

# Physiological factors in drought tolerance of various *Musa* genotypes\*

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Cultivated plantains and bananas (*Musa* spp.) are important staple crops in the humid forest and midaltitude ecologies of sub-Saharan Africa. Their water requirement is relatively high and they are very sensitive to dry soil conditions, which greatly limits their range of cultivation. While long-term drought is generally not common in traditional cultivation areas, it is a potential threat for plantains in West Africa, particularly during the short dry season. In IITA's ongoing efforts to develop broadly adapted genotypes, the study reported here attempted to differentiate plantains, bananas, and their hybrid genotypes for drought tolerance, on the basis of a sampling protocol developed to distinguish physiological responses.

## Introduction

Cultivated plantains and bananas (*Musa* spp.) are important staple crops in large parts of sub-Saharan Africa. They differ in their ecoregional distribution. Plantains (*Musa* spp. AAB group) are predominantly distributed in the humid forest lowlands of West and Central Africa, while cooking and beer bananas (*Musa* spp., AAA group) are prevalent in the highlands of East Africa. Plantains are widely grown under suboptimal conditions and apparent differences exist in cultivar adaptation to different ecologies (Plucknett 1978), particularly to dry soil conditions. From a group of cultivars studied in Central America, the plantain cv. Chataro was identified as more resistant to water deficits with adaptation to poor soils relative to other *Musa* groups (Johannessen 1970). While long-term drought is generally not common in the traditional cultivation areas, it is a potential abiotic stress for plantains in West Africa, particularly during the short dry season (associated with the harmattan winds).

The water requirement of plantains and bananas is relatively high, and these crops are very sensitive to dry soil conditions. During the 10–12 months to harvest, bananas may require 900–1800 mm of water and a single day's transpiration losses could amount to 30–63 m<sup>3</sup> ha<sup>-1</sup>; depending on

radiation, wind, and atmospheric humidity (Stover and Simmonds 1987). Moreover, the water requirement of bananas in the humid tropics is about 1–1.4 times the Class A pan evaporation (Stover and Simmonds 1987). In large-scale farming in Honduras, bananas are irrigated when soil moisture tensions exceed –0.02 MPa at 15 cm and 30 cm (as recorded by tensiometers) (Stover and Simmonds 1987).

The effects of diurnal and seasonal water deficits on plant growth and the mechanisms of water loss control for plantains and bananas are yet to be resolved. According to Stover and Simmonds (1987), prolonged water stress effects induce banana leaves to turn pale green and drop, the pseudostem to collapse, and number of hands and finger length to be reduced. Stomatal regulation in the control of water loss from the plant is highly variable, as are stomatal reactions to environmental stress factors and plant species effects (Ludlow 1980; Schultze and Hall 1982). Extent of transpirational water loss from leaves may also depend on leaf age and soil moisture availability. Stover and Simmonds (1987) stated that bananas and plantains with the B genome are the most drought tolerant of all.

The aim of this study was to establish a sampling protocol which can be used to

differentiate plantains, bananas, and their hybrid genotypes with respect to drought tolerance, using the relative importance of leaf age (younger and mature leaf vs older and senescing), leaf surface (adaxial vs abaxial), diurnal vapor pressure differential (VPD), and soil moisture status (a short transient dry period vs nonlimiting soil moisture) on stomatal conductance to water vapor.

## Materials and Methods

**Plant materials and location.** One wild diploid banana (*M. acuminata* ssp. *burmannicoides*) and 16 *Musa* cultivars—comprising three triploid plantains (*Musa* spp., group AAB), four triploid cooking bananas (*Musa* spp., group ABB), one cultivated triploid banana (*Musa* spp., group AAA), and eight tetraploid cooking banana and plantain hybrids (*Musa* spp., group AAB × AA and ABB × AA) of diverse origins—were used in the study. Leaf conductance was determined under field conditions at the International Institute of Tropical Agriculture (IITA) in Ibadan, based in the humid forest/moist savanna transition zone (210 masl, 7°30' N, 3°54' E). Annual rainfall pattern is bimodal, with about 120–128 rainy days, and it amounts to 1200–1400 mm. The rains usually begin in April and end in November, with a midseason dry spell in July and August. Total Class A pan evaporation is 1550–1600 mm. Annual mean, maximum, and minimum temperatures on this site are 24–29°C, 27–34°C, and 20–23°C, respectively. Mean relative humidity is 64–83%. The site is hydromorphic

