

COLD TOLERANCE AND ITS RELEVANCE TO MAIZE BREEDING IN NEW ZEALAND

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ABSTRACT

Low temperatures can inhibit the growth of maize plants by inhibiting germination and seedling emergence; by inhibiting photosynthetically based growth; or by freezing plant tissue. Cold tolerance can mean increased tolerance to any of these processes.

The minimum temperature for germination and emergence of maize is about 10°C. Some genotypes from the highlands of Mexico have more rapid and reliable seedling emergence and early seedling growth near 10°C than the hybrid cultivars presently grown in New Zealand.

The minimum temperature for photosynthesis in maize is generally considered to be 15°C. Genotypes from the highlands of Peru have the ability to grow photosynthetically at 13°C. These genotypes have a longer effective growing season than conventional cultivars in environments where night temperatures regularly fall below 15°C and day temperatures are not high. This occurs in many of the maize-growing regions of New Zealand.

Generally, seedling maize plants are not killed by temperatures as low as -2°C for short periods, but exposure to lower temperatures, or exposure for periods longer than 12 hours, can kill maize plants. Genetic variability exists for tolerance to mild frosts, but scarcely has this been utilized.

Temperatures in the region of the United States where all current New Zealand cultivars were selected are higher in the summer than in New Zealand. Temperatures in parts of the highlands of Mexico and Peru are lower and races of maize from these regions should provide a useful source of genes for improving the tolerance of New Zealand cultivars to low temperatures, and hence, their adaptation to the New Zealand environment.

INTRODUCTION

Hybrid maize cultivars which currently are grown commercially in New Zealand were all developed for Minnesota, Wisconsin and nearby states of the United States. The race of maize used to produce these cultivars is the U.S. Cornbelt Dent, which was synthesized from the Northern Flint and Southern Dent races about the middle of the 19th century (Anderson and Brown, 1952).

Maize is traditionally sown in Wisconsin in May at a time when the probability of frost has diminished and temperatures are rising rapidly (Table 1). However, temperatures rise at a slower rate during the

spring in New Zealand than in Wisconsin. Furthermore, mid-summer temperatures in Wisconsin are much higher than at Ruakura, in the South Auckland/Bay of Plenty region where most New Zealand maize crops are grown (Table 1). Mean maximum temperatures for Gisborne, the warmest maize growing region of New Zealand, are about 1°C higher than at Ruakura during November, December and January, but about equal during February and March (Anon, 1973). Temperatures in Palmerston North in the coolest maize growing region are lower (Table 1).

TABLE 1: Mean monthly maximum and minimum temperatures (°C) during the maize growing seasons of Ruakura and Palmerston North, New Zealand; Huancayo, Peru; Madison, Wisconsin, U.S.A.; and Atizapan, Mexico.

Month	Southern Hemisphere					Northern Hemisphere					
	Ruakura ¹		Palmerston North ²		Huancayo ³		Madison ⁴		Atizapan ⁵		
	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	
Nov.	19.9	8.9	18.5	9.7	20	6	May	20.7	7.5	23.7	4.1
Dec.	22.0	10.6	20.6	11.5	19	6	June	26.2	13.2	21.5	7.0
Jan.	23.5	11.5	21.8	12.6	18	7	July	29.8	15.7	20.4	6.6
Feb.	24.0	12.0	22.2	12.6	18	7	Aug.	28.4	14.6	21.0	6.6
Mar.	22.6	10.6	20.9	11.5	18	6	Sept.	23.1	10.3	21.2	6.9
Apr.	19.8	8.3	18.1	9.4	19	5	Oct.	16.3	4.2	21.5	4.6

¹ 1930-1970. Source: Anon (1973).

² 1928-1970. Source: Anon (1973).

³ 1948-1951 and 1955-1970. Source: Johnson (1976).

⁴ 1921-1950. Source: Waite (1960).

⁵ 1975-1977. Source: CIMMYT unpublished meteorological data.

