Thereotical and Applied Genetics 44, 304–310 (1974)

Breeding Possibilities Offered by Induced Mutations in *Durum* Wheat*

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Summary. A report on the use of mutations of agronomic value obtained in *durum* wheat in an accelerated crossing programme is given. The mutated characters used were isolated in cv. Cappelli and Russello, related respectively to a dominant short straw and a dominant earliness factor. Besides these two mutant lines, 4 other varieties were used, 80/57, Yuma, LD 357 and Kyperounda, representative of cultivated types of quite different origin. The program started in December 1965 and progressed till June 1970. During this time nine generations were grown, including two agronomic trials. Single crosses were also compared with incomplete backcrossing (3 backcrossing cycles), dominance of the factors utilized allowing backcrossing of every F_1.

Introduction

Mutation and recombination are the basis of variability in living organisms. Induction of mutations, in general, should be considered simply as a technique leading to a concentration in time and space of events theoretically possible also in nature. Cross-breeding is, on the other hand, based on the exploitation of variability, spontaneous or induced, by means of recombination followed by selection of suitable genotypes. In most cases, crosses are programmed on the basis of phenotypes (Borojevic *et al.*, 1966) and in the absence of knowledge concerning the genetic basis of variability. The picture is different when the mutation breeding method is involved. This method makes use of the mother lines, from which the mutations derive, as the basic reference for any modification isolated and considers that the modification usually has a simple genetic basis, which can be easily controlled.

The same does not apply to lines derived from natural variability, where a given character is often controlled by polygenes rather than by a single major factor. It should be noted that, in several cases, rapid progress in breeding crop plants is based on the utilization of single factors which are able to shift considerably, in the desired direction, the value of some fundamental characters more or less directly connected with the expression of yield.

Induced mutations, therefore, seem to present some advantage, when used in a cross breeding programme, over other sources of variability, at least for the character modified (Scarascia-Mugnozza *et al.*, 1972).

* – Contribution n. 374 from the Laboratorio per le Applicazioni in Agricoltura del C.N.E.N., Centro Studi Nucleari della Casaccia, S. Maria di Galeria, Roma, Italy.

This paper presents the results of crosses whose goal is mainly the transferring of shorter straw (connected with lodging resistance) and earliness. In the 5 crosses examined one parent is always represented by the line of *durum* wheat Castelporziano (Cp B132), a short straw mutant derived from Cappelli, in which this character is controlled by a single dominant factor (Bozzini and Scarascia-Mugnozza, 1967). This facilitated comparison of the results obtained by single crosses with those obtained in an incomplete backcrossing programme (3 backcrosses).

The data presented here are the result of an accelerated programme which was started in December 1965 and progressed till June 1970. During this programme, 9 generations, including two agronomic trials, were grown and analyzed.

Material and Methods

The main characteristics of the lines used are the following:

Cp B 132 (Castelporziano) – Short straw mutant from Cappelli, with high yielding potential, but consistently later than the mother variety (Bozzini and Scarascia-Mugnozza, 1970).

80/57: line obtained from the cross (Coerulescens × [Cappelli × (Tunisino × Cappelli)] selected at the University of Bari. It heads about two weeks earlier than Cappelli and has good kernel texture. Earliness is inherited as a simple mendelian factor (Bagnara *et al.*, 1971).

Rs A1: early mutant from Russello. It heads about 10 days earlier than the mother line and is one week earlier than Cappelli. The character is simply inherited.

Yuma: variety obtained in North Dakota, resistant to mildew (one dominant factor) (Bozzini, 1966) and to *Puccinia graminis tritici* (two major genes). It has been largely used as a stem rust resistance source (Vallega and Zitelli, 1968).

Kyperounda: line originally from Cyprus, with good yielding potential and resistant to drought. Medium heading.

LD 357: line obtained in North Dakota, resistant to several races of *Puccinia graminis tritici* and with good yielding ability, tillering and fertility. Medium heading.

