Photochemical efficiency of photosystem II and growth in banana passionfruit plants (*Passiflora tripartita* (Juss.) var. *mollissima* (Kunt) L.H. Bailey under salt stress

Eficiencia fotoquímica del fotosistema II y crecimiento en plantas de curuba (*Passiflora tripartita* (Juss.) var. *mollissima* (Kunth)) bajo estrés salino

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Abstract

Banana passionfruit (*Passiflora tripartita* (Juss.) var. mollissima (Kunth)) is an important crop in Colombia, with Boyacá Department contributing over half of national production. Osmotic stress is a major hindrance to production of this crop, but there exists little information on banana passionfruit responses to soil salinity. The present study aimed to evaluate growth and chlorophyll fluorescence in banana passionfruit under salt stress. A completely randomized block design was used. Plants were exposed to concentrations of 20, 40, 60, and 80 mmol NaCl kg^{-1} soil. Leaf area was reduced by 20.89, 42.91, 58.37, and 76.40%, respectively, compared to control plants in non saline conditions. Total stem length showed a reduction of 9.97, 27.28, 42.79, and 55.77%, and total dry weight per plant was reduced by 23.89, 31.49, 39.60, and 61.26%. Maximum quantum yield of photosystem II (F_v/F_m) was reduced by 11.29, 14.23, 38.89, and 92.25% under the respective treatments. Salinity thus affected all measured growth factors and photosynthesis drastically. Leaf area reduction was closely correlated to reduction in photosynthesis. Dry matter reduction also closely followed the trend in Photosystem II maximum quantum yield (F_v/F_m), which suggests that the major impact of salinity on the banana passionfruit plants was due to negative effects on photosynthesis.

Key words: Andean fruits, chlorophyll fluorescence, chlorophylls, fruit crops, non-irrigated crops, osmotic stress.

Resumen

La curuba (*Passiflora tripartita* (Juss.) var. mollissima (Kunth)) es un cultivo importante en Colombia, especialmente en el departamento de Boyacá. A pesar de que el estrés osmótico es un limitante en la producción de este cultivo, existe poca información sobre su respuesta a la salinidad. En el presente estudio se evaluó el crecimiento y la fluorescencia de la clorofila en plantas de curuba bajo estrés salino. Las plantas se expusieron a concentraciones (mmol/kg de suelo) de 20, 40, 60, y 80 de NaCl. Como consecuencia, el área foliar de la planta se redujo 20.89, 42.91, 58.37 y 76.40%, respectivamente, en relación con plantas control (condiciones no salinas). La longitud total de tallos se redujo 9.97, 27.28, 42.79 y 55.77% y el peso seco total por planta en 23.89, 31.49, 39.60 y 61.26%. La eficiencia cuántica máxima del fotosistema II (F_v/F_m) se redujo 11.29, 14.23, 38.89 y 92.25% bajo los tratamientos de salinidad; por tanto, la salinidad afectó drásticamente los parámetros de crecimiento y fluorescencia. La reducción en el área foliar se correlacionó con la reducción en la fotosíntesis. La reducción en peso seco también siguió la tendencia de la relación F_v/F_m, lo que sugiere que la mayoría de los impactos de la salinidad en las plantas de curuba se deben a los efectos negativos sobre la fotosíntesis.

Palabras clave: Clorofilas, cultivos sin riego, fluorescencia de la clorofila, frutales, frutas andinas, estrés osmótico.

Introduction

In 2009, banana passionfruit was cultivated on 1326 ha in Colombia, of which 52.6% was in the department of Boyacá (Agronet 2011). In Boyacá non-irrigated plantations have increased because farmers lack the economic resources to install irrigation systems. Non-irrigated production systems suffer plant osmotic stress due to high soil solute concentration in the dry season. Osmotic stress is a major hindrance to crop production. Salt stress has negative effects on plant growth, ion balance, and water relations (Munns, 2002).

