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GENETIC IMPROVEMENT OF *DURUM* WHEAT FOR DISEASES RESISTANCE

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To discuss the problem of genetics and breeding for disease resistance in half an hour, even for *Triticum durum* Desf., it is difficult because of the complexity and amplitude of the subject.

I will first review some general concepts of resistance using a therminology, which unfortunately is rather complicated at present. I will then discuss the concrete problems concerning diseases of *T. durum*, specifically in Italy and, in a general way, in the Mediterranean area, to which Italy belongs and from which it cannot be separated.

Finally, I shall discuss one of the many ways which might be used in solving the problems dealing with the introduction of resistance into cultivated varieties.

I believe we all agree that the cultivation of varieties resistant to diseases plays an important role in modern agriculture and no doubt has great possibilities of avoiding losses, caused by parasites in an extensively grown crop such as wheat.

Thus, the incorporation of resistance to diseases in varieties, is a tool that allows yield increase and more stable production. At the same time it reduces or avoids the use of fungicide which would increase the costs of production and might cause direct harm to man as well as alterations in the ecological equilibrium in general.

Types of resistance.

According to Vallega (1966) « we should define, for practical purpose, resistance as any character which will enable the plants to avoid or diminish the effects of parasites on the quality or quantity of the products ».

In relation to the above definition, « plants should be considered as resistant when, due to their genetic constitution, they do not permit the development of the parasite; when they present a barrier to the penetration of the parasite; when they react and thereby limit the development of the disease to different degrees; or when they reduce in any way the consequences of the attack of the parasite, either by tolerating them or recovering from their effect. We would also consider plants as resistant when, due to the particulars of their life cycle, they are not at the right stage to be attacked by the parasite when it appears ».

Thus the meaning of resistance is very broad and includs many different types of reaction of the plants.

Different resistance types can be encountered, whose inheritance may be oligogenic or polygenic. Delustrations are *specific resistance* (or vertical) in which the genetic system of resistance in the host corresponds to a virulence system in the parasite (Flor, 1955, 1956; Person, 1959); *non specific general resistance* (or horizontal), characterized by variable manifestations and with a greater complexity in its heredity; or *tolerance*, which indicates the ability of a variety to cope with severe attacks of parasites without severe losses in yield.

The aim of the plant breeders is to obtain a variety with stable resistance to diseases: this is not an easy goal, because resistance depends on the genetic systems of the host and parasite, their interaction (Loegering, 1963), and the environment.

It is fundamental in choosing parents to be used in breeding programs to have the greatest possible variability in the host (Vavilov, 1928) in order to accumulate sources of genes for reaction.

Specific resistance.

Biffen (1905) found that resistance to yellow rust depends on genetic factors inherited in a simple way. Specific resistance (or vertical resistance) plays a very important role in breeding for resistance.

Nevertheless, the great number of biotypes in parasite populations has made it difficult to obtain permanently resistant varieties. Usually the value of specific resistance is limited in space and time and remains stable only in those localities where genes for virulence which can attack the corresponding genes for resistance do not exist or do not appear (Vallega, 1940).

The causes which produce the rapid evolution in the parasite population vary. Parasites populations have an enormous plasticity and have a remarkable ability to adapt to new conditions of the environment (Watson, 1970) including variations in the host resulting from the introduction of new varieties.

When a variety becomes susceptible, it means that a change in the parasite population took place as a result of:

— new races originating through sexual mechanisms facilitated when recessive genes of virulence (Loegering, 1961) occur in a heterozygous population or as a result of heterocaryosis and somatic recombination;

— mutations to virulence;

— the extensive cultivation of a resistant variety has caused selection pressure for virulent biotypes already existing in the population, but originally very rare.

The latter phenomenum happens very often and no doubt it is the most easily recognized.

The stability of resistance in a variety depends on the possibility avoiding or at least reducing some of the evolution processes in the parasite population.

