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Nutrition and Physiology

Variation in the chemical composition and physical characteristics of grain from winter barley varieties

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Abstract. The aim of the study was to evaluate the range of variation in chemical composition and in physical parameters of grain associated with feed quality of barley under the conditions of Southeast Bulgaria. A set of 21 winter six-rowed barley varieties from different geographic origins were investigated. The study was conducted in the Institute of Agriculture – Karnobat, during the period 2013/2014 – 2014/2015. Grain samples of the studied varieties were analysed for crude protein, lysine, starch, crude fat, crude ash, crude fiber, hectoliter weight and 1000 grains weight. The coefficient of variation was the highest in crude fat (21.52%) followed by lysine (9.52%). Low variation among varieties was found in nitrogen-free extract (CV=1.56%) and hectoliter weight (CV=2.77%). Correlations of crude protein with lysine, starch and crude fiber were negative. Starch content was positively associated with crude fat and hectoliter weight. Significant negative correlation of nitrogen-free extract with crude fat and crude fiber was found. Differences in chemical composition and physical parameters of grain indicated that the studied varieties can provide a source of germplasm for breeding winter barley varieties with improved feed quality.

Keywords: barley, grain, chemical composition, physical parameters

Introduction

About 85% of the world’s barley production is used for feeding animals. Animal feeders value barley, mainly as an energy source. They prefer barley with low fiber and high starch levels (high digestible energy levels). Barley protein is also economically significant due to high level of lysine, which is important for growing pigs and poultry. As the protein level in the animal's diet increases, the value of extra protein in barley also increases.

Many studies have been conducted to determine the quality requirements of barley grain used in livestock feeding (Newman and Newman 1992ab; Hunt 1998; Svihus and Gullord, 2002; Brand et al., 2003; Biel and Jacyno, 2013). Targeted breeding of barley varieties for a definite application purpose of the grain is connected with selection according to different criteria, because “grain quality” is a complex of quantitative characteristics depending on the physical parameters of grain and their chemical composition.

Barley varies greatly in chemical composition and physical characteristics due to genetic and environmental factors and their interaction (Metayer et al., 1993; Valaja et al., 1997; Scott et al., 1998; Andersson et al., 1999; Rodehutscord et al., 2016). Precipitations, temperature and fertilization are the most important environmental factors that contribute to variations in the chemical and physical characteristics of cereal grains (Metayer et al., 1993; Jorgensen et al., 1999; Dostálová et al., 2015; Rodehutscord et al., 2016). Therefore, the characterisation of variations in the nutritional value of barley grains in a given geographic location may help to define appropriate breeding objectives for improving the feeding value of barley grains for livestock nutrition.

The aim of this investigation was to study variation in chemical composition and physical characteristics of grain associated with feed quality of barley in 21 winter barley varieties in Southeast Bulgaria conditions.

Material and methods

This research was conducted during 2013/2014 and 2014/2015 growing seasons in the experimental field of the Institute of Agriculture – Karnobat, Southeastern Bulgaria. The experiments were organized in a Randomized Complete Block Design with 4 replications on plots of 10 m².

The materials used in the present study included 21 varieties of six-rowed winter barley – Izgrev, Iz Bori, Bojin and Zemela from the Institute of Agriculture – Karnobat, Bulgaria; Atlas, Barberosse, Express, Maniton and Rebelle from France; Bronhild, Krimhild and Sigra from Germany; Finbul from Finland; Gerlach from Limagrain, Europe; Rombohedral from Hebei, China; Mlhalio and Radical from Krasnodar Lukyanenko Research Institute of Agriculture, Russia; PA8649-95 from Pensylvania, USA; GA-Lutrell from Georgia, USA; Hampus from Sweden.

