Breeding durum wheat for grain yield and quality

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Breeding durum wheat for grain yield and quality

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SUMMARY – In Cyprus the practised breeding method, which is a modification of the pedigree method, retains for subsequent exploration $F_3$ lines with a higher frequency of potential genes for high quality. Thereafter, two site replicated yield testing of the $F_4$ bulk lines at two sites increases the chances of selecting individuals in this generation, which combine acceptable grain and processing quality along with higher frequency of desirable genes for grain yield. Five spikes selected from each of the $F_4$ bulk lines with higher average yield, are retained for subsequent exploration in the $F_5$. Outstanding lines enter the preliminary yield trials. The referred methodology resulted in the development of the high yielding and quality durum wheat cultivar “Macedonia” which is grown in most of the durum wheat areas.

Key words: Durum wheat, quality, breeding, genetics.

RESUME – “Amélioration du blé dur pour le rendement et la qualité du grain”. A Chypre la méthode de sélection pratiquée, qui est une modification de la méthode sur ascendance, retient pour une exploration ultérieure des lignées $F_3$ ayant une fréquence plus élevée de gènes potentiels pour une bonne qualité. Ensuite, deux essais de rendement avec répétition pour des lignées $F_4$ en mélange dans deux sites, augmentent les chances de sélectionner des individus dans cette génération, combinant un grain et une qualité de transformation acceptables en même temps qu'une fréquence plus forte de gènes pour le rendement en grain. Cinq épis sélectionnés à partir de chacune des lignées $F_4$ en mélange avec un meilleur rendement moyen, sont retenus pour une exploration ultérieure en $F_5$. Les lignées remarquables entrent dans les essais de rendement préliminaires. La méthodologie mentionnée a donné lieu au développement du cultivar de blé dur “Macedonia” à fort rendement et bonne qualité, qui est cultivé dans la plupart des zones à blé dur.

Mots-clés : Blé dur, qualité, sélection, génétique.

Introduction

A durum wheat breeding program must be designed to ensure that any new released cultivar has acceptable agronomic characteristics to meet the demand of the farmers and the quality characteristics required by the processing industry. Thus, the plant breeder has to begin with the selection of parents for hybridization and through the long term of homozygosity is responsible for selecting the most promising lines with the desired combination of agronomic and quality traits.

The heritability is known for most of the desired quality traits and the agronomic characteristics with specific weakness on durum wheat productivity, such as late maturity, lodging, and others as plant height and spike characteristics that played a role in the plant form (Blanco et al., 1988; Joppa and Williams, 1988). Hence, these have to be selected or eliminated as soon as it is permitted by their mode of inheritance and the available breeding tools.

Breeding for quality and agronomic characteristics

Durum wheat is used for a variety of food products, such as pasta, bread, couscous, burgur, etc. It has an amber, vitreous kernel and produces a yellow milling product. The yield of semolina is an important quality character and is affected by kernel characteristics, such as vitreousness, size, weight, shape and crease form. Durum lines differ in their genetic ability to produce kernels with the desirable characteristics, but most of these are highly influenced by a complex of environmental factors at the stage of grain development. However, Henson and Waines (1983) reported that differences among cultivars in percent of vitreous kernels related to their relative ability to translocate nitrogen compounds from the leaves and stems into the kernel.
Semolina color has been emphasized in most breeding programs and it has been identified as the result of certain xanthophylls. The color of the milled products of durum wheat is highly heritable and is controlled by additive gene effects (Johnston et al., 1983). Recent studies indicate that the major genes are on chromosome 2A and 2B (L.R. Joppa, personal communication).

Spaghetti and crumb bread color is also affected by the amount of lipoxygenase. High levels of this enzyme in the milling products destroy the expected yellow color of pasta and bread products during their processing by oxidation of xanthophylls. Selection for low lipoxygenase levels in the breeding program has clearly been effective. Preliminary studies showed oligogenic action (L.R. Joppa, personal communication).

Cooking quality of spaghetti and burgur and bread characteristics are related to both quantity and, mainly, quality of the proteins present in the durum wheat endosperm. Protein content is a complexly inherited trait and varies more because of the environments than because of genetics. The proteins of wheat are divided into four classes based on solubility. The gliadins and glutenins are the important components influencing the processing and end-product quality of durum wheat. Separation of protein gliadins by polyacrylamide gel electrophoresis showed that those cultivars having a gliadin with the relative mobility (Rm) of 42 had weak gluten and those having an alternative allele coding for a gliadin with Rm of 45 had strong gluten (Damidaux et al., 1980).

Joppa et al. (1983a) and others found that a single durum wheat cultivar can have 40 or more different gliadin polypeptides and these can be used to identify a cultivar as well as to determine gluten strength. Bournouf and Bietz (1984) proposed band 45 as genetic marker for selecting strong gluten cultivars. Later, Leisle et al. (1985) found an association between glume color and gluten strength in durum wheat. They reported that glume color could be used as field marker for selecting strong gluten genotypes early in the F$_2$.

In 1987 the author, together with his professors L.R. Joppa and V. Youngs, proved the large influence of chromosome 1B$^*$ on gluten strength and its further effect on spaghetti and bread quality. Further, the chromosome 1B$^*$ was found to be without any effect on semolina color, grain yield and some other agronomic characteristics of durum wheat.

