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ORIGINAL PAPER

Photosynthetic characteristics and quality of five passion fruit varieties under field conditions

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Abstract Due to photosynthetic mechanisms respond very quickly to most stressors and due to strong concerns regarding the impact of climate change on future plant productivity, the purpose of this study was to perform a comparative analysis of in vivo photosynthetic efficiencies and fruit quality of five cultivars of passion fruit (*Passiflora edulis* Sims. f. *flavicarpa* Degener). The experiments were conducted in the northern region of Espírito Santo State using cultivars FB 200, FB 300, BRS Gigante Amarelo, BRS Sol do Cerrado, and BRS Ouro Vermelho. Analyses were performed 6 months after planting, when the plants were beginning reproduction and were repeated two times during the next 4 months until fruit ripening. Chlorophyll *a* fluorescence transient, total chlorophyll content, and gas exchange were measured in the leaves. Physical and chemical fruit attributes were also assessed. The lowest fluorescence rates were identified in the FB 300, BRS Sol do Cerrado, and BRS Ouro Vermelho cultivars, which exhibited better capacities for quinone A (Q_A) reoxidation and better electron transfer efficiencies from Photosystem II to Photosystem I acceptors. Better photochemical performances (PI_{total}) and CO_2 assimilations (*A*) resulted in higher fruit pulp yields, demonstrating the superior quality of the FB 300, BRS Sol do Cerrado, and BRS Ouro Vermelho cultivars.

Keywords Photochemical performances · Gas exchange · *Passiflora edulis* · Fruit quality · Soluble solids · Titratable acidity

Introduction

Passion fruit is an important fruit crop in many tropical and subtropical countries due to its physicochemical properties and pharmacotherapeutic effects (Cavichioli et al. 2008). Brazil is the largest world producer with approximately 650,000 tons per year, corresponding to 83 % of world production.

There are still many factors that interfere with passion fruit productivity, because the crop is susceptible to various abiotic stressors, including drought and high temperatures. To effectively maintain global production, it is necessary to use cultivars that are resistant to pests and diseases and that are adapted to regional edaphoclimatic factors and technologies. Economic losses in passion fruit production due to abiotic stressors are quite substantial; thus, the selection of cultivars with increased tolerance to drought, light stress, and changes in temperature is crucial for passion fruit growers.

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The impacts of climate change, rising temperatures, and changes in rainfall patterns are of major concern for future plant productivity (Osório et al. 2011). Water deficit and high temperatures are the most basic abiotic stress factors that restrict plant growth and productivity in the tropics, and they often occur simultaneously (Holá et al. 2010). Several studies have suggested that photosynthetic characteristics are the most suitable for use as markers for indirect breeding selection (Chaves et al. 2009; Petkova et al. 2007; Stefanova et al. 2011). In fact, photosynthetic mechanisms respond very quickly to most of the stress that plants encounter (Tóth et al. 2007). Characteristics of gas exchange, photosynthetic pigment determination, and chlorophyll *a* fluorescence have been widely tested in many plant species for possible use in breeding programs to improve plant stress tolerance (Lichtenthaler 1988; Srivastava and Strasser 1995, 1996; Bączek-Kwinta et al. 2011). Petkova et al. (2007) used chlorophyll *a* fluorescence parameters to select among 12 cultivars and lines of beans (*Phaseolus vulgaris* L.) for breeding; when cultivated in the field, these cultivars have different tolerances for high temperatures. More recently, Stefanova et al. (2011) used nine *P. vulgaris* L. accessions, three cultivars, and six lines under greenhouse conditions to study tolerance for high temperatures using changes in chlorophyll *a* fluorescence induction.

Selection of passion fruit cultivars that exhibit excellent photosynthetic performance and post-harvest fruit quality is fundamental for cultivar development. Based on this evidence, this study aimed to determine whether the photosynthetic performances of five *Passiflora edulis* Sims. F. *flavicarpa* Degener passion fruit genotypes grown under field conditions correlated with fruit quality and if net photosynthetic rate, chlorophyll *a* fluorescence parameters, or photosynthetic pigment content can be used as reliable physiological markers in selection breeding.

