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MUTATION BREEDING FOR DURUM WHEAT (*Triticum turgidum* ssp. *durum* Desf.) IMPROVEMENT IN ITALY

G.T. SCARASCIA-MUGNOZZA (1), **F. D'AMATO** (2), **S. AVANZI** (3), **D. BAGNARA** (4), **M.L. BELLI** (5), **A. BOZZINI** (6), **A. BRUNORI** (5), **T. CERVIGNI** (7), **M. DEVREUX** (8), **B. DONINI** (5), **B. GIORGI** (5), **G. MARTINI** (9), **L.M. MONTI** (10), **E. MOSCHINI** (2), **C. MOSCONI** (5), **G. PORRECA** (5), **L. ROSSI** (5)*

(1) Università della Tuscia, Viterbo; (2) Dipartimento di Biologia delle Piante Agrarie, Università di Pisa; (3) Dipartimento di Botanica, Università di Pisa; (4) INTAGRES, Roma; (5) ENEA/TECAB, Casaccia, Roma; (6) FAO, Roma; (7) CRA, Roma; (8) EUROTOM, Ispra; (9) Istit. Mutagenesi e Differ. CNR, Pisa; (10) Università di Napoli, Portici

ABSTRACT

In view of the economic importance of durum wheat in Italy and in the Mediterranean and Near East Region much effort was devoted to its genetic improvement. Lodging susceptibility and straw weakness, particularly under high fertilizer level, were the main reasons of substantially lower yields compared to bread wheat. An experimental mutagenesis programme was started in Italy in 1956 by F. D'Amato and G.T. Scarascia. It included both fundamental genetic studies and applied mutation breeding. Remarkable results were obtained at the "Laboratorio Applicazioni in Agricoltura", Casaccia Nuclear Research Center, Roma, Italy, in radiobiology, radiogenetics, cytology and cytogenetics, genetics and breeding. Selection among

*The authors were working at, or collaborating with the "Laboratorio Applicazioni in Agricoltura" at the Casaccia Nuclear Research Center.

some 1,000 induced mutants and hybridization led to 11 registered mutant varieties, six by the direct use of selected mutants and the remaining from cross-breeding. The economic benefits derived from the developed mutant cultivars are substantial. Mutant varieties have a great impact on durum wheat production, both in Italy and other countries like Bulgaria or Austria where Italian mutants have been used successfully in cross-breeding.

INTRODUCTION

Durum wheat, *Triticum turgidum* var. *durum* is a crop adapted to the semi-arid climate of the Mediterranean basin and the Near East and has been, since ancient times, a staple food for most of the people living in those regions. At present, durum wheat production is concentrated in the Near East (Turkey, Syria), Southern Europe (Italy, Greece, France, Spain, Portugal), North America (Canada, USA), and Northern Africa (Morocco, Algeria, Tunisia, Libya), (TABLE 1).

The demand for wheat has increased in the last 4 decades, particularly in Western Europe. The USA, Canada and Argentina have been the world main suppliers. The North African and Near East countries were self-sufficient, however, in the last decades they have become importers of durum wheat. To meet the increasing demand for durum wheat the producing countries had to expand the area under cultivation, develop more productive

TABLE 1. Durum wheat: Area and production, average 1976-1986 (FAO)

Region and Country	Area (x 1000 ha)	Production (x 1000 ton)
Western Europe	**2,280**	**4,971**
Portugal	22	20
Spain	116	245
France	142	485
Italy	*1,686*	*3,473*
Austria	11	38
Greece	294	663
Near East Asia	**4,642**	**6,694**
Syria	834	821
Turkey	2,932	5,236
North Africa	**3,469**	**2,969**
Libya	81	70
Tunisia	790	646
Algeria	1,132	736
Morocco	1,211	1,836
North and Central America	**3,010**	**5,674**
Canada	1,445	2,462
USA	1,510	3,114
South America	141	250
Argentina	83	158
Others (USSR, East Europe, Asia,)	**4,145**	**3,936**

TABLE 2. Durum wheat: area, yield and production in Italy, 1973-1986 (FAO)

Year	Area (x 1000 ha)	Yield (ton/ha)	Production (x 1000 ton)
1973	1,525	1.73	2,644
1974	1,563	1.81	2,836
1975	1,552	2.19	3,400
1976	1,671	1.79	2,993
1977	1,272	1.56	1,980
1978	1,672	2.08	3,472
1979	1,662	2.04	3,382
1980	1,713	2.14	3,658
1981	1,685	2.03	3,415
1982	1,701	1.72	2,933
1983	1,757	1.73	3,040
1984	1,798	2.54	4,618
1985	1,739	2.21	3,851
1986	1,862	2.36	4,385

varieties or improve the agronomic techniques. In TABLE 2 Italy's situation is reported in terms of area, yield and production. In Italy, durum wheat was traditionally grown in the South and partially in the Central regions and it has been considered a crop for poor environments. Under such circumstances yield was very low whereas bread wheat, mainly cultivated on the fertile soils of the Northern regions, gave a much higher yield. From the breeding point of view, durum wheat has not received the same attention as bread wheat. In fact the durum wheat production mostly relied on local lines selected from material introduced from North Africa and the Middle East (Senatore Cappelli, Aziziah, etc). A few cultivars were derived only from crosses (Grifoni, Garigliano, Capeiti and Patrizio).

The increased economic importance of durum wheat stimulated efforts towards the genetic improvement of this crop by using different methods such as intraspecific and/or interspecific hybridization and mutagenesis. Efforts made since 1960 by geneticists, breeders and agronomists of national and international institutions (e.g. CIMMYT) led to improved varieties which were competitive with the best bread wheat varieties in yielding ability.

STARTING MATERIALS FOR MUTATION BREEDING AND REASONS FOR THEIR CHOICE

In the mid-fifties the spectrum of durum varieties in Italy was extremely wide. Besides a few improved varieties derived from selection in populations originating in Algeria (Senatore Cappelli), Libya (Aziziah) and Sicily (Russello) and from crosses between "Cappelli" and "Tripolino" (Garigliano), a very large number of local varieties were still cultivated [31]. The choice of using these four varieties for mutation breeding was based on the following considerations:

i) they represented the best material available, adapted to the durum wheat area;
ii) they were considered to be a sample of wheats evolving on the three basic diversification areas in the Mediterranean region: - "Russello" from the fertile wheat-lands of Sicily, - "Cappelli" from the West North African environment (early, but having rather weak straw), - "Aziziah" from the Syro-Palestinian area, - "Garigliano", the best available recombinant between the East and West-North African types (good yielding but late).

These four cultivars were significant representatives of Mediterranean germplasm, having evolved over centuries, if not millennia. Mutagenesis, therefore, had a rather diversified genetic basis on which to operate. Certified seed from pure lines were available in these four varieties, to assure the basic genetic uniformity desired for experimental mutagenesis.

