexane/acetic acid, 1,000/1, Solvent B = hexane/isopropanol, 100/1. Gradient timetable at 0 min, 100/0 (%A/%B); at 8 min, 100/0; at 10 min, 75/25; at 40 min, 75/25; at 41 min, 100/0; and at 60 min, 100/0.

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## Tocopherol and Tocotrienol HPLC Analyses

Tocopherols and tocotrienols were quantified using a modified version of the previously published method (Moreau and Hicks 2005). The HPLC (Hewlett Packard model 1100 with autosampler, and detection by an HP model 1100 fluorescence detector, Agilent Technologies, Avondale, PA) with excitation at 294 nm and emission at 326 nm. The diol column and flow rates were the same as above. The binary gradient consisted of Solvent A = hexane/THF 980/20 and Solvent B = isopropanol. Gradient timetable at 0 min, 100/0 (%A/%B); at 40 min, 100/0; at 45 min, 95/5; A/B, at 50 min; 95.5; at 51 min, 100/0; and at 60 min, 100/0. The minimum limits of quantitative detection of tocols was  $\approx 0.1$  ng/injection and a standard curve was constructed with alpha tocopherol in the range of 1–200 ng/injection and this curve was used to quantify all tocopherols. The structures and retention times of the tocopherols and tocotrienols were confirmed by purchasing gelcap supplements of tocopherols (Bio E Gamma Plex, Soloray Inc. Park City, UT) and tocotrienols (Tocopherol Complex, Solgar, Leonia, NJ) at a local vitamin store:  $\alpha$ -tocopherol ( $\alpha$ T) ( $M + 1 = m/z$  431.4),  $\alpha$ -tocotrienol ( $\alpha$ T3) ( $M + 1 = m/z$  425.3),  $\beta$ -tocopherol ( $\beta$ T) and  $\gamma$ -tocopherol ( $\gamma$ T) ( $M + 1 = m/z$  416.3),  $\beta$ -tocotrienol ( $\beta$ T3) and  $\gamma$ -tocotrienol ( $\gamma$ T3) ( $M + 1 = m/z$  411.2),  $\delta$ -tocopherol ( $\delta$ T) ( $M + 1 = m/z$  402.3) and  $\delta$ -tocotrienol ( $\delta$ T3) ( $M + 1 = m/z$  397.1), were confirmed by LC-MS, performed with an MSD (Agilent 1100) equipped with an atmospheric pressure chemical ionization interface operated in the positive mode (drying gas at 6.0 L/min, nebulizer pressure at 60 psi, drying gas temperature at 350°C, vaporizer gas temperature at 325°C, Capillary voltage at 4,000 V, and corona current at 4.0  $\mu$ A, and fragmentor at 80V). All experiments were performed at least twice with triplicate samples each time. The data presented are means  $\pm$  SD.

## RESULTS AND DISCUSSION

Previously, we reported the results obtained by pearling Doyce hullless barley and examining the phytosterol levels in the pearling fines fraction (Lampi et al 2004). Pearling for 90 sec removed  $\approx 15\%$  of the mass of the kernels. We concluded the pearling fines contained  $\approx 2$  mg of total phytosterols/g of fresh weight. In the previous study, we noted that pearling caused extensive breakage of the pearled barley, so in the current study we used a scarifier instead of a pearler. Pearling and scarification are similar abrasive processes but in most pearlers the abrasive surface rotates, whereas in most scarifiers the abrasive surface is stationary and the kernels are rotated with a stator. However, the exact abrasive configuration depends on the type of pearler or scarifier.

In the current study, two cultivars of hulled barley (Thoroughbred and Nomini) and two cultivars of hullless barley (Doyce and Merlin), were scarified for 60 sec and the mass % yields of scarified fines were Thoroughbred,  $14.43 \pm 1.67$ ; Nomini,  $11.58 \pm$

$0.69$ ; Doyce,  $11.96 \pm 1.48$ ; and Merlin,  $15.16 \pm 0.39$ . These yields of fines were similar to those achieved in our previous Doyce pearling study (Lampi et al 2004). It should be noted that the fines from hulled barley would contain hulls, pericarp, aleurone, and germ; whereas the fines from hullless barley would contain mainly pericarp, aleurone, and germ, because most of the hulls ( $\approx 90\%$ ) would have fallen off in the field either before or during harvest.

