Physiological Basis of Stress Tolerance in Maize
– Effects of Shading and Drought Stress

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Introduction

Genetic improvement in maize (*Zea mays* L.) is associated with increased stress tolerance, but the physiological mechanisms that confer general stress tolerance have not been identified. Darwin suggested that hybrid vigour conferred stress tolerance and maize hybrids and their parental inbred lines could function as a model for the identification of physiological mechanisms underlying stress tolerance. This study was undertaken in an outdoor hydroponic system at Guelph, Ontario, to show how hybrids are more tolerant to environmental stresses (shading, drought, low soil N, high plant density, and low temperature) than their parental inbred lines.

Here we present data of the 2004 season for shading and drought stress on dry matter accumulation, leaf senescence, and grain yield.

Materials and Methods

Genetic material consisted of the maize hybrid CG60xMBS1236 and its parental inbred lines. The stress treatments were shading stress (55% light reduction by artificial shading vs. control, Fig. 1a) and drought stress (water supply was 50% of daily transpiration relative to its control, Fig. 1b) The stresses were imposed for a 3-week period during two developmental phases (from 1 week pre-silking to 2 week post-silking, i.e., Stress I and from 2 to 5 week post-silking, i.e., Stress II).

Plants were grown in an outdoor hydroponic system (Fig. 2). Experimental design was a strip-split plot with three replications. Dry matter accumulation and partitioning were quantified at the beginning and end of each stress treatment period. Grain yield was determined at maturity and leaf senescence was measured from silking to physiological maturity.

Fig. 1a. Plants receive 45% light in shading structure.

Fig. 1b. Pails covered with plastic bags to control water supply.

Results

Dry matter accumulation and partitioning

- Total dry matter decreased by 8 to 33% at the end of stress periods and maturity for the hybrid and its parental lines due to shading and drought stress (Table 1).
- Dry matter reductions were generally greater at Stress I than at Stress II for all three genotypes. Overall, the percentage of total dry matter reductions for the hybrid were similar to that of their two inbred parents.

Fig. 2. Outdoor hydroponic system with shading structure

Table 1. Total dry matter (TDM) and reductions relative to the control at the end of stress periods and maturity (α=0.05).

Treatment	CG60	MBS1236	CG60xMBS1236
	TDM (g plant^{-1}) or reduction (%)		
Stress I			
Control	134.2	184.2	238.9
Shading	25.2*	17.7*	25.4*
Drought	7.7*	10.3*	16.6*
Stress II			
Control	188.7	245.2	330.3
Shading	14.8*	19.6*	22.2*
Drought	2.9	3.4	15.6*
At maturity			
Control	184.6	236.7	358.0
Shading stress I	31.0*	15.1*	12.4*
Shading stress II	22.8*	15.1*	18.5*
Drought stress I	28.9*	28.2*	32.5*
Drought stress II	16.8*	12.7*	19.2*

- Root/shoot ratio was consistently higher in drought stress I than in the control and other stresses for all genotypes (Fig. 4a). Inbred lines allocated relatively more dry matter to roots than the hybrid at maturity, especially under stressed conditions (Table 2).

Table 2. Root/shoot ratio of maize under shading and drought stress at the end of stress periods and maturity.

Treatment	CG60	MBS1236	CG60xMBS1236
Stress I			
Control	0.22b	0.28c	0.26b
Shading	0.23b	0.33b	0.27b
Drought	0.29a	0.38a	0.31a
Stress II			
Control	0.13	0.24	0.17b
Shading	0.14	0.23	0.18ab
Drought	0.15	0.24	0.19a
At maturity			
Control	0.11c	0.20b	0.12b
Shading stress I	0.20c	0.20b	0.11b
Shading stress II	0.13b	0.21b	0.11b
Drought stress I	0.21a	0.30a	0.17a
Drought stress II	0.13b	0.21b	0.12b

Rate of leaf senescence

- Rate of leaf senescence was significantly lower for the hybrid compared to its parental inbreds under both stressed and non-stressed conditions (Fig. 3).

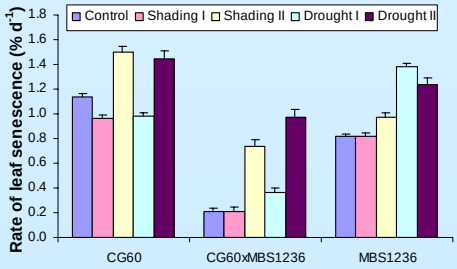

Fig. 3. Rate of leaf senescence from silking to physiological maturity for a maize hybrid and its inbred parents. The bars indicate standard errors.

- Compared with the control, rate of leaf senescence was lower or the same due to the first stress period (except drought stress for MBS1236), but the rate was greater due to the second stress period for all genotypes (Fig. 4b).

Fig. 4a. Root volume at maturity for the hybrid in control (left) and in drought stress I (right).

Fig. 4b. Maize plants of the hybrid at 7-wk after silking from shading stress I (left), the control (center), and shading stress II (right).

Grain yield and harvest index

- Heterosis for grain yield was 162% under no stress and 261% under stress conditions (mean of the four stress treatments) (Fig. 5).
- Yield reductions were 60, 29, and 17% due to shading stress and 46, 54, and 41% due to drought stress for CG60, MBS1236, and CG60xMBS1236, respectively. Yield reductions were 75, 56, and 38% for the first stress period and 31, 27, and 20% for the second stress period for CG60, MBS1236, and the hybrid CG60xMBS1236, respectively.

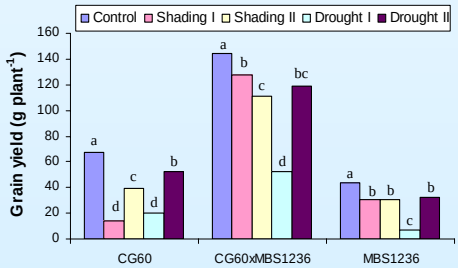

Fig. 5. Grain yield of a maize hybrid and its inbred parents under shading and drought stress.

- Harvest index (HI) was greater for the hybrid than its inbred parents in both shading and drought stress, and during both stress periods (Table 3). The lower HI in Stress I and Stress II was associated with decreased kernel numbers and kernel weight per plant, respectively (data not shown).

Table 3. Relative harvest index of a maize hybrid and its inbred parents under shading and drought stress.

Treatment	CG60	MBS1236	CG60xMBS1236
		% relative to the control	
Shading stress	55.0	81.8	97.8
Drought stress	70.0	56.8	80.0
Stress period I	38.8	54.5	78.9
Stress period II	86.3	84.1	98.9

Conclusions

- The hybrid did not show a greater tolerance to environmental stress than its inbred parents in terms of total dry matter accumulation, but it showed a greater stress tolerance for grain yield.
- The greater stress tolerance of the hybrid for grain yield could be attributed to greater stress tolerance of harvest index, i.e., the response to stress of partitioning of dry matter to the grain.