Grain samples from the studied varieties were ground in a laboratory mill with 1.0 mm sieve. Dry matter of grain samples was determined by drying the sample in an oven at 105°C until a constant weight was obtained and dry matter yield was calculated. Crude protein content (%) was determined by the Kjeldahl method, and a conversion factor of 6.25 was used to convert total nitrogen to crude protein. Lysine content (as % of crude protein) was determined by the Susoev method (Susoev, 1970). Starch content (%) was determined by the Ewers polarimetric method. Crude fat (%) was extracted with petroleum ether (boiling range of 40–60°C) by the Soxhlet extraction method. Crude ash (%) was determined by

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incineration in a muffle furnace at 550°C for 3 h. Crude fiber (%) was determined as the residue after sequential treatment with hot H2SO4 and hot NaOH according to the Weende method. Nitrogen-free extract (NFE) was calculated as follows: NFE (%) = 100 – (moisture % + crude protein % + crude fat % + ash % + crude fiber %).

Hectoliter weight (kg/hl) was determined by a volume meter and 1000-grain weight (g) was determined from the grain weight of 200 randomly taken grains multiplied by 5.

The data of two years have been summarized and Pearson correlation coefficients were estimated using the computer software system of SPSS 16.00 for Windows (SPSS Inc., 2007). The cluster analysis was performed using the Complete linkage method with software Statistica 7.0 (StatSoft Inc., 2004).

**Results and discussion**

The chemical composition and physical characteristics of grain of winter six-rowed barley varieties are presented in Table 1. The highest amount of crude protein was determined in variety Atlas (13.12%), and the lowest amount of crude protein was found in variety Barbarosse (10.75%). The concentration of protein in barley is highly dependent on the cultivar and growth conditions (Oscarsson et al., 1996; Qi et al., 2006; Arendt and Zannini, 2013).

High crude protein content in barley grain is especially important for nutrient needs of ruminants (Newman and Newman, 1992a). The mean lysine content varied from 2.32% (Zemela) to 3.14% (IZ Bori). Lysine is the first limiting essential amino acid in barley and therefore an increased lysine content in protein results in improved nutritional quality (Eggum, 1977; Munck, 1992; Jørgensen et al., 1997; Jørgensen et al., 1999). Starch content ranged from 50.73% in variety Bronhild to 57.91% in variety Izgrev. The energy value of barley largely depends on its starch content (Newman and Newman, 1992b) and according to Griffey et al. (2010) selection for high starch concentration will facilitate the development of barley cultivars better suited for use in feed. The results showed that the lowest ash content was in variety Zemela (2.50%) and the highest in variety Sigra (2.89%). Crude fat values in barley varieties varied from 1.43% (Atlas) to 3.09% (Izgrev). Crude fiber ranged between 4.38% (Veslets) and 6.94% (Mihailo). The lowest concentration of nitrogen-free extract was found in Bronhild (63.74%) and the highest in Veslets (67.02%). Maximum hectoliter weight of 70.10 kg/hl was exhibited by variety Veslets, whereas minimum hectoliter weight of 62.55 kg/hl was recorded for the variety Sigra. Data for 1000-grain weight ranged between 35.29 g and 48.90 g, maximum 1000-grain weight was recorded for variety Finbul, whereas minimum was recorded for variety Bronhild. The obtained results for the chemical and physical characteristics of barley grain are comparable with

Table 1. Mean of chemical composition and physical characteristics of grain of winter six-rowed barley varieties (2013/2014 – 2014/2015)