## Potential Value as Functional Foods

The yields of oil obtained by extracting ground kernels of hulled and hullless cultivars with hexane were 1.59–2.31 wt% (Table I). For comparative purposes, a fifth barley kernel cultivar, Sustagrain, was also ground and extracted and its oil yields were much higher (4.72%) than those of the other four barley cultivars. Sustagrain (formerly called Prowashonupana) is a barley cultivar that has a shrunken endosperm that results in reduced levels of starch and increased levels of lipids,  $\beta$ -glucans, protein, and some other nutrients (Katta et al 2003). The Sustagrain barley sample was lightly pearled by the distributor to remove the hull and it is likely that some of the pericarp, germ, and aleurone layers were also abraded.

The yields of oil in the four scarified fine fractions were 2.94–9.25 wt% (Table I). Because the oil was enriched in the scarification fines fraction, lipid analyses were only conducted on the fines fraction (no analyses were conducted on the coarse fraction). The oil yields from the fines of the two hulled cultivar were lower (2.94 and 5.33 wt%) than those from the two hullless cultivars (7.35 and 9.25 wt%). The oil yield data (wt%) was also used to calculate the grams of fines oil/100 g of kernels and the % of total kernel oil found in the fines fraction (Table I). Interestingly for the two hulled cultivars,  $\approx 20$ –40% of the kernel oil was localized in the scarification fines, whereas for the two hullless cultivars  $\approx 60\%$  of the kernel oil was localized in the scarification fines. This is presumably because in the hulled cultivars, the 60-sec scarification period removes the hull first, then a portion of the pericarp and germ. In the hullless cultivars, no hull is present, so the scarification for 60 sec removes more of the kernel, including more of the oil-rich germ than in the hulled cultivars.

Using a sensitive HPLC-ELSD method (Fig. 1) for quantitative analysis, the levels of phytosterol fatty acyl esters (SE) were 0.97–3.82 wt% in the kernel extracts and 1.1–7.15 wt% in the extracts from the scarification fines (Table I). The levels of free phytosterols (FS) was 0.23–1.76 in the kernel extracts and from 0.83–2.45 in the extracts from the scarification fines. The levels of free fatty acids in all extracts were 1.44–9.83%. The presence of free fatty acids at levels  $>3\%$  indicate that lipases are probably present in these barley fractions. If an oil or an oil-rich food product is obtained from these barley fractions, precautions may need to be taken such as the thermal pretreatment step required during the processing of rice bran oil to prevent extensive hydrolysis of the triacylglycerols during extraction and processing.

TABLE I  
Oil Yields, Phytosterols, and Free Fatty Acids in Barley Kernels and Scarification Fines<sup>a,b</sup>

Sample	Oil Yield (%)	FFA (%)	SE (%)	FS (%)	Total Oil Phytosterols (%)	Total Kernel Phytosterols
Kernels						
Thoroughbred	1.79 $\pm$ 0.05	1.87 $\pm$ 0.07	3.49 $\pm$ 0.04	1.33 $\pm$ 0.07	4.82	863
Nomini	1.71 $\pm$ 0.03	3.77 $\pm$ 0.28	3.82 $\pm$ 0.16	1.76 $\pm$ 0.08	5.58	953
Doyce	1.59 $\pm$ 0.05	6.13 $\pm$ 0.15	3.35 $\pm$ 0.13	1.32 $\pm$ 0.07	4.67	745
Merlin	2.31 $\pm$ 0.02	3.88 $\pm$ 0.13	2.24 $\pm$ 0.12	0.84 $\pm$ 0.03	3.08	710
Sustagrain	4.72 $\pm$ 0.11	6.98 $\pm$ 0.55	0.97 $\pm$ 0.05	0.23 $\pm$ 0.02	1.20	567
Scarification fines						
Thoroughbred	5.33 $\pm$ 0.13	2.88 $\pm$ 0.69	4.13 $\pm$ 0.75	1.76 $\pm$ 0.23	5.89	3,135
Nomini	2.94 $\pm$ 0.35	9.83 $\pm$ 2.20	7.15 $\pm$ 1.84	2.45 $\pm$ 0.21	9.60	1,778
Doyce	7.35 $\pm$ 0.33	2.29 $\pm$ 0.19	2.19 $\pm$ 0.14	1.36 $\pm$ 0.06	3.55	2,684
Merlin	9.25 $\pm$ 0.23	1.44 $\pm$ 0.21	1.11 $\pm$ 0.05	0.83 $\pm$ 0.08	1.94	1,798

<sup>a</sup> FFA, free fatty acids; SE, steryl esters; FS, free sterols.

