THE PRESENT STATUS OF BREEDING AUTOTETRAPLOID CEREALS

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Introduction

Autotetraploids differ from their diploid progenitors not only in morphological and cytological but also in physiological and ecological characteristics. As cell and organ sizes are usually increased in tetraploids, their total biomass, e.g. forage production, can be higher than that of diploids, depending on genetic and environmental factors (1). As far as grain production is concerned, autotetraploids are usually inferior to their diploid parents, because of disturbances of meiotic chromosome pairing, i.e. the formation of uni- and multivalents (Table 1). Incorrect and uneven distributions of chromosomes finally lead to partial pollen and seed sterility (Fig. 1). In long-term breeding programmes with tetraploids of barley (3,4,5) and rye (6) it was tried to improve their meiotic behaviour, and consequently their fertility and grain yield. Both autotetraploids are generally characterized by high levels of meiotic instability which however can be reduced by selection for high seed set. Some results are reported in the present paper.

Table 1. Meiotic Chromosome Pairing in Autotetraploid Poaceae (2)

Species	I	II	III	IV	%IV *)
Arrhenatherum elatius	-	4.3	-	4.8	68.6
Avena strigosa	0.1	5.0	0.1	4.4	62.8
Hordeum bulbosum	0.1	5.6	0.2	4.0	57.1
Hordeum vulgare	0.3	4.5	0.1	3.9	55.7
Secale cereale	0.5	6.1	0.2	3.7	52.9
Triticum monococcum	0.2	3.5	0.1	5.1	72.8

*) % of chromosomes paired as IV

Materials and Methods

Barley

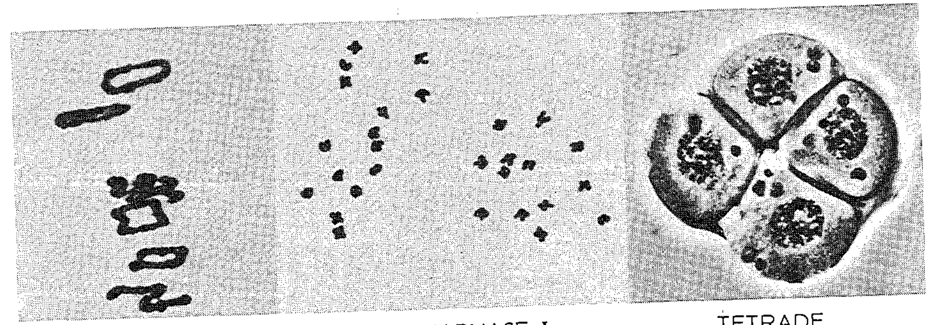
Autotetraploids (2n=4x=28) had been induced of spring barley (Hordeum vulgare L.) cultivars 'Haisa II', 'D8/55', 'D9/55', 'Weihenstephaner', and winter barley variety 'Atlas' (3). In the course of a long-term breeding programme, seeds of the autotetraploids were treated mutagenically by X-rays and EMS and were subsequently hybridized in numerous cross-combinations (4). Cross-progenies were subjected to rigid selection for high seed set following a pedigree scheme. After twelve generations of selfing and selection, an evaluation of meiotic and agronomic behaviour of the selected lines as compared to the untreated and unselected original stocks 'Haisa II', 'D8/55', 'D9/55', and 'Weihenstephaner' was carried out (4,5). Experimental materials were grown in the field of Grünbach, Bavaria, in 1975 to 1977.

Rye

Autotetraploids (2n=4x=28) had been induced of self-fertile families derived from the progeny of a cross of Secale cereale cv. 'Heine's Hellkorn' to Secale vavilovii Grossh. (7). After further selection for self-fertility and high seed set, vigorous populations had been derived which were provided by Prof. KUCKUCK, Hannover, for further examination and improvement. Cytogenetical as well as agronomic characters were evaluated in field samples grown at Grünbach in 1976 to 1978.

Table 2. Meiotic Characters of Tetraploid Barley: Chromosome Pairing in Metaphase I (5)

Material	No. of PMCs	I	II	III	IV	alternative IV (%)
		average/cell				
Original cultivars	1,273	0.13	4.34	0.08	4.76	45.0
Selected lines	1,038	0.08	4.83	0.06	4.40	55.8
Significance of difference		*	**	ns	*	***



METAPHASE I ANAPHASE I TETRADE

Figure 1. Meiotic irregularities in autotetraploid barley (2n = 4x = 28). Chromosome pairing in metaphase I, division in anaphase II, and the formation of micronuclei in quartets

Results

Barley

Meiotic chromosome pairing and distribution was shown to be more regular in selected tetraploid lines than in unselected, original stocks (5). The frequencies of univalent chromosomes and that of chromosomes paired as quadrivalents were significantly reduced, whereas the frequency of bivalents was significantly increased, as compared to the controls (Table 2). Furthermore, the rate of alternatively oriented quadrivalents was markedly increased in the selected materials. More regular behaviour of chromosomes in meiotic first metaphase (M I) finally led to higher frequencies of normal cells in anaphase I (A I) and