BREEDING OBJECTIVES

Tetraploid cultivated wheats (referred to as *Triticum turgidum* var. *durum*, durum wheat) have developed a basic adaptation to the Mediterranean environment. In the semi-arid Mediterranean climate durum wheats traditionally perform better than bread wheats (*T. vulgare*), and were preferred for such food preparation as pasta, cuscus, bulgur, etc.

In the rather dry and poor soils of the eastern Mediterranean area (350-500 mm rainfall), durum wheat varieties have weak straw (inclined to lodge under more fertile conditions), relatively short (90-120 cm), very early maturing, often waxless, insensitive to both thermo- and photo-periodism, of true spring habit. In the western Mediterranean region, with relatively higher precipitation (400-600 mm) most of the traditional varieties are relatively late in both heading and maturity (to escape late frosts which often occur), tall (120-150 cm), of better straw strength, more resistant to lodging, tolerant or resistant to some of the most serious crop diseases and pests. They are insensitive to thermo-periodism but sensitive to photoperiodism. The cultivars "Cappelli" and "Russello" are typical representatives of this latter group.

With the recently improved agronomic practice (better soil tillage and levelling, dressed seed, seeding by machine, efficient weed control, good supply of K, P, and N fertilizers, supplementary irrigation, pest control, combine harvesting, etc.) the old land races could not perform well enough. The major obstacle was lodging when soil fertility, particularly nitrogen availability, was improved. Lodging reduced yield and quality and therefore, even in potentially good soils, the performance of durum wheat was disappointing and not competitive with bread wheat. Lodging of the traditional varieties is connected with plant height and a rather poor harvest index (HI). Shortening of the culm could improve both, HI and standing ability.

The Syro-Palestinian group of varieties was characterized by earliness in all three developmental phases (from germination to spike primordia development; from spike primordia to flowering and from flowering to maturity), whereas the western Mediterranean group was characterized by lateness in all three phases. The ideal type for Italian conditions should be late in the first phase, rather early in the middle one and again late in the last one, to better cope with the average environmental characteristics and provide the necessary duration of time for optimal yield.

The main goals of the mutation breeding programme were therefore: shortening plant height, modifying leaf shape (erect leaves could be an advantage), altering the number of nodes and the length of internodes in the stem, modifying of tillering habit toward more synchronized but with similar number of tillers, maintaining or improving grain size and quality - large grain of vitreous appearance with high protein content in order to maintain high "semolina" (flour) yield and quality. Emphasis was placed on better resistance or tolerance to diseases (rusts, mildew, bunt, soil-borne fungi, etc.). Attention was also given to other types of mutation which could affect spike size, structure and fertility, and some other, potentially important characteristics such as male sterility or plant chlorophyll content.

TREATMENT METHODS AND MUTAGENS USED

Investigations of the radiation response of durum variety "Cappelli", were initiated in 1956 by F. D'Amato, G.T. Scarascia, E. Moschini and S. Avanzi at the University of Pisa, under contract with the Comitato Nazionale per le Ricerche Nucleari (C.N.R.N.)

Rome. Dry seeds, equilibrated at 11% water content, were irradiated at the Brookhaven National Laboratory, Upton, N.Y., USA with X-ray (15,000 R, 20,000 R and 25,000 R) at 250 kV, 30 mA, 980 R/min and with thermal neutrons (from 8.38 x 10^{12} Nth/cm^2) at a flux of ca. 5.82 X 10^8 Nth/cm^2/sec. For each irradiated sample, 504 seeds were sown in the experimental field of Pisa Agronomy Institute and M_1 plants were harvested individually in the summer of 1957. In the next season, spike progenies from individual M_1 plants were sown part in sand for chlorophyll mutation analysis in the greenhouse and part in the field for analysis of morphological and physiological mutants. Data were published on M_1 effects (chromosome aberrations in root meristems, survival in the field, tillering index, mature plant height, spike fertility) and on frequency of mutations in M_2 generation [40,41].

In 1958, the material was transferred from Pisa to the "Laboratorio Applicazioni in Agricoltura" at the Casaccia Nuclear Research Center, CNEN, Roma, where research was continued. Several methods of irradiation (acute, chronic, recurrent) at different ontogenetic stages of the plant (seed, growing and heading stages, pollen or both female and male gametes) were applied. Seeds of several varieties, namely: "Cappelli", "Russello", "Grifoni", "Capeiti", "Aziziah", "Garigliano", "Appulo", "Maliani 8D", "Patrizio", "Sincape 9", "Anhinga", were treated both with chemical mutagens, such as ethyleneimine (El), diethylsulphate (DES), ethyl-methane-sulphonate (EMS), and physical mutagens like X-ray, gamma rays (^{60}Co), fast neutrons (Nf), and thermal neutrons (Nth). Suitable doses/concentrations of treatment were established and the relative efficiency of the mutagens for chlorophyll and morphological mutations was determined [70].

The relative efficiency of the mutagens was established as follow: the M_2 chlorophyll mutation frequency: $EI < X < DES \leq Nf \leq EMS \leq Nth$ (the range of mutation frequency being from 1% to 24%). For morphological mutations, the relative efficiency was somewhat different: $EI < X < DS < EMS \leq Nth \leq Nf$ (the range of mutation frequency being between 1% and 41%) [28,43,67,70].

Seed treatment leads to M_1 chimeric plants whose mutated sector size has been estimated through deviations from the 3:1 segregation ratio expected from a heterozygous individual. This implies a sufficiently large M_2 population. In an attempt to overcome the chimerism, gametophyte (male or female or both) irradiation was applied to produce non-chimeric M_1 plants, heterozygous for the induced mutation(s). The analyses of segregating progenies of 2749 M_1 plants from "Capelli", scored in the greenhouse at seedling stage for chlorophyll and morphological mutations, showed the presence of mutations in 444 spikes. The mutation frequency at 1500 Rad of ^{60}Co, determined as a percentage of the segregating M_1 plant progenies analysed throughout the life-cycle, was 9.05, 4.56 and 20.04% after irradiation of male or female or both gametophytes respectively. The mutation frequency increased with the dose and reached 42.80% at 3000 Rad [46,50].

The work on mutagenic efficiency also included the use of chronic irradiation on 3 varieties: "Aziziah", "Capelli" and "Russello" from 3-leaf stage to harvest. It was shown that the achievable chlorophyll mutation frequency was lower than after acute seed irradiation and that the great majority of recoverable mutations were induced in the post-fertilization diplophase, i.e., during embryogenesis [48].

A 5-year cycle of recurrent X-ray irradiation and of combined X-ray plus EI treatment was also studied by looking for mutations affecting the time of heading, plant height and some spike characters [23,75]. The slight increase in mutation frequency and similarity in mutation spectra obtained in this experiment does not justify the extra work.

