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BREEDING FOR RESISTANCE TO ALUMINUM TOXICITY IN WHEAT

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Crop development is influenced by the interaction of many factors, including such things as soil moisture, temperature, and mineral stress. Mineral stress in plants can be caused by either nutritional deficiencies or toxicities. Deficiencies of one or more essential plant nutrients is widespread in developing countries, resulting in low productivity in vast areas of "worn out" soils. There are also large areas of the World, an estimated 2,960,800,000 hectares representing 22.46 percent of the world land area, that are adversely affected by mineral toxicities and/or deficiencies (Duval, 1976).

Among these problem soils are the highly leached acidic Oxisols and Ultisols, which are characterized by toxic levels of soluble aluminum (Al) and manganese. These soils cover approximately 1 billion hectares of the tropical and sub-tropical areas of Brazil, Southeast China, Southeast Asia, and Central Africa (Van Wambeke, 1976). Currently, these areas are either undeveloped for agriculture, or where cultivated, are of very low productivity. To meet a rapidly growing demand for food during the next four decades, these problem soils must be developed and improved in productivity. This can be done by a combination of plant improvement, corrective chemical fertilization, and improved management practices.

Aluminum and manganese toxicities are among the most important factors limiting the growth of crop plants in many acid soils of the world (Foy, 1973, 1974; Kamprath and Foy, 1971; Mc Lean, 1976; Olmos and Camargo, 1976; Da Silva, 1976). Aluminum toxicity is particularly severe below pH 5.0, but has been reported in soils with pH values as high as 5.5 (Adams and Lund, 1966; Hester, 1935). The current approach to soil fertility recommends changing the soil pH by liming, which is not always economically feasible, particularly in strongly acidic subsoils.

Fortunately, however, a range of tolerance to Al toxicity has been found to be genetically controlled in a considerable number of species and varieties of crops (Moore et al., 1976; Camargo et al., 1980; Kerridge et al., 1971; Konzak et al., 1976). Aluminum toxicity severely inhibits root growth (Foy, 1974) by preventing cell division (Clarkson, 1965, 1968; Henning, 1975) in the root apical meristem. The resulting drastically restricted root sistem makes the plant vulnerable to moisture stress and unable to utilize low levels of available essential plant nutrients.

Brazilian wheat breeders pioneered the development of selecting wheat varieties for resistance to Al toxicity. This work was initiated in 1925 (Beckman, 1976), and over the past five decades has resulted in a large number of resistant varieties. Unfortunately, without exception these varieties are of poor agronomic type and have low genetic yield potential. On the other hand, the CIMMYT wheat varieties possess broad adaptation and high genetic yield potential, but without exception are susceptible to Al toxicity and are poorly adapted to acid soils. Seven years ago, CIMMYT, in collaboration with Brazilian wheat scientists, undertook a cooperative breeding program to combine the resistance to Al toxicity of the Brazilian varieties with the high genetic yield potential and the broad adaptation of the CIMMYT varieties. Currently, there are many advanced generation wheat lines developed by this cooperative program that are in the final stages of testing. These lines combine resistance to Al toxicity, good agronomic characteristics, a broader spectrum of disease resistance, and high yield potential. This paper summarizes the CIMMYT-BRAZILIAN cooperative breeding program, the screening procedures employed, and the results so far obtained.

Laboratory screening procedure used to identify varieties and segregating generations with tolerance to Al toxicity.

The screening procedure (Polle et al., 1978) adopted at CIMMYT for detecting tolerance to soluble Al in wheat is based upon the visual estimation of the extent of hematoxylin staining of seedling roots following exposure to several levels of Al concentration.

The procedure employed consists of the following steps:

1) Expose seeds for 24 hours in aerated distilled water under light at 25°C to induce germination;
2) Transfer and expose germinated seedlings to aerated nutrient solution buffered at pH 4.0 under light at 25°C for 32 hours;
3) Transfer and expose seedlings to nutrient solution containing Al buffered at pH 4.0 under light at 25°C for

approximately 17 hours (overnight);

4) Transfer seedlings to aerated distilled water for 30-60 minutes to remove Al;

5) Transfer and expose seedlings to hematoxylin solution for 15 minutes;

6) Remove seedlings and wash roots in distilled water for 1 minute;

7) Remove and place seedling roots in aerated distilled water for 3 hours;

8) Remove seedling roots to observe differential staining in root tips, and on the basis of these observations, classify varieties and segregating populations into three categories: susceptible, moderately resistant, and resistant.

In conducting the screening tests, two varieties are used as standard checks. One is Maringa, a Brazilian variety known to be highly resistant to Al toxicity under field conditions, and the second is Jupateco 73, a CIMMYT variety known to be highly susceptible to Al toxicity.