Materials and methods

Experimental area and plant material

Seedlings of five passion fruit (*Passiflora edulis* Sims. F. *Flavicarpa* Degener) cultivars (FB 300, BRS Sol do Cerrado, BRS Ouro Vermelho, BRS Gigante Amarelo, and FB 200) were grown in tubes and irrigated with an intermittent mist system under nursery conditions and transplanted after acclimatization. The transplant took place approximately 70 days after sowing when seedlings were around 20 cm high. The seedlings were planted in 0.40 × 0.40 × 0.40 m holes with 3 × 3 m spacing (1,111 plants/ha) at the Sooretama Experimental Farm at the Capixaba Institute of Research, Technical Assistance, and Rural Extension (INCAPER), in Sooretama, ES, Brazil (19°11′30″S–40°05′46″W). The area where the research was conducted has hot, rainy summer and cool, dry winter climatic conditions with maximum temperatures typically ranging from an average of 19 °C in July to 35 °C in February and precipitation (1,252 mm per year) ranging from an average of about 40 mm in June to 200 mm in December (SIAG 2011). The plants were rained in a wire trellis system that was 1.8 m above the ground. The plants were pruned once they reached the top of the wire and had grown lateral branches, according to the recommended techniques for the cultivar. Corrections for soil acidity and fertilizer were made on the basis of soil analysis. When the plants reached the beginning of the reproductive period (6 months after planting), analyses of chlorophyll *a* fluorescence, gas exchange, and chlorophyll index were conducted in ten plants with two replicates. These evaluations were performed on five different days in an interval of 4 months corresponding to the experimental time. Physicochemical measurements were taken from ten fruits at the end of the experiment.

Measurement of the fast chlorophyll *a* transients

The OJIP fluorescence transients (10 μs to 1 s) were measured with a Handy-PEA fluorimeter (Plant Efficiency Analyser, Hansatech Instruments Ltd, King's Lynn Norfolk, UK). The measurements were performed on fully expanded young leaves in the morning (between 07:00 and 09:00 h) after acclimatizing leaves in the dark for 30 min; this period of time is long enough for complete photosynthetic oxidation. We note that O (50 μs) is the initial fluorescence level, J (2 ms) and I (30 ms) are intermediate levels, and P (approximately 300 ms in this study) is the peak level. The transients in leaves were induced by red light (peak at 650 nm) of 3,000 μmol photons m^{-2} s^{-1} provided by an array of 3 light-emitting diodes, focused on a spot of 4 mm diameter, and recorded for 1 s with 12-bit resolution. The data acquisition was at every 10 μs (from 10 μs to 0.3 ms), every 0.1 ms (from 0.3 to 3 ms), every 1 ms (from 3 to 30 ms), every 10 ms (from 30 to 300 ms), and every 100 ms (from 300 ms to 1 s). The fluorescence intensity data were then normalized for relative variable fluorescence (general symbol W): $[W_t = (F_t - F_M)/(F_M - F_0)]$, and the differences between the five cultivars were calculated using the FB 300 cultivar as a reference to obtain $\Delta W_t = F_{\text{cultivated}} - F_{\text{reference}}$ (Chen et al. 2011). The biophysical variables, of the OJIP transients, that quantify the energy flow from photosystem II (PSII) were analyzed according to the JIP test proposed by Strasser et al. (1995): RC/ABS = Absorption flux (of antenna Chls) per RC (reflecting measure for an average antenna size), TR_0/ABS = the quantum yields of primary photochemistry (reduction of primary electron quinone acceptor Q_A), ET_0/ABS = the quantum yields of electron transport from Q_A to plastoquinone pool (PQ), RE_0/ABS = the quantum yields of the reduction of PSI end electron acceptors, ET_0/TR_0 = the efficiencies/probabilities that an electron moves from Q_A to PQ, RE_0/ET_0 = the efficiencies/probabilities that an electron moves from the reduced PQ to the PSI end electron acceptors, and PI_{abs} and PI_{total} = the performance indexes PI_{abs} and PI_{total} which are products of terms expressing "potentials" for photosynthetic performance (partial potentials) at the sequential energy bifurcations from exciton to PQ reduction and to the reduction of PSI end acceptors.