<sup>b</sup> Oil yield expressed in g of oil/100 g of kernels of fines; wt % of each lipid component in the oil. Phytosterols expressed as mg/kg fresh weight.

The levels of total phytosterols were 567–953 mg/kg fw in the five samples of barley kernels and 1,778–3,135 mg/kg fw in the four scarification fines fractions (Table I). The total phytosterol value of 2684 mg/kg fw for Doyce scarification fines in the current study compares with the value of 2,000 mg/kg fw (2 mg/g fw that we reported previously for pearling fines from the same cultivar (Lampi et al 2003).

Previous reports have documented high levels of tocopherols and tocotrienols in barley cultivars (Peterson and Qureshi 1993; Wang et al 1993; Yang 2003). Falk et al (2004) recently reported that almost all of the tocopherols were in the barley germ fraction and almost all of the tocotrienols were in the endosperm and pericarp fractions. A sensitive HPLC method (Fig. 2) was used to quantitatively analyze the four tocopherol isomers and four tocotrienol isomers in the kernel and fines of hulled and hullless barleys. Using this method, all eight tocol isomers were measured in all nine barley samples (Table II). Among the eight tocol isomers, the one in the highest concentration was  $\alpha$ -tocotrienol, followed by  $\alpha$ -tocopherol in eight of the nine samples (Table II). The only exception was Sustagrain barley, where the second most abundant tocol was  $\gamma$ -tocotrienol.

The levels of total tocols (tocopherols + tocotrienols) were 84.7–198.6 mg/kg fw in the five kernel fractions and 153.4–448.8 mg/kg fw in the four scarification fines fractions (Table II). Because barley has very high levels of tocotrienols, we wanted to see whether the proportion of tocotrienols to tocopherols varied among barley cultivars and among their fines fractions so we calculated %T3 (total tocotrienols/total tocopherols plus total tocotrienols) (Table II). The %T3 value was slightly higher values in all kernel oils (70.6–75.6 among the four common hulled and hullless cultivars, and even higher for Sustagrain barley, 86.9) and lower values in the fines fractions (55.5–69.7). In most seeds, the levels of total tocotrienols are much lower than the levels of total tocopherols, so the %T3 values would be very low (perhaps 10–20%). Because there is evidence that T3 are more valuable than T (Yang, 2003), the high %T3 values for barley kernels and barley oil may indicate that this oil is more valuable than other seed oils.

### Potential Value as Functional Oils

In addition to evaluating barley kernels and scarification fines as sources of functional foods, they could also be used as a feedstock to extract a functional barley oil. The levels of the eight tocol isomers in barley oils prepared from the five kernel samples and four scarification fines samples were measured (Table III). The levels of the eight tocol isomers were similar to those previously reported in the oils prepared from other barley cultivars (Peterson and Qureshi 1993). The levels of total sterols and total tocopherols and tocotrienols in the oils were also quantitatively analyzed (Table III). The levels of total sterols in the four barley kernel oils were 1.20–5.58 g/100 g of oil. The levels of total sterols in the scarification fines oils were 1.94–9.60 g/100 g of oil.