Table 3. Late Meiotic Characters and Seed Fertility of Tetraploid Barley (5)

Material	ANAPHASE I No. of PMCs	regular (%)	QUARTETS No. of quart.	regular (%)	SEED SET 3 years (%)
Original cultivars	798	42.2	19,486	66.2	61.6
Selected lines	562	64.4	9,170	78.1	75.9

telophase II (quartets). As a consequence, the average seed set increased from 61.6 % in the original autotetraploid stocks (controls) to 75.9 % in the selected lines (Table 3). The general improvement of seed set finally led to breeding strains with greatly increased grain yield as compared to check cultivars. However, the best of the selected strains yielded not more than 67 % of the diploid control cv. 'Villa' (4).

Rye

The investigations of cytogenetical and agronomical characters of tetra-rye brought rather different results as compared to the barley tetraploids. The frequency of quadrivalents was only 0.7/pmc on the average and the corresponding mean bivalent frequency was as high as 12.3/pmc (Table 4).

Table 4. Meiotic Chromosome Pairing in Tetraploid Rye (6)

Material	No.of PMCs *)	I	II	III	IV	14 II (%)
		average/cell				
1 Tero	160	0.2	12.6	0.1	0.6	42.5
2 B III	61	0.2	12.5	0.1	0.7	44.3
3 F IV	151	0.2	12.1	0.1	0.8	33.8
4 F VIII	77	0.9	11.9	0.2	0.7	18.2
5 S I	187	0.2	12.2	0.1	0.8	36.9
Total/Average	636	0.34	12.26	0.12	0.72	35.1

*) collected from 10 plants each

As a conseqence, the seed set of the average tetra-rye populations was substantially higher than that of barley tetraploids (85 vs. 76 %). Therefore it was no surprise, when tetraploid rye populations showed comparatively high levels of grain yield. Two of the populations tested were competitive to the tetra-rye check cultivar 'Tero', and one of these populations even outyielded the winter wheat (Triticum aestivum) cv. 'Feldkrone' which was tested for comparison (Table 5).

Table 5. Performances of Tetraploid Rye Populations (8)

Material	Grain yield, % of 'Tero' 1976	1977	1978	Mean
Pop.III	100.0	94.3	94.6	96.3
Pop.IV	71.8**	83.9*	87.5**	81.1
Pop.VIII	99.0	103.5	105.6*	102.7
'Tero'	100.0	100.0	100.0§	100.0

§) = 40.8 dt/ha, wheat cv.'Feldkrone' = 100,5
*,**) significantly different from 'Tero' at p=0.05 and 0.01, resp.

Discussion

The results presented above indicate that principal differences exist between autotetraploids of self-pollinating and outcrossing cereals, respectively. Whereas induced tetraploids of self-pollinating barley are clearly inferior to their diploid counterparts with regard to grain yield, tetraploids of open-pollinating rye are certainly competitive to diploid cultivars, i.e. populations.

There are theoretical reasons to conclude that these differences in performance are due to the different modes of propagation (9). In an outcrossing population the frequency of aneuploid individuals would reach an equilibrium after several generations. On the contrary, in an inbred population the frequency of aneuploid individuals would continue to increase with additional generations (9). Since it is well documented, that aneuploids greatly contribute to low vigour, seed set, and yield of an autotetraploid population, the above explanation would leave little hope for a succesful improvement of an autotetraploid self-fertilizing crop, like barley.

Several approaches of breeding autopolyploids aimed in their cyto-genetic "diploidization" (or "allotetraploidization"), i.e. the production of genetically and cytologically diploid-like behaving polyploids (3,10). The results presented above indicate some degree of "diploidization" for rye just as for barley. However, whereas this effect is sufficient to yield highly performing populations of rye, it obviously is not sufficient to raise the yield level of barley tetraploids to the level of diploids.

In a basic approach similar to that applied for barley (3) it has been tried

recently to modify the genetical and cytological behaviour of tetraploid corn (_Zea_ _mays_, 2n=4x=40) by recurrent mutagenic treatment and random matings. By using the recessive genetic marker _wx_ it could be demonstrated, that the frequency of autosyndetic chromosome pairing was obviously reduced as compared to the original population used as a control (11); i.e.the rate of individuals expressing the recessive _wx_-phenotype (and therefore being homozygous for the _wx_-gene) was reduced relative to the control population. Therefore it could be concluded that a certain degree of preferential chromosome pairing had been induced by the treatments applied.
Consequently, further efforts to modify the cytogenetical behaviour of autotetraploid cereals seem to be promising, particularly in open-pollinating crops like rye and corn. It would be recommendable to combine the use of polyploids with that of heterosis, e.g. in a hybrid breeding programme.

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