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The articles appearing in this journal are indexed and abstracted in: EBSCO Publishing, Inc. and AGRIS (FAO). The journal is accepted to be indexed with the support of a project № BG051PO001-3.3.05-0001 “Science and business” financed by Operational Programme “Human Resources Development” of EU. The title has been suggested to be included in SCOPUS (Elsevier) and Electronic Journals Submission Form (Thomson Reuters).

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AGRICULTURAL

SCIENCE AND TECHNOLOGY

2013

An International Journal Published by Faculty of Agriculture,
Trakia University, Stara Zagora, Bulgaria
Evaluation of double haploid lines of winter malting barley using selection indices

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Abstract. Twenty two double haploid lines from winter malting barley breeding program of the Institute of Agriculture – Karnobat were tested in randomized complete block design with four replications. The objective of this study was to evaluate the breeding potential of double haploid lines of winter malting barley using multiple selection indices. Selection indices used included: Elston’s index, Baker’s index, Rank summation index and a simple-weighted index as proposed by Wehner. The significant correlation between selection indices calculated for 6 quality traits (1000 grain weight, hectoliter weight, malt extract content, protein content, germination on day 3 and grain grading) and indices based on the most important 4 (1000 grain weight, hectoliter weight, malt extract content and protein content) quality traits was found, indicating that the 4-trait indices could be substituted using 6-trait indices to save work in data collection. Selection indices were calculated using the most important 4 quality traits and grain yield. The lines A 9/16, A 8/3, A 25/19, A 15/2 combine the desired quality characteristics with high grain yield and can be selected for further evaluation in a breeding program of winter malting barley.

Keywords: winter malting barley, selection indices, quality, yield

Introduction

Barley is produced for human consumption, animal feed, pharmaceuticals, and alcoholic beverage products (Ulrich, 2011). Significant amount of barley is used for brewing. The beer industry has special and strict quality requirements. Both high grain yield and malt quality of grain are important in the development of advanced breeding lines which will potentially produce new varieties. Therefore, in malting barley breeding programs there is a need for improving many traits at the same time. One method of identifying superior genotypes for multiple traits is the use of selection indices. There are many such indices available to the breeder to aid the selection process.

Elston proposed a multiplicative index constructed without economic weighting of the traits (Elston, 1963). Index values are calculated by multiplication of phenotypic deviations for each trait in the index. Baker’s standard deviation index is a linear index based on summation of the mean of each trait divided by its standard deviation (Baker, 1986). Mulmbda and Mock (1978) described a rank summation index, which they called a “parameter-free” index. Index values are calculated by summing the ranks of the traits included in the index. Like Elston’s index, Baker’s and the rank summation indices eliminate the need to assign relative economic weights to traits. Wehner (1985) constructed the simple-weighted index, in which each trait was corrected so that its value increased as the trait improved. Next, the traits were transformed so that all traits were measured on a similar scale. Each trait then was multiplied by the fraction of 1.00 that the breeder wished to assign in to indicate its importance in the aggregate genotype.

The objective of this study was to evaluate the breeding potential of 22 double haploid lines of winter malting barley using qualitative traits and grain yield by multiple selection indices.

Material and methods

This research was conducted in the 2011 – 2012 growing season 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. Standard agronomic and plant protection practices were used. Twenty two double haploid lines of winter malting barley breeding program of the Institute of Agriculture, Karnobat, obtained via anther culture were studied. Grain yield (t/ha), 1000 grain weight (g), hectoliter weight (kg), malt extract content (%), protein content (%), germination energy (%), and grain grading (%) were evaluated. Protein content was measured by the Kjeldahl method. Malt extract content and germination were determined on the basis on EBC (Analytica-EBC, 1987).

To rank the genotypes by phenotypic values four selection indices were used in this study.

Elston’s (Elston, 1963) index \(I_e\) was calculated as follows:
\[
I_e = \left( \frac{P_i - m_i}{\sigma_i} \right) \left( \frac{P_j - m_j}{\sigma_j} \right) \ldots \left( \frac{P_n - m_n}{\sigma_n} \right)
\]
where \(P_i\) is mean of \(n\)-th trait, and \(m_i\) is minimum value for the \(n\)-th trait.