CHIMERA FORMATION FROM MUTAGEN-TREATMENT OF SEEDS

The mutagenic experiments carried out on durum wheat allowed an analysis of the chimera situation in M_1 durum plants deriving from treated seeds. More than 1,300 M_1 spikes segregating for chlorophyll mutations at seedling stage were analyzed. Because of

TABLE 3. Segregation ratios of chlorophyll mutations in M_1 spikes of durum wheat in different physical mutagenic treatment (S: seeds sown in the field; seeds sown in greenhouse and seedlings transplanted in the field at 3 leaf stage) (from D'Amato)

X-rays			Thermal neutrons			Fast neutrons			Fast neutrons				
									Experiment S			*Experiment T*	
Dose (KR)	M_1 spikes (No.)	Segregation ratio (%)	Dose (10^{12} cm²)	M_1 spikes (No.)	Segregation ratio (%)	Dose (rad)	M_1 spikes (No.)	Segregation ratio (%)	Dose (rad)	M_1 spikes (No.)	Segregation ratio (%)	M_1 spikes (No.)	Segregation ratio (%)
10	17	12.72	8.38	112	14.72	133	68	11.65	200	1117	11.55	1014	17.04
15	52	13.24	10.50	108	17.34	400	173	15.45	400	932	15.87	1021	16.05
20	44	18.50	12.60	41	17.21	533	112	19.74	800	147	12.78	901	14.10
25	14	14.90	14.70	6	23.44	666	108	18.81					
						800	69	16.35					
Total	127			267			530			2196		2936	
Segregation ratio		14.85			16.04			16.02			15.55		15.55

TABLE 4. Segregation ratio of chlorophyll mutations in M_1 spikes of durum wheat in two chemical mutagenic treatments (From D'Amato 1965, modified)

Diethyl sulphate			Ethyl methanesulphonate		
Conc. (o/oo)	M_1 spikes (No.)	Segregation ratio (o/oo)	Conc. (o/oo)	M_1 spikes (No.)	Segregation ratio (o/oo)
1,00	18	3.94	2.82	16	10.44
1,50	24	8.43	3.76	83	14.88
2,00	43	14.70	6.60	5	13.44
Total	85			104	
Segregation ratio		9.89			13.79

the high number of seedlings per spike (ca. 38 in the untreated material), it was easy to study the effects of various mutagenic treatments, doses and concentrations on the size of the mutated sectors in the M_1 spikes and plants (TABLES 3 and 4) [45]. It can be seen that i) segregation ratios increase with increasing dose and concentration, ii) the mean segregation ratios in the chemical mutagen series (11.85) were lower than those in the radiation series (15.9), and iii) the segregation ratio was higher when the M_1 seedlings were grown in greenhouses before transplantation (15.5%) compared to direct sowing in the field (14.1%). The difference between effects of radiations and chemicals, in applied doses and treatments, is clearer considering the percentage of spikes with a segregation ratio fitting the 3:1 at $p>0.05$: 76.5% after radiation and 55.5% after chemical treatments. By eliminating the bias due to differences in spike fertility and considering only the M_1 spikes with a seed number similar to the control, the mean segregation ratio was 12.6% in the radiation series and 8.7% in the chemicals.

To estimate the number of initial cells responsible for each M_1 mutated spike in various treatments, two methods were used. The first one is based on the chi-square analysis of the M_2 segregation ratios and calculation is done for the fitness of these ratios to the theoretical segregation ratios expected for a monogenic recessive mutation on the account of 1, 2, 3 or more initial cells being responsible for the organization of the M_1 spike. TABLE 5 reports the results of this analysis: the proportion of spikes formed by a single initial cell is higher (34%) in the irradiated but lower (19.7%) in the chemically-treated material. This method was improved by considering only recessive mutations that had no deficit of recessives: by using M_1 spikes segregating for "dwarf twisted", a mutation that has no deficit of recessives, 41% of M_1 spikes were considered to be formed by a single initial. By considering M_1 spikes segregating for albina, a chlorophyll mutation known to present a deficit of recessives, a lower number of spikes (32%) was attributed to a single initial cell [61].

The second method, the topographical method [45], essentially consists of localizing the position of the mutated sector (chlorophyll or other easily distinguishable morphological mutant) within the M_1 spike (Fig. 1). The use of a diagram, subdividing the spike into 8 sectors, four vertical quarters, each quarter further divided into an upper and lower half, has the advantage that even a limited number of mutants localized in a "strategic" position in the spike can provide information both on the size of the mutated sector and on the number of initial cells responsible for organizing the generative tissue of the spike [45,61]. The advantages of this method were: i) even a limited number of mutants could provide clear information on the number of initial cells contributing to the development of a particular spike after applied mutagenic treatment, and ii) it is limited to the M_2 analysis (TABLE 6). When analyzing M_1 spikes having at least 30 seedlings, more

TABLE 5. Distribution of M_1 mutated spikes of durum wheat according to the number of initial cells responsable for their organization (chi-square analysis of segregating ratio in M_2). Only spikes with at least 38 seedlings are considered (38=average number of seedlings per spike in untreated material) (From D'Amato 1965, modified)

Treatment	Number and percentage of spikes						Spikes analyzed
	No.	(%)	No.	(%)	No.	(%)	No.
Radiations*	82	34.16	56	23.33	102	42.51	240
Chemicals**	15	19.73	12	15.78	49	64.49	76
Initial cell(s) participating in spike formation	1		2		3 or more		

* X-ray, fast neutrons and thermal neutrons
** Diethyl sulphate and ethyl methanesulphonate

TABLE 6. Distribution of 85 M_1 mutated spikes according to the number of initial cells responsable for their organization as calculated by (1) chi-square analysis of the segregation ratio and (2) localization of all mutants within each spike ("topographical"). Only spikes with at least 30 seedlings are considered (From D'Amato 1965)

Type of analysis	Number and percentage of spikes					
	No.	(%)	No.	(%)	No.	(%)
Chi-square	50*	58.82	24	28.24	11	12.94
"Topographical"	67**	78.82	10	11.77	8	9.41
Initial cell(s) participating in spike formation	1		2		3 or more	

* Average segregation ratio: 25.78%
** Average segregation ratio: 22.47%

were attributed to a single initial cell by the topographycal method than by the chi-square method.