However, there exists little information on the response of banana passionfruit plants to salinity. On the other hand, studies carried out using yellow passion fruit, *Passiflora edulis*, may be useful to understanding the behavior of banana passionfruit plants exposed to salt stress, since both species belong to the same genus. Soares *et al.* (2002) found that yellow passion fruit may be considered as moderately tolerant to salinity during the initial growth phase. On the other hand, Nyagah and Musyimi (2009) categorized passion fruit seeds as very sensitive to salt stress. Their results showed that sodium chloride solution treatment notably reduced germination percentage of passion fruit seeds, as well as radicle and plumule growth. Presumably, higher salinity reduced the absorption of water and nutrients into yellow passion fruit seedlings. A possible explanation is that salinity stress causes seedling stomata to close in order to minimize water loss, which reduces production of new leaves, and thus significantly affects dry matter (DM) production (Soares *et al.*, 2002).

Photosynthesis is one of the most important metabolic processes in plants and its performance is greatly affected under stress conditions. Photosynthesis may be directly affected by salt stress interference on photosynthetic electron transport. Chlorophyll *a* fluorescence analysis is useful for measuring induced changes in the photosynthetic apparatus.

Because there is limited information regarding salinity's effect on banana passionfruit plants (*Passiflora tripartita* (Juss.) Poir. var. mollissima (Kunth) Holm-Niesen & P.M. Jørg.), the present study aimed to evaluate the growth and photochemical efficiency of photosystem II (PSII) in banana passionfruit seedlings under saline stress.

Materials and methods

The study was conducted in a greenhouse at the Pedagogical and Technological University of Colombia (UPTC), Tunja, Colombia (5° 33′ 16.25″ N, 73° 21′ 9.14″ W) at 2790 m. a. s. l. Average growth conditions inside the greenhouse were: photosynthetic photon flux of 341.71 µmol m^{-2} s^{-1}, 15.8 °C temperature and 72% relative humidity.

The Castilla cultivar of banana passionfruit was used for the experiment. Seeds were allowed to germinate in one-pound plastic bags containing a 1:1 mixture of soil and peat. Eight weeks after germination at the six-leaf stage, single seedlings were transplanted to 4 kg plastic bags filled with medium. Plantlets were daily watered with tap water and were grown up to the 8 - 10 leaf stage (18 days after transplanting), after which NaCl treatments were administered to the planting medium at concentrations of 20, 40, 60, and 80 mmol NaCl kg^{-1}. These corresponded to electrical conductivities of 2.20, 3.39, 5.47, and 8.12 $dS.m^{-1}$, respectively. Control plants were not treated with salt (electrical conductivity 0.97 $dS.m^{-1}$). To avoid osmotic shock to plants, treatments were imposed incrementally, increasing the concentration weekly until the final concentration was reached.

One hundred and twenty eight days after transplanting, chlorophyll fluorescence measurements were conducted on a fully expanded leaf of each plant, located in the middle third of the plant, using a Junior-Pam Chlorophyll Fluorometer with an actinic light pulse of 25 μmol m^{-2} s^{-1} (H. Walz, Effeltrich, Germany). Before measuring chlorophyll (Chl) fluorescence parameters (FPs), leaves were put in a dark-adapted state for 30 min using light exclusion clips. The following chlorophyll fluorescence yields (FYs) were measured: minimum Chl FY in the dark-adapted state (F_0), maximum Chl FY in the dark-adapted state (F_m). Using these parameters, were calculated the following ratios: maximum PSII photochemical efficiency $F_v/F_m = (F_m–F_0)/F_m$; maximal variable fluorescence $Fv = F_m-F_0$. Plants were harvested 138 days after transplanting. Then they were dried to determine total dry weight and dry weight of each plant organ (roots, petioles + stem + shoots and leaves), by drying in an oven at 70 °C for 48 h. The leaf area was measured using an analyzer LI-3000-A (LI-COR, Lincoln, USA). Soil salinity of all treatments was measured by determining the electrical conductivity (EC) of vacuum-pumped extracts from saturated soil.

Chlorophyll fluorescence measurements were taken on three plants for each treatment, with one leaf per plant analyzed. The plants exposed to the saline levels were arranged in a complete randomized design, with three replications and four plants per plot. All data were subjected to one-way Anova and significant differences between means were determined by Tukey's multiple-range test. Tendency curves for averages of treatments were calculated by a regression analysis, using the PASW statistics 18 program, version 18.0.0. Unless otherwise stated, differences were considered statistically significant when $P < 0.05$.