For protein content the reciprocals of the observed values were taken, because for this trait a smaller phenotypic value is desirable.

Baker’s (Baker, 1986) standard deviation index \(I_s\) was calculated as follows:
\[
I_s = \sum P_i \sigma_i
\]
where \(P_i\) is mean of \(n\)-th trait, and \(\sigma_i\) is phenotypic standard deviation for \(n\)-th mean.

The rank summation index \(I_r\) was calculated as follows:
\[
I_r = \sum \text{Rank } P_i
\]
where Rank \(P_i\) is the rank on the \(n\)-th mean (Mulmbda and Mock, 1978).

The simple-weighted index \(I_w\) as proposed by Wehner (1982) was calculated as follows:
\[
I_w = \sum a_i P_i
\]
where \(a_i\) is fraction of 1.00 indicating the importance of the \(n\)-th trait in the aggregate genotype, and \(P_i\) is scaled mean of the \(n\)-th trait, where the means are scaled so that all are on a 1 to 10 basis.

Coefficients used to construct the simple-weighted index:
Germination is critical to the malting process. A minimum of 9 DH lines are given in Table 1. Germination is an absolute requirement (Briggs, 1998). The germination was excellent for lines A8/1, A8/25, A8/35, A15/2 and A25/19. The 1000 grain weight of the breeding lines varied between 42.0 g to 55.5 g. The 10 lines showed a very high (above 48.0 g) 1000 grain weight. Grain grading is a very important quality characteristic – to ensure a good and uniform malting process there is demand for big and uniform grain size. The percentage of grains on a 2.5 x 20 mm sieve for malt barley must be no less than 91%. Of the studied lines A8/3, A8/11, A8/12, A8/19, A8/25, A15/2 and A25/19 meet this requirement for malting barley. The next important malting barley parameter is hectolitre weight. According to this character all evaluated lines exceeded the recommended level for malting barley (>70.00 kg).

Malting barley with a high protein content results in lower extract for the brewing. It also slows down water uptake during steeping, potentially affecting final malt quality. A very low protein level, on the other hand, results in lack of enzymes necessary to modify the barley kernel and to break down starch during brewing. barley used for malt should have a grain protein content not exceeding 12% (Home, 1991; Home and Elamo, 1993). Lines A8/1, A8/12, A8/25, A8/28 and A15/2 showed protein content below 12.0%. For brewing industry the highest possible extract content is demanded and in good malting barley it is over 79%. The best extract content was shown by lines A9/15, A25/19, A8/1, A8/3, A8/13 and A24/2. The extract of lines A8/7, A8/11, A8/12, A8/25, A8/33 were low. The grain yield of the breeding lines varied between 4.55 to 6.61 t/ha. Among the tested genotypes, the highest grain yield was obtained from lines

### Results and discussion

The mean values of 6 quality characters and grain yield of 22 DH lines are given in Table 1. Germination is critical to the malting process. A minimum of 95% germination on a day 3 germination test is an absolute requirement (Briggs, 1998). The germination was calculated using 6 quality traits – 1000 kernel weight, hectolitre weight, malt extract content, protein content, germination on day 3 and grain grading. Indices based on the most important 4 (1000 kernel weight, hectolitre weight, malt extract content and protein content) out of 6 quality traits were calculated – 4l, 4f, 4i, and l indices to determine whether the 4-trait indices could substitute the use of 6 traits to save work in data collection.

All four indices l, f, i, and l were calculated using the most important 4 quality traits and grain yield. The selection indices were compared using Spearman’s rank correlation (Steel and Torrie, 1980).