Gas exchange and net CO_2 assimilation

Gas exchange and net CO_2 assimilation analyses were performed on the same day and with the same leaves used to measure the transient fluorescence.

We used an infrared gas analyzer in an open system (IRGA-LCpro$^+$ System, ADC, BioScientific Ltd), which allowed us to assess the following variables: net CO_2 assimilation (A, µmol m^{-2} s^{-1}), transpiration (E, mmol m^{-2} s^{-1}), stomatal conductance (g_s, mol m^{-2} s^{-1}), and intercellular CO_2 concentration (C_i, µmol mol^{-1}). From these variables, were calculated: instantaneous carboxylation efficiency (A/C_i, µmol m^{-2} s^{-1} Pa^{-1}), water-use efficiency (A/E, µmol $mmol^{-1}$), and intrinsic water-use efficiency considering the stomatal mechanism (A/g_s, µmol mol^{-1}).

Chlorophyll index

Chlorophyll content was estimated using a portable chlorophyll meter (Model CL-01, Hansatech, King's Lynn, Norfolk, UK) in the same leaves used for fluorescence and gas exchange measurements. It's expressed as the "chlorophyll index" (Cassol et al. 2008).

Fruit physical–chemical analyses

After the leaf analyses, fruits that had reached commercial maturity were collected and taken to the laboratory, where they were cleaned with sodium hypochlorite solution and stored at room temperature until further analysis. For fruit physical and chemical parameter analyses, the juice and arils were separated from the seeds using a nylon sieve. Fruit and rind masses were weighed to calculate pulp yield.

The soluble solids (SS, °Brix) were quantified using two drops of juice for a digital refractometer reading (Mod. RTD-45, Instrutherm) with automatic temperature compensation (AOAC 1992). The pH value was recorded on a digital pH meter (model TEC-2, TECNAL, Brazil).

To determine titratable acidity (TA, citric acid %), 5 mL of juice was diluted in 50 mL of distilled water. For every 10 mL aliquot, three drops of 2 % phenolphthalein (w/v) were added. The solution was titrated with 0.1 N NaOH until reaching a permanent pink color. The acidity calculations were performed according to the equation: citric acid % = $V_g \times N \times F \times$ Ac. Eq./10 × g, where V_g = the volume of spent NaOH (mL); N = the normality of NaOH = 0.1 N; F = the correction factor obtained for standardization of NaOH = 1.00; Ac. Eq. = the passion fruit acid equivalent = 64; and g = the sample mass (1 g) (Abreu et al. 2009). The soluble solids to titratable acidity ratio was then calculated (SS/TA).

Experimental design and statistical analyses

The experimental design was completely randomized. The means represent 10 independent measurements (i.e., fluorescence, gas exchange, and chlorophyll index). The data obtained from the analyses of chlorophyll *a* fluorescence emission kinetics and the JIP test were normalized using the FB 300 cultivar as a reference. Choosing the FB 300 cultivar was justified by the fact that this cultivar has been used for a longer period of time than other cultivars, suggesting that it has the best production indices. Analyses of the total chlorophyll, gas exchange, and post-harvest indices were performed using Tukey's test at the 5 % significance level.