As far as the above-reported chimera situation in the M_1 plants of durum wheat is concerned all the results agree in the following conclusions:

1) the need to harvest M_1 plants by keeping each spike separate, because of the occurrence of different primordia in the embryo;
2) more initial cells can be present in each primordium at the time of mutagenic treatment; after mutagenic treatment other processes can occur in these initial cells [51];
3) in durum wheat, the mutated sector size can be determined by the segregation ratios, or easier by the topographical method;
4) in durum wheat, in applied doses and mutagenes, the mutated sector was found to be larger:

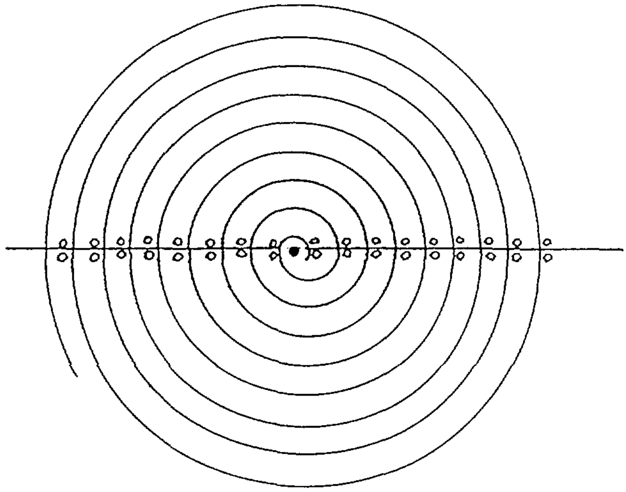

FIG.1 A diagrammatic representation of a durum wheat spike. The arrows represent the two orthostichies along which the spikelet rachillas are inserted on the rachis (points where the spiral gyres are intersected by the orthostichies). Small circles on each side of rachilla insertions represent left and right inserted florets (only floret on each side is drawn); (After D'Amato, 1965 [45]).

a) after increased doses and concentrations,
b) in radiation-derived material versus chemically-derived material,
c) when growing conditions of mutagen-treated seeds were improved.

Besides their theoretical importance, these studies have also had a practical implication in order to improve the efficiency of mutagenic treatments of durum wheat.

MUTANTS SELECTION METHODS

Most of the material treated with physical or chemical mutagenic agents consisted of seeds. The M_1 generation, was grown in the field as spaced plants in isolation, to avoid accidental outcrosses. M_1 material grown in the field was sample-harvested up to three heads per treated plant. The main spike was usually kept separate. M_2 seeds obtained from each head were planted in rows (10 x 20 cm). A row was left empty between seeds from different M_1 plants [72]. The material was analysed visually in the field at weekly intervals in winter and almost daily during booting and flowering time. Plants showing a difference from the control were labelled with plastic tags on which the difference was either colour-coded or described. Mature plants were pulled individually and tied in bundles, according to progeny. Later on all plants coming from a single M_1 spike were analysed for: main stem height, number and length of internodes, length and shape of heads, number of spikelets per head, total number of seeds per head, seed size, shape and appearance. Records were kept for each plant. The plants within each head-progeny showing a mutation were counted and segregation ratio of mutant/normal plants was calculated.

The pedigree system was strictly adhered to. In M_3 generation, seeds coming from one to three variant plants (putative mutants) were sown (usually 33 seeds per plant) together with one to three normal looking plant progenies to check for segregation from heterozygotes and to provide a control for comparison of mutants.

The M_1 plants raised from irradiated or chemically treated seeds were propagated according to the spike-progeny method and, less frequently, the bulk method. Selection of

TABLE 7. Types of induced mutations in durum wheat (from Scarascia-Mugnoza *et al.* 1968, modified)

Mutation types	Number of mutations investigated	Inheritance studied by Segregation of heterozygots	Crosses with parent
Pigmental mutations			
albina*	8	8	-
chloroalbina*	3	3	-
xanthoalbina*	2	2	-
xantha*	8	8	-
viridoalbina	4	3	1
tigrina	13	9	4
virescens	2	1	1
chlorina	8	-	8
viridis	1	-	1
anthocyanica	2	2	-
albescens	3	3	-
senescens	4	4	-
anthocyanic glume-	5	-	5
Morphological mutations			
waxless	5	-	5
elymoid	2	-	2
sphaerococcoid	5	-	5
vavilovoid	7	-	7
defective endosperm	2	-	2
dwarf*	1	1	-
dwarf twisted	11	11	-
short straw	6	-	6
solid stem	2	2	-
ligulaless	1	1	-
narrow leaves	2	-	2
Mutation affecting gametogenesis			
asynaptic	2	2	-
desynaptic	5	5	-
sticky chromosomes	1	1	-
spindle distortion	1	1	-
homoeologous pairing	1	1	-
male sterility	1	1	-
Chromosomal mutations			
translocations	2	-	2
deletions	1	-	1
duplications	1	-	1
inversions	1	-	1
trisomics	3	-	3
Total No.	126	69	57

* Lethal or sterile mutations

mutants was carried out in M_2 and M_3. The need for mutant selection in M_3 was dictated by the observation that in some experiments, especially with chemical mutagens, the M_1 mutated sector size was too small to allow the segregation in M_2 of recessive mutants. It was indeed ascertained that the number of mutations first isolated in M_3 equalled or sometimes exceeded the number of mutations recovered in M_2 [41,42,68]. For mutations of possible breeding value, selection was continued for two to three generations. It was thus possible to eliminate some deleterious genetic changes, especially reciprocal translocations, accompanying the mutation. Consequently, monogenic mutations later on acquired a typical 3:1 segregation ratio [73].

A large number of mutants were recovered possessing alterations in plant height and culm architecture. Shorter plants with better lodging resistance were particularly considered, as well as mutants for earliness or lateness. Also, mutants showing kernel modification (flintiness, size, shape, etc.) were isolated in relatively large numbers. Mutants confirmed in M_3 and M_4 but showing some degree of sterility or unfavorable characteristics, were backcrossed to the parent variety. Sometimes selection was made in BC_1 for the desirable characteristics, free from undesirable ones. Generally speaking, recombinants coming from backcrosses to the parent performed better, from an agronomic point of view, than mutants coming directly from M_2 or M_3 generations.

The spectra of morpho-physiological mutations derived from treatment of different varieties were generally different in both frequency and type of mutation, a response due to the different genotypes of the treated varieties [8,33,36, 37,65,66,67]. It is interesting to note that the cultivar "Senator Cappelli" gave the best results as to mutations of agronomic interest. In fact, three selected mutant lines showed better field performance. Two of them were finally named and released as "Castelporziano" and "Castelfusano". "Castelporziano" (about 30 cm shorter, but later in maturity than the parent variety) has distribution in the more humid areas of central Italy. This mutant has been used in crosses leading to the release of a number of varieties: "Tito", "Augusto" (Italy), "Probstdorfer Miradur", "Grandur", "Signadur" (Austria), "Lozen 76", "Zeveryana", "Sredetz" (Bulgaria). The mutant variety "Castelfusano" was also successfully used in cross breeding. This led to the development of perhaps the most successful modern Italian variety of durum wheat - "Creso" [38,39]. Collection of mutants was genetically analysed for several years and some mutants (such as lacking the Ph_1 - synaptic gene) are being used in theoretical and applied research programmes.

TYPES AND INHERITANCE OF MUTATIONS

As to the mode of inheritance of induced mutations, it must first be stated that out of 1024 chlorophyll mutations only five were found to behave as dominant or semidominant [43]. A detailed genetic and/or cytogenetic analysis was carried out on 126 independently obtained mutations, 69 of which were studied through segregation of heterozygotes and 57 through crosses of mutants to parent variety (TABLE 7). Most of the mutants behaved as recessive, some as semidominant and a very few as fully dominant [18,20,21,22,25,29,35].