The success of a breeding program using specific resistance will depend essentially on the knowledge of the pathogen population. Using individual races or pathogenic entities permits determination of factors for resistance in the host, which otherwise would be masked if mixed pathogen populations were used.

One of the ways to know in advance the eventual presence of genotypes of virulence which could destroy a new resistant variety, is to cultivate in different localities varieties with well known resistance factors preferably near-isogenic lines, carrying single factors.

While provision would be made to identify the possible variations of the pathogen, attempt would be made to stabilize the parasite through genetic equilibria in host-pathogen systems.

The acquired experience, after many years of breeding for specific resistance in many countries of the world, suggests the best methods by which specific resistance can be efficiently used.

Varieties with a single factor for resistance have less possibility to keep their resistance in comparison to those which have a number of different factors for specific resistance as well as factors for non specific resistance. The development of varieties with several different genes for specific resistance could be a way to avoid sudden and unexpected changes in the parasite (Vallega, 1966; Watson, 1970). The success of several modern varieties, which at present control black rust in different parts of the world, depends on the multiple genes for specific resistance which are incorporated in them.

Rajaram (1968) examined bread wheat varieties which showed a low coefficient of infection to black rust and found that in all these varieties a large number of genes were incorporated to give resistance to many races. The same is true for some *durum* wheats from North-Dakota (Yuma, Ld 390, Wells, Lakota, 6062/6142, D 6722, Ld 393/2, Langdon/3/Ld 398/2/ST 464, D 6515) as well as for some selections of Giorgio, Gerardo and Alex obtained in Italy (V.Z. 482, V.Z. 484, V.Z. 492 and Alex 281). These selections were from crosses with North-Dakota selections which had a low coefficient of infection to black rust in different parts of the world (Kilpatrick, personal communication, data from the International Wheat Rust Nursery). According to Atwall and Watson (1956), Ataullah (1963a), Williams and Gough (1965), Zitelli and

Vallega (1968) and Zitelli (1968), many factors for specific resistance are present in these varieties and lines.

The success of varieties with a broad genetic resistance base might also be due to the relationships among the different genes for resistance giving a complementary or additive effect.

Horizontal resistance.

Horizontal resistance which implies a rather limited attack of the parasite can maintain the stability of the parasite population. This character for the cereal rusts generally is expressed in the adult plant stage, while in the seedling stage the varieties are susceptible. Field resistance is governed by more than one genetic factor (polygenes) and usually is independent of other types of resistance. Horizontal resistance, called by Caldwell (1968) and Hooker (1967) as a « slow rusting », does not avoid the beginning of the infection, but delays the rate of growth of the infection, thus allowing the plant to reach maturity with reduced infected tissues (Browning and Frey, 1969).

Horizontal resistance is considered useful to reduce variation in the parasite population. It may combine in a same variety different genetic systems responsible for reduced rate of penetration of the leaf, fewer lesions per unit area, smaller lesions, fewer spores per lesion, restriction on rate of growth and sporulation over a shorter period. The main disadvantage of this type of resistance is that often it is sensitive to environmental changes (Vallega, 1966; Van Der Plank, 1968 and Watson, 1970). Horizontal resistance can be ascertained only if environmental conditions allow a continuous growth of the parasite. It is only under such conditions that its effectiveness can be measured in a variety that is cultivated extensively. It is difficult to measure horizontal resistance in small experimental plots.

Tolerance.

Tolerance can be determined only by the effect exerted on production (Simons, 1969). It perhaps is impossible to estimate tolerance on segregating generations. Proper techniques are necessary in order to select effectively for this character. On the other hand, Schafer (1971) says that tolerance is based on an arbitrary designation of disease intensity. Therefore a better knowledge of the specific mechanism of tolerance is needed to allow evaluation of the plant by some intermediate process rather than by the final result. It is possible that when the biochemistry of disease, especially the host-parasite interaction, is better known progress might be more rapid (Schafer, 1971). Thus it appears to be very difficult to estimate tolerance during the first phases of the breeding work, however, tolerant varieties could be used as recurrent parents and combined with specific resistant factors.