Results

Chl *a* fluorescence transients of the dark-adapted leaves of five passion fruit (*Passiflora edulis* Sims. F. *Flavicarpa* Degener) cultivars (FB 300, BRS Sol do Cerrado, BRS Ouro Vermelho, BRS Gigante Amarelo, and FB 200) are shown, on logarithmic time scale from 10 µs up to 1 s, in Fig. 1a. All curves show the typical OJIP shape (the O, J, I, and P steps are marked in the plot), with similar maximum variable fluorescence ($F_M - F_0 = F_V$), demonstrating that all samples were photosynthetically active. It appears that FB 200, BRS Gigante Amarelo and BRS Ouro Vermelho cultivars had the highest fluorescence levels (Fig. 1a) and, these differences can be observed in more detail in Fig. 1b. The relative variable fluorescence in step J (W_J) increased 25 % (FB 200), 10 % (BRS Gigante Amarelo), and 8 % (BRS Ouro Vermelho) in these three cultivars compared to FB300.

An increase in fluorescence during the J–I phase was also observed. The relative variable fluorescence in step I (W_I) increased 15 (FB 200), 9 (BRS Gigante Amarelo), and 3 % (BRS Ouro Vermelho) compared to FB 300 whereas

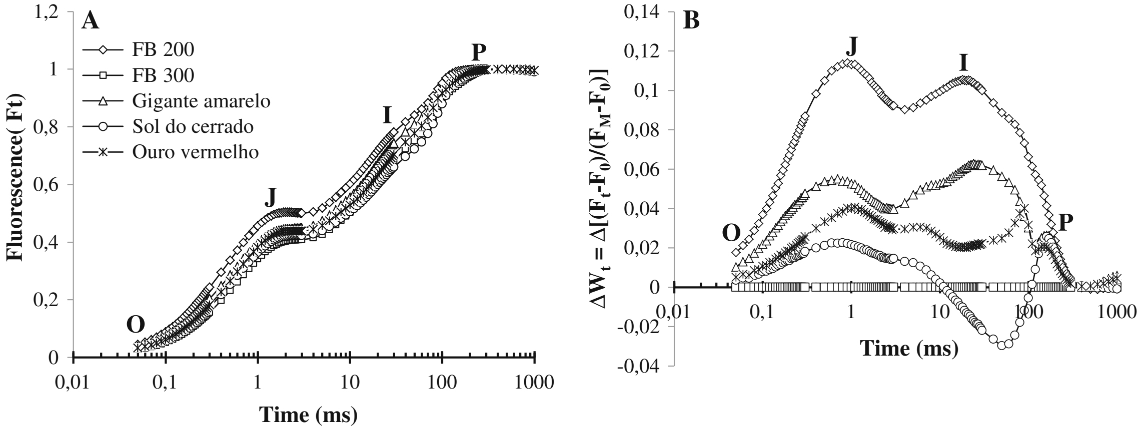

Fig. 1 **a** Chlorophyll *a* fluorescence transients (OJIP) from dark-adapted leaves of five passion fruit (*Passiflora edulis* Sims. F. *flavicarpa* Degener) cultivars given on a logarithmic time scale and expressed as relative variable fluorescence (W_t), i.e. double normalized at the F_0 and F_M points. **b** The differences of the five cultivars using FB300 as a reference (ΔW_t). FB 200 (*diamond*), FB 300 (*squares*), BRS Gigante amarelo (*triangles*), BRS Sol do Cerrado (*circles*), BRS Ouro Vermelho (*asterisk*). Each *curve* represents the mean of 10 independent transients

the later I–P phase, which occurred between 30 and 150 ms, was also higher for three cultivars.

Overall, there were only small variations between BRS Sol do Cerrado and FB 300 cultivar. Both cultivars, exhibited similar photochemical behavior, with BRS Sol do Cerrado cultivar 3 % more fluorescence in W_J and 3 % less in W_I, whereas the I–P phase was slightly lower than in the FB 300 cultivar (Fig. 1b).

The structural and functional parameters affecting photosynthetic behavior of the plants were also characterized from the fluorescence transients shown in Fig. 2. Here, all the fluorescence traces of the plants were normalized using the FB 300 cultivar as a reference. The radar plot shows in highlights the BRS Sol do Cerrado cultivar compared to other cultivars, presenting higher values, especially in the flow of electrons from PSI, i.e., from of the reduced plastoquinone pool to the final electron acceptors.