The vast majority of mutations was found to be monogenic recessive. This was also true for characters which were generally considered to have a polygenic basis, such as plant height and spike length [5,19,79]. Two mutations of evolutionary interest, *sphaerococcoid,* induced in cultivar "Cappelli", and *elymoid* induced in the varieties "Aziziah" and "Capeiti", gave a 3:1 segregation when crossed to the parental cultivars but a 15:1 segregation in crosses with lines of *T. carthlicum* and with the cultivar "Cappelli" [19]. This data confirms that *Triticum turgidum* var. *durum* is a highly diploidized tetraploid species [43,73]. Few mutations were semidominant: e.g. tigrina, increased grain size, solid stem [9,16,44]. A short-straw mutation isolated in M_2 from "Cappelli" in 1958 was later shown to be monogenic and dominant. It drastically reduced culm length (to 70-80% of parent variety) without any negative effect on spike morphology or fertility [22,82]. The line carrying that mutation (Cp B132) was later released under the name

"Castelporziano". The genetic effects of mutations for short straw have been shown to be additive for mutations induced in different varieties as well as for different mutations isolated in the same variety, as in the case of the mutants Cp B132 and Cp C48 both induced in the cultivar "Cappelli".

CYTOGENETICS

Most of the durum wheat mutants were analysed from cytological and cytogenetic points of view. In particular, those lines which showed abnormalities such as sterility at different levels or distortions in the segregation ratio were systematically subjected to analyses in mitosis and meiosis [17,26,27,30,32,47,51,52,53,54,58,59,60]. One of the aspects to be clarified in connection with the induction of mutations by different mutagenic agents was the relationship between phenotype and damage at chromosome level. It was found that the application of radiations, particularly neutrons, induced a higher level of chromosome aberrations as compared to chemical mutagens [1,2,3,4,49].

A high frequency of the mutants, up to 85%, had one or more translocations. Contrary to the expectations based on what occurs in diploid species such as barley, the correlation between translocations and semi-sterility appeared not fully applicable to tetraploid species like durum wheat. Yet, as to the mutation frequency, particularly chlorophyll mutations, durum wheat behaved very similar to diploid species; thus proving its high level of diploidization. Besides the high number of reciprocal translocations which became homozygous and remained stable e.g. in the mutants released as new varieties such as "Castelporziano" and "Castelfusano", other types of chromosome aberrations were also found in the screened material. A consistent number of mutants had problems with the meiotic process, ranging from desynapsis and stickiness to spindle distortion. In the progenies of plants carrying detectable abnormalities at the chromosome level aneuploid plants with chromosome numbers ranging from 27 to 64 were found. This was the raw material in the development of trisomic lines in durum wheat [56]. The complete set of trisomic lines was established in collaboration with A. Blanco, University of Bari, by utilizing the "conversion technique" based on crossing and backcrossing nullitetrasomic lines of common wheat "Chinese Spring" with "Cappelli" [55,57]. Recent analysis of the karyotypes of mutants revealed the presence of inversions, deletions and duplications. They have very likely been much more frequent than the simple karyotype analysis could pick up at that time.

A deletion observed in the long arm of the most heterobrachial chromosome (chromosome 5B) proved to be very interesting. In crosses with rye and *Aegilops longissima*, such a line called DES 35 (because of an apparent desynapsis) showed a high degree of homoeologous pairing, thus proving to be a mutant without the Ph_1 gene which in *Triticum* prevents the pairing between the homoeologous chromosomes. This character has been largely exploited in common wheat for the introduction of alien variation dealing mainly with disease resistance. The same should occur in durum wheat through the use of such a mutation.

AGRONOMIC EVALUATION OF MUTANT LINES

Mutagenic experiments carried out at the Casaccia Centre with traditional, Italian durum varieties, as well as with more modern cultivars of various sources, have led to hundreds of mutant lines. Especially in early years, when the work was performed on old Italian varieties characterized by tall culm and high susceptibility to lodging, the emphasis in screening focused on short culm mutants, expected generally to be more lodging resistant. This character has allowed an expansion of the durum cultivation on more fertile soils, and improvement of production through application of more intensive farming techniques in the traditional areas of cultivation. Short culm mutations were found frequently, whatever the treated genotype. Their selection was easy by visual inspection. Most of the short culm mutants showed detrimental changes in other agronomically

TABLE 8. Number of mutant lines tested in the period 1961-1967 (from Scarascia-Mugnozza *et al.* 1968)

Tested lines	1961 and 1962			1963 and 1964			1965			1966			1967		
	No.	Better than Cappelli		No.	Better than Cappelli		No.	Better than Cappeli		No.	Better than Cappeli		No.	Better than Cappeli	
		(No.)	(%)		(No.)	(%)		(No.)	(%)		(No.)	(%)		(No.)	(%)
Mutants															
a) old	-	-	-	44	0	0.0	13	2	15.3	5	5	100.0	10	9	90.0
b) new	127	23	18.1	45	6	13.3	3	3	100.0	14	7	50.0	1	1	100.0
Total	127	23	18.1	89	6	6.7	16	5	31.2	19	12	63.1	11	10	90.0

relevant characteristics, such as vigor, seed setting or time of ripening. The better ones were included in a nationwide network of trials, with the aim of evaluating their agronomic potential [10,11,12,85].

Hundreds of mutant lines from the old Italian varieties "Cappelli", "Garigliano", "Grifoni", "Russello" and "Aziziah" were tested within this programme. The results are summarized in TABLE 8. Reference is made to the cultivar "Cappelli", as the standard variety at that time, both in Italy and other Mediterranean countries. Due to the selection applied, an increase in the percentage of mutant lines performing better than the standard "Cappelli" can be observed over the years [79]. The following general features of short straw durum wheat mutant lines could be observed:

1. high frequency of short straw lines occurred among mutants from the tallest variety, "Cappelli";
2. with the exception of a few cases, shorter culms were determined, at least in "Cappelli", by proportional shortening of all internodes;
3. most short straw mutants in "Cappelli" and "Grifoni" were somewhat later than their parent variety, whereas in "Garigliano" the opposite was true;
4. lodging resistance showed a clear positive correlation with culm length reduction [79].