Low temperatures can affect the growth of maize plants in at least three distinct ways.

1. By inhibiting or slowing germination and seedling emergence.
2. By inhibiting or slowing photosynthetically based growth.
3. By freezing plant tissue.

The objective of the maize breeding and physiology programme of the Plant Physiology Division, DSIR, is to identify sources of genes for improving the growth and yield of maize plants at low temperatures and to incorporate these genes into agronomically acceptable cultivars for New Zealand conditions.

GERMINATION AND SEEDLING EMERGENCE

Germination and seedling emergence of maize, which is dependent on the utilization of endosperm reserves, is possible at temperatures as low as 10°C (Blacklow, 1972; Eagles and Hardacre, 1979a). Below this temperature seedling emergence is very slow and damage from seed-rotting micro-organisms can reduce plant populations ultimately grain yields.

Much of the early work on germination and emergence had the aim of identifying genotypes with greater ability to withstand fungal attack in cold, wet soil without the protection of fungicides. Genetic variation exists in maize for this trait and appears to be predominately a property of the female (Pinnell, 1949; Pesev, 1970). This is not surprising, as the outermost layer of tissue of the maize kernel, the pericarp, is of maternal origin.

Genetic variability also exists in maize for speed and reliability of emergence near the 10°C threshold when fungal attack has been suppressed (Mock and Eberhart, 1972; Mock and Skrdla, 1978; Eagles and Hardacre, 1979a). Again, the contribution of the female parent appears to be much greater than the contribution of the male (Eagles and Hardacre, 1979a). Speed of emergence is independent of kernel weight, which is predominantly a maternally inherited character (Eagles and Hardacre, 1979a,b), so in my opinion a satisfactory explanation for the predominant influence of the female parent on early seedling growth has not been made.

Faster emerging genotypes maintain a growth and development advantage at least until the 3rd leaf is emerging (Eagles and Hardacre, 1979b), and probably for much longer (Cardwell *et al.*, 1979). Conceivably, faster emerging genotypes utilize endosperm reserves faster than slower emerging genotypes (Derieux, 1978; Eagles and Hardacre, 1979b), perhaps because of a faster, or more efficient respiration-based growth at low temperatures.

Some lines selected from Pool 5, a broad-based maize population developed in the highlands of Mexico (CIMMYT, 1974), had much faster and more reliable emergence at 10°C and 15°C day/10°C night conditions than hybrid cultivars based on Cornbelt Dent germplasm (Eagles and Hardacre, 1979a,b). Further experiments with a wider range of hybrid cultivars and Cornbelt Dent populations have confirmed the superior seedling emergence characteristics of these selections at a range of low temperatures, and suggested that the source of the genes for superior emergence in Pool 5 may be

Conico, a highland race from Mexico (Eagles, in preparation).

Imbibition of low moisture kernels (6%) at temperatures near 5°C can produce malformed seedlings, and reduced seedling growth rates, when plants are returned to warm conditions (Cal and Obendorf, 1972). The effect of imbibition at low temperatures can be alleviated by using kernels with a moisture content above 13% (Cal and Obendorf, 1972). Genetic variation exists in maize for the trait and again appears to be predominantly a property of the female parent (Cal and Obendorf, 1972).

PHOTOSYNTHETICALLY BASED GROWTH

Photosynthesis occurs slowly, or not at all, below 15°C in North American and European cultivars (McWilliam and Naylor, 1967; Alberda, 1969). Continual exposure to temperatures below 15°C in light results in the failure of the photosynthetic system and is characterised by chlorosis of the leaves followed by the development of necrotic patches and ultimately death of the plant (McWilliam and Naylor, 1967; Taylor and Rowley, 1971). Plants grown initially under warm conditions (23°C day / 11°C night), then moved to cooler conditions (17°C day/5°C night), show a reduced chlorophyll concentration per unit leaf area, reduced photosynthetic rates and drastically reduced growth rates (Teeri *et al.*, 1977). Thus, periods of cooler weather, typical of those which occur during the November and December in New Zealand, can drastically reduce growth rates in maize.