Results and discussion

Plant growth

The plant growth response of banana passionfruit plants to salinity produced statistically significant differences ($P < 0.05$) in terms of leaf area, total stem length, and total dry weight per plant. In comparison with control plants, plants exposed to 20, 40, 60, and 80 mmol NaCl reduced leaf area by 20.89, 42.91, 58.37, and 76.40%, respectively. In the same order, total stem length showed a reduction of 9.97, 27.28, 42.79, and 55.77% with relation to control plants. Total dry weight per plant was reduced by 23.89, 31.49, 39.60, and 61.26% (Table 1).

Leaf growth inhibition is seen as an adaptive response to salinity and water deficiency. Plants with lower leaf area can cut water losses by slowing transpiration, and thus delay the onset of more severe stress (Casierra-Posada *et al.*, 2006). Increased dead leaves are another contributing factor to leaf area reduction. In fact, the leaf death rate increased in plants experiencing saline stress when compared with control plants. Increased leaf death under saline stress is generally attributed to toxic levels of salt accumulation (Munns, 2002).

Table 1. Growth in banana passion fruit (*Passiflora tripartita* (Juss.) Poir. var. mollissima (Kunth) Holm-Niesen and P.M. Jørg.) exposed to different levels of NaCl salinity.

NaCl (mmol)	Electrical conductivity (dS m^{-1})	Leaf area (cm^2)	Total stem length (cm)	DM per plant (g)
0	0.97	938.61 e*	897.20 c	30.47 d
20	2.20	742.45 d	807.70 c	23.19 c
40	3.39	535.81 c	652.40 b	20.87 bc
60	5.47	390.71 b	513.25 a	18.40 b
80	8.12	221.49 a	396.78 a	11.80 a

* Means followed by the same letter are not statistical different according to Tukey's adjustment for multiple comparison test ($P < 0.05$).

Casierra-Posada y Roa (2006) exposed *P. ligularis* plants to water stress, and found that stressed plants presented a 35.8% reduction in total stem length compared to control plants watered with a normal regime. This result can be compared to the behavior of *P. tripartita* plants in the present study, as both are rapidly-growing plants of the same genus, and both water and osmotic stress have similar effects on plant growth (Munns, 2002).

Dry matter distribution in different plant organs is another factor that is strongly influenced by saline conditions. While DM accumulation in leaves was inversely proportional to NaCl concentration in the substrate, a higher proportion of DM was allocated to roots with increasing soil salinity, with statistically significant differences ($P < 0.05$) for both parameters. DM allocation to stems and branches showed no statistically significant difference (Figure 1).

The results in this study agree with Awang *et al.* (1993) who reported a reduction in total dry weight of leaves as salinity lowered plant growth parameters. Casierra-Posada and García (2005) mention that salinity negatively affects leaf growth and induces an increase in relative root weight, as roots tend to grow in order to reduce toxic ion concentration in tissues through dilution, and in order to explore the soil to find areas of lower toxic concentration.

Chlorophyll fluorescence measurement

F_v/F_m represents the maximum quantum yield of photosystem II, which in turn is highly correlated with the quantum yield of net photosynthesis. The present study found highly significant differences ($P < 0.01$) for this variable between treatments. Compared to the control plants, F_v/F_m was reduced by 11.29, 14.23, 38.89, and 92.25%, respectively, in treatments with 20, 40, 60, and 80 mmol NaCl (Figure 2). Up to 40 mmol NaCl the reduction can be considered moderate, but beyond this value, the ratio F_v/F_m found in plant leaves is drastically reduced, especially with a concentration of 80 mmol NaCl in the substrate.

Elevated salinity can further reduce photosynthesis by lowering stomatal conductance and thus depressing carbon uptake, and/or by inhibiting photochemical capacity (Dubey, 1997). Salinity has been shown to affect reaction centers of PSII either directly or through accelerated senescence (Kura-Hotta *et al.*, 1987). Maximal quantum yield of PSII (F_v/F_m) was reduced with increasing salt concentration in the present study, especially at very high concentrations. Electron flow was severely affected with 80 mmol NaCl.