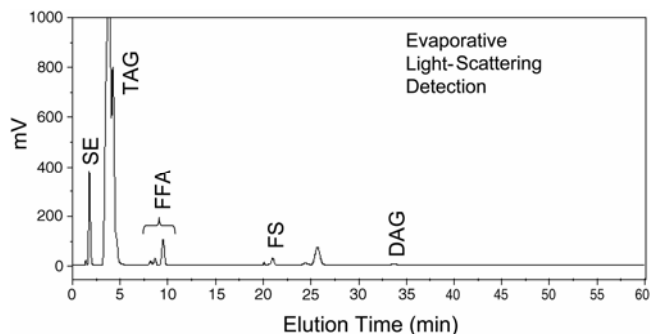
Most experts currently concur that it is necessary to consume at least 1 g of phytosterols/day to see a significant reduction in LDL cholesterol (Moreau et al 2002). However, there is some evidence that lower levels of dietary phytosterols may also cause a significant reduction in LDL cholesterol if they occur in certain food matrices (Ostlund 2003; Jenkins 2003). Assuming a dosage of one tablespoon (15 mL) per day, a person could conceivably consume barley oil with a concentration of  $\approx 6$  g of total sterols/100 mL of oil and ingest  $\approx 1$  g of phytosterols/day, which is considered enough to exhibit a significant (measurable) reduction in LDL cholesterol (Moreau et al 2002). The total levels of tocotrienols in the oils obtained from kernel and scarification fines fractions were 291.1–612.6 mg/100 g of oil (2,911–6,126 mg/kg of oil). These total tocotrienol values are all much higher than those that have been reported in two other oils that are being marketed as high in tocotrienols: palm oil (530 mg/kg) and rice bran oil (770 mg/kg) (Yang 2003). In addition to being effective antioxidants,

there is evidence that tocotrienols may lower LDL cholesterol by inhibiting cholesterol synthesis (Qureshi et al 1991; Parker et al 1993).

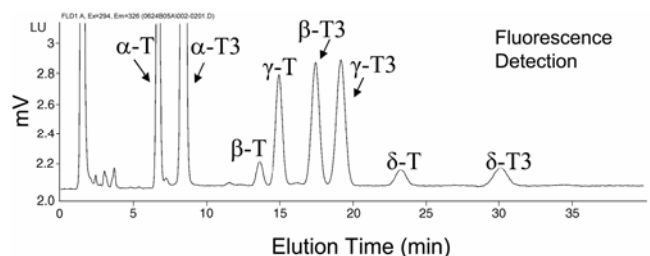
The levels of tocopherols and tocotrienols reported by Wang et al (1993) for hullless barley kernels and hullless barley pearling fines were similar to those that we report here. However, they did not report the levels of tocotrienols in the oils obtained by extracting pearling or scarification fines.

For the current study, we chose to use a fixed scarification time of 60 sec that abraded 11–15% of the hull and pericarp (Table I). It should be noted that for any of the barley cultivars, the scarification time could be optimized to increase or decrease the yield of scarification fines and increase or decrease the yield and composition of oil obtained. However, optimizing the composition and value of the oil is not necessarily correlated with optimizing oil yields. For instance, Merlin scarification fines contain the highest level of oil (9.25%) and extracting that oil, originating from only 15% of the kernel weight, and these numbers can be used to calculate that 60% of the oil that originated in the kernel ends up in the fines fraction. However, this oil has the lowest concentration of total sterols of any of the scarification fines oils tested, only 1.94 g/100 g of oil. On the other hand, Nomini scarification fines contain only  $\approx 3\%$  oil by weight and that oil represents only 20% of the total kernel oil. However, the oil is very concentrated in total sterols with 9.6 g/100 g of oil. These factors are related to the percentage of hulls, pericarp, and germ fractions that are being fractionated and pooled in these processes and this interaction will need to be taken into consideration when optimizing the yield and quality of oils from these barley cultivars and fractions.

It is interesting to note that the levels of total tocols are always higher in the kernel oils than in the scarified fines oils from the corresponding cultivars. This indicates that tocols are more concentrated in the endosperm than in the hull/pericarp. In contrast, in three out of four cultivars, the levels of total sterols are higher in



**Fig. 1.** HPLC chromatogram showing peaks of phytoesters and other non-polar lipid classes in unrefined oil obtained by extracting ground Doyce barley kernels with hexane. Detection with an evaporative light-scattering detector (ELSD). SE, steryl esters; TAG, triacylglycerols; FFA, free fatty acids; FS, free sterols; DAG, diacylglycerols.



**Fig. 2.** HPLC chromatogram showing peaks of tocopherols and tocotrienols in unrefined oil obtained by extracting ground Doyce barley kernels with hexane. Detection with a fluorescence detector (294 nm excitation and 326 nm emission). Abbreviations: T, tocopherol; T3, tocotrienol.