The FB 300 and BRS Sol do Cerrado cultivars displayed the highest performance indices (PI_{total}). In the FB 300 cultivar, the energy cascade beginning with the first absorption of radiant energy in PSII (PI_{abs}) was critical for securing the elevated PI_{total}. The high photochemical efficiency of PSI for BRS Sol do Cerrado was also decisive in achieving the highest PI_{total} value (Fig. 2).

Although the FB 200, BRS Gigante Amarelo, and BRS Ouro Vermelho cultivars had lower RC/ABS values compared to FB 300, the RE_0/ABS values (quantum yields of the electron transport from Q_A^- to the PSI electron acceptors) were 36 and 8 % lower, respectively, than both the FB 300 and BRS Sol do Cerrado.

It should also be noted that F_V/F_M (=$TR_0/ABS = \varphi_{P0}$), a parameter that represents the maximum PSII quantum yield in dark-adapted samples and that is often used to express plant physiological condition, exhibited no significant differences among cultivars.

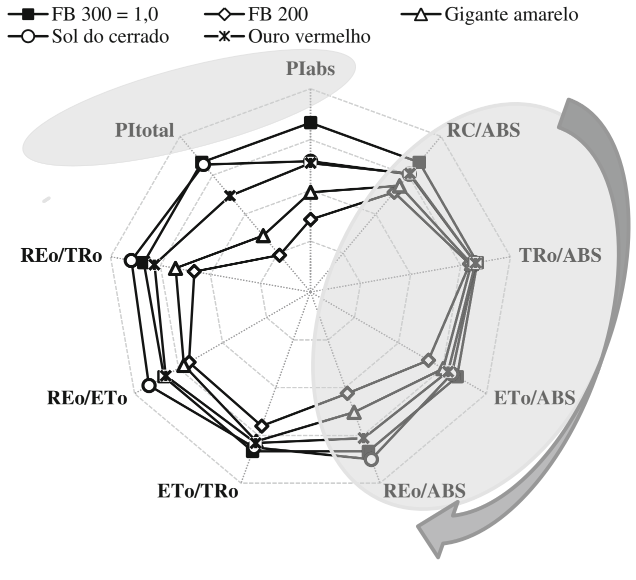

Fig. 2 Radar-plot of fluorescence transient chlorophyll *a* parameters deduced from the analysis of the JIP-Test, evaluated from the perspective of nine parameters organized and separated into three groups: performance indices (PI_{abs}, and PI_{total}), movements of electrons through the system (RC/ABS, TR_0/ABS, ET_0/ABS) indicated by *arrow*, and RE_0/ABS) and cascade of quantum yield (ET_0/TR_0, RE_0/ET_0, and RE_0/TR_0). Each parameter is expressed as fraction relatively to the values of cv. FB300 as a reference (regular *circle* with value 100 % = 1)

In this experiment, the FB 300 and BRS Sol do Cerrado cultivars had the lowest fluorescence rates and the highest net CO_2 assimilation (*A*) rates. The BRS Sol do Cerrado, FB 300, and BRS Ouro Vermelho cultivars had the highest chlorophyll levels compared to the FB 200 and BRS Gigante Amarelo cultivars (Table 1).

Table 1 Chlorophyll index (a.u.), intercellular CO_2 concentration (C_i, µmol mol^{-1}), transpiration (E, mmol m^{-2} s^{-1}), stomatal conductance (g_s, mol m^{-2} s^{-1}), net carbon assimilation rate (A, µmol m^{-2} s^{-1}), water-use efficiency (A/E, µmol $mmol^{-1}$), intrinsic water-use efficiency considering the stomatal mechanism (A/g_s µmol mol^{-1}), and instantaneous carboxylation efficiency (A/C_i, µmol m^{-2} s^{-1} Pa^{-1}) of five passion fruit (*Passiflora edulis* Sims. F. *flavicarpa* Degener) cultivars ($n = 10$)