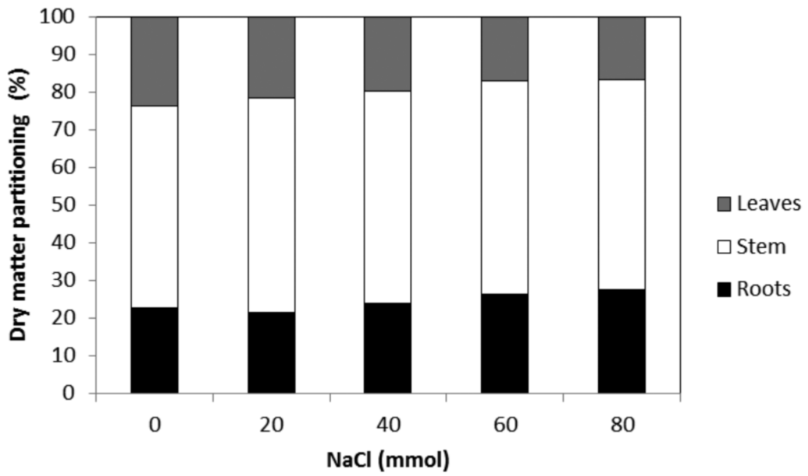

Figure 1. Dry matter partitioning in banana passionfruit plants (*Passiflora tripartita* (Juss.) Poir. var. mollissima (Kunth) Holm-Niesen & P.M. Jørg.) exposed to salt stress.

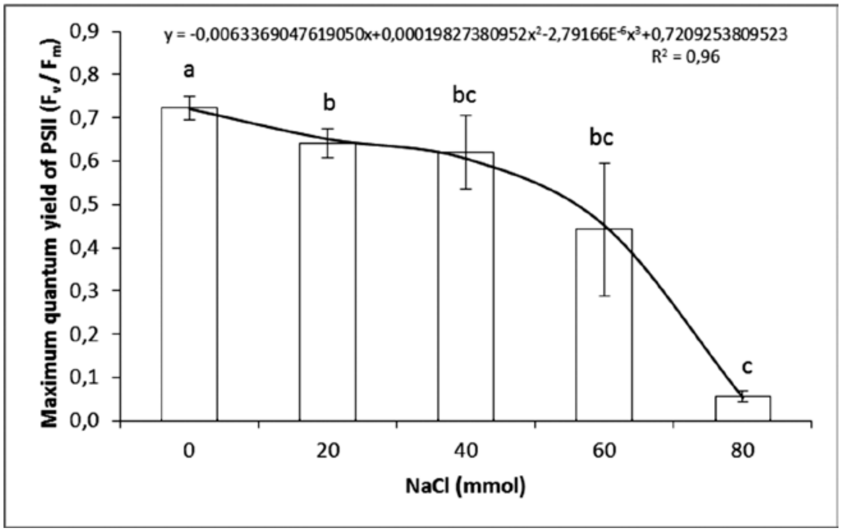

Figure 2. Effect of salt stress levels on quantum yield in dark adapted leaves of banana passionfruit plants (*Passiflora tripartita* (Juss.) Poir. var. mollissima (Kunth) Holm-Niesen & P.M. Jørg.). Means followed by the same letter are not statistically different according to Tukey's adjustment for multiple comparison test ($P < 0.05$).

Conclusions

- Saline conditions drastically reduced a number of growth factors in banana passionfruit. Leaf area, stem length, and DM weight all went down strongly with increasing salt concentration. PSII quantum yield also suffered an extreme reduction with increasing salinity.
- Data from the current experiment clearly support the general correlation between photosynthetic capacity and leaf area. Furthermore, the reduction of leaf area, PSII quantum yield, and the other factors measured in salt-affected banana passionfruit induced a reduction in DM production. This dry matter reduction closely follows the trend in PSII maximum quantum yield (F_v/F_m), which suggests that the major impact of salinity on the passionfruit plants was due to negative effects on photosynthesis.

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