**TABLE II**  
**Individual Tocopherols (T) and Tocotrienols (T3) in Barley Kernels and Scarification Fines**

Sample	$\alpha$ -T	$\beta$ -T	$\gamma$ -T	$\delta$ -T	$\alpha$ -T3	$\beta$ -T3	$\gamma$ -T3	$\delta$ -T3	Total T	Total T3	Total T + T3	T3 <sup>c</sup> (%)
Kernels												
Thoroughbred	20.1 ± 1.0	1.6 ± 0.0	15.1 ± 0.4	4.6 ± 0.2	76.1 ± 2.8	12.4 ± 2.2	18.6 ± 0.8	2.6 ± 0.2	41.4	109.7	151.1	72.6
Nomini	18.0 ± 0.3	0.9 ± 0.1	12.4 ± 0.1	2.6 ± 0.1	60.7 ± 1.2	6.5 ± 0.3	11.0 ± 0.2	2.0 ± 0.2	33.9	80.2	114.1	70.6
Doyce	18.7 ± 0.1	1.9 ± 0.1	10.0 ± 1.3	2.1 ± 0.1	51.4 ± 2.4	11.5 ± 0.7	13.5 ± 0.7	3.1 ± 0.4	32.7	79.5	112.2	70.9
Merlin	14.7 ± 0.8	1.5 ± 0.1	3.5 ± 0.2	0.9 ± 0.1	46.5 ± 1.8	5.0 ± 0.2	11.2 ± 0.5	1.4 ± 0.1	20.6	64.1	84.7	75.7
Scarification fines												
Sustagrain	17.6 ± 1.3	2.8 ± 0.4	4.2 ± 0.3	1.5 ± 0.1	119.0 ± 5.1	18.6 ± 0.6	31.3 ± 1.3	3.6 ± 0.2	26.1	172.5	198.6	86.9
Thoroughbred	77.7 ± 4.9	4.8 ± 0.5	52.9 ± 8.7	16.7 ± 1.0	188.3 ± 29.6	12.5 ± 2.0	50.9 ± 7.3	6.2 ± 0.9	152.1	257.9	410.0	62.9
Nomini	37.4 ± 3.5	1.7 ± 0.1	23.8 ± 1.5	5.8 ± 0.7	65.9 ± 3.3	2.6 ± 0.1	15.1 ± 0.5	1.9 ± 0.1	67.8	85.6	153.4	55.5
Doyce	101.7 ± 1.1	8.9 ± 0.1	51.7 ± 2.0	12.3 ± 0.7	173.8 ± 21.6	16.5 ± 2.6	43.6 ± 4.6	9.0 ± 1.8	174.6	242.9	417.5	58.2
Merlin	92.3 ± 2.9	9.0 ± 0.6	26.1 ± 0.8	8.6 ± 0.6	231.5 ± 8.7	14.5 ± 0.0	59.3 ± 1.8	7.5 ± 0.6	136.0	312.8	448.8	69.7

<sup>a</sup> T, tocopherol; T3, tocotrienol; fw, fresh weight.

<sup>a</sup> Expressed as mg/kg fw.

<sup>c</sup> T3/Total T+T3.

**TABLE III**  
**Individual Tocopherols (T) and Tocotrienols (T3) in Oils Obtained by Extracting Barley Kernels and Scarification Fractions<sup>a</sup>**

