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Derivate OJIP Variables in Sugarcane to Predict Cane Weight, Sucrose Content, and Sugar Yield

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Abstract*—The amount of carbohydrates in sugarcane directly results from photosynthesis. This means that we can predict the weight of the cane, sucrose content, and sugar yield by examining the photosynthesis process. One way to measure the amount of photosynthesis is by using chlorophyll fluorescence or the OJIP test. This study aimed to determine the dominant OJIP variable that could predict cane weight, sucrose content, sugar yield, and measurement time. The study was conducted at the Asembagus Experimental Station in Situbondo Regency, East Java, Indonesia, from December 2016 to October 2017 using two-bud stem cuttings from 18 sugarcane clones and arranged them in a Randomized Block Design with three replications. Each clone in one replication was planted in five rows, each row being five meters long, and the center-to-center distance was 130 cm. OJIP variables were measured during the stalk elongation phase and the maturity phase. The results showed that sugarcane clones influenced OJIP variables other than Fv/Fm, cane weight, sucrose content, and sugar yield. The most accurate time for measuring OJIP variables was during the maturity phase. The dominant OJIP variables that could predict cane weight and sugar yield were TRo/RC, DIo/CS, ABS/RC, and PI (79.4% and 76.0%). The dominant predictors of yield were RC/CSo, RC/CSm, DIo/CS, PI, ABS/RC, and ETo/RC (92.9%). This study found that measuring OJIP variables during the maturity phase is ideal for predicting cane weight, sucrose content, and sugar yield. The OJIP test can quickly identify high-yielding sugarcane varieties.

***Keywords*— Sugarcane; photosynthesis; maturity; OJIP; two-bud stem cutting.**

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I. INTRODUCTION

Cane weight and sucrose content make up the sugar yield-thus, the sugar yield can be predicted from the two components [1], [2]. Cane weight is influenced by the carbohydrate available for stalk growth during the elongation and maturity phases [3]. During the cane elongation phase, an increase in carbohydrates available for cane growth is followed by an increase in cane weight and vice versa [4]–[7].

The maturity phase of sugarcane means the storage of stored carbohydrates (sucrose) in the stalk it can determine the sugar yield and cane weight [6], [8]–[10]. The amount of stored carbohydrates is determined by the amount of carbohydrates available to the stalk during maturity. Carbohydrates available for stalks are used for stalk growth and stored carbohydrates. If sugarcane uses more carbohydrates for growth, it will hold less, resulting in a lower yield. Therefore, during the maturity phase, sugarcane requires dry environmental conditions to produce a high yield [1], [3]. From the explanation above, it can be concluded that the carbohydrates available for growth during the elongation and maturity phase can predict cane weight, sucrose content, and sugar yield. Carbohydrates available for growth are the residue of photosynthesis after being used for respiration.

Thus, photosynthesis is the primary key to predicting cane weight, sucrose content, and sugar yield. Therefore, a decline in photosynthesis rates will reduce the number of carbohydrates available for cane growth during the elongation phase and carbohydrates stored (sucrose) during the maturity phases [3], [7], [9], [11].

Photosynthetic measurements are done in the CO_2 fixation phase by calculating the amount of CO_2 used in photosynthesis. Along with technology development, photosynthetic measurements can now be done in the early phase of photosynthesis, called chlorophyll fluorescence. Chlorophyll fluorescence or OJIP is a simple and non-invasive method for monitoring changes in photosynthetic processes by measuring the radiation emitted by leaves [12]–[14]. It is possible to calculate variables that can estimate energy absorption by antenna system pigments, exciton capture by the reaction center, and subsequent electron transport to the final electron acceptor [15]–[17]. These measurements provide a constellation of structural and functional variables that characterize the behavior of PS II [18], [19] and have been widely used to study PS II activity in various plants [17], [19]. For example, the canola cultivars under salt stress [20] use it on *Alternanthera tenella* colla under copper stress [21] use it on *Hordeum spontaneum* and *Sorghum bicolor* under water stress, and use it on canola cultivars under light stress [22].

There is a lack of information on the dominant OJIP variables that can predict cane weight, sucrose content, and sugar yield. It is also unclear whether the measurement time should be during the elongation or maturity phase. To address these issues, a study was conducted to identify the dominant OJIP variables that can predict cane weight, sucrose content, and sugar yield, considering the measurement time. This knowledge can help determine which parents to cross to breed sugarcane more efficiently, leading to the development of new high-yielding varieties in a shorter time.

II. Materials and Method

A. Study Site and Materials.

The study was conducted at the Asembagus Experimental Station, Situbondo Regency, East Java, Indonesia, from December 2016 to October 2017. The soil type in the study site is Entisol. The physical and chemical properties of the soil are listed in Table 1. The rainfall during the study is shown in Fig 1.