The crosses taken into consideration in this paper are the following: (80/57 × Cp B 132); (Rs A1 × Cp B 132); (Yuma × Cp B 132); (Kyperounda × Cp B 132); (LD 357 × Cp B 132). Cp B 132 was used as recurrent parent in the backcrossing programme only for the cross (Yuma × Cp B 132). The purpose of this last cross was to transfer into Cp B 132 the mildew and stem rust resistance of Yuma. In the other crosses and backcrosses the main purpose was to transfer the short straw of Cp B 132 into the other genotype.

Dominance of the character allowed backcrossing of every F_1 generation. A summary of the crossing and testing programme is presented in table 1.

Table 1. *Crossing and testing programme (Dec. 1965—June 1970)*

Period	Generations	Location	Modality
Dec. 1965 June 1966	parental lines	growth room	spaced plants
June 1966 Sept. 1966	F_1	growth room	spaced plants
Oct. 1966 Jan. 1967	F_2-F_1 Bc 1	growth room	spaced plants
Feb. 1967 May 1967	F_3-F_1 Bc 2	growth room	spaced plants
June 1967 Aug. 1967	F_1 Bc 3	growth room	spaced plants
Sept. 1967 Dec. 1967	F_2 Bc 3	growth room	spaced plants
Dec. 1967 June 1968	F_4-F_3 Bc 3	field	spaced plants
Dec. 1968 June 1969	F_5-F_4 Bc 3	field	spaced plants + agron. trials
Dec. 1969 June 1970	F_6-F_5 Bc 3	field	spaced plants + agron. trials

Material in growth rooms was given a photoperiod of 18 hours light (at least 12.000 lux), and a temperature of 18 °C during darkness and 25 °C during light; single plants were grown in plastic pots (800 cc of soil), watered daily and given Hoagland nutrient solution 3—4 times. Under these conditions, one generation was accomplished in 90—110 days. In the field, control lines were sown between every 15—20 hybrid progenies, in order to minimize eventual field distortion. Every hybrid or control progeny grown in the field consisted of a group of 20—40 plants; a lower number was used in the growth room because of shortage of space; each cross was represented by 60 to 230 distinct progenies in F_4 or F_3 Bc 3 (F_3 after the 3rd backcross) grown in the field. Material grown in the field was spaced 10 × 10 cm.; the agronomic trials used 2—3 replications of 1—3 m² (1 to 3 rows of 3 × 0.33 m.).

The results reported in this paper refer to the last 3 generations. It should be noted that moderate selection pressure was applied in each generation and in the desired direction (short straw, earliness, disease resistance, kernel aspect, agronomic value, etc.) by visual selection (Bozzini, 1968). A very good correlation between material grown in the field and material grown in the climatic chambers was found for short straw and earliness. This correlation allowed the correct selection for these characters at each growth room generation.

Some of the lines derived from the crosses between 80/57 and B 132 and between Rs A1 and B 132 were tested in 1969; they were retested, after a selection cycle, in 1970 with other lines derived from all the other crosses performed.

Experimental Results

Results on plant height and heading date obtained in control progenies (means of about 20 plants) grown in 1967—68 are reported in fig. 1.

The distribution of average plant heights and heading dates recorded for the cross 80/57 × B 132 and its progenies (F_4 and F_3 Bc 3) is presented in fig. 2. The hybrid progenies do not represent the total variability derived from the cross because, with some exceptions, all late and tall material was eliminated in previous generations. Most of the progenies were already largely homogeneous for the characters considered. Some of them were even directly tested the next year in agronomic trials (see table 2); the great majority, however, was grown the following year as spaced plants in the field and only tested two years later in preliminary trials (104 lines). It is evident