### Table 1. Mean values for 6 quality characters and grain yield of 22 DH lines

<table>
<thead>
<tr>
<th>No</th>
<th>DH lines</th>
<th>Germination energy, %</th>
<th>1000 grain weight, g</th>
<th>Hectolitre weight, kg</th>
<th>Grading &gt; 2.5mm, %</th>
<th>Extract content, %</th>
<th>Protein content, %</th>
<th>Grain yield, t/ha</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>A 8/1</td>
<td>99.8</td>
<td>47.0</td>
<td>81.7</td>
<td>84.8</td>
<td>79.2</td>
<td>11.93</td>
<td>5.15</td>
</tr>
<tr>
<td>2</td>
<td>A 8/3</td>
<td>97.0</td>
<td>50.0</td>
<td>79.5</td>
<td>92.8</td>
<td>79.1</td>
<td>13.42</td>
<td>6.48</td>
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<td>3</td>
<td>A 8/6</td>
<td>96.8</td>
<td>42.5</td>
<td>73.9</td>
<td>75.9</td>
<td>78.6</td>
<td>13.17</td>
<td>4.96</td>
</tr>
<tr>
<td>4</td>
<td>A 8/7</td>
<td>97.5</td>
<td>44.5</td>
<td>72.7</td>
<td>80.5</td>
<td>77.5</td>
<td>13.67</td>
<td>4.86</td>
</tr>
<tr>
<td>5</td>
<td>A 8/8</td>
<td>97.8</td>
<td>42.5</td>
<td>73.4</td>
<td>78.9</td>
<td>77.8</td>
<td>13.67</td>
<td>4.91</td>
</tr>
<tr>
<td>6</td>
<td>A 8/11</td>
<td>98.0</td>
<td>50.5</td>
<td>82.2</td>
<td>91.6</td>
<td>76.6</td>
<td>13.67</td>
<td>4.90</td>
</tr>
<tr>
<td>7</td>
<td>A 8/12</td>
<td>99.3</td>
<td>48.0</td>
<td>79.9</td>
<td>91.7</td>
<td>76.1</td>
<td>11.93</td>
<td>4.55</td>
</tr>
<tr>
<td>8</td>
<td>A 8/13</td>
<td>97.3</td>
<td>45.5</td>
<td>81.5</td>
<td>79.2</td>
<td>79.2</td>
<td>13.00</td>
<td>5.53</td>
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<tr>
<td>9</td>
<td>A 8/19</td>
<td>97.0</td>
<td>50.0</td>
<td>81.2</td>
<td>95.4</td>
<td>76.2</td>
<td>13.17</td>
<td>5.11</td>
</tr>
<tr>
<td>10</td>
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<td>52.5</td>
<td>81.4</td>
<td>94.7</td>
<td>73.4</td>
<td>13.17</td>
<td>5.38</td>
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<td>46.5</td>
<td>81.5</td>
<td>84.5</td>
<td>77.9</td>
<td>11.93</td>
<td>5.30</td>
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<td>A 8/28</td>
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<td>46.5</td>
<td>74.0</td>
<td>88.7</td>
<td>78.3</td>
<td>11.93</td>
<td>4.84</td>
</tr>
<tr>
<td>13</td>
<td>A 8/33</td>
<td>97.3</td>
<td>50.0</td>
<td>73.5</td>
<td>85.6</td>
<td>77.5</td>
<td>12.43</td>
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<tr>
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<td>47.0</td>
<td>75.0</td>
<td>85.7</td>
<td>79.4</td>
<td>12.43</td>
<td>5.26</td>
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<tr>
<td>15</td>
<td>A 9/8</td>
<td>95.3</td>
<td>43.5</td>
<td>79.3</td>
<td>72.5</td>
<td>77.8</td>
<td>13.10</td>
<td>5.28</td>
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<tr>
<td>16</td>
<td>A 9/10</td>
<td>98.0</td>
<td>49.0</td>
<td>83.5</td>
<td>90.8</td>
<td>78.5</td>
<td>13.67</td>
<td>6.38</td>
</tr>
<tr>
<td>17</td>
<td>A 9/12</td>
<td>98.0</td>
<td>43.0</td>
<td>80.7</td>
<td>75.2</td>
<td>77.6</td>
<td>14.17</td>
<td>5.45</td>
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<td>18</td>
<td>A 9/15</td>
<td>98.5</td>
<td>43.0</td>
<td>79.7</td>
<td>74.9</td>
<td>80.4</td>
<td>13.10</td>
<td>5.50</td>
</tr>
<tr>
<td>19</td>
<td>A 9/16</td>
<td>96.3</td>
<td>49.0</td>
<td>83.3</td>
<td>71.0</td>
<td>78.4</td>
<td>12.61</td>
<td>6.61</td>
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<tr>
<td>20</td>
<td>A 15/2</td>
<td>100.0</td>
<td>51.0</td>
<td>81.6</td>
<td>91.2</td>
<td>78.6</td>
<td>11.86</td>
<td>6.04</td>
</tr>
<tr>
<td>21</td>
<td>A 24/2</td>
<td>96.3</td>
<td>42.0</td>
<td>82.2</td>
<td>76.0</td>
<td>79.4</td>
<td>12.36</td>
<td>5.96</td>
</tr>
<tr>
<td>22</td>
<td>A 25/19</td>
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<td>80.3</td>
<td>12.85</td>
<td>6.09</td>
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<tr>
<td>23</td>
<td>Obzor</td>
<td>98.5</td>
<td>45.0</td>
<td>73.5</td>
<td>82.6</td>
<td>78.4</td>
<td>13.42</td>
<td>6.04</td>
</tr>
<tr>
<td>24</td>
<td>Emon</td>
<td>97.0</td>
<td>51.0</td>
<td>73.9</td>
<td>95.4</td>
<td>79.6</td>
<td>12.75</td>
<td>5.80</td>
</tr>
</tbody>
</table>