<table>
<thead>
<tr>
<th>Varieties</th>
<th>Crude protein, %</th>
<th>Lysine, %</th>
<th>Starch, %</th>
<th>Ash, %</th>
<th>Crude fat, %</th>
<th>Crude fiber, %</th>
<th>Nitrogen-free extract</th>
<th>Hectoliter weight, kg/hl</th>
<th>1000 grains weight, g</th>
</tr>
</thead>
<tbody>
<tr>
<td>Veslets</td>
<td>12.06</td>
<td>2.82</td>
<td>53.73</td>
<td>2.67</td>
<td>1.74</td>
<td>4.38</td>
<td>67.02</td>
<td>70.10</td>
<td>48.81</td>
</tr>
<tr>
<td>Izgrev</td>
<td>11.09</td>
<td>3.07</td>
<td>57.91</td>
<td>2.67</td>
<td>3.09</td>
<td>6.27</td>
<td>64.89</td>
<td>69.15</td>
<td>43.41</td>
</tr>
<tr>
<td>IZ Bori</td>
<td>11.22</td>
<td>3.14</td>
<td>52.34</td>
<td>2.60</td>
<td>1.45</td>
<td>5.64</td>
<td>66.86</td>
<td>67.65</td>
<td>40.68</td>
</tr>
<tr>
<td>Bojin</td>
<td>11.35</td>
<td>2.98</td>
<td>52.82</td>
<td>2.61</td>
<td>1.71</td>
<td>6.33</td>
<td>65.63</td>
<td>68.45</td>
<td>46.53</td>
</tr>
<tr>
<td>Zemela</td>
<td>13.00</td>
<td>2.32</td>
<td>52.21</td>
<td>2.50</td>
<td>1.88</td>
<td>4.55</td>
<td>65.60</td>
<td>69.15</td>
<td>40.63</td>
</tr>
<tr>
<td>Atlas</td>
<td>13.12</td>
<td>2.35</td>
<td>53.98</td>
<td>2.68</td>
<td>1.43</td>
<td>5.54</td>
<td>64.77</td>
<td>69.90</td>
<td>45.29</td>
</tr>
<tr>
<td>Barbarosse</td>
<td>10.75</td>
<td>3.11</td>
<td>54.01</td>
<td>2.73</td>
<td>1.47</td>
<td>5.96</td>
<td>66.78</td>
<td>69.25</td>
<td>35.69</td>
</tr>
<tr>
<td>Bronhild</td>
<td>12.84</td>
<td>2.74</td>
<td>50.73</td>
<td>2.80</td>
<td>2.15</td>
<td>6.18</td>
<td>63.74</td>
<td>64.10</td>
<td>35.29</td>
</tr>
<tr>
<td>Express</td>
<td>11.87</td>
<td>2.41</td>
<td>53.35</td>
<td>2.78</td>
<td>2.53</td>
<td>6.27</td>
<td>64.27</td>
<td>69.30</td>
<td>47.88</td>
</tr>
<tr>
<td>Finbul</td>
<td>12.38</td>
<td>3.01</td>
<td>52.88</td>
<td>2.65</td>
<td>2.00</td>
<td>6.25</td>
<td>64.14</td>
<td>68.20</td>
<td>48.90</td>
</tr>
<tr>
<td>Gerlach</td>
<td>11.76</td>
<td>2.86</td>
<td>54.73</td>
<td>2.64</td>
<td>1.87</td>
<td>5.75</td>
<td>66.12</td>
<td>67.70</td>
<td>48.64</td>
</tr>
<tr>
<td>Hampus</td>
<td>11.09</td>
<td>2.55</td>
<td>57.73</td>
<td>2.59</td>
<td>2.59</td>
<td>6.80</td>
<td>64.61</td>
<td>69.80</td>
<td>45.54</td>
</tr>
<tr>
<td>Maniton</td>
<td>11.68</td>
<td>2.78</td>
<td>52.97</td>
<td>2.61</td>
<td>2.31</td>
<td>5.37</td>
<td>66.05</td>
<td>68.45</td>
<td>48.80</td>
</tr>
<tr>
<td>Rebelle</td>
<td>11.47</td>
<td>2.89</td>
<td>52.14</td>
<td>2.74</td>
<td>2.34</td>
<td>6.75</td>
<td>64.36</td>
<td>67.75</td>
<td>40.10</td>
</tr>
<tr>
<td>Krimhild</td>