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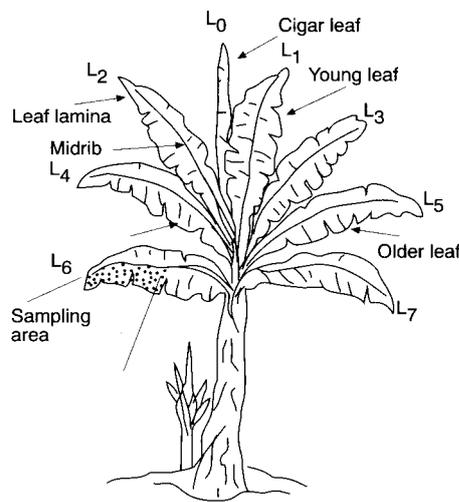
and the soils are slightly acidic, of the Oxic Paleustalf type.

**Field trials.** Plantain and banana plantlets obtained after *in vitro* rapid multiplication (Vuylsteke 1990) were raised in a nursery for 8–10 weeks and planted on 23 August 1991, a timing which coincides with the midseason dry spell. There were five plants per clone, spaced 2 m within a row and 3 m between rows in two replications in a randomized complete block design. Between and around the clonal plots, border rows of banana cv. Valery were planted. The crop was maintained weed-free without supplementary irrigation. Management practices were those recommended by Swennen (1990), but without mulching.

Two *in situ* leaf evaluations were made on the first ratoon crop (second crop) during a 2-week period in October and November 1992. The first evaluation followed a short dry spell of five rain-free days where the evapotranspirational demand was high. The second evaluation was immediately following two days of rain and hence soil was at field capacity. Selected plants of the ratoon crop were at the peak of the vegetative growth phase; they had 5–10 fully expanded leaves, were about to flower, and were approximately 3 m tall.

*In situ* leaf diffusive resistance measurements were taken on two types of leaves: mature but relatively young leaves and old senescing leaves. The young leaf was the second or third fully expanded leaf below the cigar leaf at the apex of the plant and the old leaf was the fifth or sixth leaf below the apex which had approximately 25% senescent (yellowing) leaf area (Fig. 1). Young leaves at the second or third position below the apex were those that had recently attained full expansion and were photosynthetically fully functional, whereas in old leaves senescence had begun. Young leaves were near the top of the plant canopy and were exposed to full sunlight, whereas the old leaves were under partial shade from the leaves above them.

Diffusive resistance measurements were taken in the morning between 0800 and 1000h and in the afternoon from 1330–1530h on both the abaxial and adaxial surfaces of the selected leaves. One young and one old leaf were selected for measurement on each plant. Readings were taken on the distal half of green and healthy leaves towards the tip region of the lamina and away from the midrib region.



**Figure 1.** Leaf conductance was monitored on young (L1 and L2) and old (L5 and L6) leaves. L0 to L7 are photosynthetically active leaves. Sampling area was the distal half of the selected leaves away from the midrib on both adaxial and abaxial leaf surfaces.

Leaf diffusive resistances were monitored with an automatic Delta-T devices porometer model Mk3 (Cambridge CB1 OEJ, UK). Leaf resistances ( $r_l$ ), expressed as second per millimeter, were obtained using a calibration curve for the appropriate relative humidity and temperature. Calibration curves were obtained prior to and during the measurement period at approximately 45-min intervals, using a perforated plate with known resistances (Ekanayake and de Jong 1992). Leaf stomatal conductance to water vapor ( $g_l$ ) was calculated as the reciprocal of the leaf resistance ( $g_l = [1/r_l]$ ) and expressed as millimeters per second. Leaf temperatures were also monitored. A swing type wet and dry bulb hygrometer (Model Bs 2842

Casella, London, UK) was used to determine the leaf to air temperature gradient, based on which leaf to air vapor pressure deficit (VPD) was calculated. Photosynthetic photon flux density (400–700 nm) was also monitored using a quantum sensor (Licor Model 192SA, Licor Inc., Lincoln, Nebraska, USA).

All data were analyzed by a two-way analysis of variance for each sampling period, leaf, and surface. A combined analysis was also done over the two sampling periods, similar to that used for perennial crops over years (Nevado and Ortiz 1985). Principal component analyses were done for each sampling period, based on the means of all measured traits [a combination of leaf surface (adaxial or abaxial)  $\times$  leaf age (young or older)  $\times$  sampling hour (morning or afternoon)]. This statistical approach was used to determine if the pattern of variation or leaf conductance was associated with the taxonomic grouping or parentage.