The use of one or another type of resistance will depend on the problem to be solved and the environmental conditions under varieties are to be cultivated. Thus the methods to be followed in the breeding program will depend on the type of resistance being used.

PATHOLOGICAL SITUATION IN ITALY.

As I said at the beginning, shall Inow review the actual pathological problems of *durum* wheat in Italy and, by extension, in all of the Mediterranean area.

Recent agronomic techniques, the expansion of cultivation outside traditional areas and the introduction of varieties with different genotypes have modified the equilibrium which was established over long periods of time between old populations of *durum* wheat and the parasites. Consequently it became essential to breed varieties resistant to the more common diseases, such as rust and mildew, and others which are becoming more and more important, such as septoriosis, helminthosporiosis and bunt.

It has been ascertained that all the old cultivated Italian varieties are very susceptible to black rust, brown rust and mildew, while they showed a certain resistance to bunt and septoriosis.

Grasso (1968), in an exhaustive review of his and other work on bunt carried out in Italy over a period of 50 years, has demonstrated a generally high degree of resistance in *durum* wheat, particularly the varieties Russello S.G.7, Cappelli, Azizia, Garigliano and Capeiti 8. These results were partially corroborated by Bozzini (1971) in an analysis on the resistance of mutant lines to bunt.

Rosielle (1972) examined the behaviour of 7500 varieties of wheat, including 2000 of *durum*, with respect to artificial infections in the field by *Septoria tritici*. He found that among the 48 varieties which demonstrated a certain degree of resistance, Cappelli, Azizia, Garigliano and Capeiti 8 were resistant or even immune.

It is important therefore that in the breeding program be retained the resistance of these older *durum* varieties.

Some of our observations (unpublished) indicate the importance of this. Some lines of *durum* developed in Northern Italy, which have resistance to rusts and mildew, derived from *Agropyron glaucum*, are highly susceptible to bunt when they are cultivated in the Southern regions, outside their adaptability area.

In the South of Italy, the main region where *durum* wheat has always been cultivated, the epidemies by black rust and mildew were sporadic. In some years severe epidemies developed while in other years the disease did not appear at all.

Thus natural or man-made selection of forms carrying specific or horizontal resistance or tolerance is difficult.

BREEDING FOR DISEASES RESISTANCE IN *T. durum.*

The breeding program carried out in Italy to find a better way to solve these disease problems has been in operation for more than a decade. This program has not neglected the most important agronomic and commercial traits.

In 1960 a search was started for sources of disease resistance to black and brown rusts and mildew in order to have at our disposal the widest possible material of different genetic origin. Materials were obtained from many areas particularly from the centers of origin of wheat. The collections of *durum* and other species of wheat were observed for reaction under natural infection and in the greenhouse to single races which represent the most common races in Italy as well as those which are uncommon but carry important pathogenic factors. The latter will detect the presence of resistance factors that, otherwise, might be masked.

It must be remembered that the identification of resistance factors depends essentially on the use of proper cultures of the parasites. Such investigation is very important in an environment like Italy, where there are a great number of genes for virulence among the parasite species. There is also the possibility that new virulence genes of pathogens, such as the rusts, might be transported from other countries of the Mediterranean area by long-distance dissemination.

Studies on the distribution of physiological races of black and brown rust in Italy were started many years ago by Professor Cesare Sibilia and have been carried on by his collaborators.

In conducting this research particular consideration should be given to the factors for virulence present in the areas near to the centers of origin of the host, because combined with the extreme variability of the host there exists similar variability in the parasite (Vavilov, 1949-50). For instance, in Ethiopia, center of origin of *durum* wheat, black rust races can be found with factors of virulence not present elsewhere (Habel Hak, 1970).