TABLE I
PHYSICAL AND CHEMICAL CHARACTERISTICS OF SOIL IN THE STUDY SITE (ASEMBAGUS EXPERIMENTAL STATION)

Soil characteristics	Value
pH 1:1 H_2O	7.0
pH KCl 1 N	6.8
C-Organic (%)	0.56
N-total (%)	0.06
C/N	9,3
P Olsen (mg kg^{-1})	51.38
K (NH_4OAC 1N pH:7) (me/100 g)	1.42
Na (NH_4OAC 1N pH:7) (me/100 g)	1.09
Ca (NH_4OAC 1N pH:7) (me/100 g)	11.58
Mg (NH_4OAC 1N pH:7) (me/100 g)	1.81
CEC (me/100 g)	15.87
Total bases	15.90
Base Saturation (%)	100
Sand (%)	81
Silk (%)	19
Clay (%)	0

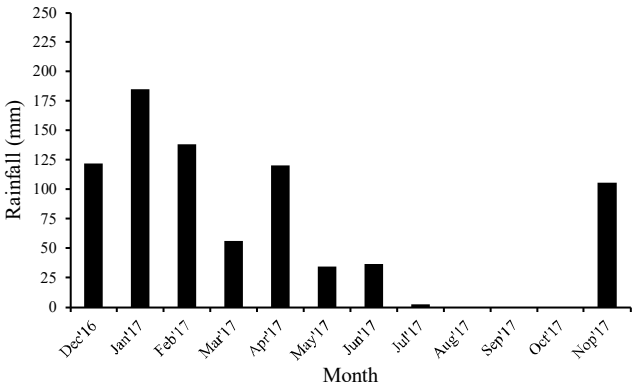

Fig. 1 Rainfall during the study

The clones used were taken from a collection of sugarcane germplasm owned by the Indonesia Sweeteners and Fibers Crops Research Institute. Starting in June 2022, the Indonesian Sweetener and Fiber Crops Research Institute was integrated into the National Research and Innovation Agency of the Republic of Indonesia by Presidential Regulation No. 78 of 2021. We used two-bud stem cutting from 18 sugarcane clones (17, 87, 90, 104, 212, 351, 354, 451, 452, PBG 2, 386 SOF 1118, PRG 881, MLG 19, 400 SOF 1172, 400 SOF 1132, PA 02.18, PS 881, and Cening). Other materials were inorganic and organic fertilizers, pesticides, and other supporting materials. The tools included a refractometer, polarimeter, Chlorophyll Fluorometer type OS-30p+, and other supporting tools.

B. Experimental Design and Culture Practices.

The 18 sugarcane clones were arranged in a Randomized Block Design with 3 replications. OJIP variables were measured in the stalk elongation phase and the maturity phase. Each clone in one replication was planted in 5 rows, each 5 meters long. The center-to-center (CTC) distance was 130 cm. Before planting, we applied manure to each row with a dose of 10 t ha^{-1}. Each row was planted with 10 sugarcane stalks (stem cutting).

The maintenance of sugarcane included replanting, fertilizing, earthing up, irrigating, and controlling pests and diseases. Replanting was done 2-3 weeks after planting by planting available stem cuttings to replace the dead, damaged, or unhealthy stem cuttings planted; replanting aimed to ensure that the plant population remained as planned. Fertilizers were applied twice: 1 and 3 months after planting. Fertilizers were applied to each row, approximately 10 cm from the stalk base. We used 750 kg Phonska and 625 kg Za per hectare. Phonska was applied to the first fertilization and Za to the second fertilization. Earthing-up was done twice by piling up soil from the left and right of the row to the top of the row. It was

done after the first and second fertilization. Irrigation was applied 3 times from May to July.

The sugarcane was harvested 12 months after planting. First, all cane stalks with a minimum length of 150 cm and a minimum diameter of 2 cm on rows 2, 3, and 4 were cut from their base. Then, the stalks were cleaned from the dried leaves, and the top of the stalks was cut.

C. Cane Weight, Commercial Cane Sugar, and Sugar Yield Measurement.

Cane weight was measured by weighting (CW) and counting the number of stalks harvested on each plot (NS). Cane weight (CP) was measured with the following formula:

$$CP = \frac{CW}{NS} \quad (1)$$

Sucrose content was observed by measuring fiber content, Brix, and Pol. We took a random sample of harvested cane stalks comprising 6 from each block and each replication. The stalk sample was weighted (WS) and squeezed with a sample mill for its juice. The resulting juice was weighted (JW).

Brix of the sugarcane juice was measured using a hand refractometer, while Pol was measured using a polarimeter. The juice value (JV) is calculated with the following formula:

$$JV = Pol - (0.4\ x\ (Brix - Pol)) \quad (2)$$

Sucrose content (SC) is calculated with the following formula:

$$SC\ (\%) = FP\ x\ NN \quad (3)$$

Sugar yield (SY) is measured with the following formula:

$$SY = \frac{CP\ x\ SC}{100} \quad (4)$$

D. OJIP Variables Measurement.

Observations of OJIP variables (chlorophyll fluorescence) were carried out in the elongation phase (5 months after planting) and the maturity phase (10 months after planting). Chlorophyll fluorescence was measured with a Chlorophyll Fluorometer on fully-opened upper leaves following the procedure for using the tool [23]. For each clone in one replication, we took 3 samples. Before measurement, the sample leaves were conditioned in the dark for 30 minutes. The data recorded in the tool included the quantum yield of primary photochemistry PSII (Fv/Fm and Fv/Fo), relative variable fluorescence at phase J of fluorescence transient curve (Vj), performance index (PI), the net rate of PS II closure (Mo), the specific flux (flux per active PSII reaction center) of absorption (ABS/RC), trapping (TRo/RC) and electron transport (ETo/RC), dissipation flux per excited cross-section (DIo/CS), electron transport flux per excited cross-section (ETo/CS), the efficiency with which an exciton captured in the reaction center can move an electron from QA^- to the intersystem electron acceptor (ETo/TRo), and the density of the reaction center when all reaction centers are open (RC/CSo) and when all PSII reaction centers are closed (RC/CSm).