Derieux (1978), working under cool field conditions in the north of France, considered low temperature effects were most critical immediately after the exhaustion of the endosperm reserves. This stage occurs when 4 to 5 leaves are visible and coincides with the period when the ear shoots are initiated (Hanway, 1971; Derieux, 1978). This stage occurs in November or early December in New Zealand, and conceivably low temperatures at this time could reduce grain yield by reducing grain number. Thus, genotypes capable of effective photosynthesis at lower temperatures at this stage of growth could be of great value in cool temperate regions.

Recently, we have shown that races of maize from above 2600m altitude in the Andes of Peru have the ability to grow photosynthetically at 13°C (Hardacre and Eagles, 1980). Hybrid cultivars typical of those grown commercially in New Zealand were unable to grow photosynthetically at this temperature. Furthermore, Pollmer (1969) found that crosses between highland Peruvian populations and European flint or U.S. dent genotypes had superior growth to other genotypes under cool conditions in the field in Germany. Criollo de Toluca, a Conico population from about 2600m altitude in Mexico, was unable to grow at 13°C, but crosses between Criollo de Toluca and U.S. dent inbred lines were able to grow at 13°C (Hardacre and Eagles, 1980). This population, and the highland Peruvian populations, could contribute the genes required for the improvement of the growth of maize cultivars in cool temperate regions.

FROST DAMAGE

Frost damage is a hazard to maize production in spring when plants are small and in autumn when physiological maturity is approaching. Freezing temperatures during summer would be devastating to a maize crop, but rarely occur in established maize growing regions.

Young maize plants can be damaged by exposure to temperatures of -1°C to -2°C for periods of less than 12 hours, but in general will not be killed by frosts of this magnitude (Aberg and Akerberg 1958; Buican, 1969; Shaw 1977). Exposure to -2°C for longer periods, or exposure to lower temperatures will kill maize plants (Buican, 1969).

The growing point of a maize plant is below the soil surface until six leaves have emerged (Hanway 1971). Minimum soil temperatures are usually higher than minimum air temperatures on a frosty morning, and this helps to protect the growing point from frost damage (Shaw, 1977).

Genetic variability exists for seedling tolerance to mild frost damage (Aberg and Akerberg, 1958; Buican, 1969; Gupta and Kovacs, 1976). However, I have been unable to find any reference to an extensive search for genotypes with superior tolerance to frosting. High altitude races from Peru and Mexico have not been extensively tested, although field observations by plant physiologists and plant breeders at the International Maize and Wheat Improvement Center (CIMMYT) in Mexico have suggested that Peruvian and Mexican races may be tolerant of light frosts (Dr G. O. Edmeades, personal communication).

Little research has been done on the effect of frosts on maize during the autumn grain-filling period. Obviously, a severe frost would kill the plants and grain-filling would cease. However, considerable increases in grain weight sometimes occur by the transfer of soluble carbohydrates from the stalks to the grain after the leaves are killed by a frost (Daynard *et al.*, 1969). However, this transfer inevitably depletes the soluble carbohydrates in the stalk and markedly increases the susceptibility of the plants to lodging (Mortimore and Ward, 1964).

RELEVANCE TO MAIZE BREEDING IN NEW ZEALAND

McCormick (1979) has shown that poor maize in the South Auckland/Bay of Plenty region are associated with cool spring temperatures. Therefore, maize yields in this region, and probably most other regions of New Zealand, should be improved by genetically improving the tolerance of New Zealand cultivars to low spring temperatures. Furthermore, because both day and night temperatures in summer are lower in New Zealand than in Wisconsin (Table 1), tolerance to high temperatures should be less important in New Zealand.

