Tropical Agricultural Research (2022) 33(1): 67-79

Contents available at: Sri Lanka Journals Online

Tropical Agricultural Research

Journal Home Page: https://tar.sljol.info

Effects of Elevated Temperature and CO_2 on Biomass and Sucrose Accumulation of Selected Sugarcane Genotypes

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ARTICLE INFO

Article history:
Received: 22 June 2021
Revised version received: 21 September 2021
Accepted: 21 October 2021
Available online: 01 January 2022

Keywords:
Biomass accumulation
Elevated CO2 and temperature
Open-top chambers
Sucrose accumulation
Sugarcane

Citation:
De Silva, A.L.C., De Costa, W.A.J.M., and L.D.B. Suriyagoda (2022). Effects of Elevated Temperature and CO2 on Biomass and Sucrose Accumulation of Selected Sugarcane Genotypes. Tropical Agricultural Research, 33(1): 67-79.

DOI: http://doi.org/10.4038/tar.v33i1.8536

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ABSTRACT

Global warming cause due by increasing atmospheric CO_2 concentration, and the resulting increase in air temperature is a considerable challenge in crop production. Hence, the objectives of this study were to determine the: (a) responses of biomass and sucrose accumulation of sugarcane to elevated CO_2 (ECO_2) and elevated temperature (ET_a), both individually and together, and (b) genotypic variation of these responses. A three-factor factorial experiment considering the combination of CO_2 concentrations and temperatures as the main-plot factor and eight sugarcane varieties as the sub-plot factor arranged in a split-plot design in open-top chambers. Plots in open field conditions were the negative control. The main plot factor had four levels, combinations of ambient/elevated CO_2 concentrations (344-351/777-779 ppm) and ambient/elevated temperatures (34.9-35.6/36.6-38.4 °C). Significant treatment × variety interaction effects observed on the number of shoots per hill, sucrose% (Pol), and pure obtainable cane sugar (POCS) in cane juice. Genotypic variations were significant in all variables measured. Elevated T_a increased the number of shoots per hill in 4 out of 8 varieties. Biomass accumulation of sugarcane on the dry weight basis did not respond clearly to the simulated future climatic conditions. The response of Pol and POCS to ECO_2 and the combination of ECO_2 and ET_a varied depending on varieties with decreased, increased, or no response. Notably, Pol and POCS in the variety SL88116, which had higher respective values at ambient and simulated future climatic conditions, were not affected by either ECO_2 or ET_a individually or in combination. The responses and the significant genotypic variation observed in sucrose accumulation to ECO_2 and ET_a, both individually and together, demonstrate considerable scope in sugarcane to breed varieties to maintain the stability of sugar recovery in CO_2-rich warm climates.

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INTRODUCTION

Increasing atmospheric CO_2 concentration and resulting increase of air temperature (T_a) has variable impacts on the productivity of sugarcane depending on varieties and growing conditions (Marin *et al*., 2013, 2014). Therefore, determining the impacts of climate change on the growth and productivity of sugarcane is vital to sustaining an adequate supply of sugar and its by products to meet their increasing demand in the future. Biomass and sucrose accumulation of sugarcane shows variable responses to elevated CO_2 (ECO_2) and temperature (ET_a) depending on the specific growing conditions. For example, several studies conducted using potted plants grown in open-top chambers (OTCs) under well-watered conditions show that biomass accumulation of sugarcane increases at ECO_2 (Vu *et al*., 2006; De Souza *et al*., 2008; Vu and Allen, 2009; Allen *et al*., 2011; Marin *et al*., 2013). Vu *et al*. (2006) has shown ECO_2 increases sucrose accumulation as well. In contrast, Stokes and colleagues did not observe a stimulation of biomass accumulation in ECO_2 under well-watered conditions (Stokes *et al*. (2016), which agrees with the majority of research findings on C_4 species (Lawlor and Mitchell, 1991; Bowes, 1993; Kimball *et al*., 2002; Kim *et al*., 2006; Leakey *et al*., 2006, 2009). Elevated CO_2 has been shown to induce shifts in the carbon and nitrogen dynamics, and consequently, changes in the source-sink interactions within crops (Wolfe *et al*., 1998). Furthermore, the interactive effects of ECO_2 and ET_a on the physiology and growth of plants differ depending on their genetic make-up and ecological adaptation (Eller *et al*., 2013). Therefore, it is likely that the magnitude of the impacts of increasing atmospheric CO_2 could be different on different crops grow under varying environmental and management conditions (Chaves and Pereira, 1992; Leakey *et al*., 2006).