LSD 0.05% 1.5 3.5 3.7 8.1 1.6 0.69 0.66
A/8, A/8/10, A 9/16, A 15/2 and A25/19 but were not significantly different than those obtained in standard variety Obzor.

In our study we used simple selection indices for evaluation of breeding lines (Table 2). The main advantage of the simple indices is that they do not require estimates of genetic parameters and are easy to construct, while the main disadvantage is that they do not take into account the inheritance of traits or their phenotypic or genetic associations. According to the multiple selection indices I_s and l_t for six and for four studied traits and the I_s, we observe superior malt quality of grain in DH lines A 25/19, A 15/2 and A 8/1, which present high values of germination energy, TGW and hectoliter weight associated with high extract contain. The high quality potential of these lines can be used in a breeding program of winter barley for malting purposes. An inferior quality of grains was observed in lines: A 9/8, A 8/8, A 8/7 according to the l_s, l_t and l_s indices and in lines A 8/12, A 8/25, A 8/7 according to the l_s index.

The l_s, I_s, l_t and I_s indices were significantly correlated with each other, indicating that any of those 4 indices can be substituted for the other (Table 3). Furthermore, the 4I_s and 4I_t were strongly correlated with l_s.

| Table 2. Selection indices values for quality characters |
|---------------------------------|-----|-----|-----|-----|-----|-----|
| № | DH lines | 6I_s | 4I_s | 6I_t | 4I_t | I_s |
| 1 | A 8/1 | 38.6 | 19.8 | 183.7 | 105.6 | 28.5 | 44.5 | 2.2 |
| 2 | A 8/3 | 44.3 | 20.5 | 180.6 | 103.5 | 48.5 | 71.5 | 1.8 |
| 3 | A 8/6 | 13.8 | 6.9 | 175.0 | 100.0 | 67.5 | 105.5 | 1.5 |
| 4 | A 8/7 | 19.1 | 6.6 | 175.1 | 98.8 | 83.0 | 111.0 | 1.1 |
| 5 | A 8/8 | 16.5 | 5.6 | 174.7 | 98.7 | 83.5 | 113.5 | 1.2 |
| 6 | A 8/11 | 44.8 | 21.2 | 180.1 | 102.5 | 50.2 | 71.0 | 1.3 |
| 7 | A 8/12 | 40.6 | 15.9 | 181.7 | 103.4 | 50.5 | 63.5 | 0.9 |
| 8 | A 8/13 | 28.3 | 18.1 | 178.9 | 103.5 | 43.0 | 78.0 | 1.9 |
| 9 | A 8/19 | 45.7 | 19.3 | 179.9 | 102.5 | 56.0 | 76.5 | 1.2 |
| 10 | A 8/25 | 47.9 | 19.2 | 180.8 | 101.4 | 52.0 | 59.0 | 0.9 |
| 11 | A 8/27 | 33.3 | 17.8 | 180.6 | 104.5 | 41.5 | 73.5 | 2.0 |
| 12 | A 8/28 | 32.4 | 10.7 | 180.7 | 102.8 | 50.0 | 67.0 | 1.8 |
| 13 | A 8/33 | 29.5 | 12.9 | 178.5 | 102.3 | 55.5 | 85.5 | 1.5 |
| 14 | A 8/35 | 33.0 | 13.3 | 181.3 | 103.1 | 41.5 | 55.5 | 1.9 |
| 15 | A 9/8 | 14.0 | 12.5 | 174.5 | 101.3 | 65.0 | 112.0 | 1.5 |
| 16 | A 9/10 | 45.7 | 22.9 | 181.2 | 103.6 | 43.0 | 64.0 | 1.6 |