## Results and Discussion

### Leaf age effects on leaf conductance.

There were distinct differences in leaf conductance between young and old *Musa* leaves compared in this study. Leaf conductances to water vapor diffusion of young leaves were greater than those of the old leaves, both in the morning and in the afternoon, irrespective of the soil moisture status, on both abaxial and adaxial surfaces (Table 1). When sampled under a dry spell ( $S_1$ ), these differences attained significance ( $P \leq 0.05$ ) in the afternoon. Young leaves thus were transpiring at a much higher rate than old leaves, and recording up to 2 to 3-fold the rate of water loss from the abaxial leaf surfaces in the

**Table 1.** Mean leaf conductance to water vapor ( $\text{mm s}^{-1}$ ) and percent change in leaf conductance on the adaxial and abaxial surfaces of young and old leaves in the morning and in the afternoon at two different sampling periods, after a dry spell and after rain, IITA, Ibadan, Nigeria, 1992.

Leaf surface and sampling period	Time of day				% change in leaf conductance	
	0800–1000		1330–1530		Young	Old
	Young	Old	Young	Old		
Adaxial						
S1 (dry)	0.26	0.23	0.17	0.10	-34.6	-56.5
S2 (wet)	0.19	0.17	0.36	0.28	89.5	64.7
Mean	0.23	0.20	0.27	0.19	27.5	9.1
Abaxial						
S1 (dry)	1.93	1.13	3.52	1.22	82.4	8.0
S2 (wet)	2.43	0.94	5.78	2.88	137.9	206.4
Mean	2.18	1.03	4.65	2.05	110.2	107.2

% change in conductance = [(afternoon - morning)/morning]  $\times$  100.

afternoon. A similar decline in leaf conductance to water vapor diffusion as leaves aged and approached senescence has been reported for both annuals and perennials (Field 1987). In this particular study, the cause of the onset of senescence of old leaves was not differentiated.

The relative change in conductance from morning to afternoon was greater in young than in old leaves, particularly on the abaxial surface, suggesting that old *Musa* leaves show a reduction in their stomatal opening in response to light and VPD. Stomatal conductance is highly correlated with the mesophyll photosynthetic rates even in the senescing leaves (Field 1987). In a study of *Nicotiana glauca* plants, stomatal function appeared to be regulated in senescing leaves to optimize carbon gain and not water loss (Heaton et al. 1987). The *Musa* leaves in our study seemed to follow a similar behavioral pattern. Heaton et al. (1987) also mention that the presence of functional stomata probably prevents senescing leaves from premature desiccation, thus enhancing the process of nutrient reallocation to juvenile tissue during growth.

**Adaxial vs abaxial leaf surface of young and old leaves.** Water vapor conductance of the adaxial surface relative to the abaxial surface, when compared across leaf age and time of day, was about 10 times greater and ranged from about 5 times greater (old leaves, morning) to 17 times greater (young leaves, afternoon) (Table 1). When soil moisture was nonlimiting, conductances in the abaxial surface of young leaves differed by a factor of 13, while those of the old and senescing leaves differed by a factor of 5.5. The number of stomata in the abaxial surfaces is 3–4 times greater than in the adaxial surfaces (Simmonds 1962; Stover and Simmonds 1987), and they are distributed nonrandomly over the leaf surface with clustering near the leaf apex relative to the leaf base (Simmonds 1962). Leaf conductance in the afternoon was much greater on the abaxial surfaces of both young and old leaves. For example, conductance to water vapor diffusion of young leaves on their lower surfaces was 16 to 21 times greater than on the adaxial surface. Young leaves recorded the highest conductance rate ( $5.78 \text{ mm s}^{-1}$ ) on their abaxial surface in the afternoon, when soil moisture was nonlimiting. The differences in leaf conductance between adaxial and abaxial surface obtained in this study accord with known stomatal distributions

for *Musa* spp. (Stover and Simmonds 1987).