E. Statistical Analysis.

Data were analyzed for variance and continued with Duncan's double distance test (DMRT) at a 5% significance level using MSTAT software Version 4.00/EM. Multiple linear regression analysis (Stepwise analysis) between sugarcane weight, sucrose content, and sugar yield with OJIP variables was done to determine how OJIP variables influenced the three agronomic variables. OJIP variables with an influence level > 5% were the dominant variables influencing the three agronomic variables.

III. Results and Discussion

A. Cane Weight, Commercial Cane Sugar, and Sugar Yield

Cane weight, commercial cane sugar, and sugar yield were affected by sugarcane clones (Table 2). Clones 17, 87, 104, 212, 354, 386 SOF1118, Cening, and PBG 2 produced the highest cane weight (1,444 to 1,647 kg stalk-1). The highest sucrose content was found on PA 02.18, PRG 881, and PS 881 (11.66 to 11.86%). The highest sugar yield was obtained for 104, 386 SOF1118, and PS 881 (0.153-0.164 kg $stalk^{-1}$).

TABLE II
CANE WEIGHT, COMMERCIAL CANE SUGAR, AND SUGAR YIELD OF SUGARCANE CLONES

Clones	Cane weight (kg $stalk^{-1}$)	Commercial Cane Sugar (%)	Sugar yield (kg $stalk^{-1}$)
17	1.617 a	6.07 g	0.098 gh
87	1.560 a	6.33 fg	0.102 f-h
90	1.338 b-d	6.25 f-g	0.085 h
104	1.629 a	9.43 bc	0.153 ab
212	1.617 a	8.31 c-e	0.134 bc
351	1.198 d	10.17 b	0.122 c-f
354	1.600 a	7.74 d-f	0.126 cd
451	1.213 d	8.00 c-e	0.097 gh
452	1.000 e	9.39 bc	0.093 h
386 SOF1118	1.647 a	9.91 b	0.164 a
400 SOF1132	1.247 cd	9.85 b	0.125 c-e
400 SOF1172	1.355 b-d	7.71 d-f	0.104 e-h
Cening	1.481 ab	6.94 e-g	0.105 d-h
MLG 19	1.276 cd	9.16 b-d	0.116 c-g
PA 02.18	0.978 e	11.86 a	0.116 c-g
PBG 2	1.444 a-c	9.46 bc	0.136 bc
PRG 881	0.899 e	11.69 a	0.104 e-h
PS 881	1.358 b-d	11.66 a	0.159 a

Notes:
1) Values in the same column followed by the same letters were not significantly different at a 5% significance level based on the Duncan Multiple Range Test
2) NS = not significantly differed

Interaction between environmental conditions and clones affects cane weight, sucrose content, and sugar yield [8], [9], [24]. If the environmental conditions are homogeneous, the three agronomic variables are influenced by clones. We used homogenous environmental conditions in this present study, so differences in results were due to the clones used. The differences in cane weight, sucrose content, and sugar yield are due to differences in the clones used [8], [25].

B. OJIP Variables

Sugarcane clones did not affect Fv/Fm but affected other OJIP variables when measured during the elongation and maturity phase (Tables 3 and 4). The highest Fv/Fo measured during the elongation phase came from clones 17, 90, 351, 400 SOF1172, 400 SOF1132, PA 02.18, PBG 2, PRG 881, and PS 881. The highest Fv/Fo measured during the maturity phase came from clones 351, 386 SOF1118, PA 02.18, and PS 881.

TABLE III

THE MAXIMUM PHOTOCHEMICAL QUANTUM YIELD OF PSII (FV/FM AND FV/FO), RELATIVE VARIABLE FLUORESCENCE AT PHASE J OF FLUORESCENCE TRANSIENT CURVE (VJ), PERFORMANCE INDEX (PI) AND NET RATE OF PS II CLOSURE (MO), THE SPECIFIC FLUX (FLUX PER ACTIVE PSII REACTION CENTRE) OF ABSORPTION (ABS/RC), TRAPPING (TRO/RC) AND ELECTRON TRANSPORT (ETO/RC), THE SPECIFIC FLUX OF DISSIPATION PER EXCITED CROSS SECTION (DIO/CS), THE EFFICIENCY WITH WHICH AN EXCITON CAPTURED IN THE REACTION CENTRE CAN MOVE AN ELECTRON FROM QA- TO THE INTERSYSTEM ELECTRON ACCEPTOR (ETO/TRO) AND ELECTRON TRANSPORT PER EXCITED CROSS SECTION (ETO/CS), DENSITIES OF REACTION CENTER WHEN ALL REACTION CENTERS OPENED (RC/CSO) AND WHEN ALL REACTION CENTERS PSII CLOSED (RC/CSM) OF OF SUGARCANE CLONES ON STALK ELONGATION PHASE.

