INTERNATIONAL
Agrophysics
www.international-agrophysics.org

Int. Agrophys., 2013, 27, 403-408
doi: 10.2478/intag-2013-0010

Physicochemical and grinding characteristics of dragonhead seeds

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Received August 23, 2012; accepted December 19, 2012

A b s t r a c t. The results of investigations on the physicochemical and grinding characteristics of Moldavian dragonhead seeds are presented. The data obtained showed that the physical properties (average size, sphericity, surface area, 1 000 seed mass, dynamic angle of repose, coefficient of static friction, and bulk and true densities) of the white and blue form of dragonhead seeds were not significantly different. Both forms of dragonhead showed similar levels of protein (average of 21%), whereas the blue form of dragonhead had a lower fat content (average of 23.1%) and higher mucilage content (13.35%) in comparison to the blue form of seed (24.6 and 9.95%, respectively). Antioxidant capacity of dragonhead seeds was comparable for both forms and averaged about 40%, which corresponded to EC50 values of 0.12 and 0.13 mg ml^{-1} for the white and blue forms, respectively. The grinding material showed similar particle size distribution of ground material for both forms of dragonhead seeds. The lowest values of specific grinding energy were obtained for the white form of dragonhead seeds, those for the blue form were significantly higher. Grinding of dragonhead seeds using a screen 2.0 mm mesh size caused screen hole clogging. This problem did not occur when dragonhead seeds were mixed with wheat grain.

K e y w o r d s: dragonhead, seed, physicochemical properties, grinding

INTRODUCTION

The plant *Dracocephalum moldavica* L. commonly known as Moldavian balm or Moldavian dragonhead is a perennial herb belonging to the *Lamiaceae* (*Labiatae*) family. It is native to central Asia and is naturalized in eastern and central Europe (Dastmalchi *et al.*, 2007; Said-Al-Ahl and Abdou, 2009). It is also an introduced plant to the northeastern United States. There are two common forms of dragonhead, with white and blue flowers, differing mainly in their flowering period. It flowers mainly in July and sets fruit in August, and contains flavones, terpenes, proteins, polypeptides and 16 amino acids, of which 8 are essential (Sultan *et al.*, 2008). It is frequently consumed as food and drug additives. Dragonhead seed yield is about 1 600 and 1 900 kg ha^{-1} for the white and blue form, respectively (Hanczakowski *et al.*, 2009). Seeds are rich in fatty oil, whose content ranges from 18 to 29%. This oil is rich in unsaturated fatty acids (about 90%), principally the linolenic and linoleic acids (about 60 and 20%, respectively) which belong to essential fatty acids (Domokos *et al.*, 1994). Apart from this, dragonhead seeds (DHS) contain about 21% of protein with beneficial amino acid composition and high biological value (Hanczakowski *et al.*, 2009). DHS are an excellent source of mucilage with the soluble fraction of dietary fibres.

These interesting properties categorise DHS into the group of raw materials suitable for nutraceuticals, food supplements, and functional food applications. However, information on its use in the food industry is rather scarce, possibly due to its limited application and lack of thorough scientific knowledge in this area. Some studies are focused mainly on the properties of green parts of Moldavian balm (Hanaa *et al.*, 2007). The physical properties of agricultural materials are well documented for many crops. However, there are no publications concerning other physical properties of DHS, important from the processing point of view.

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Fragmentation is one of the most important processes in food and feed grain processing. The grinding results depend on the properties of raw materials and the grinding method. The knowledge about the grinding ability allows a conclusion about the method of size reduction. There are no papers concerning studies of DHS fragmentation.

Therefore, the aim of the work was to evaluate the physicochemical properties of DHS. The process of seed pulverization was also evaluated and the grinding energy indices were determined. Furthermore, the process of seed pulverization of a DHS and wheat grain mixture was studied.

MATERIALS AND METHODS

The seeds (DHS) of two different flowering forms (blue and white) of Moldavian dragonhead (*Dracocephalum moldvica* L.) were subjected to the analysis. The DHS came from the field experiment conducted at experimental fields belonging to the Medical University of Lublin. They were collected in September 2009, cleaned in an air screen cleaner and dried at 40°C using a laboratory dryer to reach a moisture content of 6% w.b. The initial moisture content of DHS was checked by oven drying at 105±1°C for 24 h. The moisture content of the DHS was 6.11 and 6.03% for the white and blue forms, respectively.