It is known that there are differences in stomatal distribution among different ploidy levels; samples taken on the adaxial surface of the leaf lamina about one-third of the length from the apex indicated a stomatal density of  $47 \text{ mm}^{-2}$  for diploids (i.e., Calcutta 4),  $35 \text{ mm}^{-2}$  for triploids, and  $18 \text{ mm}^{-2}$  for tetraploids (Simmonds 1962). Stomatal density and distribution pattern over the adaxial and abaxial surfaces of the leaf, and stomatal size can strongly affect the degree of stomatal sensitivity to ambient and soil moisture conditions. Leaf resistance measurements reflect the bulk resistance to water loss, combining both the stomatal and cuticular activities.

**Stomatal response to a short dry spell vs nonlimiting soil moisture.** It was expected that the effects of a short dry spell were more likely to be detected in stomatal conductance recorded in the afternoon. Since the dry spell was short, it was also expected that leaf water deficit and, similarly, leaf conductance would be comparable, in the morning, to that of plants in moist soil conditions. The recorded conductances accord with these expectations.

An effect of the dry spell was detected in stomatal conductances. Plants exposed to the short dry spell had relatively marked lower conductance values on the abaxial surface irrespective of leaf age in the afternoon, especially those plants grown under nonlimiting soil moisture (Table 1). This demonstrates a response of plants by stomatal closure to reduce immediate water loss when there is a transient water deficit. A second finding was that in the morning and in moist conditions, conductance values for the adaxial leaf surface of both leaf types were lower than those obtained after the short dry spell. According to Sloten and Weert (1973), stomata of banana leaves began to close soon after they opened in the morning when soil moisture tension reached about  $-0.04 \text{ MPa}$ .

**Changes in diurnal irradiance and VPD and relationship to stomatal conductance.** Irradiance levels changed 1.5 to 3-fold from morning to afternoon. Recorded measurements were 230–550 and 900–1100  $\text{mE m}^{-2} \text{ s}^{-1}$ . Similarly VPD increased from 0.7 to 1.2 kPa in the morning to 2.1 to 2.3 kPa in the afternoon (as can be inferred from data in Table 1). Under a transient dry spell, response was negative on adaxial

surfaces and positive on abaxial surfaces. The positive response was more marked on young leaves than on mature leaves. However, when soil moisture was not limiting, responses of old leaves on the abaxial surface were smaller than those of young leaves (Table 1).

Our conductance data indicated fully open stomata of young leaves in the afternoon between 1400 and 1600h in response to changes in diurnal VPD, in agreement with previous reports (Aubert and Catsky 1970; Chen 1971; Ke 1979). Stover and Simmonds (1987) observed that on cloudy or rainy days, stomatal opening was smaller than that of a sunny day. Light regulation of stomatal opening of banana leaves has been reported independent of the photoperiodic regime (Brun 1961a,b, 1965).

A plant that maintains a high stomatal conductance in the morning and appears highly sensitive to changes in VPD in the afternoon (as expressed by reduced conductance) would be most adapted not only to long dry spells (El-Sharkawy et al. 1985) but also to short dry conditions (our data); it would save water. A higher sensitivity of stomata also ensures continued photosynthesis under conditions that do not limit water, as suggested by a marked positive correlation between the apparent photosynthetic rate and the maximal stomatal conductance for C3 plants (El-Sharkawy et al. 1985) such as plantains and bananas (Stover and Simmonds 1987). Stomatal conductance data indicated that except for the adaxial leaf surface during a dry spell, conductances increased from morning (8%) to afternoon (206%) (Table 1). Positive response was higher in the young and older *Musa* leaves when soil moisture was not limiting.

**Genotypic differences on leaf conductance.** Principal component analysis for leaf conductance measured during a short dry spell did not indicate any grouping of genotypes based on their known genomic designations. Genotypes Pelipita, Obino l'Ewai, Agbagba, and TMPx 548-4 had reduced water loss against a high leaf-air VPD, and they could be regarded as potential water savers (drought tolerant) for short dry spells. Genotypes such as Bobby Tannap, Valery, and hybrids TMPx 597-4, TMPx 1112-1, and TMPx 2796-5 could be more susceptible to short dry spells due to their higher rates of water vapor loss. Our data indicated that for young leaves in the afternoon AAB plantains had a higher conductance ( $5.19$  and  $9.17 \text{ mm s}^{-1}$ ) than