Clones	Fv/Fm	Fv/Fo	Vj	PI	Mo	ABS/RC	TRo/RC	ETo/RC	DIo/CS	ETo/TRo	ETo/CS	RC/CSo	RC/CSm
17	0.759ns	3.19 a-c	0.349 d-f	5.35 d-g	0.303 b-f	1.143 a-c	0.196 bc	0.564 c-e	0.276 b-f	0.651 b-d	81.23 cd	143.8 c-e	605.1 d-f
87	0.742	2.94 b-d	0.338 d-f	5.60 d-f	0.265 d-g	1.060 cd	0.175 c-f	0.521 d-f	0.274 b-f	0.662 b-d	83.58 b-d	160.6 b-d	631.4 c-e
90	0.770	3.36 ab	0.271 hi	11.03 a	0.196 h	0.920 de	0.138 f	0.513 d-f	0.211 g	0.729 ab	98.03 a	192.2 a	837.8 a
104	0.743	2.96 b-d	0.268 hi	6.59 b-d	0.248 f-h	1.269 ab	0.181 cd	0.699 a	0.322 ab	0.732 ab	94.45 ab	138.3 ef	542.8 e-g
212	0.728	2.74 cd	0.368 c-e	3.99 g-i	0.349 bc	1.290 a	0.218 ab	0.590 b-d	0.352 a	0.632 c-e	80.17 cd	138.3 ef	517.3 fg
351	0.760	3.18 a-c	0.275 g-i	7.25 bc	0.244 f-h	1.187 a-c	0.177 c-e	0.658 ab	0.286 b-e	0.725 ab	92.23 a-c	144.6 c-e	606.8 d-f
354	0.730	2.75 cd	0.302 f-i	5.73 d-f	0.252 f-h	1.151 a-c	0.175 c-f	0.584 b-e	0.315 ab	0.698 a-c	85.61 bc	150.4 c-e	568.8 d-f
451	0.744	2.98 b-d	0.277 g-i	7.61 b	0.246 f-h	1.191 a-c	0.176 c-e	0.630 a-c	0.316 ab	0.723 ab	89.79 a-c	151.4 c-e	618.5 c-e
452	0.735	2.85 cd	0.381 b-d	5.98 c-f	0.230 gh	0.829 e	0.142 ef	0.379 g	0.220 fg	0.619 c-f	73.36 de	193.9 a	749.2 b
386 SOF 1118	0.746	2.98 b-d	0.319 e-h	6.18 c-e	0.249 f-h	1.049 cd	0.170 c-f	0.533 d-f	0.267 b-g	0.681 a-c	85.52 bc	160.5 b-d	637.2 cd
400 SOF 1132	0.749	3.03 a-d	0.333 d-g	7.19 bc	0.258 e-h	1.009 c-e	0.168 c-f	0.496 ef	0.256 c-g	0.667 b-d	82.37 cd	172.9 b	702.9 bc
400 SOF 1172	0.750	3.06 a-c	0.331 d-g	5.53 d-f	0.298 c-g	1.199 a-c	0.198 bc	0.598 b-d	0.303 a-d	0.669 b-d	84.90 b-d	141.9 de	580.4 d-f
CENING	0.736	2.85 cd	0.432 ab	3.20 i	0.415 a	1.305 a	0.232 a	0.541 c-f	0.348 a	0.568 ef	66.41 ef	122.2 f	475.2 g
MLG 19	0.718	2.59 d	0.460 a	3.44 hi	0.366 ab	1.073 b-d	0.186 bc	0.400 g	0.307 a-c	0.540 f	61.53 f	155.3 b-e	561.6 d-f
PA 02.18	0.749	3.03 a-d	0.343 d-f	5.85 c-f	0.270 d-g	1.072 b-d	0.175 c-f	0.525 d-f	0.277 b-f	0.657 b-d	84.96 b-d	161.3 b-d	636.5 cd
PBG 2	0.760	3.18 a-c	0.412 a-c	4.53 f-i	0.321 b-e	1.030 cd	0.188 bc	0.461 fg	0.248 d-g	0.588 d-f	67.78 ef	148.3 c-e	620.6 c-e
PRG 881	0.758	3.17 a-c	0.411 a-c	4.78 e-h	0.326 b-d	1.039 cd	0.185 bc	0.462 fg	0.251 c-g	0.589 d-f	66.54 ef	143.1 de	599.3 d-f
PS 881	0.777	3.48 a	0.247 i	10.57 a	0.193 h	1.026 cd	0.146 d-f	0.605 b-d	0.228 e-g	0.753 a	94.70 ab	164.1 bc	732.0 b

Values in the same column followed by same letters were not significantly different at 5% level base on the Duncan Multiple Range Test. NS = non significant.