Before using a certain wheat variety which carries specific resistance factors in a breeding program, it is useful to determine the number of factors involved, the mechanism of inheritance, and the relationships with other, already known, factors. This will avoid the use of different wheat varieties carrying the same factors. It is always helpful to use monogenic lines in these studies in order to conduct more accurate tests of allelism and linkage.

When it becomes difficult to find resistant factors within *T. durum*, an attempt must be made to transfer the genes for resistance from other species or genera or to induce mutations.

For example Rusmini in Italy has transferred the resistance to mildew and some black rust races from *Agropyron glaucum* to *durum* wheats.

The first sources of resistance to black rust (Table 1) studied, were a group of wheats from North Dakota: Yuma, Ld 390, Lakota and Wells,

TAB. I - SOURCES OF RESISTANCE TO PUCCINIA GRAMINIS TRITICI USED IN BREEDING WORK IN ITALY

ORIGINAL SOURCES OF RESISTANT GENES		DURUM VARIETIES CARRYING RESISTANT GENES	LINES IN WHICH RESISTANT GENES HAVE BEEN INCORPORATED	NEW DURUM VARIETIES CARRYING RESISTANT GENES
			× CAPPELLI = V.Z. LINES × GIORGIO LINES (← ALEX LINES)	→ GERARDO
T. DICOCCUM	KHAPLI	YUMA *	× CAPPELLI² = ALEX LINES	→ ALEX 281
		LD 390	× CAPPELLI	→ GIORGIO
		ROMAN SELECTION	× GIORGIO	→ GERARDO
	VERNAL	WELLS		
		LAKOTA	× CAPPELLI - - - -	
		S.T. 464		
		BELADI 116**	× CAPPELLI - - - -	
T. DURUM		BALADI P.I.57662		
		GAZA		
		TREMEZ MOLLE		
		PALESTINA P.I.94701		

* also resistant to mildew
** " " " leaf rust

which were known to carry many resistant factors (Ataullah, 1963; Williams and Gough, 1965; Zitelli, 1968). These factors were derived from *T. durum* and from *T. dicoccum* (Briggle and Rettz, 1963): Vernal and Khapli.

These factors, particularly those present in Khapli, were of great importance in controlling the pathogen entities existing in Italy and in the Mediterranean area. Genes of virulence on Vernal were found with a certain frequency in Italy (Zitelli and Vallega, 1968). With respect to the races used, the factors carried by Lakota, Wells, Ld. 390 and Alex 281 (a derived line from Ld 390) are identical. On the other hand, Yuma, which originated from the same cross, carries factors different from those of the above group (Zitelli, 1968).

Two of these wheats, Yuma and Lakota, have also been used by Bozzini (1966) and Bagnara (1971) respectively, in their breeding programs to introduce resistance to black rust.

Some Giorgio lines have inherited all the factors of Ld 390 from the cross of Cappelli with F_2 plants of [(Yt 54-N10B)BY^2] Ld 390-II 14587; others of greater agronomic interest have inherited only one factor from Ld 390, which gives resistance to all the races present in Italy except to the race 116 (Zitelli and Vallega, 1971). This phenomenum of « genetic erosion » is commonly observed when varieties carrying many factors of resistance are used as parents and when the pathogen population carries factors for virulence which cover up the corresponding factors for resistance during the screening process.

In order to introduce additional resistant factors other varieties have been examined. It has been found that the resistance of ST. 464 is conditioned by two factors for resistance with regard to the races present in Italy, however at least one of them is probably the S_{13} of Khapli.

These results are similar to those obtained by Heermann *et al.* (1957), Kenashuk, Anderson and Knott (1959), Heermann (1960), Ataullah (1963b), Williams and Gough (1968) working with different races.

A genetic analysis of Beladi 116 indicates two independent factors (Zitelli, 1972a) which appear different from those carried by Khapli and ST. 464. Weeraratne and Williams (1971) have found at least three factors for resistance in this wheat. At present, studies are being carried on with Gaza, Tremez Molle, and Palestina (P.I. 94701).