	Chl	C_i	E	g_s	A	A/E	A/g_s	A/C_i
FB 300	43.23 b	193.83 a	2.45 a	0.16 a	16.76 a	6.84 ab	107.02 a	0.08 b
FB 200	25.38 c	152.66 b	1.48 b	0.11 b	10.86 bc	7.30 a	93.08 b	0.07 bc
Gigante amarelo	23.35 c	134.83 bc	2.18 a	0.15 a	12.15 b	5.57 b	77.56 c	0.09 b
Sol do cerrado	67.05 a	138.33 bc	2.36 a	0.18 a	18.07 a	7.63 a	102.30 a	0.13 a
Ouro vermelho	44.07 b	131.11 bc	2.10 a	0.13 ab	14.79 ab	7.04 a	113.81 a	0.11 ab

Values followed by different letters are significantly different ($p \leq 0.05$; Tukey test) for each parameters

Table 2 Fresh weight of fruits (g), pulp yield (g), soluble solids (SS °Brix), titratable acidity (TA-citric acid %), and SS/AT ratio of five passion fruit (*Passiflora edulis* Sims. F. *flavicarpa* Degener) cultivars ($n = 10$)

	Fresh weight (g)	Pulp yield (g)	SS °Brix	TA	SS/TA
FB 300	313.7 ± 28.8 a	169.4 ± 14.9 ab	14.2 ± 0.37 a	4.19 ± 0.26 a	0.34 ± 0.03 a
FB 200	163.0 ± 10.6 b	96.8 ± 4.4 bc	13.1 ± 0.95 a	2.98 ± 0.76 b	0.48 ± 0.15 a
Gigante amarelo	129.8 ± 11.6 b	65.4 ± 2.2 c	10.7 ± 0.24 b	2.92 ± 0.33 b	0.37 ± 0.07 a
Sol do cerrado	333.0 ± 16.9 a	200.0 ± 6.9 a	13.8 ± 0.49 a	2.94 ± 0.17 b	0.47 ± 0.05 a
Ouro vermelho	269.0 ± 23.6 a	160.9 ± 15.3 ab	13.3 ± 0.94 a	3.45 ± 0.49 ab	0.38 ± 0.06 a

Values followed by different letters are significantly different ($p \leq 0.05$; Tukey test) for each parameters

Due to the lower transpiration rate (E) in FB 200 and the higher transpiration rate in BRS Gigante Amarelo, the water-use efficiency value, expressed as the A/E ratio, was higher for FB 200 and lower for BRS Gigante Amarelo. Regarding intrinsic water-use efficiency (A/gs), FB 200 and BRS Gigante Amarelo had the lowest rates (Table 1).

The fruits of BRS Gigante Amarelo and FB 200 had lower biomass and pulp yields. The BRS Gigante Amarelo also exhibits lower soluble solid (SS) values. In contrast, FB300 displayed soluble solid (SS) values within market standards (14 °Brix) (Table 2). A higher SS content in the pulp explains the high titratable acidity (4 %) and, represents an important point for processing because it would be necessary to reduce the acidifier added to juice from highly acidic fruit.

Regarding the values of the soluble solids:titratable acidity ratio (SS/TA) comparison of the five cultivars did not showed statistic differences. Taking into consideration that the ratio indicated balance between the two components, specifying the minimum solid contents on the maximum acidity to determine the real flavor most accurately, for the passion fruits commercially, the minimum soluble solids content (%) is 14 and the maximum titratable acidity content (%) is 3.5 (Chitarra and Chitarra 2005), resulting in an 4.0 SS/TA, a value reached only by FB300 tested in the present study.