TABLE IV

THE MAXIMUM PHOTOCHEMICAL QUANTUM YIELD OF PSII (FV/FM AND FV/FO), RELATIVE VARIABLE FLUORESCENCE AT PHASE J OF FLUORESCENCE TRANSIENT CURVE (VJ), PERFORMANCE INDEX (PI) AND NET RATE OF PS II CLOSURE (MO), THE SPECIFIC FLUX (FLUX PER ACTIVE PSII REACTION CENTRE) OF ABSORPTION (ABS/RC), TRAPPING (TRO/RC) AND ELECTRON TRANSPORT (ETO/RC), THE SPECIFIC FLUX OF DISSIPATION PER EXCITED CROSS SECTION (DIO/CS), THE EFFICIENCY WITH WHICH AN EXCITON CAPTURED IN THE REACTION CENTRE CAN MOVE AN ELECTRON FROM QA- TO THE INTERSYSTEM ELECTRON ACCEPTOR (ETO/TRO) AND ELECTRON TRANSPORT PER EXCITED CROSS SECTION (ETO/CS), DENSITIES OF REACTION CENTER WHEN ALL REACTION CENTERS OPENED (RC/CSO) AND WHEN ALL REACTION CENTERS PSII CLOSED (RC/CSM) OF SUGARCANE CLONES ON MATURITY PHASES

Clones	Fv/Fm	Fv/Fo	Vj	PI	Mo	ABS/RC	TRo/RC	ETo/RC	DIo/CS	ETo/TRo	ETo/CS	RC/CSo	RC/CSm
17	0.617 NS	1.88 gh	0.483 bc	2.52 gh	0.488 b	1.713 a	0.229 a	0.483 b-d	0.742 a	0.517 cd	67.45 e-g	137.7 gh	427.8 hi
87	0.633	1.85 gh	0.398 de	5.70 b-d	0.231 e-g	0.939 ef	0.132 f-h	0.316 fg	0.392 de	0.602 b-c	74.84 c-e	302.4 a	893.6 b
90	0.613	1.64 h	0.355 e	2.38 gh	0.274 d-f	1.343 b-d	0.174 b-e	0.551 b	0.518 c	0.645 ab	80.81 b-d	166.0 e-g	435.6 hi
104	0.685	2.20 e-g	0.486 bc	3.40 fg	0.414 bc	1.157 c-e	0.192 a-d	0.376 ef	0.367 d-f	0.514 cd	60.35 gh	189.0 d-f	605.9 e-g
212	0.670	2.28 c-g	0.400 de	3.40 fg	0.273 d-f	1.136 c-e	0.166 c-f	0.459 c-e	0.404 de	0.600 bc	76.11 b-e	196.0 de	645.2 ef
351	0.728	2.70 a-c	0.358 e	7.49 a	0.191 fg	0.680 fg	0.117 gh	0.307 fg	0.181 i	0.642 ab	80.86 b-d	326.7 a	1184.4 a
354	0.648	1.98 f-h	0.343 ef	4.15 ef	0.398 bc	1.778 a	0.210 ab	0.732 a	0.648 b	0.657 ab	85.80 b	112.0 h	344.7 i
451	0.652	1.91 f-h	0.421 c-e	3.26 fg	0.292 de	0.998 ef	0.156 d-f	0.350 fg	0.356 d-g	0.579 bc	67.08 e-g	225.5 b-d	672.3 d-f
452	0.676	2.09 f-h	0.278 f	6.50 ab	0.176 g	1.016 de	0.130 f-h	0.512 bc	0.328 e-g	0.722 a	101.38 a	250.3 bc	769.4 cd
386 SOF 1118	0.710	2.66 a-d	0.388 de	5.84 bc	0.274 d-f	0.957 ef	0.149 e-g	0.400 d-f	0.283 gh	0.612 a-c	71.91 d-f	177.5 e-g	650.5 ef
400 SOF 1132	0.699	2.36 c-f	0.543 ab	2.39 gh	0.411 bc	1.019 de	0.174 b-e	0.312 fg	0.296 f-h	0.457 de	45.96 i	164.3 e-g	527.6 gh
400 SOF 1172	0.646	1.94 f-h	0.609 a	1.62 h	0.464 b	1.152 c-e	0.151 e-g	0.258 g	0.429 d	0.391 e	46.38 i	172.8 e-g	530.0 gh
CENING	0.642	1.96 f-h	0.541 ab	1.46 h	0.478 b	1.399 bc	0.211 ab	0.392 ef	0.528 c	0.459 de	54.29 hi	137.8 gh	412.8 i
MLG 19	0.672	2.23 d-g	0.608 a	1.53 h	0.643 a	1.580 ab	0.212 a	0.386 ef	0.534 c	0.392 e	44.54 i	111.3 h	367.5 i
PA 02.18	0.754	3.07 a	0.379 e	5.23 cd	0.336 cd	1.165 c-e	0.198 a-c	0.541 bc	0.289 f-h	0.621 a-c	77.50 b-e	157.6 e-g	647.2 ef
PBG 2	0.656	2.36 c-f	0.460 cd	6.94 a	0.194 fg	0.616 g	0.110 h	0.262 g	0.160 i	0.540 b-d	62.40 f-h	218.3 cd	699.6 de
PRG 881	0.718	2.63 b-e	0.458 cd	4.71 de	0.284 d-f	0.833 e-g	0.151 e-g	0.329 fg	0.219 hi	0.542 b-d	60.20 gh	257.9 b	854.7 bc
PS 881	0.739	2.85 ab	0.345 ef	4.72 de	0.293 de	1.154 c-e	0.192 a-d	0.558 b	0.303 fg	0.655 ab	84.69 bc	152.2 fg	586.6 fg

Values in the same column followed by same letters were not significantly different at 5% level base on the Duncan Multiple Range Test. NS = non significant.