Sample	$\alpha$ -T	$\beta$ -T	$\gamma$ -T	$\delta$ -T	$\alpha$ -T3	$\beta$ -T3	$\gamma$ -T3	$\delta$ -T3	Total T	Total T3	Total T + T3
Kernels											
Thoroughbred	112.1 ± 5.4	8.7 ± 0.2	84.3 ± 2.3	25.8 ± 0.9	424.9 ± 15.8	69.3 ± 2.1	103.9 ± 4.4	14.5 ± 0.9	230.9	612.6	843.5
Nomini	105.0 ± 1.8	5.3 ± 0.3	72.3 ± 0.6	15.0 ± 0.3	355.3 ± 6.8	37.9 ± 1.7	69.4 ± 1.1	11.8 ± 1.0	197.6	474.4	672.0
Doyce	117.4 ± 0.6	11.9 ± 0.6	62.7 ± 8.2	13.5 ± 0.9	323.6 ± 14.8	72.3 ± 4.6	84.8 ± 4.2	19.5 ± 2.6	205.5	500.2	705.7
Merlin	92.6 ± 5.1	9.3 ± 0.5	22.0 ± 1.3	5.6 ± 0.4	292.7 ± 11.5	31.3 ± 1.0	70.4 ± 2.9	8.7 ± 0.7	129.5	403.1	532.6
Sustagrain	37.2 ± 2.7	5.9 ± 0.9	8.8 ± 0.6	3.2 ± 0.3	252.1 ± 10.7	39.5 ± 1.3	66.4 ± 2.8	7.7 ± 0.5	55.1	365.7	420.8
Malted barley	111.0 ± 0.8	5.2 ± 0.3	20.6 ± 0.8	1.2 ± 0.2	397.8 ± 22.7	61.4 ± 2.8	86.4 ± 5.0	24.6 ± 1.6	138.0	570.2	708.2
Germ											
Wheat germ	410.2 ± 12.8	200.0 ± 12.4	4.4 ± 0.4	–	6.6 ± 0.8	39.6 ± 2.8	17.0 ± 0.6	–	614.6	63.2	677.8
Scarification fines											
Thoroughbred	145.8 ± 9.1	9.1 ± 1.0	99.3 ± 16.4	31.3 ± 1.8	353.3 ± 55.3	23.5 ± 3.8	95.5 ± 13.7	11.7 ± 1.6	285.5	484.0	769.5
Nomini	127.2 ± 11.9	5.7 ± 0.5	81.0 ± 5.1	19.6 ± 2.5	224.3 ± 11.2	9.0 ± 0.3	51.3 ± 1.7	6.5 ± 0.3	233.5	291.1	524.6
Doyce	138.3 ± 1.5	12.1 ± 0.2	70.4 ± 2.7	16.6 ± 1.0	236.4 ± 29.4	22.5 ± 3.6	59.3 ± 6.3	12.3 ± 2.4	237.4	330.5	576.9
Merlin	99.8 ± 3.1	9.7 ± 0.7	28.2 ± 0.9	9.3 ± 0.6	250.3 ± 9.4	15.7 ± 0.3	64.1 ± 1.9	8.1 ± 0.7	147.0	338.2	485.2

<sup>a</sup> Expressed as mg/100 g of oil.

scarification fines oils than in the kernel oils of the corresponding cultivars. This indicates that sterols are more concentrated in the hull/pericarp than the endosperm.

Although Sustagrain barley has higher kernel oil yields than the other kernels, it is interesting to note that it has the lowest levels of phytosterols and the second lowest levels of tocopherols/g of kernel. Among the five cultivars, Sustagrain barley does have the highest concentration of tocotrienols in its kernels (Table II) but because it has much more oil than the other kernels, the tocotrienols are diluted in the oil and Sustagrain barley oil has the lowest levels of total tocotrienols (Table III).

In conclusion, although the levels of oil in barley kernels are probably not sufficiently high to consider them as an economical feedstock to produce barley oil, the levels of oil in the scarification fines from the two hullless barley cultivars are probably sufficiently high (7–9%) to consider their use as a feedstock to produce barley oil. The levels of oil in these hullless barley scarification fractions are similar to the levels of oil in wheat germ (~9%), which is used as a feedstock for wheat germ oil. The levels of total phytosterols in barley oil are sufficiently high that barley oil could be considered as a feasible source of dietary phytosterols. Because there is a large variation (1.94–9.60 g/100 g of oil) in the levels of phytosterols in the various kernel oils and scarification fines oils (Table III), there is also a large variation in amount that would need to be ingested (10.41 g of oil from Nomini fines vs. 52 g of oil from Merlin fines) to obtain the 1 g of total phytosterols that are considered to be the amount required to ensure a significant reduction in serum cholesterol (Moreau et al 2002). Also, as noted previously, the levels of tocotrienols in barley oil are

several-fold higher than those in any other oil, and are high enough to consider commercializing barley oil as a functional oil high in tocotrienols.

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