All physical properties of DHS (average size, sphericity, surface area, 1000 seed mass, dynamic angle of repose, coefficient of static friction on the glass, mild steel and plywood surfaces and, bulk and true densities) were measured using standard methods (Mohsenin, 1980). In the present study, the physical properties of seeds were determined at a moisture content of 6.0% w.b. (adequate for seed storage). It is worth noting that the physical properties of seed are affected by the moisture content (Aghkhani *et al.,* 2012). An increase in moisture causes seed swelling and thus a seed size increase. An increase in seed moisture also causes an increase in the mass of 1 000 seeds, true density, angle of repose, and coefficients of friction, but bulk density and shear force are decreased (Dziki *et al.,* 2009; Ogunsina *et al.,* 2011; Panasiewicz *et al.,* 2009; Yurtlu *et al.,* 2010).

Analyzes of the chemical properties involved determination of the total protein content using the Kjeldahl method with a Kjel-Foss Automatic (N = 5.83) instrument (Model 16210, Denmark), the crude fat content (AOAC, 1995), the mucilage content according to Polish Pharmacopoeia (2002), the total phenolic content (TPC) using the Folin-Ciocalteau reagent (Singleton and Rossi, 1965), expressed as gallic acid equivalent (GAE); in milligrams per gram of sample, and antioxidant capacity in terms of free radical scavenging activity with an ABTS decolorization assay (Re *et al.,* 1999). Sample concentration providing 50% of antioxidant activity (EC_{50}) was calculated from the graph plotting inhibition percentage. The analyzes were conducted in four replications.

After preliminary cleaning and weighing, seeds of individual dragonhead forms (blue and white, moisture content of 6% w.b.) were ground using a laboratory hammer mill POLYMIX-Micro-Hammermill MFC equipped with a screen with round holes of 2.0, 2.5 and 3.0 mm holes. The use of the smallest hole diameter (2.0 mm) caused grinding problems (the holes were clogged). Therefore, dragonhead seed was mixed 1:1 with wheat grain (*cv*. Zorza, moisture content of 10.1% w.b.) and pulverized. The proportion of the mixture was evaluated on the basis of a preliminary study. Additionally, the wheat grain was pulverized for comparison. The amount of energy consumed during grinding was obtained by means of a power transducer (PP71B5, LUMEL, Poland), a data acquisition and computer system that recorded the data measured by the transducer. The grinding energy was calculated using special computer software. Detailed description of the measuring stand and energy consumption was described by Dziki *et al.* (2012). The sieving test was used to determine the particle size distribution of the pulverized material. Sieving was carried out for 5 min using a laboratory screen (Thyr 2, SASKIA, Germany), and separation into fractions was performed using sieves of mesh sizes of 0.800, 0.630, 0.500, 0.400, 0.315 and 0.200 mm. Based on the particle size, the distribution of the average particle size (d_p) was calculated as follows:

$$d_p = \sum_{i=1}^{n} \Phi_i d_i \text{, (mm)} \tag{1}$$

where: Φ – represents the differential weight (kg kg^{-1}) of particles passing through the aperture size d_i (mm).

The specific grinding energy (E_r) was determined as the ratio of the grinding energy to the mass of the material taken for grinding. The grinding efficiency index (E_f) was calculated as the ratio of the surface area of the pulverized material to the grinding energy. The surface area of the pulverized material was evaluated according to the procedure described by Jha and Sharma (2010). The Sokolowski grinding index (K_s) was also calculated:

$$K_s = \frac{E_r}{\frac{1}{\sqrt{d_p}} - \frac{1}{\sqrt{D_p}}} \text{, (kJ kg}^{-1}\text{ mm}^{0.5}\text{)} \tag{2}$$

where: E_r is the specific grinding energy (kJ kg^{-1}), and D_p is the size of DHS, and this parameter was calculated according to procedure described by Dziki and Laskowski (2010).

