Effect of Chilling on Growth and Dry Matter Production of Sweet Potato

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Abstract

The effects of chilling on growth and dry matter production of five Indonesian sweet potato clones were investigated. From the results of the growth analysis, it was concluded that rapid induction of tuber formation should be the most important selection criterion for sweet potato cultivation in areas with temperature limitations to use a minimum growth period of 3-5 months most effectively. The evaluation of leaf chlorophyll fluorescence and 'Kryoscan' freezing point measurements indicated that these techniques cannot successfully be applied to screen sweet potato clones for their tolerance to chilling stress.

Keywords: chilling, chlorophyll fluorescence, Kryoscan, sweet potato

Introduction

Sweet potato *Ipomoea batatas* L. (Lam.) belongs to the family Convolvulaceae. Its origin is in the tropical America, from where it was spread over most of the world's tropical, sub-tropical and warmer temperate regions. The optimum temperature for growth and tuber production range between 21°C and 29°C. When temperatures are below 15°C to 10°C, growth is severely retarded and at 10°C sweet potato will begin to show chilling effects (Nonnecke, 1989). Frost sensitivity restricts sweet potato cultivation in temperate regions to areas with a minimum frost-free period of 4-6 months and relatively high temperatures during the cold period. The optimum temperature for tuber production is about 25°C in combination with a slight cooling overnight. Cultivation of sweet potato in temperate region and/or at high altitudes is limited by temperature and hence research is necessary to improve

chilling tolerance of this important crop. It is the objective of the present investigation to evaluate the chilling sensitivity of several Indonesian clones and additional ones from Thailand and Africa.

Materials and Methods

At the end of summer, in August 1998, one-month old, rooted cuttings of the Indonesian clones 'Dayak', 'CIP-1', 'AB94078.1', 'AB94001.8', and 'AB95001.4' were planted in 20 l pots in a sand-soil mixture and grown in the greenhouse at the experimental station Marhof of the University Bonn to simulate the conditions of a short vegetation period limited at the end of the season by chilling and cold stress. Average temperatures at day and night were 24°C/19°C in August, 20°C/16°C in September, 15°C/11°C in October, and 12°C/9°C in November. The corresponding overnight minimum temperatures were 15°C, 14°C, 6°C and 5°C, respectively. From September to December five plants per clone were harvested at the 10th of each month. Fresh and dry mass of roots, tubers (if present), stems and leaves as well as leaf number and leaf area were recorded. Growth of the clones was compared using the statistical package SPSS (Chicago, USA) and a 5% probability level was accepted to indicate significant differences.

In a second experiment, chlorophyll fluorescence of chilled and cold-stressed sweet potato was recorded in order to test this technique as a rapid measurement to assess the tolerance of cultivars to chilling and cold stress. From the above described growth experiment, the clones 'CIP-1', 'AB94078.1', and 'AB94001.8' were selected together with 'AB94065.4' from Indonesia and 'Eland' from South Africa. Four months old plants were exposed to different temperatures overnight for four days with the exception of the coldest treatment, which was tested for only one night, because all plants were strongly affected or already dead thereafter. Between 20.00 and 2.00 o'clock, plants were kept at 10 ± 1°C (15°C in the first experiments) and between 2.00 and 8.00 o'clock at 15 ± 1°C, 7 ± 1°C, 3.5 ± 1°C, 1° ± 1C, -1 ± 1°C or -3 ± 1°C, respectively. During the day, plants were grown in a growth chamber at about 22°C, 70% relative humidity, 300 µmol m^{-2} s^{-1} PAR and 360 ppm CO_2. Chlorophyll fluorescence was measured every afternoon and basal

fluorescence (Fo), maximum fluorescence (Fm), variable fluorescence (Fv), and optimum quantum yield (Fv/Fm) were recorded according to Schreiber et al. (1995). For each clone, four plants were investigated and chlorophyll fluorescence of five fully expanded leaves per plant was measured. Mean values were calculated per plant and compared statistically.

In a third experiment, the 'Kryoscan' Multichannel-Exothermic-Measurement-System was evaluated in order to test its potential for screening sweet potato for chilling and cold stress tolerance. The freezing point of 2 mm - leaf discs from fully expanded sweet potato leaves of plants grown in the greenhouse in June 2000 was determined by reducing the temperature within the 'Kryoscan' at a rate of 2°C per minute. The plants of the growth as well as the chlorophyll fluorescence experiments were investigated in addition to clone 'Thai' from Thailand and cv. 'Kwarangwana' from Central Africa.