| 17 | A 9/12 | 20.4 | 13.2 | 175.6 | 100.1 | 74.5 | 107.5 | 1.1 |
| 18 | A 9/15 | 22.9 | 15.0 | 179.2 | 102.9 | 49.0 | 78.0 | 1.8 |
| 19 | A 9/16 | 23.6 | 22.6 | 178.7 | 105.0 | 33.0 | 79.5 | 1.9 |
| 20 | A 15/2 | 48.3 | 23.1 | 185.3 | 106.4 | 21.0 | 32.0 | 2.2 |
| 21 | A 24/2 | 21.5 | 15.5 | 178.1 | 103.8 | 39.0 | 80.5 | 1.9 |
| 22 | A 25/19 | 60.7 | 30.7 | 187.0 | 107.5 | 17.0 | 21.0 | 2.2 |
| 23 | Obzor | 24.4 | 8.8 | 183.7 | 105.6 | 69.5 | 93.5 | 1.4 |
| 24 | Emon | 42.8 | 16.4 | 180.6 | 103.5 | 36.0 | 56.5 | 1.9 |

| Table 3. Spearman rank correlations among selection indices calculated for quality characters |
|---------------------------------|-----|-----|-----|-----|-----|-----|
| Index | 6I_s | 4I_s | 6I_t | 4I_t | 6I_s | 4I_t |
| 4I_s | 0.798** | 0.785** | 0.558** | 0.504* | 0.653** | 0.717** |
| 6I_s | 0.535* | 0.729** | 0.579** | 0.824** | 0.855** | 0.700** |
| 6I_t | 0.862** | 0.598** | 0.754** | 0.869** | 0.489* | |
| I_s | 0.236 | 0.464* | 0.375 | 0.751** | 0.179* | |

** Correlation is significant at the 0.01 level, * Correlation is significant at the 0.05 level.
index. When the coefficients used to construct the simple-weighted index were 0.6 for grain yield and 0.4 for the four quality traits, lines A 9/16, A 8/3, A 25/19, A 15/2 had the highest index value. These lines can be selected for further evaluation in a breeding program of winter malting barley. The genotypes possessing the best combination of traits of economic importance were identified and hence are recommended to be utilized directly or included in a hybrid programme for varietal development. Our study also demonstrates that simple selection indices can be successfully used in barley breeding when it is needed to evaluate a large number of lines for many traits simultaneously.

### Conclusion

The significant correlation between selection indices calculated for 6 quality traits (1000 grain weight, hectoliter weight, malt extract content, protein content, germination on day 3 and grain grading) and indices based on the most important 4 quality traits (1000 grain weight, hectoliter weight, malt extract content and protein content) it was found that the 4-trait indices could substitute the use of 6-trait indices to save work in data collection.

Lines A 9/16, A 8/3, A 25/19, A 15/2 combine the desired quality characteristics with high grain yield and can be selected for further evaluation in a breeding program of winter malting barley.

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