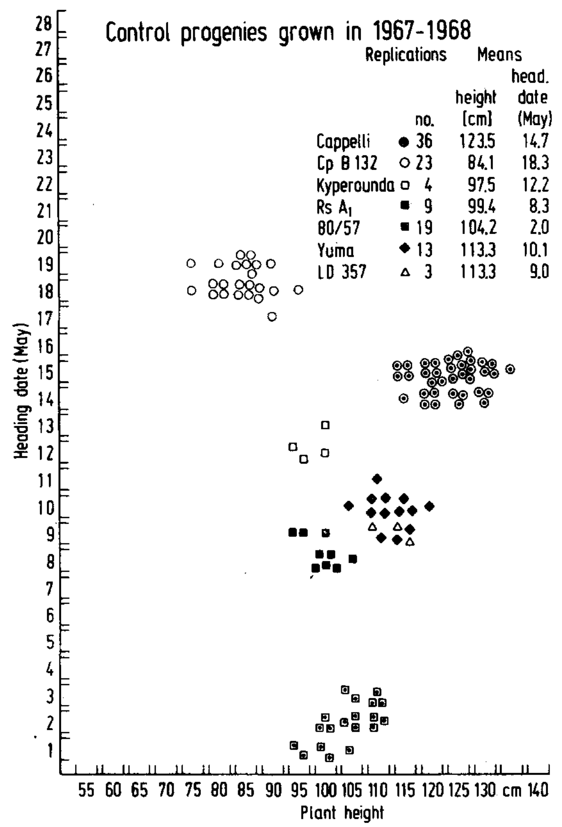


Fig. 1. Distribution of control progenies as to plant height and heading date ascertained in field in 1967—1968. Each point represents the mean obtained from about 20 plants

Table 2. *Results of agronomic trials performed in 1969 and 1970 with lines (FC) selected from the cross (80/57 × CpB132) in 1968*

Lines	Yield (q/ha)		Hect. weight		Height (cm)		Yellow berries %		Lodging index (0–5 max)		Heading date	
	1969	1970	1969	1970	1969	1970	1969	1970	1969	1970	1969	1970
Cp B132	45.3	37.0	84.6	83.6	104.0	99.0	43.3	14.3	0.6	0.5	15.6/5	19.3/5
80/57	36.2	41.1	83.0	82.7	110.5	110.5	3.6	4.0	4.0	5.0	1.3/5	24.0/4
Mean and S. E. of 14 hybrid lines tested in 1969	48.9 ±1.7		83.4 ±0.2		92.3 ±1.7		26.8 ±2.0		1.0 ±0.3		10.3/5 ±0.4	
Mean and S. E. of 7 selected hybrid lines tested in 1970		52.7 ±1.2		84.7 ±0.3		93.5 ±2.2		24.3 ±2.0		0.3 ±0.1		11.8/5 ±0.9
Max. value reached in hybrid lines	60.6	57.6	84.3	85.4	88.0	85.3	12.3	10.0	0.0	0.0	10.0/5	8.3/5

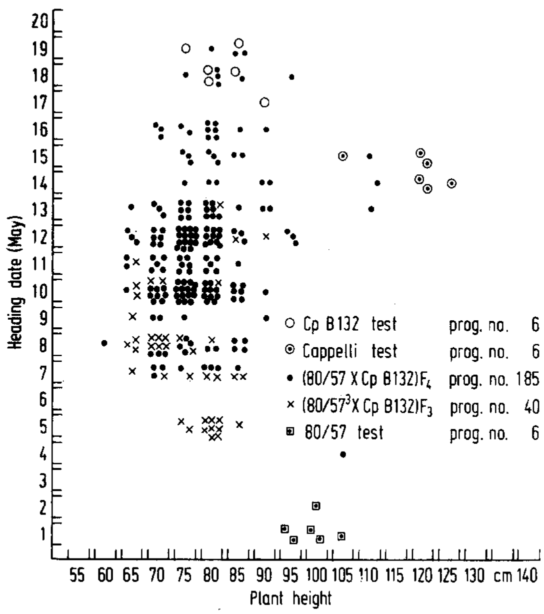


Fig. 2. Distribution of control parental lines and hybrid progenies of the cross (80/57 × Cp B 132) as to plant height and heading date ascertained in the field in 1967–1968

