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Photosynthesis of field-grown Arracacha (*Arracacia xanthorriza* Bancroft) cultivars in relation to root-yield

Ramón E. Jaimez [a,*], Norka Santos [b], Bruno Añez [a], Jorge Vásquez [a], Wilmer Espinoza [a]

[a] *Universidad de Los Andes. Instituto de Investigaciones Agropecuarias. Apartado 77 La Hechicera. Mérida 5101, Venezuela*
[b] *Universidad de Los Andes. Facultad de Ciencias. Departamento de Biología. La Hechicera, Mérida 5101, Venezuela*

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ABSTRACT

There has been limited research on measuring potential differences in leaf gas exchange of Arracacha (Peruvian parsnip, *Arracacia xanthorriza* Bancroft) cultivars, as affected by different environments, as well as its relation to storage root-yield. The present paper reports field measurements of leaf CO_2 assimilation rates (A) for five contrasting cultivars grown at two different high-altitude locations. Using a design of plots chosen at random with three repetitions, commercial root production was determined in the two locations at different altitude (1580 and 1930 m). Daily leaf gas exchange was repeatedly monitored with a portable open-mode infrared gas analyzer at different times in both locations during the growth cycle. Root-yield, leaf area and dry weight were measured. Significant differences in leaf photosynthetic rate and in specific leaf area (SLA) were observed among cultivars. Cultivars with high SLA, had high CO_2 assimilation. Mean (A_n) and total (A_{tot}) of CO_2 assimilation and SLA were significantly correlated with storage root-yield across cultivars and locations. The three cultivars with the greatest commercial root production also had the highest maximum values for A and the highest specific leaf area, indicating that these two parameters can be used to select for highly productive cultivars of *A. xanthorriza*.

1. Introduction

Arracacha (*Arracacia xanthorrhiza* Bancroft) is a root vegetable whose nutritional value and various commercial possibilities have not yet been thoroughly developed and exploited in most Central and South American countries (Montaldo, 1991). In Venezuela, according to the records of the Ministry of Agriculture (MAC, 1996), the average national annual production of Arracacha in the period 1992 to 1996 was approximately 21 500 t. Seventy percent of the total production came from highlands of the Venezuelan Andes, a trend that remained constant for the last 25 years.

A typical feature of most farmer's cultural practices with this crop is the use of a mixture of cultivars, especially those with white and yellow roots. In various areas of cultivation there is always a mixture of autochthonous and introduced cultivars. These farmer's traditional practices were not based on precise knowledge of how different cultivars react to variations in the texture and nutritional qualities of soils. Information on root-yield for each cultivar is limited (Pineda, 1988; Noguera, 2001) and usually consists of the national total reported production. In addition, relevant physiological information is very limited in Arracacha (Hermann, 1997; Libreros, 2001). This deficiency of information hinders the evaluation, selection and improvement of yields. There have been programs for improvement and selection in Brazil taking into account yield, disease resistance, culinary features and durability after harvesting (Giordano et al., 1995).

Some physiological characteristic, for example harvest index (economic root-yield/total biomass) and leaf area duration, have been utilized as rapid and nondestructive tools in tropical root crops breeding programs such as in cassava (El-Sharkawy, 2004, 2006a,b). Net photosynthetic rate (A) has been a common criteria to identify possible lines of genotypes adapted to specific environment and with higher yield (El-Sharkawy, 2006b). Such evaluations have been done with crops such as cassava (El-Sharkawy et al., 1990; El-Sharkawy, 2004, 2006a,b), asparagus (Faville et al., 1999; Ball and Kelly, 1999), maize (Crosbie and Pearce, 1982), soybean (Dornhoff and Shibles, 1970; Ashley and Boerma, 1989) and peas (Mahon and Hobbs, 1981). Some modern cultivars used today have higher A associated with that of their predecessor also is correlated with higher yield (Blum, 1990; Morrison et al., 1999; Gutiérrez-Rodriguez et al., 2000). However, poor correlation between A and yield have been reported in barley (Berdahl et al., 1972), and oilseed rape (Chongo and McVetty,

* Corresponding author. Tel.: +58 74 2401587; fax: +58 74 2401503.
E-mail address: rjaimez@ula.ve (R.E. Jaimez).

Abbreviations: A, net photosynthetic rate; A_n, mean CO_2 assimilation; A_{tot}, total daily assimilation of CO_2; A_{max}, maximum CO_2 assimilation; E, transpiration; g_s, leaf conductance; dap, days after planting.

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2001). In some cases even negative correlation existed between maximum leaf photosynthesis and productivity (Evans, 1993). Nonetheless, Lawlor (1995) pointed out that there are some contradictions in the results for different crops in this respect because, limiting environmental and plant factors for yield and photosynthesis interact strongly. Therefore, it is important to evaluate optimal environmental conditions and better understand the mechanisms underlying biomass production under a range of conditions. There has been no evaluation of variations in the rate of photosynthesis that may correlate with root production in *Arracacia xanthorriza*. However, root-yield was significantly correlated with *A* in large accessions of cassava under field conditions in several locations and altitudes (El-Sharkawy et al., 1990; El-Sharkawy, 2004, 2006a,b).

It will be useful to know if high yields of Arracacha are related to high rates of assimilation or if they are independent of root production owing to variations in the distribution patterns of assimilates among different plant organs. The purpose of this research was to evaluate the relationship between root production in *A. xanthorriza* and the rate of CO_2 assimilation in five contrasting cultivars currently used in the Venezuelan Andes and to see if the assimilation rate can be used as an indirect factor to select highly productive cultivars. As far as we know this is the first comparative study of varieties of Arracacha involving gas exchange characteristics and their relationship to root production under field conditions.