The measurements of grinding energy were replicated 10 times. The particle size distribution was evaluated three time, and the values of grinding indices were calculated from the average particle size.

The obtained data was further subjected to a statistical analysis and the consequent evaluations were analyzed with the variance analysis using the Statistica 6.0 software (StatSoft, Inc., Tulsa, USA). Moreover, standard deviations and the 95% levels of confidence were evaluated. The statistical differences between the treatment groups were estimated with Tukey test. All the statistical tests were carried out at the significance level of $\alpha = 0.05$.

RESULTS AND DISCUSSION

The physical and chemical properties of DHS are presented in Table 1. The physical properties were similar for both dragonhead forms. The length, width and thickness ranged from: 2.50 to 2.87, 1.20 to 1.35, and 0.75 to 0.92 mm, respectively. The geometric mean diameter varied from 1.31 to 1.49 mm while the corresponding surface area ranged from 5.37 to 7.00 mm^2. The values of specificity obtained for both forms of dragonhead were similar (0.52), which indicates that the seed shape makes it difficult to roll on a surface. In their investigations of sesame seed, Tunde-Akintunde and Akintunde (2004) obtained a similar range for these properties working with sesame seed. The rather flat shape of the seeds enables the seeds to slide and this property is important in the development of hopper and dehuller designs for DHS.

Similar values of 1000 seed mass were obtained for both forms of dragonhead (1.92 and 1.96 g for the white and blue form, respectively). The seeds had a bulk density of 615-635 kg m^{-3} and true density of 1 185-1 202 kg m^{-3}. The angle of repose ranged from 25 to 31°. Similar values of the coefficient of static friction against glass, mild steel and plywood were obtained for both forms of dragonhead (average of 0.36, 0.48, and 0.43, respectively).

Both forms of dragonhead were characterized by similar levels of protein (average of 21%), whereas the white form of dragonhead had a significantly higher fat content (average of 24.6%) and lower mucilage content (9.95%) in comparison to the blue form (23.1 and 13.35%, respectively). Similar levels of protein and fat content in DHS were found by Hanczakowski *et al.* (2009).

A higher TPC was found for the blue form of dragonhead (5.32 mg GAE g^{-1}), compared with 4.97 mg GAE g^{-1} in the white form. These values were significantly higher than those obtained for wheat bran in the study by Zhou and Yu (2004). They reported that the phenolic content in 70% ethanol and 70% methanol extracts averaged 0.84 and 1.00 mg GAE g^{-1}, respectively.

Antioxidant capacity of DHS was comparable for both forms and averaged about 40% which corresponded to EC_{50} values of 0.12 and 0.13 mg ml^{-1} for the white and blue forms, respectively. These activities were several times higher than those obtained for wheat wholemeal, buckwheat flour (Sedej *et al.,* 2010) and spelt (Gawlik-Dziki *et al.*, 2012). In the light of these data, DHS could be used for production of functional foods.

T a b l e 1. Physicochemical properties of dragonhead seed (moisture content 6.0% w.b.)

Properties	Form	
	White	Blue
Lenght (mm)	2.71±0.13	2.76 ±0.10
Width (mm)	1.27±0.06	1.31±0.08
Thickness (mm)	0.84±0.04	0.85±0.06
Geometric diameter (mm)	1.42 ±0.03	1.45 ±0.04
Sphericity	0.52 ±0.13	0.52 ±0.10
Surface area (mm^2)	6.33 ±0.31	6.55 ±0.34
Mass of 1 000 seed (g)	1.92±0.06	1.96±0.05
Bulk density (kg m^{-3})	621±5.60	628±7.00
True density (kg m^{-3})	1 190 ±4.80	1 197 ±6.20
Angle of repose (°)	28±1.30	29±1.40
Static coefficient of friction on:		
- glass	0.36±0.01	0.35±0.01
- mild steel	0.47±0.01	0.48±0.01
- plywood	0.43±0.02	0.42±0.01
Protein content (%)	21.13±0.10	20.93±0.07
Fat content (%)	24.6±0.40	23.10±0.20
Mucilage content (%)	9.95±1.24	16.35±1.65
Total phenolics content (mg GAE g^{-1})	4.97±0.02	5.32±0.02
Total antioxidant capacity (EC_{50} mg ml^{-1})	0.12±0.01	0.13±0.01