The assessment of the changes in yield components of mutants that outyielded their parent varieties was difficult due to genotype and environment interactions. Most often, however, the better performance of the mutants accounted for a higher number of caryopses per spike and/or a better tillering capacity. In some instances (mutant line Cp B144 from Cappelli), lower percentages of "yellow berry" grains, regarded as a sign of good quality, were observed [79]. Some short straw mutants from "Cappelli" were also tested for their capability of exploiting progressively higher nitrogen levels of soil [6,62,64,71]. At a low nitrogen level both mutants and parent variety failed to lodge,

Table 9. Characteristics of 9 mutant lines and respective parent varieties of durum wheat (From Scarascia-Mugnozza *et al*. 1968; modified)

Parent varieties, mutant lines and varieties released	Culm length (% of parent variety)	Mean number of internodes	Lodging index*	Heading date	Yield (% of parent variety)
Cappelli	122 cm	7.97	2.5	7.5 May	3915 kg/ha
Cp F136	66.27	8.10	0.0	+4.0	106.50
Castelporziano (Cp B132)	72.95	7.80	0.0	+2.0	117.95
Cp B144	79.50	8.00	0.0	+0.5	101.07
Castelfusano (Cp C48)	82.79	7.85	0.1	+0.8	113.34
Garigliano	108 cm	6.59	3.6	3.6 May	3890 kg/ha
Ga A7	89.6	5.90	1.4	-1.7	103.60
Castelnuovo (Ga B125)	91.8	6.25	0.8	+0.4	106.70
Grifoni	98 cm	6.88	2.6	1.3 May	3950 kg/ha
Casteldelmonte (Gr A145)	78.2	5.95	0.0	+3.2	107.30
Aziziah	100 cm	6.57	2.4	3.0 May	3670 kg/ha
Az B155	87.5	6.75	0.0	+2.4	107.20
Russello	138 cm	6.00	5.0	3.0 May	3113 kg/ha
Rs A1	76.8	5.75	4.6	-12.0	115.90

*0 = No lodging; 5 = maximum lodging

TABLE 10. Grain yield of durum wheat mutants and varieties, 1965-1968 (From Scarascia-Mugnozza *et al.* 1972)

Entry	Yield (kg/ha)	Duncan's multiple range test					
IT06 Ga B125	3348.24	x					
Capeiti	3325.74	x	x				
IT09 Gr A145	3263.38	x	x				
IT04 Cp A26	3221.89		x	x			
IT07 Ga A7	3213.33		x	x			
IT08 Cp B132	3050.45			x			
Mean of all local varieties	3008.01			x			
IT02 Rs Al	2995.79			x	x		
IT05 Cp C48	2972.90			x	x	x	
IT01 Az B155	2878.94				x	x	x
IT03 Cp B144	2816.54					x	x
Cappelli	2723.02					x	x

TABLE 11. Grain yield of durum wheat mutants and varieties, 1968-1969 (From Scarascia-Mugnozza *et al.* 1972)

Entry	Yield (kg/ha)	Duncan's multiple range test			
UN02 Capeiti	3167	x			
IT09 Gr A145	3122	x			
IT06 Gaa B125	2965	x	x		
Mean of all local varieties	2930	x	x		
IT07 Ga A7	2920	x	x		
IT02 Rs A1	2829	x	x	x	
IT01 Az B155	2688		x	x	x
IT08 Cp C48	2656		x	x	x
IT05 Cp C48	2613		x	x	x
IT03 Cp B144	2435				

TABLE 12. Agromonic evaluation of two durum wheat mutant varieties in comparison to the original parent variety Cappelli (Scarascia-Mugnozza *et al.*, 1972)

Variety	Culm length (cm)	No. of inter-nodes	Uppermost internode (cm)	Uppermost internode % of culm	Lodging index *	Main spike length (mm)	No. of spikelets per main spike	Fertility of spikelets	Mean No. of cary-opses per spike	1000 kernels weight	Yellow berry (%)	Volume weight	Heading date (with reference to Cappelli)
Capelli	120.00	7.97	52.60	37.80	3.55	71.90	24.30	2.03	22.88	56.53	8.2	83.64	
Castelporziano (CNEN, Cp B132)	90.70	7.80	34.37	33.70	0.89	66.15	23.09	2.07	24.60	55.82	16.8	83.57	+ 2 days
Castelfusano (CNEN, Cp C48)	104.70	7.85	45.33	38.70	1.57	64.97	23.13	2.16	25.80	54.66	7.60	83.05	+ 0.8 days

* 0 = no lodging; 5 = maximum lodging

thereby permitting an unbiased comparison among genotypes as to their ability to utilize soil fertility. Under these conditions, two of the three tested mutants outyielded "Cappelli", suggesting that the plant metabolism itself had been positively affected [71]. TABLE 9 reports the agronomic characteristics of the best mutant lines of each of the cultivars "Cappelli", "Garigliano", "Grifoni", "Aziziah" and "Russello", as assessed in several years of field evaluation. A common, remarkable feature is the much improved resistance to lodging, a slight-to-highly improved yielding ability, and an altered heading time: generally later in mutants from late parent varieties [63,77,79].

Considering the great economic interest of durum wheat to several countries of the Mediterranean basin and the Near East region, the best mutant lines were further tested in a series of trials conducted under the auspices of FAO/IAEA under a wide range of environments [14,15,80,81,84,85]. Eight mutant lines were included. They were compared with two local checks selected by each cooperator, and with two Italian standards: "Cappelli" and "Capeiti". The trials started in 1965/66, and were carried out for four years at 57 locations in 16 countries. TABLE 10 reports the average grain yield for the first three years in all locations.

Best yielding were the mutant lines: "Ga B125" from the cultivar "Garigliano", and "Gr A145" from the cultivar "Grifoni", as well as the Italian standard "Capeiti". All three significantly outyielded the overall mean of the local checks. The average performance of the latter was biased by the frequent inclusion of very productive local bread varieties. TABLE 11 reports grain yields measured in the fourth year of trials. These data show an essential similarity with the performances observed in the previous three-year period. The best yielders were again "Capeiti", "Gr A145", "Ga B125", as well as another mutant line from "Garigliano", "Ga A7".

VARIETIES RELEASED FROM DIRECT USE OF MUTANTS

After six years of tests covering the whole area of traditional durum cultivation in Italy, as well as regions of potential adaptation for this cereal, the lines "Cp B132" and "Cp C48" from "Cappelli", were registered and released under the names of "Castelporziano" and "Castelfusano" [74,76,78,83]. A synopsis of the characteristics of these varieties, as compared to "Cappelli", is reported in TABLE 12. Furthermore, a diallel analysis [5] following crosses among mutants and between mutants and parental varieties led to the assessment of the relationships shown in TABLE 13.

TABLE 13. Morphological and physiological characteristics of two mutant varieties compared to parental variety Capelli (Scarascia-Mugnozza *et al.*, 1972)

Parental variety and mutants	No. of culms	Length of main culm	No. of internodes	Length of upermost internode	Main spike length	No. of spikelets per main spike	Heading date
Cappelli	A	A	A	A	A	A	A
"Castelporziano"	B	B	B	B	A	B	B
"Castelfusano"	C	C	A	C	A	C	A

Both tables indicate that besides a drastic reduction in culm length, series of other characters were significantly changed. Both short culm mutations behave as monogenic; dominant in "Castelporziano" and recessive in "Castelfusano". These varieties are well adapted to soils where neither nutrients nor water supply are limiting factors, especially during the particularly critical phase of grain filling. Therefore, they have proven to be better adapted to new, more favorable regions rather than to traditional areas of durum cultivation. After exhaustive testing, in Italy and abroad, two other mutant lines from the cultivars "Grifoni" and "Garigliano", were released with the names of "Casteldelmonte" and "Castelnuovo", respectively. Their agronomic performance, morphological and physiological traits, are reported in TABLES 9, 10 and 11, where they are still named with their early serial numbers "Gr A145" and "Ga B125". Both have manifested very pronounced adaptability and high yielding, short straw and satisfactory lodging resistance, and a heading time earlier than mutants obtained from "Cappelli". Another high yielding short straw mutant from cultivar "Aninga" was released in 1987 under the name of "Icaro".