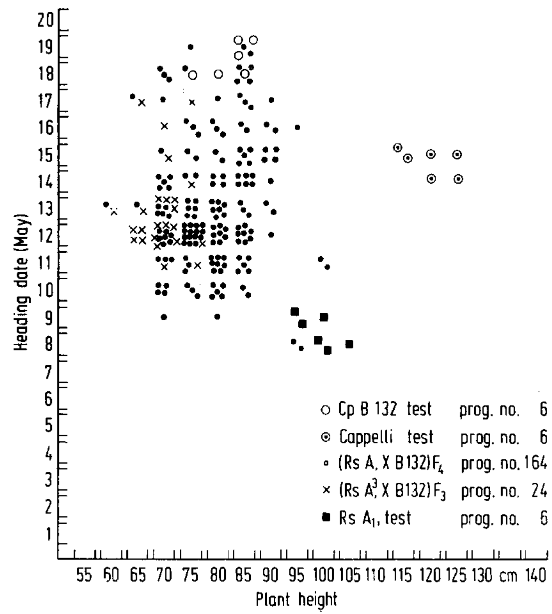


Fig. 3. Distribution of control parental lines and hybrid progenies of the cross (Rs A1 × Cp B 132) as to plant height and heading date ascertained in the field in 1967–1968

from fig. 2 that straw length in most of the progenies was similar to or shorter than in Cp B 132. Several were in 65 cm class. None of the short-straw hybrid lines was as early as 80/57. The earliness of this parent was approached only by lines derived from the backcrossing programme. The recovery of early lines with short straw was easier after incomplete backcross than after a single cross. Out of 40 backcross lines, 30 headed before May 9 and were shorter than 90 cm., whereas only 21 similar selections could be made from the 185 lines derived from single crosses. If we consider that 80/57 has Cappelli in its pedigree, it might be concluded that these lines acquired 2 agronomically important features in the genetic background of Cappelli, which is well known for its good technological quality and its high agronomic adaptability (Bozzini, 1970). Tables 2 and 3 present the main agronomic features of these lines grown in 1969 and 1970. It is clear that a very consistent increase in lodging resistance, a decrease in plant height, a reasonable level of yellow berries percentage and earliness were obtained; this leads to a striking increase in yield (up to 30–50% over the best parent).

In fig. 3 and tables 4 and 5, results of the crossing programme between Rs A1 and Cp B 132 are presented. Here too, transgressive segregation for plant height was achieved, some lines being more than 20 cm, shorter than Cp B 132, the shortest parent. In this cross, progenies almost as early as Rs A1 were recovered. Practically speaking, Rs A1 reaches the earliness level of Capeiti and Patrizio, two varieties grown nowadays in Italy essentially for their earliness. Backcrossing does not lead to any clear advantage in this cross. Data presented show a reduction of 10—20 cm. in some of the hybrid lines compared with the shortest parent. Yield is clearly increased and an improvement is evident in practically all the characters analyzed.

Table 3. *Results of agronomic trials performed in 1970 with lines (FD) selected in 1969 from the cross (80/57 × CpB132)*

Lines	Yield (q/ha)	Hectol. weight	Height (cm)	Yellow berries %	Lodging index (0—5 max)	Heading date (May)
Cp B132	35.5	81.8	101.0	20.5	0.3	17.0/5
80/57	26.2	78.9	114.5	1.5	4.0	26.5/4
Mean and S. E. of 104 hybrid lines tested	40.4 ±4.8	81.9 ±0.1	93.0 ±0.8	18.6 ±0.9	0.5 ±0.1	11.8/5 ±0.4
Mean of 19 selected lines	47.0 ±1.1	82.5 ±0.2	87.1 ±1.1	19.3 ±1.5	0.4 ±0.1	0.9/5 ±0.8
Max. value reached in hybrid lines	56.5	83.5	80.0	9.5	0.0	1.0/5