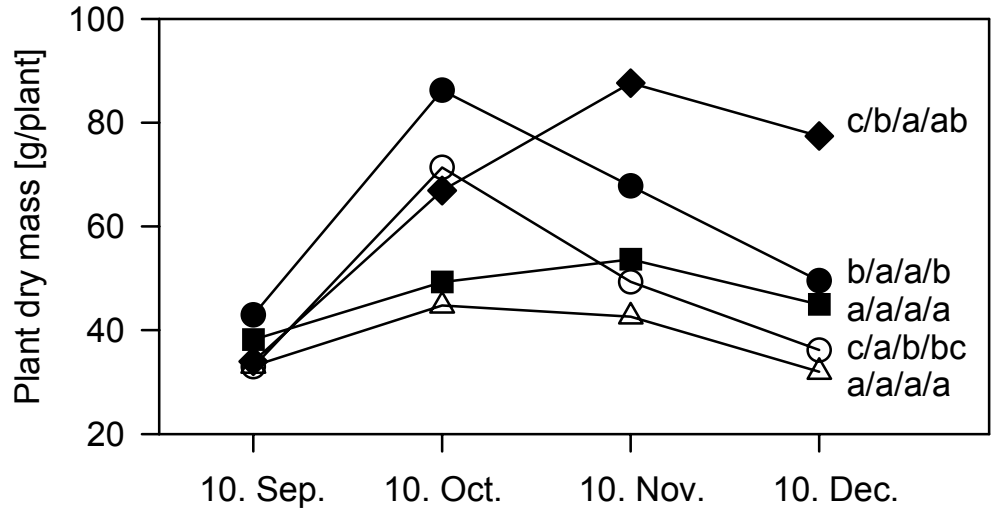

Figure 1. Mean plant dry mass (n = 5) and differences within clones by Duncan tests with respect to harvest date (◆ = 'AB95001.4', ● = 'AB94078.1', ■ = 'CIP-1', ○ = 'Dayak', ∆ = 'AB94001.8').

Results

Sweet potato growth

With regard to whole plant biomass (Fig. 1), the studied sweet potato clones can be subdivided into three groups. In the first, which includes 'CIP-1' and 'AB94001.8', plant dry mass did not increase significantly, indicating growth-inhibition at average temperatures below 20°C during

the day and 16°C overnight. In the second and third group, plant dry mass increased significantly in September and beginning of October at a rate of 1.1 to 1.4 g per day. For ‘Dayak’ and ’AB94078.1’, however, dry mass decreased significantly in October or remained unchanged. In December, the dry mass reached values as low as in September. Only clone ‘AB95001.4’ showed a significant biomass increment of 0.7 g per day in October and in the first week of November at average day/night temperatures above 15°C/11°C. In November, dry mass of this clone was in tendency reduced.

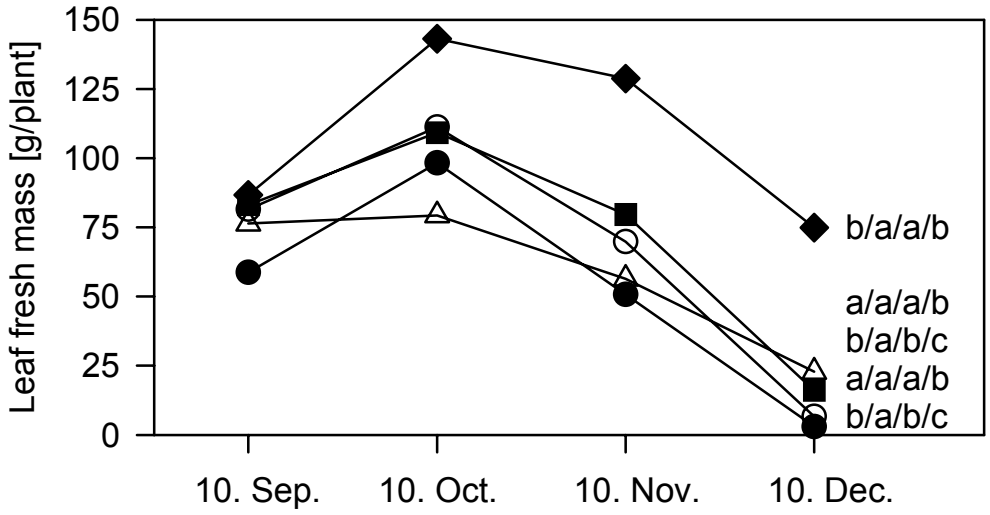

Figure 2. Mean leaf fresh mass (n = 5) and differences within clones by Duncan and Wilcoxon (AB94001.8) tests with respect to harvest date (◆ = ‘AB95001.4’, ● = ‘AB94078.1’, ■ = ‘CIP-1’, ○ = ‘Dayak’, ∆ = ‘AB94001.8’).