Individual factors have been or are being isolated for the creation of near-monogenic lines from some of these wheats.

The sources of resistance to brown rust (Table 2) at our disposal were all found within the *durum* species.

F_2 plants from the cross [(Yt 54-N10B)BY^2] Ld 390 - II 14587 showed resistance to brown rust as well as to black rust.

This resistance to brown rust was transferred to the Giorgio lines through crosses with Cappelli. From the behaviour of the Giorgio lines and further genetic analysis, it became evident that the factors condition-

TAB.2 – SOURCES OF RESISTANCE TO PUCCINIA RECONDITA USED IN BREEDING WORK IN ITALY

ORIGINAL SOURCES OF RESISTANT GENES	DURUM VARIETIES CARRYING RESISTANT GENES	LINES IN WHICH RESISTANT GENES HAVE BEEN INCORPORATED	NEW DURUM VARIETIES CARRYING RESISTANT GENES
		ROMAN SELECTIONS	
	(Yt 54–N10–B)BY^2/Ld 390, II 14587, F_2 plants	×CAPPELLI → GIORGIO LINES →	GIORGIO
		GIORGIO 324 × ALEX LINES, V.Z. ", ITALIAN VARIETIES →	GERARDO
T. DURUM	BELADI 116•, KYPEROUNDA F.S. 50–17, TREMEZ MOLLE•, GAZA•	×CAPPELLI ------	
		×CAPPELLI ------	

• also resistant to stem rust

ing resistance to brown rust are independent from those which confer resistance to black rust (Zitelli, 1972b).

We have also found field resistance (horizontal) factors to brown rust different and independent from the race specific factors in some « Giorgio » and « Gerardo » lines. This is a remarkable result and of importance since such resistance is more permanent.

In Beladi 116 it has also been established that resistance to brown rust is conditioned by two factors independent from those for black rust (Zitelli, 1972a).

At present, other sources of resistance like Kyperounda F.S. 50.17, Tremez Molle and Gaza are under analysis.

Generally the sources of resistance genes to stem and leaf rust are available in wheats poor from the agronomic and quality point of view, thus complicating their use in breeding programs.

Consequently, as a first step these genes for resistance have been transferred to traditional Italian varieties, especially Cappelli. In the second step, resistant lines derived from these crosses and backcrosses have been used for further work.

Resistance to mildew has been transferred in *T. durum* from other species (Table 3). In effect, the variety Yuma, which has been the main source of resistance used in breeding, has the resistant factors derived from *T. dicoccum* cvs. Vernal and Khapli. The Italian mildew population carries genes for virulence on Vernal but the Khapli factors have been effective (Zitelli and Vallega, 1968). However, it is known that there are genes for virulence on Khapli in Brazil (Scharen, personal communication) in Sweden (Lejerstam, personal communication) and in France (Grignac, personal communication). This suggests the necessity to use more than one source of resistance.

In Italy factors for resistance to mildew have been transferred to *T. durum* from *T. timopheevi*, through the bread wheat, Wisconsin sel. C.I. 12632 by Tosoni, and from *Agropyron glaucum* by Rusmini.

Genetical analysis of *durum* wheats to which the resistant factors of Wisconsin sel.C.I. 12632 have been transferred, demonstrate the presence of two factors, one of them with incomplete dominance, confirming what had been found in bread wheats (Zitelli, 1972a).

The resistance derived from *Agropyron glaucum* is intermediate and conditioned by many partially recessive factors. Other sources of resistance to mildew have been found in *T. monococcum* and *T. timopheevi*. These species also carry genes for immunity to *Septoria tritici* and *nodorum*.

Bozzini (1966) has used *T. carthlicum* in his breeding program for resistance to mildew.