<td>12.96</td>
<td>2.44</td>
<td>52.22</td>
<td>2.50</td>
<td>2.64</td>
<td>5.69</td>
<td>63.80</td>
<td>68.80</td>
<td>45.33</td>
</tr>
<tr>
<td>Sigra</td>
<td>11.59</td>
<td>2.75</td>
<td>51.97</td>
<td>2.89</td>
<td>1.52</td>
<td>5.62</td>
<td>66.22</td>
<td>62.55</td>
<td>37.19</td>
</tr>
<tr>
<td>Rombohedral</td>
<td>12.65</td>
<td>2.69</td>
<td>53.34</td>
<td>2.81</td>
<td>2.02</td>
<td>5.16</td>
<td>64.65</td>
<td>70.00</td>
<td>38.41</td>
</tr>
<tr>
<td>Mihailo</td>
<td>11.12</td>
<td>3.03</td>
<td>56.71</td>
<td>2.61</td>
<td>2.26</td>
<td>6.94</td>
<td>64.61</td>
<td>67.20</td>
<td>37.80</td>
</tr>
<tr>
<td>PA&amp;649-95</td>
<td>11.66</td>
<td>3.06</td>
<td>55.19</td>
<td>2.59</td>
<td>2.18</td>
<td>5.79</td>
<td>65.18</td>
<td>69.20</td>
<td>35.99</td>
</tr>
<tr>
<td>Radical</td>
<td>12.08</td>
<td>2.64</td>
<td>54.90</td>
<td>2.59</td>
<td>1.77</td>
<td>5.43</td>
<td>65.87</td>
<td>67.15</td>
<td>41.62</td>
</tr>
<tr>
<td>GA-Lutrell</td>
<td>12.00</td>
<td>2.49</td>
<td>55.77</td>
<td>2.64</td>
<td>2.16</td>
<td>6.32</td>
<td>64.31</td>
<td>69.55</td>
<td>44.44</td>
</tr>
<tr>
<td><strong>Mean</strong></td>
<td><strong>11.89</strong></td>
<td><strong>2.77</strong></td>
<td><strong>53.89</strong></td>
<td><strong>2.66</strong></td>
<td><strong>2.05</strong></td>
<td><strong>5.86</strong></td>
<td><strong>65.21</strong></td>
<td><strong>68.26</strong></td>
<td><strong>42.71</strong></td>
</tr>
<tr>
<td><strong>Minimum</strong></td>
<td><strong>10.75</strong></td>
<td><strong>2.32</strong></td>
<td><strong>50.73</strong></td>
<td><strong>2.50</strong></td>
<td><strong>1.43</strong></td>
<td><strong>4.58</strong></td>
<td><strong>63.74</strong></td>
<td><strong>62.55</strong></td>
<td><strong>35.29</strong></td>
</tr>
<tr>
<td><strong>Maximum</strong></td>
<td><strong>13.12</strong></td>
<td><strong>3.14</strong></td>
<td><strong>57.91</strong></td>
<td><strong>2.89</strong></td>
<td><strong>3.09</strong></td>
<td><strong>6.94</strong></td>
<td><strong>67.02</strong></td>
<td><strong>70.10</strong></td>
<td><strong>48.90</strong></td>
</tr>
<tr>
<td><strong>CV%</strong></td>
<td><strong>5.94</strong></td>
<td><strong>9.52</strong></td>
<td><strong>3.57</strong></td>
<td><strong>3.75</strong></td>
<td><strong>21.52</strong></td>
<td><strong>11.42</strong></td>
<td><strong>1.56</strong></td>
<td><strong>2.77</strong></td>
<td><strong>11.14</strong></td>
</tr>
</tbody>
</table>
those reported by Griffey et al. (2010), Makeri et al. (2013), Biel and Jacyno (2013), and Alijošius et al. (2016).