Because the leaf represent the plant organ, which is responsible for the CO_2-assimilation and biomass production, and because leaves are especially exposed to chilling stress, their responses to low temperatures were evaluated in detail (Fig. 2). In clone ‘AB94001.8 and cv. ‘Dayak’ leaf fresh mass did not rose significantly in September or later, but it did so in the other clones. In ‘AB94078.1’ and ‘CIP-1’, leaf fresh mass decreased significantly in October, in ‘AB95001.4’ not before November. An increase of leaf fresh mass may be related to leaf enlargement, but may also be due to the development of new leaves. On the other hand, severe chilling and cold stress may result in leaf fall. Corresponding responses of the investigated sweet potato were assessed by counting leaf numbers (Fig. 3). This parameter was significantly reduced already

in October in clone ‘AB94001.8’. It remained unchanged from the 10th September to the 10th October in clones ‘AB94078.1’, ‘Dayak’, and ‘AB95001.4’ and rose significantly in ‘CIP-1’. Noteworthy, leaf number was not significantly reduced in ‘AB95001.4’ during the entire experiment, whereas it decreased significantly from the 10th October on in all the other clones, when average day/night temperatures were at or below 15°C/11°C and the minimum temperature reached 6°C.

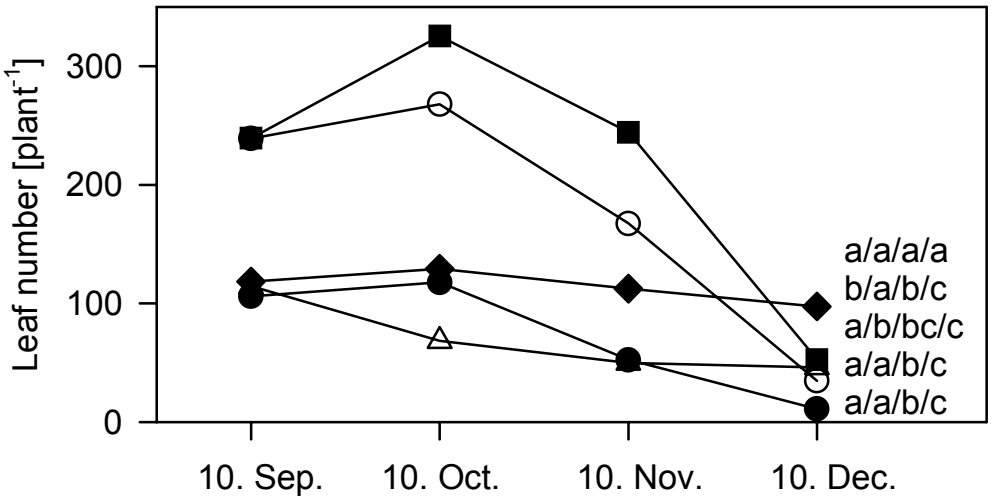

Figure 3. Mean leaf number (n = 5) and differences within clones by Duncan tests with respect to harvest date (◆ = ‘AB95001.4’, ● = ‘AB94078.1’, ■ = ‘CIP-1’, ○ = ‘Dayak’, ∆ = ‘AB94001.8’).

Tuber development is of practical importance for sweet potato cultivation. This parameter revealed distinct differences between the clones (Fig. 4). A significant amount of tuber was only produced in clone ‘AB94078.1’, where tuber fresh mass rose from the 10th September to the 10th October by a rate of 5.2 g per day, and from the 10th October to the 10th November by 5.6 g per day. Until the 10th December tuber fresh mass was significantly reduced by 2.6 g per day. The second best clone in tuber production was ‘AB94001.8’, which increased tuber fresh mass significantly only in September and beginning of October by a rate of 1.5 g per day. Clones ‘AB95001.4’ and ‘CIP-1’ developed only rather small tubers by the end of the experiment and cv. ‘Dayak’ no tubers at all.