The particle size distributions of the preliminary ground dragonhead, wheat and their mixture are presented in Table 2. The particle size distribution is very important from the technological point of view and has an influence on the food processing and final product quality. The results showed that the lowest mass fraction of fine particles (<0.2 mm) was obtained for dragonhead. These trends were observed for both seed forms of and for each screen size. The mass of those particles was several times higher for the mixture of dragonhead with wheat and the highest for wheat grain. A reverse relationship was found for the mass fraction of coarse particles (>1.6 mm). The highest mass fraction of these particles was obtained for ground DHS and the lowest for pulverized wheat. Only when the 2.5 mm screen was used, the mass fraction of those particles was slightly higher for ground wheat with comparison to the blue form of pulverized dragonhead seeds. The highest and similar values of d_p were obtained for both forms of dragonhead (0.64 and 0.71 mm for 2.5 and 3.0 screen diameter, respectively). The values of d_p obtained for the mixture of dragonhead with wheat were significantly lower (0.59 and 0.67 mm, for 2.5 and 3.0 screen diameter, respectively), whereas d_p obtained for the seed mixture during fine grinding (screen diameter 2.0 mm) was similar to d_p obtained for pulverized wheat kernel (Fig. 1).

The lowest values of E_r were obtained for the white form of DHS (average 24.8 and 16.9 kJ kg^{-1} for screen size 2.5 and 3.0 mm, respectively). The values of E_r obtained for the blue form were significantly higher (34.2 and 20.3 kJ kg^{-1}, respectively) and comparable with the values for the mixture of wheat with dragonhead (Fig. 2). Wheat kernel was characterized by the highest value of E_r (average 61.0, 44.2, and 35.5 kJ kg^{-1} for screen size 2.0, 2.5 and 3.0 mm, respectively). The grinding energy consumption depends on many of factors, such as raw material properties, the method of grinding, and especially the degree of fineness (Dziki, 2008).

The DHS differs significantly from wheat grain in both physical properties and chemical composition. Dragonhead seed is characterized by *ca.* twelve times higher content of fat in comparison to wheat grain. This causes grinding problems manifested by clogging of screen holes and a lower degree of fineness. However, the values of E_r did not confirm that seed of dragonhead seed is more resistant to size reduction than wheat seed. Thus, other grinding energy indices were determined, such as E_f and K_s, which additionally take into account the degree of fineness. The highest values of E_f were obtained for the white form of dragonhead and for screen size 3.0 mm (average 0.58 m^2 kJ^{-1}). The lowest E_f was found for the blue form of dragonhead and for wheat grain (average 0.28 and 0.40 m^2 kJ^{-1} for screen size 2.5 and 3.0 mm, respectively). The values of E_f obtained for the mixture of dragonhead with wheat increased as the screen size increased (average from 0.38 to 0.53 m^2 kJ^{-1}). However, for both dragonhead forms, in the increase of screen diameter from 2.0 to 2.5 mm had only a slight influence on E_f (Fig. 3).

Table 2. Particle size distribution of the ground dragonhead, wheat and their mixture samples

Sample	d_w**	Range of class (mm)								
		>1.6	1.0-1.6	0.8-1.0	0.63-0.8	0.5-0.63	0.4-0.5	0.315-0.4	0.2-0.315	<0.2
DWF*	2.5	–	9.6a	11.6a	25.6a	23.4a	10.4a	7.1a	8.5a	3.7a
	3	–	16.0b	16.2b	20.7b	18.4b	9.1b	5.9b	8.6a	5.2b
DBF	2.5	–	8.1c	10.0c	26.3c	25.0c	12.0c	8.8c	6.8b	3.0c
	3	–	20.1d	15.8d	19.6d	19.9d	8.7be	5.6b	7.8c	2.4c
MDWW	2	–	5.5e	4.8e	18.0e	17.4e	10.6a	11.1d	16.0d	16.7d
	2.5	0.2a***	10.5f	11.6a	19.1f	17.1e	9.6b	7.9eg	9.7e	14.3e
	3	0.5b	19.9d	11.4ah	19.6f	12.6f	6.6d	7.3eh	10.7f	11.4f
MDBW	2	–	4.9g	3.1f	19.2f	18.6b	11.0a	9.8f	17.8g	15.7g
	2.5	0.2a	9.2ai	9.3g	21.0bg	17.8be	9.2b	8.1g	11.5h	13.8e
	3	0.4b	18.3c	11.2h	21.9g	12.9f	8.0e	6.2b	9.8i	11.4f
WK	2	–	3.1h	11.2h	22.7h	18.1e	8.1e	8.2g	7.4cj	21.1h
	2.5	0.1a	9.0i	15.9d	23.0h	14.7g	7.1d	5.8b	7.1j	17.2i
	3	0.1a	14.4j	16.4b	21.4bg	13.0f	6.0f	6.8h	6.8b	15.1g