2. Materials and methods

Two experiments were conducted in two different agroecological systems. The first experiment was carried out near Capuri (8°10′N, 71°35′W), 1580 m a.s.l. Average annual precipitation is 1140 mm and the annual mean temperature 19 °C (Noguera, 2001). The second experiment was at the Universidad de Los Andes, Agricultural Research Station, Santa Rosa (8°38′N, 71°10′W) 1930 m a.s.l. Mean annual precipitation is 2039 mm and the annual mean temperature 17.1 °C (Jaimez et al., 2001). Both locations are in the state of Mérida, Venezuela. Five cultivars of *A. xanthorriza* were used: *Bandera* (Ban), *Cebollo* (Ce), *Chamero* (Cha), *Cacho Buey* (Cb), *Bayuelo* (Ba). All but Bandera (white roots) have yellow roots. Further information and descriptions of these cultivars can be found in Faillace et al. (1972) and Noguera (2001).

The propagules were planted on June 20, 2001 and September 12, 2004 in Capuri and Santa Rosa, respectively. Propagules were planted at 0.50 m intervals between plants and with 0.40 m between rows in both locations according to Añez et al. (2001). A complete randomized block design with three replicates was used. Each plot had 42 plants. Fertilizer was applied 40 days after planting (dap) using 600 kg per hectare of commercially produced 12–12–17–2, following recommendations of Añez et al. (2002). Plants were watered every 5 days during dry periods in both locations.

2.1. Leaf gas exchange and growth

Net CO_2 assimilation (A), transpiration (E) and leaf conductance (g_s) measurements were made at 90 and 151 in Capuri and at 75, 97,124, 182, 253 and 305 dap in Santa Rosa on fully expanded leaves (five plants of each cultivar, randomly selected from the plots) every two hours using a portable open gas exchange system (LCA-4, ADC, England). Integration curves of daily CO_2 assimilation (from 8:00 to 15:30 h) were carried out to obtain total daily assimilation of CO_2 (A_{tot}) (Rada et al., 1996). Micrometeorological measurements were carried out simultaneously. Air and leaf temperature were measured with Chromel–Alumel thermocouples (36 gauges). Relative humidity was measured with a digital humidity meter (Extech instrument). These variables were used to determine leaf to air vapor pressure difference (VPD). Additionally photon flux density (PFD) was measured with a sensor on the leaf chamber of LCA-4. Measurements were made at ambient CO_2 concentrations between 340 and 365 μmol mol^{-1} in both locations.

Plant growth measurements were taken at the Santa Rosa site. Harvests dates corresponded to the same days gas exchange measurements were done. For each harvest, three adjacent plants were selected following the IBSNAT methodology (IBSNAT, 1990). Plants were separated into leaves, stems and root. The leaf area was measured using a leaf area meter (LICOR 1200). Dry weight per plant of all components (leaves, stems, and roots) were obtained after oven-drying at 70 °C to constant weight. In these experiments, evaluation of commercial root-yield (roots weighing more than 70 g) and total yield were conducted. The last harvest was carried out at 449 and 306 dap in Capuri and Santa Rosa, respectively.

Regressions were done between assimilation rates (mean CO_2 assimilation, (A_n), maximum CO_2 assimilation (A_{max}) and $A_{tot,}$) and root-yield in order to examine variations between cultivars. Production data was analyzed with ANOVA and the differences between cultivars were obtained using Tukey test ($p < 0.05$).

3. Results

PFD close to 1950 μmol m^{-2} s^{-1} were obtained at noon for both locations. After 15:00 PFD declined to 450 μmol m^{-2} s^{-1} due to cloud formation which happens frequently in high Andean locations (Fig. 1). Air temperature varied from 20 to 26 °C at Capuri and 22 to 27 °C at Santa Rosa. The highest relative humidity was obtained in Santa Rosa (Table 1). Leaf temperature varied between 20.0 and 27.4 °C for plants at Santa Rosa and between 19.1

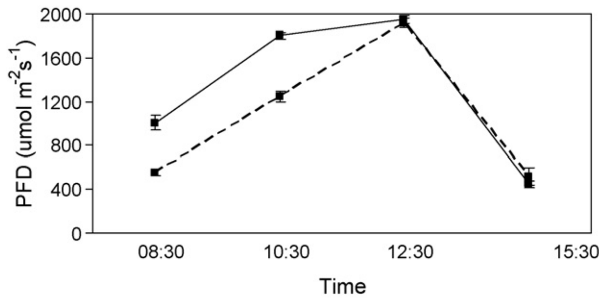

Fig. 1. Averages of photon flux density (PFD) during sunny days at Capuri (– – –) and Santa Rosa sites (—). Bars correspond to one standard error from mean.

Table 1
Mean maximum and minimum air temperature and relative humidity during measurement period (8:30–15:30 h) for the two study sites. Standard error from the mean in parenthesis

Location	Minimum temperature (°C)	Maximum temperature (°C)	Minimum relative humidity (%)	Maximum relative humidity (%)
Capuri	20.3 (0.4)	26.6 (0.3)	55.8 (1.3)	82.3 (0.8)
Santa Rosa	22.3 (0.5)	27.2 (0.5)	52.2 (0.4)	92.5 (2.0)