The highest Vj measured during the elongation phase came from clones Cening, MLG 19, PBG 2, and PRG 881. The highest Vj measured during the maturity phase came from clones 400 SOF1132, 400 SOF1172, Cening, and MLG 19. The highest PI measured during the elongation phase came from clones 90 and PS, while during the maturity phase, it came from clones 351, 452, and PBG 2. The highest Mo measured during the maturity phase came from clone Cening, while during the maturity phase came from clone MLG 19. The highest ABS/RC measured during the elongation phase came from clones 17, 104, 212, 351, 354, 451, 400 SOF1172, and Cening, while during the maturity phase came from clones 17, 354, and MLG 19. The highest TRo/RC measured during the elongation phase came from clones 212 and Cening, while the maturity phase came from clones 17, 104, 354, Cening, MLG 19, PA 02.18, and PS 881. The highest ETo/RC measured during the elongation phase came from clones 104, 351, and 451, while during the maturity phase came from clone 354. The highest DIo/CS measured during the elongation phase came from clones 104, 212, 354, 451, 400 SOF1172, Cening, and MLG 19, while the maturity phase came from clone 17.

Moreover, the highest ETo/TRo measured during the elongation phase came from clones 90, 104, 351, 354, 451, 386 SOF1118, and PS 881, while during the maturity phase, it came from clones 90, 351, 354, 452, 386 SOF1118, PA 02.18, and PS 881. The highest ETo/CS measured during the elongation phase came from clones 90, 104, 351, 451, and PS 881, while the maturity phase came from clone 452. The highest RC/CSo measured during the elongation phase came from clones 90 and 452, while during the maturity phase came from clones 87 and 351. The highest RC/CSm measured during the elongation phase came from clone 90, while during the maturity phase came from clone 351.

The maximum quantum yield of primary photochemistry (Fv) is standardized with the values of Fm and Fo, so we obtain Fv/Fm = (Fm-Fo)/Fm and Fv/Fo = (Fm-Fo)/Fo. The Fm value was relatively high (485.11 to 671.17) in the elongation phase and 608.44 to 760.50 in the maturity phase, while the Fo value was relatively low (144.67 to 211.78) in the elongation phase and 148.56-174.50 in the maturity phase. The significant differences in the value of Fm and Fo caused the Fv/FM values to be less diverse, while the Fv/Fo values to be diverse. This condition caused Fv/Fm to be unaffected by the clones, while the Fv/Fo was affected by the clones. Studies on sugarcane under aluminum stress [24], [26] and on *Alternanthera tenella* colla under copper stress and sweet potato under copper stress also slow low diversity of Fv/Fm values and diverse Fv/Fo values [24]. However, the study on *Chenopodium quinoa* shows different Fv/Fm values due to water stress [12].

The morphology of sugarcane leaves, including the number of stomata, the number of epidermal cells, the polar diameter of the stomata (stomata length), the equatorial diameter of the stomata (stomata width), the thickness of the epidermis on the lower and upper surfaces, the thickness of the mesophyll, the thickness of the upper cuticle, the polar diameter of the bulliform cells, the number of bulliform cells, the diameter of the bundle sheath cells, the thickness of the phloem, the number of metaxylem vessels, the diameter of the metaxylem vessels, and the distance between the vascular bundles, are affected by the clone [2], [34]. In addition, leaf color, wax layer thickness, leaf hair density, and sugarcane leaf thickness are influenced by the clones used [29], [30]. Differences in leaf morphology cause differences in the amount of light received, reflected, and absorbed by the leaves [30]–[35]. Such conditions cause the Fv/Fo, Vj, PI, and Mo values produced by each sugarcane clone to differ in the stem elongation and maturity phases. Two sugarcane clones respond differently to water availability and aluminum levels in producing Fv/Fo, Vj, PI, and Mo values (30). Different leaf thickness and chlorophyll content in leaves affect the number of reaction centers [3]. The thicker the leaf and the higher the chlorophyll content, the more reaction centers the leaf has. Leaf thickness and chlorophyll content in leaves are one of the characteristics of sugarcane clones [12], [39]. This condition causes the sugarcane clones to affect RC/CSo and RC/CSm.

The absorption energy (ABS) will be absorbed (TR). The energy will be partly used for electron transport (ET) and partly lost as heat energy (DIo) [18], [38]. Different ABS/RC values are caused by differences in antennas in the photosystem complex [29], [30], [39], [40]. The difference in ABS/RC causes differences in the values of DIo/RC, TRo/RC, ETo/RC, and ETo/TRo obtained [19], [33]. The difference in antennas in the photosystem complex is caused by differences in the cultivars used [12], [18], [19]. This causes the sugarcane clones to influence the values of ABS/RC, DIo/CS, TRo/RC, ETo/RC, ETo/TRo, and ETo/CS. The different canola cultivars result in different ABS/RC, DIo/CS, TRo/RC, and ETo/RC values [15].