Even though CIMMYT has been primarily concerned with evaluating and screening wheat and triticale varieties for tolerance to Al, we have been recently exploring in a preliminary way the reaction of other crop species, such as, rye, barley, sorghum, and millet to variable concentrations of Al. The concentrations used in these tests, together with the reaction of the different crop plant varieties, are shown in Table 1.

Cultivars of rye and triticale are resistant to a concentration of 2.3 mM of Al, while all other crops reported here are susceptible to that concentration. The only exception to this is one variety of Pearl millet C, which is moderately resistant to 2.40 mM of Al. Two cultivars of barley, and four cultivars of sorghum are susceptible to concentrations of 0.67 mM and 1.40 mM of Al, respectively. Among the wheat cultivars, two durums are susceptible, while bread wheats show differential reactions to the concentrations of 1.4 mM and 1.9 mM, and are uniformly susceptible to 2.3 mM of Al. It is obvious that cultivars of rye, triticale, and pearl millet C should have better performance in Al toxic acid soils.

<u>The use of cooperative shuttle - breeding programs between Mexico and Brazil for the development of aluminum tolerant, disease resistant, high-yielding varieties adapted to acid soils</u>.

Most Brazilian wheat varieties tend to grow tall and lodge, as well as produce spikes with only two or (rarely) three grains per spikelet. These two defects together largely account for their low genetic yield potential.

The CIMMYT wheat breeding program has attempted, during the last seven years, to breed high-yielding, semi-dwarf, broadly adapted varieties with high levels of tolerance to soluble aluminum. This project has evolved into a cooperative effort between CIMMYT and three Brazilian wheat programs: (1) EMBRAPA at the National Wheat Research Center at Passo Fundo, (2) FECOTRIGO at Cruz Alta (Passo Fundo and Cruz Alta are located in the State of Rio Grande do Sul), and (3) OCEPAR at Cascavel (located in the State of Paranâ). Crosses between Al tolerant Brazilian varieties and the broadly adapted, high-yielding, semi-dwarf CIMMYT varieties (Table 2) are conducted and selections are made in segregating generations at two locations in Mexico: 1) the CIANO Research Center, Ciudad Obregon, Sonora, located at 28°N latitude and 40 meters above sea level, and 2) the CIMMYT Research Center at Toluca, State of Mexico, at 19°N latitude and an elevation, 2,560 meters.

The broad adaptation combined with the high genetic yield potential and the broad spectrum of rust resistance of the CIMMYT semi-dwarf wheat varieties triggered the so-called "Green Revolution", which began in Mexico and subsequently spread to many other parts of the world. In large part, the wide adaptation and broad spectrum of disease resistance of the CIMMYT varieties is attributable to the shuttling of genetic materials in alternate segregating generations between the two aforementioned Mexican States, which are very diverse in climatic and ecological conditions. In Ciudad Obregon, the plantings are made in November when days are growing shorter, whereas the plantings in Toluca are made in May when the days are getting longer. Consequently, the shuttling of plants from alternate generations at these two locations made possible the indentification of photo insensitive lines.

CIMMYT efforts to develop high-yielding aluminum tolerant varieties has serious obstacles to overcome. There are no suitable and readily accessible locations in Mexico for establishing breeding nurseries on soils with high levels of acidity and soluble Al. Consequently, CIMMYT has been forced to rely heavily on the laboratory screening test described earlier for identifying progenitors and progenies with good levels of tolerance to Al toxicity. When the results from the laboratory screening tests are combined with the cooperative shuttle breeding effort, the results have been very positive. Promising segregating materials identified in the laboratory are selected and grown under three different acid soil conditions in Brazil, and at the two non-acidic sites at Toluca and Ciudad Obregon, Mexico. Response information is then opportunely transmitted to all collaborators by telex. Data on laboratory responses and field performance under extremely acid soil conditions are highly correlated and complement one another.

Four-hundred and twelve advanced generation lines of bread wheat were produced by the shuttle program by the end of 1980. These lines have combined the Al tolerance of Brazilian wheats with the high yield potential of CIMMYT semi-dwarf wheats. Small samples of these varieties were distributed in Cameroon, Ethiopia, Kenya, Malawi, Mozambique, Rwanda, Tanzania, Zambia, India, Brazil, Ecuador, Guyana, and Paraguay; where acidity poses problems in wheat production. Preliminary screening results from Brazil, Ecuador, Zambia, and Kenya indicate that the performance of these lines is superior with respect to Al tolerance. A considerable number of these lines also appear to possess an unusually broad spectrum of resistance to a complex of leaf diseases, including several species of *Fusarium*, *Helminthosporium* and *Septoria*. We believe that this combination of resistance to Al toxicity in high-yielding semi-dwarf wheat may further broaden the adaptation of CIMMYT wheats to problem soils.