**Table 2. Leaf conductance ( $\text{mm s}^{-1}$ ) of 17 *Musa* spp. genotypes measured on (a) the abaxial surfaces of young leaves in the afternoon, (b) the adaxial surfaces of old leaves in the morning taken at two sampling periods, and the percentage increase in conductance of abaxial leaf surface from morning to afternoon (photosynthetic photon flux density in the morning: 230–550  $\mu\text{E s}^{-1} \text{mm}^{-2}$ ; in the afternoon: 900 to 1100  $\mu\text{E s}^{-1} \text{mm}^{-2}$ ).**

Clone	Percentage/ Ploidy level	Abaxial surface		Adaxial surface		% change in conductance <sup>a</sup>	
		Young leaves	Old leaves	1	2	1	2
		1 <sup>b</sup>	2				
TMPx 548-4	OL <sup>c</sup> × C4	1.97	8.83	0.14	0.10	43.2	89.9
TMPx 548-9	OL × C4	5.11	6.84	0.18	0.06	82.0	78.8
TMPx 597-4	OL × C4	1.97	3.04	0.22	0.19	9.6	33.2
TMPx 582-4	BT × C4	6.04	6.27	0.33	0.05	80.8	27.4
TMPx 2796-5	BT × PL	2.91	4.60	0.30	0.11	56.7	73.0
TMPx 1112-1	FR × C4	2.53	2.43	0.19	0.18	40.7	49.4
TMPx 1658-4	OL × PL	1.23	3.39	0.21	0.26	-56.1	1.2
TMBx 612-74	Blu × C4	5.48	6.06	0.41	0.15	-9.7	78.4
Bluggoe	ABB	2.33	2.51	0.38	0.15	39.1	55.8
Pelipita	ABB	3.41	4.61	0.22	0.20	57.5	79.3
Fougamou	ABB	1.90	2.46	0.24	0.25	-14.3	77.2
Cardaba	ABB	4.79	3.86	0.14	0.18	69.7	60.8
Valery	AAA	1.74	10.83	0.20	0.12	56.3	58.6
Calcutta 4	AA	2.84	3.98	0.19	0.06	78.2	20.9
Agbagba	AAB	3.12	5.73	0.20	0.17	80.8	28.8
Bobby Tannap	AAB	11.90	18.42	0.01	0.06	95.1	95.1
Obino l'Ewai	AAB	0.54	3.36	0.27	0.55	-26.4	5.7
LSD (0.05 combined over sampling periods)		0.6		0.01		—	

a. Means of the lower surface of young leaves; % change in leaf conductance = [(afternoon-morning)/morning] × 100.

b. Sampling period 1 indicates measurements after a short dry spell and the sampling period 2 indicates measurements after rains.

c. OL = Obino l' Ewai; C4 = Calcutta 4; BT = Bobby Tannap; PL = Pisang Lilin; FR = French Reversion somaclonal variant of cv. Agbagba and Blu = Bluggoe.

ABB cooking bananas (3.11 and 3.61  $\text{mm s}^{-1}$ ) both during a dry spell and when soil moisture was not limiting, respectively. Behavior of old leaves was reversed during a dry spell but not significantly.

Cooking banana cultivars Fougamou and Bluggoe had the highest potential for restricting water use, because of their ability to close their stomata during the afternoon. The plantain cultivar Bobby Tannap appeared to be less sensitive to transient dry spells since its stomata did not close in the afternoon (Table 2). Banana cultivar Valery had very high conductances in the afternoon on the abaxial surface when soil moisture was not limiting but it also had a high percentage response irrespective of soil moisture, indicating poor adaptation to relatively dry conditions. Plantain cultivars Obino l'Ewai and Agbagba had more pronounced stomatal closure in the afternoon. This indicated the existence of differences between the plantain cultivars within the same taxonomic group (*Musa* spp., AAB group). Preliminary data suggest that the selection of potential drought tolerant genotypes is possible within this germplasm, but it may warrant more testing

in drought-prone field sites. Plantain cultivar Obino l'Ewai had a negative conductance response from morning to afternoon. The hybrids TMPx 548-4 and TMBx 612-74 had a lower potential for water saving than their respective parents, Obino l'Ewai and Bluggoe.

In conclusion, it is apparent that *Musa* genotypes have differences in their stomatal sensitivity based on the age of the leaf. These differences are modulated by environmental factors, such as irradiance, VPD, and soil-plant water relations. The behavior of these genotypes in terms of conductance response could differ when exposed to more acute and longer durations of water deficit. Further studies are needed to differentiate the photosynthetic capacity of *Musa* leaves of different ages relative to their regulation of water loss.

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