C. The Relationship of OJIP variables with Cane Weight, Sucrose Content, and Sugar Yield.

The stepwise analysis between sugarcane weight and OJIP variables resulted in a correlation coefficient of 0.667 in the elongation phase and 0.863 in the maturity phase (Table 5). These results mean that the 12 OJIP variables affected cane weight with a total effect of 66.70% in the elongation phase and 86.33% in the maturity phase. Thus, it can be concluded that the appropriate time for measuring the OJIP variable to predict the cane weight was during the maturity phase.

TABLE V
REGRESSION COEFFICIENTS AND CONTRIBUTION VALUES ON THE RELATIONSHIP OF OJIP VARIABLES WITH CANE WEIGHT ON THE ELONGATION AND MATURITY PHASES

OJIP variables	Elongation Phase		Maturity Phase	
	Regression Coefficient	Contribution Values (%)	Regression Coefficient	Contribution Values (%)
Fv/Fo	-0.494	1.76	0.421	1.51
Vj	1.652	0.00	-3.486	0.61
PI	-0.583	3.53	-0.679	5.17
Mo	3.307	5.64	-0.782	0.30
ABS/RC	-7.722	4.58	19.314	19.15
TRo/RC	0.940	0.35	-11.832	35.25
DIo/CS	2.840	5.29	-6.868	19.79
ETo/RC	-4.625	5.29	-1.300	0.61
ETo/TRo	5.636	0.35	-3.595	0.00
ETo/CS	1.915	16.57	-0.376	0.61
RC/CSo	-1.722	22.92	0.315	0.91
RC/CSm	7.195	2.09	-0.724	2.43
Intercept	-5.740		8.835	
Correlation coefficient	0.677		0.863	
Total contribution		67.70		86.33

Vj, Mo, TRo/RC, DIo/CS, ETo/TRo, ETo/CS, and RC/CSm positively affected cane weight during the elongation phase, while other variables negatively affected cane weight. Fv/Fo, ABS/RC, and RC/Cso positively affected cane weight during the maturity phase, while other variables negatively affected cane weight. During the elongation phase, RC/CSo, ETo/CS, Mo, DIo/CS, and ETo/RC became the dominant OJIP variables affecting cane weight with a total effect of more than 50%. During the maturity phase, TRo/RC, DIo/CS, ABS/RC, and PI became the dominant OJIP variables affecting cane weight with a total effect of more than 70%.

The stepwise analysis of sucrose content resulted in a correlation coefficient of 0.800 during the elongation phase and 0.979 during the maturity phase (Table 6). During the elongation phase, Fv/Fo, Vj, PI, Mo, ABS/RC, and ETo/CS positively affected sucrose content, while other variables negatively affected sucrose content. Variables with the most dominant effect, with a total effect of 80%, were, from the highest effect to the lowest, RC/CSm, RC/CSo, Fv/Fo, TRo/RC, PI, DIo/CS, and ABS/RC, respectively. During the maturity phase, Fv/Fo, ABS/RC, and RC/CSm positively affected sucrose content, while other variables negatively affected sucrose content. The OJIP variables with the most dominant effect, with a total effect of more than 75%, were, from the highest effect to the lowest, RC/CSo, RC/CSm, DIo/CS, dan PI, respectively. Thus, the best time to measure OJIP variables to predict sucrose content was during the maturity phase.

TABLE VI
REGRESSION COEFFICIENTS AND CONTRIBUTION VALUES ON THE RELATIONSHIP OF OJIP VARIABLES WITH SUCROSE CONTENT ON THE ELONGATION AND MATURITY PHASES

OJIP variables	Maturity phase			
	Regression Coefficient	Contribution Values (%)	Regression Coefficient	Contribution Values (%)
Fv/Fo	1.452	10.08	0.323	3.31
Vj	0.286	0.00	-1.198	0.00
PI	1.069	7.73	-0.456	9.94
Mo	0.222	0.00	1.711	0.00
ABS/RC	11.435	6.72	6.158	8.28
TRo/RC	-8.012	9.75	-1.388	1.65
DIo/CS	-3.942	7.06	-2.571	11.60
ETo/RC	-0.432	0.00	-2.459	8.28
ETo/TRo	-4.974	0.00	0.408	0.00
ETo/CS	0.101	0.00	0.056	0.00
RC/CSo	1.912	18.82	-0.956	34.92
RC/CSm	-2.644	19.83	0.976	19.93
Intercept	4.411		1.430	
Correlation coefficient	0.800	80.00	0.979	97.90
Total contribution				

The analysis of the relationship of sugar yield with OJIP variables resulted in a correlation coefficient of 0.729 during the elongation phase and 0.847 during the maturity phase (Table 7). Thus, the 12 OJIP variables affected sugar yield with a total effect of 72.90% during the elongation phase and 84.71% during the maturity phase. TRo/RC, DIo/CS, ETo/TRo, ETo/RC, and RC/CSm negatively affected sugar yield during the elongation phase, while Fv/Fo, Mo, ABS/RC, and RC/CSm positively affected sugar yield during the maturity phase. The OJIP variables measured during the maturity phase contributed higher to sugar yield than during the elongation phase. Thus, the best time to measure OJIP variables to predict sugar yield was during the maturity phase.