*DWF – dragonhead (white form), DBF – dragonhead (blue form), MDWW – the mixture of dragonhead (white form) and wheat, MDBW – the mixture of dragonhead (blue form) and wheat, WK – wheat kernel, **d_w – screen hole diameter, *** the values designated by the different letters in the columns of the table are significantly different (α = 0.05).

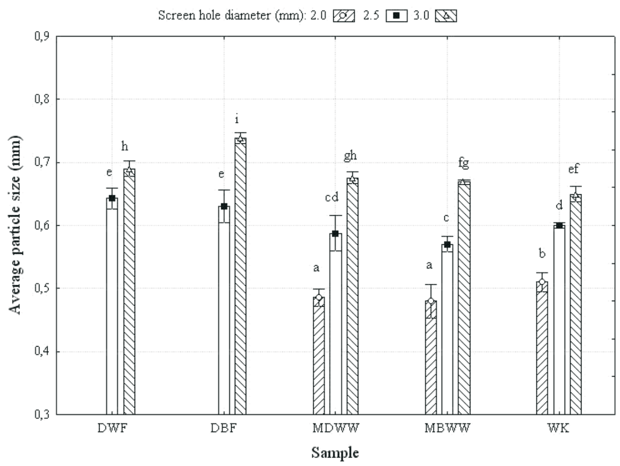

Fig. 1. Average particle size of ground samples (the 95% interval of confidence was marked); the values designated by the different letters for individual samples are significantly different ($\alpha = 0.05$). Explanations as in Table 2.

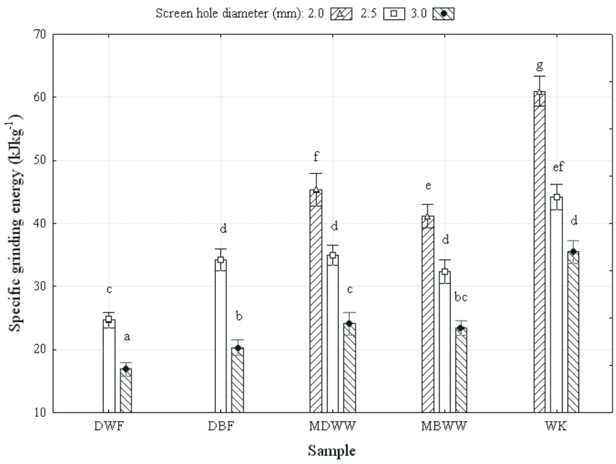

Fig. 2. Specific grinding energy of DHS, wheat and their mixture (the 95% interval of confidence was marked); the values designated by the different letters for individual samples are significantly different ($\alpha = 0.05$). Explanations as in Table 2.

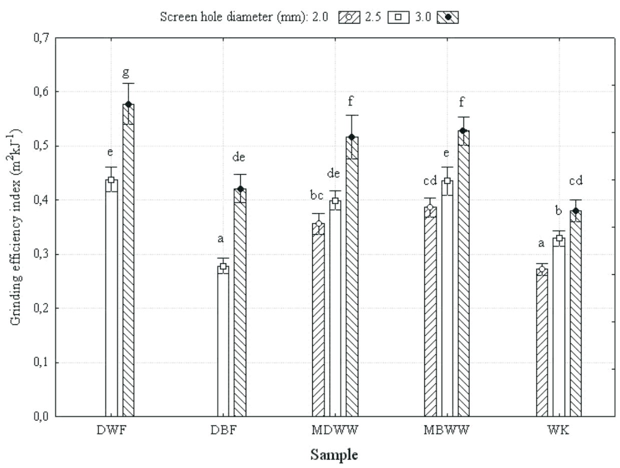

Fig. 3. The grinding efficiency index of DHS, wheat and their mixture (the 95% interval of confidence was marked); the values designated by the different letters for individual samples are significantly different ($\alpha = 0.05$). Explanations as in Table 2.