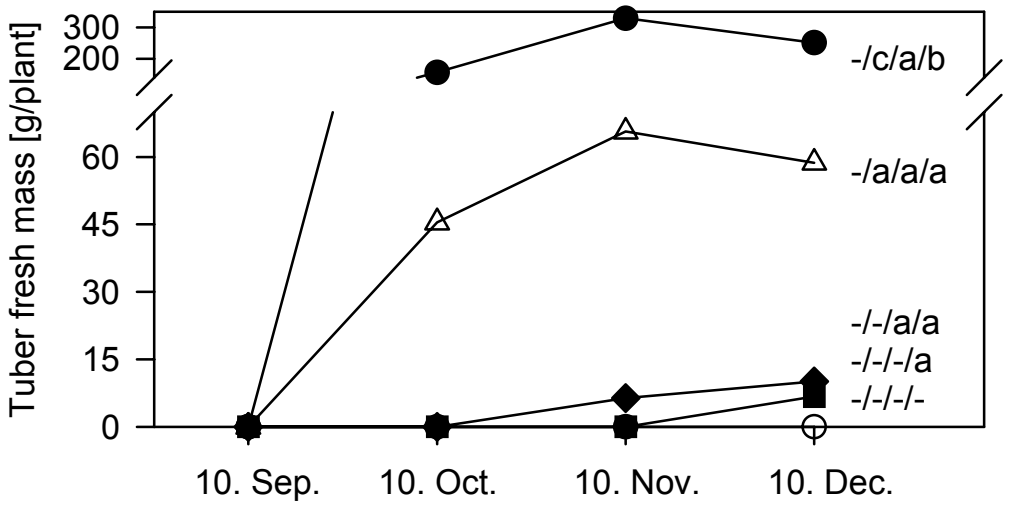

Figure 4. Mean tuber fresh mass (n = 5) and differences within clones by Duncan or t-tests with respect to harvest date (◆ = 'AB95001.4', ● = 'AB94078.1', ■ = 'CIP-1', ○ = 'Dayak', Δ = 'AB94001.8').

Assessment of chilling stress resistance by chlorophyll fluorescence

For chlorophyll fluorescence, the optimum quantum yield Fv/Fm was found to be the most informative parameter to describe the effects of chilling and cold stress on fully expanded sweet potato leaves (Table 1), maybe because it combined stress effects on basal fluorescence (Fo), maximum Fluorescence (Fm) and variable fluorescence (Fv = Fm - Fo).

Table 1: Optimum quantum yield of sweet potato clones after exposure to low temperatures over night for 6 hours (n = 4). Different letters within a column indicate significant differences by Duncan or Wilcoxon tests.

Temperature	AB94001.8	AB94065.4	AB94078.1	Eland	CIP-1
15°C	0.82 ± 0.01 a	0.81 ± 0.01 a	0.83 ± 0.01 a	0.82 ± 0.01 a	0.81 ± 0.01 a
7°C	0.83 ± 0.01 a	0.81 ± 0.01 a	0.83 ± 0.01 a	0.81 ± 0.02 a	0.80 ± 0.01 a
3.5°C	0.78 ± 0.02 a	0.69 ± 0.05 a	0.78 ± 0.03 a	0.81 ± 0.02 a	0.77 ± 0.01 a
1°C	0.72 ± 0.06 a	0.72 ± 0.03 a	0.69 ± 0.04 a	0.70 ± 0.06 c	0.62 ± 0.02 b
-1°C	0.67 ± 0.30 a	0.78 ± 0.02 a	0.76 ± 0.04 a	0.76 ± 0.03 b	0.69 ± 0.05 ab
-3°C	0.28 ± 0.44 a	0.44 ± 0.38 a	0.54 ± 0.30 a	0.04 ± 0.01 d	0.06 ± 0.04 c

The statistical evaluation of the data did not reveal any significant temperature effect for the clones 'AB94001.8', 'AB94065.4', and 'AB94078.1', whereas Fv/Fm was significantly reduced in 'Eland' and 'CIP-1' at temperatures at or below 1°C. Nevertheless, it is well known that a value for Fv/Fm below 0.8 usually indicates a stress of the

photosynthetic system. This threshold value was reached in all clones at 3.5°C, with the exception of cv. 'Eland', which passed the limit at 1°C. A visual evaluation revealed that all plants survived the chilling stress between 15 and 1°C. At -1°C one of four plants of 'AB94001.8' and 'Eland' died. All plants of 'Eland' and 'CIP-1' did not survive -3°C. In addition, three of four plants of 'AB94001.8' and 'AB94065.4' and two of four of 'AB94078.1' died. Thus, 'AB94078.1' seems to be the most cold resistant clone and 'Eland' as well as 'CIP-1' the least. This result was not reflected by the threshold value of 0.8 for Fv/Fm, but in tendency by the statistical evaluation.

Assessment of chilling stress resistance with the 'Kryoscan'
Determining the freezing point with the 'Kryoscan' Multichannel-Exothermic-Measurement-System of 2 mm - discs cut from fully expanded sweet potato leaves did not reveal significant differences between the clones. The measured mean values varied between -9.6°C and -11.0°C.