The OJIP variables with the most dominant effect on sugar yield during the elongation phase, with a total effect of more than 60%, were RC/CSm, PI, ETo/CS, ETo/RC, and PI. The OJIP variables with the most dominant effect on sugar yield during the maturity phase, with a total effect of more than 70%, were, from the highest effect to the lowest, TRo/RC, DIo/CS, ABS/RC, and PI.

Harvested cane weight is the accumulation of (1) carbohydrates available for cane growth during the elongation and maturity phase and (2) carbohydrates stored (sucrose) during the maturity phases. Sugarcane keeps carbohydrates in the stem tissue as sucrose. Carbohydrates available for growth are the residue of photosynthesis after being used for respiration.

TABLE VII
REGRESSION COEFFICIENTS AND CONTRIBUTION VALUES ON THE RELATIONSHIP OF OJIP VARIABLES WITH SUGAR YIELD ON THE ELONGATION AND MATURITY PHASES

OJIP variables	Elongation Phase		Maturity Phase	
	Regression Coefficient	Contribution Values (%)	Regression Coefficient	Contribution Values (%)
Fv/Fo	0.436	1.94	0.362	0.58
Vj	1.608	0.00	-5.300	0.29
PI	0.793	10.97	-1.233	8.83
Mo	1.830	2.58	3.479	0.45
ABS/RC	5.065	3.23	27.501	20.29
TRo/RC	-5.936	12.90	-13.002	23.51
DIo/CS	-1.624	2.58	-10.417	23.51
ETo/RC	-2.650	2.58	-5.149	3.78
ETo/TRo	-1.138	0.00	-2.801	0.14
ETo/CS	1.471	16.13	-0.126	0.14
RC/CSo	0.116	0.00	-0.817	2.90
RC/CSm	-1.705	20.00	0.342	0.29
Intercept	0.085		9.845	
Correlation coefficient	0.729	72.90	0.847	84.71
Total contribution				

Fluorescence chlorophyll (OJIP variable) analysis provides quick insight into the ability of plants to photosynthesize to tolerate environmental pressure [17], [23], [41]. This condition caused the OJIP variables observed in the elongation phase to contribute significantly (82.34%) in influencing sugarcane weight, yet it contributed only 73.20% and 71.72% in influencing sucrose content and sugar yield. The OJIP variables observed in the maturity phase contributed 86.33%, 97.88%, and 84.71% influencing sugarcane weight, sucrose content, and sugar yield, respectively. Thus, observing OJIP variables in the maturity phase is more appropriate for predicting sugarcane productivity, sucrose content, and sugar yield [18], [19], [21], [23], [33].

The light energy the leaves receive is absorbed by the chlorophyll, and some of the energy is reflected. The absorbed energy (ABS) partially undergoes adsorption (TR), and the rest turns into heat and fluorescent energy (dissipate = DI) [18], [19], [31]. The absorbed energy is then used for electron transport (ET). In general, an increase in the light energy absorbed in chlorophyll causes an increase in the photosynthesis rate so that carbohydrates are available for growth and storage. This condition causes ABS/RC to positively affect cane weight, sucrose content, and sugar

yield. Likewise, the higher the dissipated energy (DIo/RC), the lower the energy used for electron transport (ETo/RC), so DIo/CS negatively affects cane weight, sucrose content, and sugar yield.

In stepwise analysis, Xn negatively affects Y, which can have two meanings. First, it means the individual influence of Xn on Y is negative. Second, it means the individual influence of Xn on Y is positive, but the positive value is below the positive value of the combined effect of the X value. In the case of TRo/RC, which negatively affects cane weight and sugar yield, the second meaning applies. The TRo/RC value is the reduction of the ABS/RC value with the DIo/CS value. The ABS/RC has a positive effect, and DIo/CS has a negative effect, so TRo/RC individually has a positive effect on the two agronomic variables [23], [41].

The Performance Index (PI) describes the overall expression of the plant's internal strength in dealing with environmental conditions. PI depends on the three functional stages of photosynthetic activities by the RC PSII complex (light energy absorption, excitation energy absorption, and the conversion of absorbed energy to electron transport in PSII) [12], [18], [31]. In this study, the excitation energy absorption (TRo/RC) and the conversion of the adsorbed energy to electron transport (ETo/RC) negatively affected cane weight, sucrose content, and sugar yield. Thus, PI negatively affected the three agronomic variables.

IV. CONCLUSION

The OJIP variables, other than Fv/Fm, observed in the elongation and maturity phase were influenced by sugarcane clones. Our findings confirmed that the maturity phase was the best time for measuring OJIP variables to predict cane weight, sucrose content, and sugar yield. The dominant OJIP variables as predictors of cane weight and sugar yield were TRo/RC, DIo/CS, ABS/RC, and PI, with an accuracy of 79.4% and 76.0%, respectively. The dominant predictors of sugar yield were RC/CSo, RC/CSm, DIo/CS, PI, ABS/RC, and ETo/RC, with an accuracy of 92.9%. The OJIP test can quickly identify high-yielding sugarcane varieties.

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