Breeding for grain yield

In contrast to the quality traits and some specific agronomic traits correcting the productivity of durum wheat, grain yield is generally accepted as an inherited factor with hundreds of genes being involved. Gable (1962) pointed out that as the number of genes involved in the inheritance of a trait becomes greater, so does the influence by the environment. This indicated that the breeder is ineffective in selecting for yield either on an individual F$_2$ plant basis or on a line basis in the F$_3$ and/or in the later generations, because of the great heterozygosity and the genotype by environment interaction.

The likelihood of fixation for two or three pairs of neutral alleles as early as F$_2$ increases rapidly. In contrast for 10 pairs of genes the likelihood of fixation in the F$_4$, is only 0.06%. Thus, unless the number of loci is very small it seems unlikely that any individuals with the potential to produce the very best possible segregant will survive into the sample of near homozygous lines, where intensive evaluation for overall worth usually begins. One obvious countermeasure is to grow the largest feasible F$_3$ population and eliminate in generations F$_2$ through F$_5$, all individuals with visible or potentially measurable agronomic and quality defects. Thereafter, replicated progeny yield testing increases the chances of retaining individuals with higher frequency of desirable genes for yield early in the F$_5$. Five spikes selected from each F$_4$ bulk lines with higher average yield, are retained for subsequent exploration in the F$_5$. Outstanding F$_6$ lines enter the preliminary yield trials (Table 1).

Evaluation

The referred methodology resulted in the development of the high yielding and quality durum wheat cultivar “Macedonia” which is grown in most durum wheat areas of Cyprus (Josephides, 1994). Macedonia originated from a cross made in 1984 (KIA * 2/VIC CYD85-345-18D-OP-3P-OP) between the cultivar Vic introduced from North Dakota State University, USA, having high quality processing
characteristics, and Karpasia, the commercially grown durum wheat cultivar in Cyprus. The $F_1$ was grown at ICARDA’S summer nursery. In the next growing season (1984-1985) plants selected from the $F_2$ generation were backcrossed to Karpasia. The consequent breeding methodology used up to the BC1F$_6$ generation is as stated in Table 1. Macedonia was evaluated in the multienvironmental testing program of the Institute at a total of 22 environments in three growing seasons (1990-1993). It gave the highest grain yield, 5731 kg/ha, which was 9%, 12%, 13% and 53% higher than the yield of Karpasia, Mesaoria, Aronas and Kyparouna, respectively. The main agronomic characteristics of Macedonia were similar to those of Karpasia. Mean values for the grain quality characteristics were: volume weight 77 kg/hL and vitreous kernels 91% compared to 78 kg/hL and 95% of Karpasia, respectively. Macedonia had also strong gluten and higher yellow pigment than Karpasia.

Table 1. Approach to breeding superior quality and high yielding durum cultivars

<table>
<thead>
<tr>
<th>Year</th>
<th>Breeding materials</th>
<th>Location</th>
<th>Selection and testing methodology</th>
</tr>
</thead>
<tbody>
<tr>
<td>I a) Make the cross</td>
<td>Athalassa, summer nursery ICARDA</td>
<td>F$_1$ generation</td>
<td>1000-2000 plants/cross</td>
</tr>
<tr>
<td>b) F$_1$ generation</td>
<td></td>
<td></td>
<td>a) Select among crosses. Discard weak, late, susceptible crosses.</td>
</tr>
<tr>
<td>II F$_2$ generation</td>
<td>Dromolaxia (rainfed conditions)</td>
<td></td>
<td>b) Select within crosses for disease resistance, straw stiffness, maturity, glume color, if brown vs white exists. Take one head from each selected plant; 100-200 heads.</td>
</tr>
<tr>
<td>III F$_3$ generation</td>
<td>Akhelia</td>
<td></td>
<td>Head rowed F$_3$ lines-1.0 m length. Discard weak, late, susceptible lines. Harvest bulk remaining lines. Eliminate lines with poor kernel characteristics (size, shape, vitreousness, and diseases), weak gluten and low yellow color.</td>
</tr>
<tr>
<td>IV F$_4$ generation</td>
<td></td>
<td>a) Morokambos (fertile rainfed conditions)</td>
<td>Two location, replicated progeny yield testing. Record grain yield, and other agronomic characteristics. Before harvesting take 5 to 10 spikes from one rep. and one location. Evaluate agronomically selected lines for gluten strength, volume weight, kernel weight, vitreousness and yellow color. Thresh only those spikes which come from F$_4$ lines with higher average yield and superior quality.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>b) Dromolaxia (rainfed conditions, previous planted land)</td>
<td></td>
</tr>
<tr>
<td>V F$_5$ generation</td>
<td>Akhelia (irrigated conditions or summer nursery)</td>
<td></td>
<td>Head rows, as in the F$_3$ generation.</td>
</tr>
<tr>
<td>VI F$_6$ generation</td>
<td>a) Dromolaxia</td>
<td>Preliminary yield trials in simple lattice design.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>b) Morokambos (as in the F$_4$ generation)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>VII-X F$_7$-$F_9$ generation</td>
<td>Multi environmental testing</td>
<td>Identify the overall worth durum wheat cultivar.</td>
<td></td>
</tr>
</tbody>
</table>

However by the year 2000 a new durum wheat cultivar, named Vergina, will be proposed for release. It originated from a back cross made in 1986 (LLOYD/KIA * 3 CYD86-510-14D-OP-9P.2P-OP) between the cultivar Lloyd introduced from North Dakota State University, USA, and the Cyprus cultivar Karpasia. Vergina is a cultivar complementary to Macedonia. It has similar grain yield and other
agronomic characteristics, but higher hectoliter weight and less stiff gluten which is baked to better Cyprus bread than Macedonia.

References