According to Wolfe (personal communication) the factor of *T. carthlicum* is located on chromosome 2 A. One of the Khapli fac-

TAB. 3 - SOURCES OF RESISTANCE TO ERYSIPHE GRAMINIS USED IN BREEDING WORK IN ITALY

ORIGINAL SOURCES OF RESISTANT GENES	VARIETIES CARRYING RESISTANT GENES	LINES IN WHICH RESISTANT GENES HAVE BEEN INCORPORATED	NEW DURUM VARIETIES CARRYING RESISTANT GENES
T. DICOCCUM (KHAPLI, VERNAL)	YUMA x CAPPELLI →	V. Z. LINES x GIORGIO LINES →	GERARDO
T. TIMOPHEEVI	WISC. SEL. C.I. 12632 →	I.S.C. 6375, I.S.C. 6378	
AGROPYRON GLAUCUM →	→	→	I.S.C. 6000
T. CARTHLICUM			
T. MONOCOCCUM *			
T. TIMOPHEEVI *			

* also resistant to SEPTORIA

tors is also located on this chromosome and has been transferred to the bread wheat Chancellor.

In conclusion, in order to obtain success in the breeding of *durum* wheat for resistance to diseases it is necessary to:

1) have at our disposal as many sources of different resistant factors as possible. In this respect international cooperative research is essential, so that broad based information can be obtained.

2) carry out the breeding program in such a way as to introduce continuously different resistant factors. This will enable us to compete with the variation in the pathogenicity which naturally occurs in the parasites.

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ABSTRACT

The cultivation of resistant varieties appears without any doubt a mean of great possibilities allowing to avoid yield losses caused by diseases in an extensive crop, such as wheat. Consequently, the incorporation of resistance or, at least, of tolerance to diseases in wheat varieties is a tool that allows yield increase, but especially it offers a satisfactory yield stability.

Furthermore, in considering the *durum* wheat, the equilibrium that had been established in certain regions during long periods between old populations and parasites has been changed by the recent agronomic tecniques, the expansion of the cultivation outside the traditional areas and the introduction of varieties with different genotypes. As a consequence, it has become necessary to breed varieties resistant to the most common diseases, such as rusts, mildew and others which are becoming more and more important, as septoriosis, helminthosporiosis and bunt.

It is of basic importance, in the work of genetic improvement for resistance, the availability of the greatest variability which permits to pick up the most interesting resistance sources, their nature and the best way to use them.

The study of the genetic variability of the host, the parasite and their complex as well as the study of the nature and the inheritance mechanism conditioning resistance, are indispensable to give a scientific basis to breed resistant varieties.

IL MIGLIORAMENTO GENETICO DEL FRUMENTO DURO PER RESISTENZA ALLE MALATTIE

RIASSUNTO

La coltivazione di varietà resistenti è un mezzo efficace per evitare perdite nelle rese a causa delle malattie in una coltivazione estensiva come quella del frumento. Di conseguenza l'incorporazione della resistenza, o almeno della tolleranza, alle malattie nelle varietà di frumento è un mezzo che permette di aumentare le rese ma specialmente offre una maggiore stabilità di produzione.

Inoltre, considerando il frumento duro, le recenti tecniche agronomiche, l'espansione della coltivazione al di fuori delle aree tradizionali e l'introduzione di varietà con differente genotipo hanno modificato l'equilibrio che si era stabilito in alcune regioni per lunghi periodi tra le vecchie

popolazioni e i parassiti. Pertanto si è reso necessario costituire varietà resistenti alle più comuni malattie, come la ruggine e l'oidio e altre che stanno assumendo sempre una maggiore importanza come septoria, elmintosporio e carie.

È essenziale nel lavoro di miglioramento genetico per resistenza avere a disposizione la maggiore variabilità possibile per scegliere le fonti di resistenza più interessanti e conoscere la loro natura e il modo migliore per usarle.

Lo studio della variabilità genetica dell'ospite, del parassita e del loro insieme, ed anche lo studio della natura e dei meccanismi ereditari che condizionano la resistenza sono indispensabili per conferire una base scientifica alla costituzione di varietà resistenti.