Vu and Allen (2009) show significant increases and genotypic variation in biomass accumulation of sugarcane in response to ET_a. In addition, they observe amplification of the stimulation of biomass accumulation of sugarcane when ECO_2 is combined with ET_a. In contrast, Allen *et al*. (2011) show that the increasing trend of biomass and sucrose accumulation in sugarcane at ECO_2 is down-regulated when ECO_2 is combined with ET_a. Only limited work reported on the response of sugarcane growth and yields to climate change (Vu *et al*., 2006; De Souza *et al*., 2008; Vu and Allen, 2009; Allen *et al*., 2011; Stokes *et al*., 2016). Even such experiments have been conducted at the lower temperature range, where the daily mean temperature did not exceed 29 °C while being less than 25 °C for most of the crops' duration. The net assimilation rate of sugarcane shows a positive correlation with air and soil temperature (Venkataramana *et al*., 1984). However, increasing temperatures increase respiration rates (Atkin and Tjoelker, 2003) resulting in a decrease in growth and sucrose accumulation. Therefore, even though growth and sucrose accumulation may increase with ET_a up to an optimum temperature, further temperature increases are likely to reverse this response. Accordingly, the objectives of this study were to determine responses, and genotypic variations of biomass and sucrose accumulation of sugarcane to ECO_2 and ET_a expected in the future.

METHODOLOGY

Experimental location and period

The experiment was conducted in open top chambers (OTCs) installed in the research farm of the Sugarcane Research Institute (SRI), Uda Walawe, Sri Lanka (6°24'40"N latitude, 80°50'17"E longitude and 76 m altitude) from 12th September 2017 to 25th September 2018. The experimental site has an average annual rainfall of 1450 mm with a distinctly bimodal distribution. The average annual minimum and maximum temperatures and daily pan evaporation rates were 22 °C and 32 °C and 5 mm/day, respectively (Panabokke, 1996). The soil has been classified as Walawe Series of Reddish Brown Earth (RBE), in the great group of Rhodustalfs (order Alfisols, suborder Ustalfa) soils and has a sandy clay loam texture (De Silva and Dassanayake, 2010).

Design and construction of open top chambers

Twelve OTCs were constructed with ion bars covered with UV-treated 200-gauge polythene (Figure 1). The frame of OTCs was approximately circular (3 m in diameter) with 12 sides fitted together. Its total height was 3 m and had an open-top (1.5 m in diameter). The vertical beams were bent, at a height of 2.5 m, inwards to form a frustum at the open top with a diameter of about 2 m. It maintains air temperature (T_a) within OTCs in near-natural conditions with a diurnal variation pattern similar to open field conditions (Norby *et al*., 1997; Welshofer *et al*., 2018).

Elevation of atmospheric CO_2 and temperature

The methodology used in elevating, maintaining, and monitoring atmospheric CO_2 and temperature is described in detail in De Silva (2021) and De Silva *et al.* (2021). Air blowers (0.25 kW) were used to maintain the adequate air circulation in all OTCs. The CO_2 level in designated OTCs elevated during the daylight hours (*i.e.* 0630 – 1800 hours) by injecting pure CO_2 through a gas regulator and a hose from 31 kg CO_2 cylinders housed outside the chambers. The required CO_2 concentration in the chamber was maintained by adjusting the pressure of release of CO_2 from the cylinders. The pressure of CO_2 release from the cylinder was set at 5 bars during the daylight hours when CO_2 was being injected into the OTCs. The concentration of CO_2 within the OTCs was monitored using the IEQ Chek environmental quality monitor (Bacharach Inc.). The T_a in designated OTCs elevated via heating coils installed in the air blowers. A heating unit had three 1 kW heaters. Each unit of heaters and air blower was manufactured as a single compound unit and was housed outside each chamber. The ambient or heated air was pumped to the chamber via an underground PVC pipe, connected to an adjustable polythene tube laid within the plot around the middle and perimeter of the OTC. The supply of CO_2 with ambient or heated air was also circulated within the chamber using the same mechanism as the air supply. The height of the polythene tubes was raised gradually with time as the height of the canopy increased. A daytime mean temperature elevation of up to 3.5 °C above the prevailing ambient T_a achieved by a thermostat in the heating unit of the air blower and a temperature sensor installed at canopy level in the middle of the OTC. The thermostat was adjusted so that the heating unit switched off when T_a in the middle of the OTC as sensed by the temperature sensor exceeded 35 °C. The heating unit switched back on when T_a decreased below 35 °C. Elevation of CO_2 and T_a in OTCs was done daily from 0630 to 1800 h to coincide with daylight hours following globally-adopted standard methodology (Norby *et al*., 1997; Welshofer *et al*., 2018).

Figure 1: Field view of open top chambers before (A) and after (B) planting of sugarcane

Experimental design and treatments

Three experimental treatment factors, *viz.* CO_2 and T_a in the growing environment and sugarcane varieties, arranged in a three-factor factorial treatment structure, laid out in a split-plot design with three replicates. Four CO_2 × T_a treatment combinations and an open field treatment were main-plot factors while eight varieties constituted the sub-plot factor. Two levels each of CO_2 and T_a ('ambient' and 'elevated') formed the four CO_2 × T_a combinations in OTCs. Within each of the three main plots in the split-plot design, the four CO_2 × T_a combinations in OTCs and ambient CO_2 × T_a combination in the open field were randomized. The open field plots, established in the same field but 20 m away from OTCs, also had the same dimensions as the plots within OTCs.