Discussion

All oxygenic photosynthetic organisms investigated so far using this method have shown the polyphasic rise with the basic steps O–J–I–P and minor differences among different phenotypes (Strasser et al. 2000). The present investigation no way differs from earlier investigations (Fig. 1a). The shape of the O–J–I–P transient is very sensitive to stress caused by changes in different environmental conditions. Our data revealed, in O–J phase, a possible deficiency in the capacity to re-oxidize quinone A (Q_A^-) in the FB 200, BRS Gigante Amarelo, and BRS Ouro Vermelho cultivars. A higher value in the O–J phase was more evident for the FB 200 cultivar (Fig. 1b). This first phase of the OJIP curve (O–J) represents the accumulation of reduced quinone A (Q_A), i.e., a reduction of the acceptor side of photosystem II (PSII) (Smit et al. 2009). These results indicate damage in PSII, possibly due to a deficiency in the reoxidation capacity of Q_A, leading to inefficient electron transport in the intersystem to PSI. Similarly, Smit et al. (2009) observed an increase in fluorescence during the O–J phases when studying different trifluoroacetate concentrations in bean plants, which indicated Q_A^- accumulation.

An increase in fluorescence during the J–I phase was also observed, representing a progressive reduction in electron transport from the plastoquinone "pool" in the intersystem (Tóth et al. 2007).

Finally, the highest values found for the I–P phase in the three cultivars may suggest reduced electron transport capacity from the intersystem to Photosystem I (PSI). Oukarroum et al. (2009) described similar results obtained in 10 drought-stressed barley and 9 chickpea varieties. These authors suggested that the relative loss of the I–P phase seems to be related to a loss of photosystem I (PSI) reaction centers.

Furthermore, the OJIP curves revealed that the FB 200, BRS Gigante Amarelo, and BRS Ouro Vermelho cultivars had a lower Q_A^- re-oxidation capacity in photosystem II (PSII), causing an accumulation of reduced Q_A and consequently decreasing electron transport from that point on. This is reflected in PSI activity, where the final electron acceptors for the intersystem are located.

According to Strasser et al. (2004), a more detailed OJIP curve is obtained when applying the JIP test. The resulting parameters of this test make it possible to assess the specifics of the fluorescence transient kinetics and to quantify the photochemical performance from the early photochemical absorption in the antenna complex to the final reduction of electron acceptors in PSI (Yusuf et al. 2010).

Electron absorption (RE_0/ABS), capture (RE_0/TR_0), and transport (RE_0/ET_0) efficiencies were higher in PSI for the FB 300 and BRS Sol do Cerrado (Fig. 2); thus, there was a higher PSI quantum yield in these cultivars. These data confirm those presented in the OJIP curves, in which plants of the BRS Sol do Cerrado variety exhibited the lowest values during the I–P phase, indicating greater electron transfer capacity to the PSI acceptors.

In field conditions, high temperature is usually associated with high light intensity and drought, which exacerbate the damages in PSII (Lichtenthaler 1988; Srivastava and Strasser 1995; Petkova et al. 2007; Oukarroum et al. 2009). Our results from the analysis of the fluorescence transients with the JIP test showed that, under conditions of field experiments, the plants FB 300, BRS Sol do Cerrado, and BRS Ouro Vermelho cultivars exhibited increased efficiency for energy conservation and increased stability.

The maximum quantum yield of PSII photochemistry, as analysed by TR_0/ABS, did not decrease. Similarly, Vieira et al. (2010), working with different ammonium sulfate concentrations in pineapple, also identified no significant differences in the TR_0/ABS values. This parameter, $F_V/F_M = TR_0/ABS$, has been substituted or supplemented with the PI_{total} because it is the product of four other parameters that demonstrate the higher photochemical performance efficiencies of the sampled leaves. The performance index, PI_{total}, incorporates the maximal performance for electron transport from water to PQ and PC per chlorophyll (PI_{abs}) and the performance to reduce an end electron acceptor at the PSI acceptor side, $\delta R_0/(1 - \delta R_0)$ (Strasser et al. 2010). The results of our test, confirm that FB 300 and BRS Sol do Cerrado cultivars displayed the highest performance indices (PI_{total}). In the FB 300 cultivar, the energy cascade beginning with the first absorption of radiant energy in PSII (PI_{abs}) was critical for securing the elevated PI_{total}. The high photochemical efficiency of PSI for BRS Sol do Cerrado was also decisive in achieving the highest PI_{total} value. A dramatically decrease of PI_{total} in the FB 200, not only revealed that loss of PSII activity but also from the damage of PSI structure and function.