Alondra - an exception

Alondra is a semi-dwarf high-yielding variety moderately tolerant to Al, and is derived from the cross D6301-Nainari 60 x Weique - Red Mace x Ciano^2-Chris, (CM11683). Alondra's tolerance to Al is believed to be inherited from the rye variety Weique. In Alondra, the chromosome 1B is substituted by 1R (Mujeeb, Personal Communication). This variety shows a moderate level of Al tolerance in Brazilian acid soils, but a completely susceptible reaction to Al toxicity in our laboratory tests. Tests conducted at Washington State University have shown that the Al tolerance of Alodnra is due to its ability to extract and utilize phosphorus under a low level of availability, rather than resistance to Al toxicity per se (Konzak, Personal Communication). This being true, a breeding system can be developed in which the resistance to Al toxicity of Brazilian varieties could be combined with the efficiency of Alondra to extract and utilize phosphorus (which is a limiting factor in acid soils).

Triticale - an alternative crop for acid soils

It has become evident in recent years, that triticales are relatively better adapted than wheats in acid soils with high levels of soluble Al (Table 1). Under these soil conditions, triticales will out-yield wheats, including the Al tolerant Brazilian varieties, by from 50 to 100 percent. If the grain quality (plumpness) can be improved and combined by breeding with earlier maturity, triticale may become an important commercial crop in some problem acid soils where wheats develop poorly.

Varieties of crop plants with tolerance to aluminum toxicities and other mineral stresses are not an elixir for solving food production problems.

Considerable progress has already been made in breeding wheat varieties with higher levels of tolerance to aluminum toxicity and (in other cases) the ability to extract essential plant nutrients from soils of low fertility. This does not imply, however, that we can anticipate harvesting high grain yields without employing good agronomic and fertilization practices so that essential plant nutrients are restored to levels which permit the economic production of reasonable yields of grain. What these new developments do imply is that if dynamic breeding programs are continued, it may be possible to breed better varieties that have the genetic potential to produce acceptable but modest levels of grain yield with lower levels of fertilizer application (i.e. N,P, K,Ca,Mg, S or minor nutrients).

Table 1. Reaction of crop plant varieties to three levels of soluble Aluminum.

CROP	VARIETY	mM of Al. 1.4	mM of Al. 1.9	mM of Al. 2.3
Bread Wheat:	Maringa	R	R	S
	C N T 8	S	S	S
	Alondra S 16	S	S	S
	Pavón 76	R	S	S
	Jupateco 73	S	S	S
Durum Wheat:	Yavaros 79	S	S	S
	Mexicali 75	S	S	S
Rye:	Snoopy	R	R	R
	Prolific	R	R	R
	Blanco	R	R	R
Triticale:	Cananea 79	R	R	R
	Caborca 79	R	R	R
		mM of Al. 0.30	**mM of Al. 0.50**	**mM of Al. 0.67**
Barley:	Cerro Prieto	R	MR	S
	Apizaco	R	MR	S
		mM of Al. 0.60	**mM of Al. 1.00**	**mM of Al. 1.40**
Sorghum:	PR 81A-F_3 B	R	MR	S
	BTP - 144	R	S	S
	A.A.S.	R	S	S
	Cold Tolerant	R	S	S
		mM of Al. 1.60	**mM of Al. 2.00**	**mM of Al. 2.40**
Millet: Proso Millet	B80-29	S	S	S
	B80-44	MS	MS	S
Foxtail millet	# 58	R	S	S
	# 445	R	S	S
	Pearl Millet C	R	MR	MR

R= Resistant
MR= Moderately Resistant
S= Susceptible

Table 2. List of Brazilian Al toxicity resistant varieties and CIMMYT semi-dwarf high-yielding wheats used in breeding at CIMMYT

Al Toxicity Resistant Varieties	Semi-dwarf high yielding CIMMYT Lines
Pel 72018, S12-B8 x Pj, Pat 8 B15, Maringa,Cinquentenario, PAT 19, IAS 54, IAS 63, PF 70354, IAS 58, IAS 62, CNT 7, PF 72640, PAT739, Horto, PAT 49, Pel 72380-Atr 70, PAT 10, Abura, Jacui, PF 70402, PAT 72160, Lagoa Vermelha, CEP 74230	Pavon 76, Chuckar "S". Aldan"S", Kalyan-Blue bird, Bananaquit, Siskin, Musala, Alondra"S", Emu, Madeira"S", HD2182

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