10. Haploidy in rye

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1. Introduction

Rye (*Secale cereale* L.) has its origin in southwest Asia. From there it was probably distributed to Russia, and later to western Europe. Only 2–3% of total cereal production falls to rye. Approximately 90% of rye production is concentrated in Europe. The distribution of rye is restricted to the area between the 50th and 60th degree of northern latitude. Due to its relative tolerance for a range of soil and climatic conditions, *S. cereale* is grown mainly in northern regions, where other cereals often fail. In southern regions, rye competes with wheat as bread grain for human nutrition. Today, the main rye growing area is eastern Europe with approximately 14 million hectares per year. In 1993 the EU produced 4 million tons of rye on slightly over 1 million hectares. Within the EU countries, Germany is the major rye producer with 3 million tons on 650 000 hectares.

Rye is an open-pollinating species with a gametophytic self-incompatibility system. In contrast to wheat, barley or oats, where homozygous lines are released as cultivars, rye cultivars are highly heterozygous. Until 20 years ago, breeding progress in *S. cereale* was achieved through the continuous development of either open-pollinated or synthetic cultivars. A notable step forward in breeding efficiency took place after some biological peculiarities were discovered: the self-incompatibility mechanism can be neutralized by

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genes for self-fertility. The incorporation of such genes enables the breeder to produce inbred lines through continuous selfing (Geiger, 1982). The "Pampa" cytoplasm was discovered representing a source of cytoplasmatic male sterility (cms) which facilitates crossing among inbred lines (Geiger & Schnell, 1970). Fertility can be restored by the introduction of restoration genes into the pollinating parent (Geiger, 1972). These prerequisites enable exploitation of heterosis in rye through breeding of hybrid cultivars. The first hybrid cultivars were released in 1984 and since then have become increasingly important in commercial rye breeding (Geiger, 1990). The major advantages of hybrid over open-pollinated cultivars are increased yield of about 10–15% and improved lodging resistance due to shorter straw. In 1993 the acreage of hybrid cultivars was 15% in the EU, but had already reached 43% in Germany.

The production of haploids and subsequent development of doubled haploid lines (DHL) have proven valuable in plant breeding and biotechnology. The incorporation of DHL in breeding is advantageous for several reasons: the production of DHL hastens the development of homozygous lines by 4–5 generations compared to inbred lines developed conventionally by selfing. However, in hybrid breeding, testing for combining ability is the most time consuming process. This cannot be reduced by the DHL approach. Since conventional breeders usually start testcrossing in early selfing generations, only one or two years can be saved in the hybrid breeding process, especially in winter cereals like rye. Nevertheless, for special breeding purposes, where unselected lines are desired, full advantage can be taken of the above-mentioned time saving procedure. Using DHL, the increased genotypic variance of the line *per se* and its testcross performance lead to a better differentiation of quantitative traits. Consequently, this results in higher and more predictable gain from selection (Geiger, 1985). The uniformity of DHL facilitates plant variety protection. This will become more important when even greater homogeneity of cultivars will be demanded by governmental regulations.

While DHL are of interest in commercial plant breeding, they are also valuable for scientific purposes related to plant breeding. In mapping studies, DHL are especially useful because they are true-breeding. This allows large scale evaluations, which result both in increased accuracy of character assessments and also in higher efficiency of mapping quantitative trait loci (QTL). Depending on heritability, under certain circumstances, DHL can be used more efficiently as a mapping population than F_2 or F_2-derived populations (Melchinger, 1990). In transformation experiments, microspores are attractive as recipients of foreign DNA and might become more important for genetic transformation of cereals. Recently, successfully transformed (unicellular) barley microspores have been regenerated into fertile, completely homozygous plants, yielding transgenic DHL (Jähne *et al.*, 1994).

The practical use of DHL in rye breeding needs, as the basic requirement, the production of large numbers of doubled haploids without serious geno-