Table 4. *Results of agronomic trials performed in 1969 and 1970 with lines (FC) selected in 1968 from the cross (Rs A1 × Cp B132)*

Lines	Yield (q/ha)		Hect. weight		Height (cm)		Yellow berries %		Lodging index (0—5 max)		Heading date (May)	
	1969	1970	1969	1970	1969	1970	1969	1970	1969	1970	1969	1970
Cp B132	45.3	37.0	84.6	83.6	104.0	99.0	43.3	14.3	0.6	0.5	15.6	19.3
Rs A1	37.1	45.9	81.7	82.9	112.3	118.2	43.3	12.6	2.0	3.9	6.6	6.0
Mean and S. E. of 4 lines tested in 1969	51.2 ±0.8		81.2 ±0.6		89.6 ±1.6		40.4 ±3.5		0.4 ±0.2		11.6 ±1.2	
Mean and S. E. of 3 lines tested in 1970		46.0 ±1.6		83.0 ±0.5		89.3 ±4.2		31.2 ≥1.7		0.5 ±0.3		12.6 ±1.5
Max. values reached in hybrid lines	52.6	48.1	83.4	83.6	85.0	81.0	35.5	28.3	0.2	0.0	9.5	11.0

Table 5. *Results of agronomic trials performed in 1970 with lines (FD) selected in 1969 from the cross (Rs A1 × Cp B132)*

Lines	Yield (q/ha)	Hectol. weight	Height (cm)	Yellow berries %	Lodging index (0—5 max)	Heading date (May)
Cp B132	40.8	83.4	96.0	27.5	0.0	16.0
Rs A1	34.5	79.2	109.0	8.0	0.5	6.5
Mean and S. E. of the 50 lines tested	42.4 ±4.3	81.0 ±0.2	93.9 ±1.1	34.1 ±2.2	0.0 —	12.5 ±0.4
Mean and S. E. of the 17 lines selected	44.6 ±0.7	81.4 ±0.2	89.4 ±1.8	26.4 ±3.5	0.0 —	11.5 ±0.6
Max. value reached in hybrid lines	50.0	84.0	78.0	4.0	0.0	8.5

Results of the cross (Yuma × B 132) are shown in fig. 4 and table 6. Transgressive segregation was obtained for both plant height and earliness. Backcrossing to B 132 led to a trend towards lateness. Since the main purpose of this cross was to transfer disease resistance into Cp B 132 (a goal achieved in several of the tested lines), any other positive result is to be considered highly significant. The fact that no improvement of yield could be obtained is not surprising if one considers the low combining ability of Yuma with regard to yield performance (Bozzini, unpublished data).

Results of the cross (Kyperounda × B 132) are presented in fig. 5 and in table 7. Only transgressive segregation for plant height was achieved. Very few short lines tended to approach the earliness level of Kyperounda. Except for earliness, a clear gain was observed in every character taken into consideration. The rather high level of production of Kyperounda makes the result obtained even more significant. The high level of lodging resistance should also be stressed.

Fig. 6 and table 8 present results obtained in the cross (LD 357 × Cp B 132). The short-straw level of Cp B 132 was obtained in both backcrosses and single crosses; earliness did not reach the level shown by the earliest parent (LD 357). Results of agronomic trials are also rather encouraging: in all characters except earliness, clear advantages were achieved. Of particular interest is the yielding ability, which reaches high levels in several lines.