USE OF MUTANTS IN HYBRIDIZATION AND RELEASED VARIETIES

Induced durum wheat mutants have been intensively utilized in hybridization programmes, pursuing a wide range of goals. Most frequently, the objectives have been:

i) combination in the same genotype of two or more mutations affecting different characters;

ii) accumulation in the same genotype of two or more mutations affecting the same character, in order to increase the phenotypic expression of this character;

iii) transfer of mutation into another genetic background that can be improved by the mutated character.

Mutant lines from the varieties "Cappelli", "Garigliano", "Capeiti", "Aziziah", "Grifoni" and "Russello" were hybridized to obtain, in one genotype, mutations for short straw, early heading and maturity time (Bagnara and Rossi, unpublished). Whenever the crossed mutant lines were derived from the same parent variety, therefore sharing the same genotypic background, a smaller size F_2 population was screened. Nevertheless, it was also considered that co-induced minor mutations may modify the expected expression of the major mutation or increase the variability of other quantitative traits. Hybridization between mutants with the same character was widely adopted in the durum programme at Casaccia. This was very often applied to mutants with reduced culm length to obtain a more drastic expression of the mutated character.

The best results were obtained from the cross between "Castelporziano" and "Castelfusano", both short straw mutants from "Cappelli" [7]. Selection in segregating generations led to the isolation of some lines, homozygous for both mutations, with a culm shorter than either parent (TABLE 14).

TABLE 14. Reduction of culm length, in comparison to parent variety "Cappelli", in two mutants and their recombinant line homozygous for both mutations (Bagnara *et al.*, 1971)

Line	Culm length (cm)	Percent of Cappelli
Cappelli	128	100
Castelfusano	106	83
Castelporziano	94	73
Double homozygote	72	57

The effect of the simultaneous presence of both mutations in the same genotype on a culm length was almost additive. Other characters were also affected: the recombinants were slightly later in heading and maturity time, had a higher grain volume weight and yielded more, not only in respect to "Cappelli", but also in respect to both parental mutants, as reported in TABLE 15.

TABLE 15. Grain yield of "Cappelli", two short straw mutants and their recombinant line homozygous for both mutations (Bagnara *at al.*, 1971)

Line	Grain yield (kg/ha)	Percent of Cappelli
Cappelli	3800	100
Castelporziano	4775	126
Castelfusano	4700	124
Double homozygote	5560	146

These results support the hypothesis that both mutant lines also carried other mutations than those affecting culm length, with negligible phenotypic expression. Thus when they were crossed, recombinant genotypes could arise, differing from parental lines for a great number of characters.

Another hybridization programme carried out at Casaccia involved several mutants with an earlier heading time, obtained from the cultivar "Capeiti". In this case also, the effects of mutations were additive, leading to recombinant lines that were as early as, or earlier than, the presently cultivated bread wheat cultivars (Bagnara and Rossi, unpublished).

Mutants showing poor fitness, even with some mutations of potential value, commonly occurred in the Casaccia durum wheat mutation breeding programme. This was attributed either to deleterious co-induced mutations or to pleiotropic effects of some mutations. Working under the former hypothesis, a common procedure was to backcross the mutant to the parent variety, then select for a recombinant without undesirable effects. However, in the case of a reduction of fitness due to pleiotropic action of mutated genes, positive results could only be achieved by crossing a mutant with genetically different varieties. Progress from backcrosses of a mutant to the parent variety are shown in TABLE 16.

TABLE 16. Best grain yields recorded among F_5 lines from backcrosses of short straw mutants to parent variety "Cappelli" (Bagnara *et al.*, 1971)

Cross	Grain yield	Percent	
	(kg/ha)	of mutant	of Cappelli
Cappelli x Castelporziano	5342	116	135
Cappelli x Castelfusano	4795	106	121
Cappelli x Cp B144	4795	116	121

A large corresponding programme of crossing mutants to other varieties was carried out at Casaccia. Results indicated that mutants generally possessed good combining ability, giving rise to new lines whose agronomic features were definitely superior to both parents. Two main subprogrammes were realized. In one, the Japanese bread wheat "Norin 10" was crossed with North American durum wheat. From this cross, a line characterized by short straw, resistance to brown rust, average leaf size, contemporary tillering, and average grain size, with a structure similar to that of *T. turgidum* was selected. This line was crossed to the slightly shorter and more productive "Cappelli" mutant, Cp B144, with grains of superior technological quality and very high volume weight. After selection and rigorous field testing, two cultivars originating from that cross were released in 1974: "Creso" and "Mida".

In the other subprogramme, the short straw mutant (Castelporziano) from "Cappelli", with a very high lodging resistance and good grain quality, was crossed to the North American variety Lakota, characterized by a taller, flexible culm, resistance to stem rust, average earliness, small, erect leaves, and good grain yield. After massive selection and careful and extensive field testing, one line was released, with the name "Tito". "Tito" is very lodging resistant, because of its culm, and at the same time, is short but also flexible. It also shows few, small and erect leaves, is active in photosynthesis, has abundant tillering and is resistant to stem rust. It also possesses high spike fertility; caryopses smaller than "Cappelli", but of good quality; and average ripening time. TABLE 17 reports a synthesis of field tests concerning "Creso", "Tito" and "Mida", where the performance of these new varieties is compared with "Castelporziano" and the cultivar "Cappelli".