Discussion
From a practical point of view, tuber production is usually the most important parameter for sweet potato cultivation. In the present growth experiment, only 'AB94078.1' produced a considerable amount of tubers. This clone started tuber development quite early after two months and continued tuber growth until the 10th November. Clone 'AB94001.8' started tuber development also after two months, but tuber growth rate was 3.5 times less when compared with 'AB94078.1' and significant only in September.
With regard to leaf growth and development, clones 'AB95001.4' and 'CIP-1' were best. Whereas 'CIP-1' was characterised by the largest leaf number, 'AB95001.4' developed the largest leaf area of single leaves, resulting in the largest leaf fresh mass of all clones tested. In addition, 'AB95001.4' did not suffer from leaf fall as much as the other ones. When comparing 'AB94078.1' with 'AB95001.5', it is obvious that the latter clone invests a larger amount of photoassimilates into the development of leaves, whereas in 'AB94078.1' the tubers represent a

stronger sink. Remarkably, ‘AB94078.1’ is characterised by the smallest leaf fresh but the largest tuber fresh mass of all studied clones.
To summarise, if cultivation of sweet potato in temperate region and/or at high altitudes is limited by temperature, cultivars that develop tubers very early at expense of leaves have a serious advantage, because they can produce a considerable yield within a minimum frost-free period of 3-5 months.
The improvement of chilling tolerance of leaves is a second important character for the optimisation of sweet potato growth and yield in colder regions. In our experiment, clone ‘AB94001.8’ and cv. ‘Dayak’ stopped significant leaf development and leaf expansion at an average day/night temperature of 20°C/16°C (minimum temperature 14°C). Leaf development stopped at the same temperature in ‘AB95001.4’ and ‘AB94078.1’, but leaf growth continued and was inhibited only at an average day/night temperature of 15°C/11°C (minimum temperature 6°C). Only in clone ‘CIP-1’ both, leaf development and expansion, were inhibited at the latter temperature. This result is in agreement with previous observations, that growth is severely retarded, when temperatures drop below 15-10°C (Nonnecke, 1989).
With regard to the growth analysis of leaves, the studied sweet potato clones can be subdivided into two groups with different chilling sensitivities: ‘AB94001.8’ and ‘Dayak’ were slightly more sensitive than ‘AB95001.4’, ‘AB94078.1’, and ‘CIP-1’.
Three of the clones used in the sweet potato growth experiment, ‘AB94001.8’, ‘AB94078.1’, and ‘CIP-1’, were also used to assess chilling and cold stress tolerance by chlorophyll fluorescence. However, the latter experiment indicated that ‘CIP-1’ is less tolerant than ‘AB94001.8’ and ‘AB94078.1’. This discrepancy can be explained by assuming differences in chilling and cold stress tolerance between the clones. Because chlorophyll fluorescence parameters such as Fv/Fm did not indicate significant effects at temperatures at and above 3.5°C for ‘AB94001.8’, ‘AB94078.1’ and ‘CIP-1’, we conclude that chlorophyll fluorescence may not be able to assess differences in chilling tolerance. Whether or not the comparatively high Fv/Fm value of cv. ‘Eland’ at 3.5

°C indicates a considerable chilling tolerance of this cultivar has to be tested in further growth experiments.
With regard to cold stress, it was found that ‘Eland’ and ‘CIP-1’ were more sensitive than ‘AB94001.8’, ‘AB94065.4’ and ‘AB94078.1’. This result was reflected by optimum quantum yield of chlorophyll fluorescence. However, this relationship is of minor importance, because a visual evaluation of plants gives the same kind of information.
The determination of the freezing point of leaf discs with the ‘Kryoscan’ Multichannel-Exothermic-Measurement-System did not reveal any significant differences between the tested nine sweet potato clones. The mean values varied between -9.6°C and -11.0°C and are well within the range usually recorded for leaves (Blaich, written communication, 2000). The ‘Kryoscan’ cannot be used to screen sweet potato clones for chilling or cold stress tolerance.

References

Nonnecke IL (1989) Vegetable production. ”An AVI book” New York, London, Melbourne.
Schreiber U, Bilger W, Neubauer C (1995) Chlorophyll fluorescence as a nonintrusive indicator for rapid assessment of in vivo photosynthesis. In Ecophysiology of Photosynthesis (Hrgs. Schulze E-D, Caldwell MM), 49-70. Springer Verlag, Berlin Heidelberg, Deutschland.