Table 6. *Results of agronomic trials performed in 1970 with lines (FD) selected in 1969 from the cross (Yuma × CpB132)*

Lines	Yield (q/ha)	Hectol. weight	Height (cm)	Yellow berries %	Lodging index (0—5 max)	Heading date (May)
Cp B132	29.5	76.6	95.0	2.5	0.0	22.0
Yuma	37.2	82.2	121.0	5.5	2.5	14.0
Mean and S. E. of the 20 lines tested	29.7 ±5.5	78.0 ±0.5	91.4 ±0.8	8.3 ±1.6	0.0	16.5 ±1.3
Mean of the 4 selected lines	32.7 ±0.8	80.3 ±0.7	91.6 ±2.1	6.5 ±0.6	0.0 —	10.8 ±3.8
Max. value reached in hybrid lines	34.0	82.0	91.0	±2.5	0.0	6.0

Table 7. *Results of agronomic trials performed in 1970 with lines (FD) selected in 1969 from the cross (Kyperounda × Cp B132)*

Lines	Yield (q/ha)	Hectol. weight	Height (cm)	Yellow berries %	Lodging index (0—5 max)	Heading date (May)
Cp B132	33.7	81.9	99.5	25.5	0.0	17.0
Kyperounda	53.5	82.3	108.5	26.5	2.5	8.5
Mean and S. E. of the 25 lines tested	40.7 ±14.1	80.5 ±0.4	90.0 ±1.1	25.8 ±1.6	0.0 —	16.3 ±0.2
Mean of the 5 lines selected	49.7 ± 2.5	82.1 ±0.5	88.8 ±1.5	22.9 ±4.2	0.03	16.1 ±0.5
Max. value reached in hybrid lines	58.0	83.1	84.5	9.0	0.0	15.0

Table 8. *Results of agronomic trials performed in 1970 with lines (FD) selected from the cross (LD357 × Cp B132) in 1969*

Lines	Yield (q/ha)	Hectol. weight	Height (cm)	Yellow berries %	Lodging index (0—5 max)	Heading date (May)
Cp B132	40.5	83.4	102.5	33.0	0.6	14.0
LD 357	38.5	83.7	123.5	29.0	0.3	8.5
Mean and S. E. of the 12 lines tested	44.1 ±2.7	83.2 ±0.3	97.6 ±1.0	49.2 ±4.5	0.1 ±0.1	11.6 ±0.4
Mean of the 5 lines selected	48.0 ±0.8	83.2 ±0.3	97.0 ±1.4	41.8 ±4.2	0.1 ±0.1	10.6 ±0.2
Max. value reached in hybrid lines	49.5	84.2	91.5	27.5	0.0	10.0

Discussion

The first point to be made concerns the speed of the programme. All the lines investigated being spring types, it was possible to grow 6 generations in 18 months. Each generation required, on average, 110 days. Under field conditions these same experiments would have required 9 years instead of 4.

A second general remark concerns the recovery of a large proportion of individuals with straw shorter than their shortest parent. In all instances, genes controlling the length of straw in parents other than Cp B 132 have an additive action. The fact that lines from 10 to 20 cm. shorter than Cp B 132 (particularly in backcrosses) were often recovered, confirms the genetical interpretation of this finding.

The desired degree of earliness was not reached. Only in the cross Kyperounda × Castelporziano did a few lines approach the earliest parent. This behaviour should be attributed to the association of the short-straw factor present in Cp B 132 with lateness (2—3 days). On average, such a degree of lateness was present in all crosses and backcrosses and may be considered as a case of true pleiotropism. Probably, a modification of auxin balance could be related to height reduction and heading time. In other crosses, in which the short-straw factors used were not derived from Cp B 132, earliness over that of the earliest parent was clearly obtained (Bozzini, 1970).