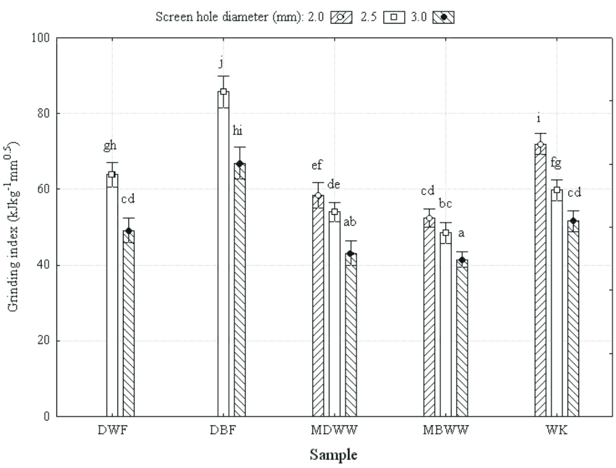

Fig. 4. Sokołowski grinding index of DHS, wheat and their mixture (the 95% interval of confidence was marked); the values designated by the different letters for individual samples are significantly different ($\alpha = 0.05$). Explanations as in Table 2.

The values of K_s are presented in Fig. 4. The highest values of this index were obtained for the blue form of dragonhead (average 67.0 and 85.8 kJ kg^{-1}mm$^{0.5}$ for screen size 3.0 and 2.5 mm, respectively) and the lowest for the mixtures of both DHS forms with wheat (average 42.3, 51.3 and 55.4 kJ kg^{-1}mm$^{0.5}$ for screen sizes 3.0, 2.5 and 2.0 mm, respectively). The values of K_s obtained for the white form of dragonhead and for screen sizes 2.5 and 3.0 mm were not significantly different from the values of K_s obtained for wheat grain. This index is often determined as a grinding characteristic of raw materials and depends mainly on their mechanical properties. Pujol *et al.* (2000) showed in the process of milling that K_s values ranged from 22 kJ kg^{-1}mm$^{0.5}$ for soft common wheat to 54 kJ kg^{-1}mm$^{0.5}$ for durum wheat. In turn, Dziki and Laskowski (2010) found that during the impact grinding of wheat grain, the K_s values changed from 40 to 103 kJ kg^{-1}mm$^{0.5}$ and were mainly influenced by the degree of fineness of the particles.

CONCLUSIONS

1. The data obtained showed that the physical properties of the white and blue forms of dragonhead seed were not significantly different. Besides, the seed of dragonhead was characterized by similar physical properties to those of sesame seed.

2. The blue form of dragonhead seed contained a significantly higher amount of mucilage in comparison to the white form, whereas similar levels of protein content and fat content were obtained for both forms of seed.

3. The grinding results showed similar particle size distribution of ground material for both forms of dragonhead. The pulverized seed of dragonhead was characterized by several times lower mass fraction of fine particles (< 0.2 mm) in comparison to ground wheat grain, whereas the mass fraction of coarse particles (> 1.6 mm) was similar both for wheat and dragonhead.

4. Grinding of dragonhead seed using a screen with a hole diameter of 2.0 mm caused clogging of screen holes. It is worth nothing that this problem did not occur when dragonhead seed was mixed with wheat grain (1:1). This kind of ground mixture can be used as a food additive.

5. The seed of the blue form of dragonhead was characterized by higher values of specific grinding and a lower value of grinding efficiency in comparison to the white form.

6. Finer grinding of dragonhead is possible by mixing it with wheat grain. Moreover, the grinding characteristics of raw materials could not rely only on particle size distribution and E_r, especially for plant granular materials strongly differing in size and other properties.

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