According to Baker (2008), the higher the plant capacity for transferring electron energy ejected from pigment molecules to form the NADPH, ATP and reduced ferredoxin, the greater the CO_2 assimilation capacity in the biochemical phase of photosynthesis. Our results show that the FB 300, BRS Sol do Cerrado, and BRS Ouro Vermelho cultivars had the best net photosynthesis rates (A). Thus, it could be deduced that the energy captured and transported in the photochemical steps of these cultivars produced greater CO_2 fixation capacities. The higher g_s and A/C_i values obtained in the three cultivars make it possible to infer higher biochemical activities of photosynthesis (Zhang et al. 2001).

The FB 200 cultivar showed a lower RC/ABS because the uncaptured energy dissipated as heat (non-photochemical quenching) and fluorescence. The low RC/ABS could explain the decline in apparent carboxylation efficiency (A/C_i) of this cultivar, which was almost 50 % lower than that of the BRS Sol do Cerrado cultivar. In orange trees, A and A/C_i were significantly reduced when plants had been subjected to nocturnal chilling (Machado et al. 2010).

van Heerden et al. (2007) observed a good correlation between a decline in CO_2 assimilation capacity and a decline in the performance index (PI_{abs}) values in two desert shrubs. They suggested that this observation is evidence for a link between changes in the properties of the OJIP transient and the overall photosynthetic capacity. According to Melo et al. (2010), studies of physiological parameters and chlorophyll *a* fluorescence are important for elucidating factors that influence plant growth potential. These authors have found highly significant correlations between photosynthetic efficiency and watermelon fruit quality.

The FB 300 cultivar exhibits soluble solid (SS) values within market standards (14–16 °Brix). This represents an important point for processing because it would be necessary to reduce the acidifier added to juice from highly acidic fruit (Beckles 2012). Thus, the FB 300 cultivar displayed the best quality standards that are required by the juice industry, probably due to better use of absorbed photochemical energy (Abreu et al. 2009). Citadin et al. (2008), working with the three BRS cultivars, found that Sol do Cerrado had higher SS content compared to Gigante

Amarelo and Ouro Vermelho cultivars, supporting the results of this study. The authors also measured a pH ≤ 3, as was also shown in this study. These greater fruit biomasses can be explained by higher carbon assimilation, measured as higher net photosynthesis (A) rates in FB 200 and BRS Gigante Amarelo. This confirms the notion that plants with higher photosynthetic efficiencies will produce fruit with higher photoassimilate contents, as evidenced in this study (Oms-Oliub et al. 2011).

Thus, it can be concluded that greater capacity for capturing light energy in the antenna complex and better photochemical use (PI_{total}), followed by enhanced CO_2 fixation (A), resulted in higher fruit pulp yields in the FB 300, BRS Sol do Cerrado, and BRS Ouro Vermelho cultivars.

Conclusions

Chlorophyll *a* fluorescence, photosynthesis, and chlorophyll index can be used as reliable physiological markers for early breeding generations.

Chlorophyll *a* fluorescence kinetics allowed for accurate assessment of the photosynthetic apparatus functional states in passion fruit cultivars, indicating that FB 300, BRS Sol do Cerrado, and BRS Ouro Vermelho are more photosynthetically efficient and have better fruit quality, thus confirming that this technique can be used for indirect breeding selection of genetic material.

Author contribution Gama VN and Cunha JT performed the experiments. Gama VN and Lima IM were responsible for crop management and were also involved in preparation of the manuscript. Bacarin MA was responsible for analysis of the physiological data, and was also involved in preparation of the manuscript. Silva DM conceived and designed the experiments was involved in interpretation of physiological results and also took part in preparation of the manuscript.

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