As far as the main characters analyzed are concerned, lines presenting the desired phenotype were in all instances recovered from backcrosses. This confirms the extreme value of the short-straw dominant factor induced in Cp B 132 and of the earliness factor (Bagnara *et al.*, 1971) induced in Rs A1. Theretically, the wohle programme could have been accomplished in 2 years (agronomic trials excluded), a much shorter period than the time required for a mutation breeding experiment. It is necessary to

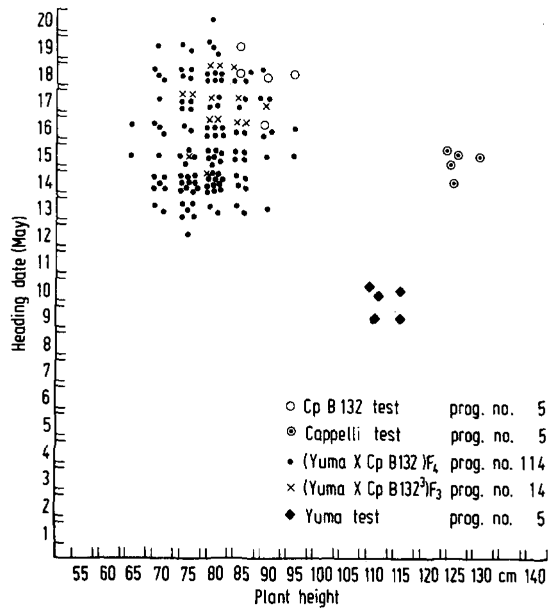


Fig. 4. Distribution of control parental lines and hybrid progenies of the cross (Yuma × Cp B 132) as to plant height and heading date ascertained in the field in 1967–1968

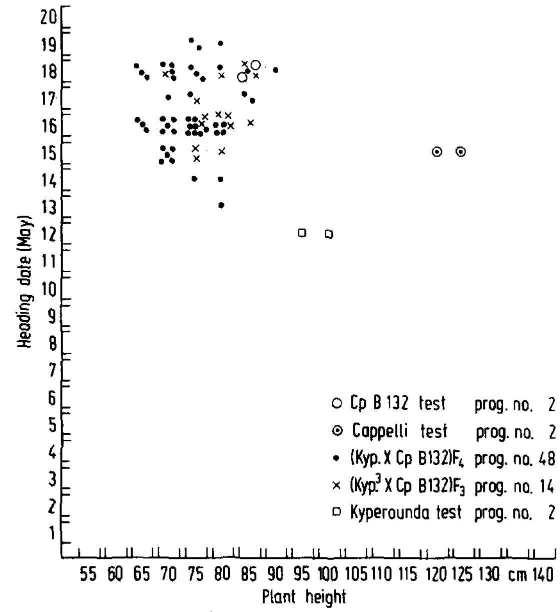


Fig. 5. Distribution of control parental lines and hybrid progenies of the cross (Kyperounda × CpB 132) as to plant height and heading date ascertained in the field in 1967–1968

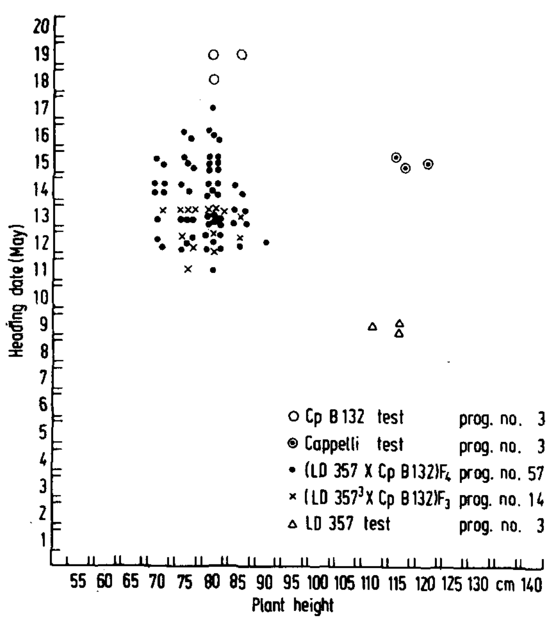
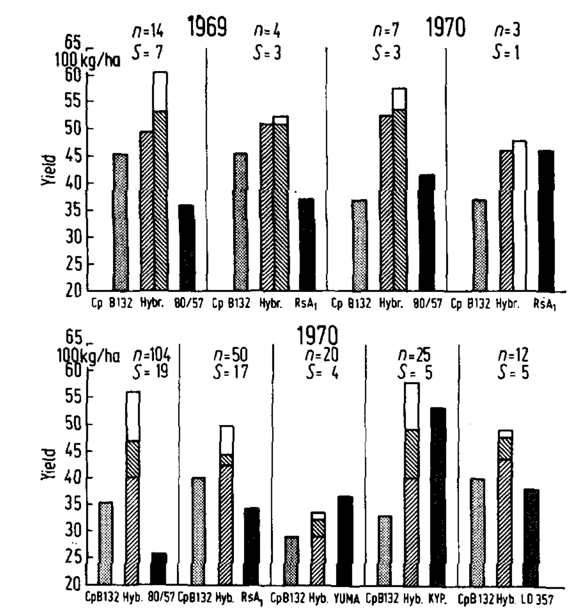