Varieties Zemela, Bronhild, Krimhild and Rombohedral were found to possess above 12.5% protein in grain. Izgrev, IZ Bori, Barbarosse, PA8649-95 and Mihailo had a high percentage of lysine in grain protein. A favorable combination of high protein, lysine, hectoliter weight and 1000-grain weight was found in variety Finbul.

The highest coefficient of variation (CV) was shown by crude fat (CV=21.52%), followed by crude fiber (CV=11.42%). The lowest values of CV were shown by nitrogen-free extract and hectoliter weight (CV=1.56% and CV=2.77%).

The correlation coefficients among the studied characteristics were presented in Table 2. Crude protein had a significant negative correlation with lysine, starch and crude fiber. Similar results have been reported by a number of other researchers in diverse environments (Briggs, 1978; Griffey et al., 2010; Pasam et al., 2012). Starch content in grain was positively associated with crude fat and hectoliter weight. Crude fat content had a positive correlation with starch and crude fiber and a negative correlation with nitrogen-free extract. Significant negative correlations between crude fiber and nitrogen-free extract were found. Hectoliter weight had a positive correlation with starch content and 1000-grain weight and negative

<table>
<thead>
<tr>
<th></th>
<th>Lysine</th>
<th>Starch</th>
<th>Crude ash</th>
<th>Crude fat</th>
<th>Crude fiber</th>
<th>Nitrogen-free extract</th>
<th>Hectoliter weight</th>
<th>1000 grains weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crude protein</td>
<td>-0.676*</td>
<td>-0.476*</td>
<td>-0.069</td>
<td>-0.093</td>
<td>-0.493*</td>
<td>-0.400</td>
<td>0.035</td>
<td>0.116</td>
</tr>
<tr>
<td>Lysine</td>
<td>1</td>
<td>0.128</td>
<td>0.093</td>
<td>-0.097</td>
<td>0.269</td>
<td>0.367</td>
<td>-0.172</td>
<td>-0.257</td>
</tr>
<tr>
<td>Starch</td>
<td>1</td>
<td>-0.263</td>
<td>0.415*</td>
<td>0.357</td>
<td>-0.041</td>
<td>-0.416*</td>
<td>0.115</td>
<td></td>
</tr>
<tr>
<td>Crude ash</td>
<td>1</td>
<td>-0.159</td>
<td>0.113</td>
<td>0.041</td>
<td>-0.448*</td>
<td>-0.315</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Crude fat</td>
<td>1</td>
<td>0.427*</td>
<td>0.616**</td>
<td>0.209</td>
<td>0.178</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Crude fiber</td>
<td>1</td>
<td>-0.531*</td>
<td>-0.149</td>
<td>-0.096</td>
<td>0.006</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nitrogen-free extract</td>
<td>1</td>
<td>-0.029</td>
<td>0.425*</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 2. Pearson correlation coefficients between the chemical and physical characteristics of grain of winter six-rowed barley varieties (2013/2014 – 2014/2015)

Figure 1. Cluster diagram of 21 winter six-rowed barley varieties on the basis of chemical and physical characteristics of grain (2013/2014 – 2014/2015)
correlation with crude ash content. Kaur et al. (2016) also reported positive association between starch content and hectoliter weight. Significant positive correlation between starch and test weight was found by Cambell et al. (1995) and Griffey et al. (2010).

The dendrogram of the evaluated barley varieties is presented in Figure 1. The varieties were grouped into two clusters at a linkage distance of about 0.27 units. The first cluster is composed of 10 genotypes. The group is mainly characterized by low values for hectoliter weight and 1000-grain weight. The second cluster included 11 varieties with high hectoliter weight and 1000-grain weight. The groupings indicated no correspondence between geographical origin and clustering pattern. Two of the Bulgarian varieties Zemela and Iz Bori are situated in the first cluster and the other three Veslets, Izgrev and Bojin – in the second cluster. This might be explained by the fact that the qualitative traits are complex variables and depend on the interaction of a significant number of gene expressions not being related to the geographic origin.

Conclusion

The present study showed considerable differences in chemical and physical characteristics of barley grain in winter barley varieties grown in Southeast Bulgaria conditions. The highest coefficient of variation (CV) was shown by crude fat (CV=21.52%), followed by crude fiber (CV=11.42%). The lowest values of CV were shown by nitrogen-free extract and hectoliter weight (CV=1.56% and CV=2.77%). Correlations of crude protein with lysine, starch and crude fiber were negative. Starch content was positively associated with crude fat and hectoliter weight. Significant negative correlation of nitrogen-free extract with crude fat and crude fiber was found. Differences in chemical composition and physical parameters of grain indicated that the studied varieties could be potentially utilized in breeding of winter barley varieties with improved feed quality.

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S. Peeva, E. Raichev, D. Georgiev, A. Stefanov
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