TABLE 17. Average grain yield of mutant varieties "Creso", "Tito", "Mida" and the control cultivars "Castelporziano" and "Capeiti", in field tests in Central Italy (Bozzini and Bagnara, 1974)

No. of tests	Cultivar	Grain yield (kg/ha)	Superiority in respect to control (%)
	Creso	5164	-
51	Capeiti	4145	25
	Castelporziano	4139	25
	Tito	5191	-
27	Capeiti	4194	24
	Castelporziano	4224	23
	Mida	4884	-
25	Capeiti	4128	18
	Castelporziano	4094	19

TABLE 18. Agronomic performance of durum mutant varieties "Augusto", "Tito" and "Casteldelmonte" (Bagnara and Porreca, 1977)

Cultivar	Grain yield kg/ha*	Test weight kg/hl	Yellow berry (%)	Culm length (cm)	Lodging index**	Heading date
Augusto	5654	78	14	89	0.1	9 May
Tito	5204	76	11	100	1.0	11 May
Casteldelmonte	5068	79	12	94	3.7	7 May

* Average over 9 locations in Central Italy, during 6 years

** 0 = no lodging; 5 = maximum lodging

"Creso" and "Mida", in particular, produce grain with extremely high volume weight and very low "yellow berry" percentages, if properly cultivated. In fact, all three cultivars, "Creso", "Mida" and "Tito", have very high requirements in terms of soil fertility and water supply and, in general, good agronomic practices. Furthermore, due to the short culm, their yield potential is only expressed when a careful weed control is applied. For this reason the area of cultivation is not one traditionally planted with durum wheat but the one presently used for growing high yielding bread wheat cultivars. More recently, the desire was expressed by the farming community, for cultivars resistant to lodging, but not so extremely short in culm length, so that easy weed control could be achieved. The release of cultivar "Augusto", in 1977, was an attempt to respond to those needs [13]. "Augusto" was derived from a cross between a sister line of "Tito" and the mutant cultivar "Casteldelmonte". TABLE 18 reports the main agronomic features of cultivar "Augusto", as compared to "Tito" and "Casteldelmonte".

The data suggests a significant yield superiority of cultivar "Augusto", as compared to both "Tito" and "Casteldelmonte". The culm length of "Augusto" is possibly determined by an interaction of the two short straw mutations contributed by "Castelporziano" (monogenic dominant) and "Casteldelmonte" (monogenic recessive). However, while the presence of the "Castelporziano" short straw gene is confirmed in "Augusto" by the segregation patterns, the same cannot be concluded for the gene from cultivar "Casteldelmonte". The shorter culm (about 10%) of cultivar "Augusto" as compared to "Tito", suggests the presence of the "Casteldelmonte" mutations, as well. The maturity time of "Augusto" (earlier than Tito) is similar to the cultivar "Casteldelmonte", considered to be well adapted to conditions of Central Italy. "Augusto" is resistant to the local races of stem rust, but is susceptible to leaf rust. It represents a class of cultivars carrying induced short straw genes, rather than the widely used "Norin 10" genes. The short to medium culm length coupled with a pronounced culm flexibility, accounts for their resistance to lodging and permits more effective weed control.

ECONOMIC BENEFITS DERIVED FROM CULTIVARS OBTAINED BY MUTATION BREEDING

The extensive durum wheat mutation breeding work resulted finally in the obtention of 11 registered varieties (TABLE 19). Six of them stem from the direct use of induced mutants, the rest being the result of cross breeding. Among the varieties released to farmers "Creso" became the leading Italian variety with the highest percentage of durum certified and distributed seed (TABLE 20).

Creso has high and stabile yielding capability, good adaptability and grain quality. Its contribution to durum wheat production has permitted Italy to attain self-sufficiency. The cultivated area under this variety has constantly increased in the last 15 years, reaching more than 1/3 of the total Italian area cultivated under durum wheat. Estimating increase of 0.9 ton/ha of "Creso" over the other varieties it is possible to calculate a total yearly gain for Italy of 400,000 tons, equivalent to an economic profit per year of ca. 180 million US Dollars. Therefore, in the last decade "Creso" cultivation gave a total economic gain estimated at some 1,800 million US Dollars. "Creso" still remains (1992), the variety with the highest percentage of certified seed. Meanwhile, five new varieties derived from "Creso" were released in the last five years, namely: "Bravo" (selection from Creso); "Messapia" (Mex/Crane x Creso); "S. Alberto" (Creso x Linea 17); "Vento" (Linea 28-10/Linea 17 x Creso) and "Arcangelo" (Creso x Appulo).

CONCLUSIONS

The durum wheat research programme at the Laboratory "Applicazioni in Agricoltura", Casaccia Nuclear Center of the National Committee for Nuclear Energy (CNEN now ENEA), Roma, Italy, has demonstrated that of some 1000 mutants obtained

TABLE 19. Durum wheat varieties derived from mutation induction or from the use of mutants in cross breeding, released in Italy.

New cultivar	Parent variety or mutant crosses (mutant underlines)	Date of release	Mutagen used	Main improved attributes
Castelfusano	Cappelli	1968	thermal neutrons	Short straw, lodging resistance, yielding ability.
Castelporziano	Cappelli	1968	thermal neutrons	Short straw, lodging resistance, yielding ability.
Casteldelmonte	Grifoni	1969	fast neutrons	Short straw, lodging resistance, yielding ability.
Castelnuovo	Garigliano	1971	X - ray	Short straw, lodging resistance, yielding ability.
Creso	Cp B144 x [(Yt 54-N1OB x Cp2-63) x Tc3]	1974		Short and stiff straw, lodging resistance, leaf rust resistance, grain quality and test weight, good yield ability.
Mida	Cp B144 x [(Yt 54-N1OB x Cp2-63) x Tc3]	1974		Short and stiff straw, lodging resistance, leaf rust resistance, grain quality and test weight, good yield ability.
Tito	Castelporziano x Lakota	1975		Lodging resistance, erect leaves, profuse tillering. stem rust resistance, high yielding.
Augusto	[Castelporziano x Lakota] x Casteldelmonte	1976		Lodging resistance, effective weed control, resistance to stem rust, high yielding.
Icaro	Anhinga	1988	fast neutrons	Short and stiff straw, lodging resistance, good yield.
Ulisse	Selection among plants of Creso population	1988		Stiff straw and lodging resistance, high yield.
Peleo	Creso x Crane	1989		Lodging resistance, early ripening, high yield.

TABLE 20. Percentage of certified seeds of the main durum wheat varieties cultivated in Italy (1974-1992)

Variety	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1990-92 Average
Patrizio	33.4	31.0	21.3	17.6	12.6	10.8	9.2	8.0	4.2	2.7	3.1	0.0
Capeiti	29.8	26.1	25.4	20.5	17.7	20.0	16.1	16.0	11.9	8.5	7.2	0.6
Appulo	18.6	22.6	24.9	24.9	26.1	26.1	27.2	26.5	26.3	21.3	22.0	6.0
Creso	1.1	5.0	16.5	25.3	32.0	33.1	39.9	42.0	47.0	58.3	53.3	23.3

from mutagenic treatment, 262 could be regarded as worthy of further investigation for breeding purposes. The extensive selection and hybridization work resulted finally in the obtention of 11 registered varieties. Of them, 6 resulted from direct selection of induced mutants, the rest being the result of cross breeding. Taken as a whole, the 20 years activity on durum wheat at the Laboratory "Applicazioni in Agricoltura", while contributing fundamental information on genetics, cytogenetics, evolution of the species, has resulted also in a relevant financial return. This was achieved with the creation of new varieties which have a clear impact on durum wheat production in Italy and other countries of the Mediterranean and Near East Region.

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Mutation Breeding Review
Joint FAO/IAEA Division of Nuclear Techniques
in Food and Agriculture
International Atomic Energy Agency
Wagramerstrasse 5, P.O. Box 100
A-1400 Vienna, Austria

93-05070