Fig. 6. Distribution of control parental lines and hybrid progenies of the cross (LD 357 × CpB 132) as to plant height and heading date ascertained in the field in 1967–1968



	CpB132	Hyb.	80/57	CpB132	Hyb.	RsA1	CpB132	Hyb.	YUMA	CpB132	Hyb.	KYP.	CpB132	Hyb.	LD 357
Head. date [May]	17.0	11.8	26.5/4	16.0	12.5	6.5	22.0	16.5	14.0	17.0	16.3	8.5	14.0	11.6	8.5
Height [cm]	101.0	93.0	114.5	96.0	93.9	109.0	95.0	91.4	121.0	99.5	90.0	108.5	102.5	97.6	123.5
Lodg. ind.	0.3	0.5	4.0	0.0	0.0	0.5	0.0	0.0	2.5	0.0	0.0	2.5	0.6	0.1	0.3

▨ Mean of lines tested
▧ Mean of lines selected
□ Yield of the best line
n Number of lines tested
S Number of lines selected

Fig. 7. Summary of yield performances of hybrids and parental lines in 1969–1970

stress the outstanding breeding value of these mutations, which, because of their dominance, allow backcrosses every generation.

In hybrid lines, yield increases 20 to 30% over the best parental variety were often obtained. This also applied to the other characters (weight per hectolitre, percentage of yellow berries, lodging resistance) which were improved in several cases, or maintained at the level of the best parent.

Gustafsson and his associates (1971) have recently stressed the value in barley breeding of induced mutations. After the first approval of Pallas in 1958, 12 more years have led to the approval of a second mutant case and 5 mutant crosses. This gives a clear demonstration of both the value of mutants directly used and the breeding value of sharp modification of the characteristics of high agronomic value induced by mutagenic treatments. As in barley, also in our *durum* wheat programme, it seems that an induced useful *mutation* modifying an important character has a higher value than the *mutant* line first carrying the improved characteristics. From two barleys mutants (Pallas and Mari) in fact, came four other varieties after transferring and combining the mutation into other genotypes.

Our data demonstrate that the Swedish barley work is not an exception, but could be the rule, if mutation breeding is properly applied.

Crop plants are artificial yielding machines: sharp and favourable modifications are certainly the exception after a mutagenic treatment, but drastic changes are often extremely useful when a plant becomes a crop plant. Short straw, from a general biological point of view, could be an unfavourable characteristic for plants in the wild, where strong intergeneric and interspecific competition exists, but can be a very favourable characteristic if only intravarietal competition is at work.

And again, under intensive cultivation short straw could be useful, but might be harmful in an extensive type of cultivation because of weed competition, etc.

It is nowadays common knowledge that mutagenesis can give sharp changes toward shorter plants in nearly every crop tested, resulting in agronomic advantage (Sigurbjörnsson and Micke, 1969). It seems that enough data, in a number of crops, now demonstrate the value of induced mutations in plant breeding.

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Received July 27, 1973
Communicated by H. Stubbe

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