Races of maize from highland areas of Peru and Mexico should be good sources of genes for improving the growth of New Zealand maize cultivars at low temperature. In my plant breeding programme, I have concentrated on Pool 5, a CIMMYT population containing germplasm predominantly from the highlands of Mexico but also from the highlands of

Peru and other regions of the world with cool summers (CIMMYT, 1974). I have also used San Geronimo, from the Mantaro Valley near Huancayo, Peru, and Criollo de Toluca, from near Atizapan in the Toluca Valley of Mexico. Temperatures in both these places are lower than in New Zealand during the day, and much lower at night (Table 1). In fact, normal temperature conditions at Huancayo are only slightly warmer than the $17^{\circ}\text{C}/5^{\circ}\text{C}$ stress conditions imposed by Teeri *et al.* (1977).

No wonder that centuries of evolution in these climatic conditions have produced races with better tolerance of low temperatures than the U.S. Cornbelt Dent race which is currently used to produce all New Zealand cultivars.

When grown at Palmerston North, neither Criollo de Toluca nor San Geronimo were agronomically attractive. Criollo de Toluca had very weak roots and San Geronimo was late to silk and had poor resistance to cob rots. The American breeders hold the highland Peruvian races in low esteem (Goodman and Bird, 1977), as do the Germans (Pollmer, 1969). A three replicate experiment conducted on the Aorangi Farm near Palmerston North in the 1978-1979 season confirmed the low yield potential of both populations and the late silking, late maturity of San Geronimo (Table 2). The population of 69,000

TABLE 2: Grain yields, grain moisture on 7 May 1979 and silking data for two exotic races of maize, their crosses to two widely used U.S. Cornbelt Dent inbred lines, and some check hybrids.

Genotypes	Silking (Days after 1.1.79)	Grain at harvest (%)	Yield moisture (tonnes/ha)
San Geronimo	45	55.9	1.4
Criollo de Toluca	36	30.9	4.9
A619 x San Geronimo	36	40.0	11.5
A619 x Criollo de Toluca	34	34.4	15.0
A619 x A632	28	31.0	12.9
W117 x San Geronimo	35	37.0	11.4
W117 x Criollo de Toluca	31	32.0	11.4
W117 x A632	28	27.9	12.4
W346	25	26.1	11.7
INRA 200	18	29.2	8.9
A641 x W182 BN	26	20.9	13.6
L.S.D. (P= 0.05)	4	3.5	2.3

Sown: 25 October 1978

Harvested: 7 May 1979

Population: 69,000 plants/ha.

plants/ha was too high for these races and most plants failed to produce an ear. In my crossing nursery, where the population was 34,000 plants/ha, most plants produced ears, so yields probably would have been higher at lower densities. When San Geronimo and Criollo de Toluca were crossed to the elite U.S. inbred lines A619 and W117, yields produced were similar to those of the U.S. hybrids A619 x A632, W117 x A632, A641 x W182BN and W346 and higher than the yield of the European hybrid INRA 200 (Table 2). The U.S. hybrids used were similar to hybrids grown commercially in New Zealand.

In the United States, crosses between exotic races

and elite, adapted germplasm usually do not produce yields as high as that from an adapted hybrid, and when they do, the grain moisture contents are higher than for the adapted hybrid (Kramer and Ullstrup, 1959). Grain moisture contents of the crosses of San Geronimo and Criollo de Toluca with A619 and W117 were higher than for A619 x A632 or W117 x A632, but not markedly so for crosses involving Criollo de Toluca (Table 2). Silking dates were also later for crosses involving the two highland populations (Table 2). Nevertheless, considering the poor adaptation of San Geronimo and Criollo de Toluca to the plant density used in this experiment, the yields obtained for the crosses of San Geronimo and Criollo de Toluca with A619 and W117 were remarkable, which strongly suggests that a programme to introgress genes from these highland races into elite U.S. inbred lines or synthetic populations should produce cultivars with superior adaptation to New Zealand conditions.

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