Eight commercial sugarcane (*Saccharum* hybrid spp.) varieties (*i.e*. Co775, SL7130, SL8306, SL88116, SL906237, SL924918, SL96128, and SL96328) were randomized separately within the two halves of each OTC and open field plots. Each variety was planted as 2 m rows spaced at 1.3 m. Therefore, each half of the OTC contained one row each from all eight varieties. As the eight varieties did not differ substantially in their plant and canopy architecture, the crop within each main plot (*i.e*. an OTC or an open field plot) was considered one contiguous population of sugarcane plants.

Crop establishment and management

Crop rows were established using single-budded seed-cane setts of the eight varieties. Each row consisted of four seed-cane setts of each variety. Hence, there were eight hills of each variety in a given OTC arranged in two rows with one row in each half of the OTC. Additional hills were established along the borders of the plots within OTCs to minimize the border effects. Crops were maintained with recommended fertilizer application and plant protection measures under well-watered conditions. Irrigation was provided at 0.15 m^3 of water per plot at 5-day intervals, while the soil water potential in the top 1 m was maintained above -0.05 MPa.

Monitoring environmental conditions

Micro-climatic conditions in OTCs were monitored continuously by installing sensors and data loggers (WatchDog1000 series micro stations model 1400, Spectrum Technologies, Inc. USA). Four temperature sensors (A, B, C, and D) were placed outside the OTC (A), and within it at 30 cm soil depth (B), at the soil surface (C), and in the air 2 m above the soil surface (D). The sensors monitored T_a continuously and recorded at 5-minute intervals. In addition, CO_2, relative humidity (RH%), and T_a in the chambers were monitored using the IEQ Chek environmental quality monitor (Bacharach Inc., USA) while taking physiological measurements. During the experimental period, daily meteorological conditions in the experimental site, *i.e*. rainfall, minimum and maximum T_a and, relative humidity (RH%), were recorded at the SRI weather station located near the experimental field.

Estimation of biomass and sucrose accumulations

One sugarcane bush in each sub-plot was uprooted for biomass estimation on 77, 121, 156,187 and 370 days after planting (DAP). Roots, stems, leaves with the immature top of canes, and trash separated and oven-dried at 105 °C to a constant weight. The biomass of each portion of canes was estimated. The number of shoots, stem diameter, the height of all shoots at the leaf of a top visible dewlap (TVD), and the number of leaves in each sub-plot taken, and above-ground total biomass per stalk and bush, was estimated. Biochemical analysis of juice quality parameters such as Brix, pol, purity, pure obtainable cane sugar (POCS), and fiber percentages in all stalks in the subplots, was done in the laboratory after harvesting sugarcane at the end of the experiment *i.e* 370 DAP.

Statistical analysis

The significance of treatment effects on measured variables was tested by analysis of variance (ANOVA) in the general linear models procedure (SAS® Studio, SAS Institute Inc. 2021). When the CO_2 × T_a × variety interaction was significant ($p<0.05$), the effects of CO_2 and T_a on tested variables were evaluated for each variety separately. The following pre-planned mean contrasts were used to separately test the significance of the effects of elevated CO_2 (ECO_2), elevated T_a (ET_a) and the combination of ECO_2 and ET_a in each variety:

Effect of $ECO_2 = x_{CeTa} - x_{CaTa}$

Effect of $ET_a = x_{CaTe} - x_{CaTa}$

Combined effect of ECO_2 and $ET_a = x_{CeTe} - x_{CaTa}$

where, x_{CeTa}, x_{CaTa}, x_{CaTe} and x_{CeTe} were the respective means of treatment combinations, elevated CO_2 + ambient T_a (C_eT_a), ambient CO_2 + ambient T_a (C_aT_a), ambient CO_2 + elevated T_a (C_aT_e), elevated CO_2 + elevated T_a, (C_eT_e). The 'chamber effect' (*i.e*. effect of the presence of the chamber) was estimated as the difference between the respective variable means of the C_aT_a and the open field treatment.

RESULTS AND DISCUSSION

Environmental conditions in the treatments

During the daylight hours, CO_2 enrichment increased CO_2 in OTCs having the ECO_2 treatment by 433 ± 2.6 and 435 ± 3.4 ppm, respectively in C_eT_a

and C_eT_e relative to C_aT_a (Table 1). During the night time, all five treatments had their respective CO_2 within a very narrow range (mean CO_2 363 – 405 ppm). The open field treatment showed a slightly higher CO_2 compared to C_aT_a and C_aT_e during the day and in comparison, to all treatments during the night (Night time data are not shown).

Open top chambers containing ECO_2 and ET_a treatments, both individually and in combination, had higher air temperatures than the OTCs consist of the C_aT_a treatment during the daylight hours (Table 1). Mean temperature elevation was the highest in C_eT_e with 3.46 ± 0.03 °C. The corresponding temperature elevations in C_aT_e and C_eT_a were 1.72 ± 0.03 °C and 0.70 ± 0.02 °C, respectively. Air temperatures within OTCs having elevated ECO_2 and ET_a treatments were higher than C_aT_a during the night as well (Night time data not shown). Notably, T_a in the OTCs containing C_aT_a was higher than in the open field plots, with mean temperature elevations of 1.63 ± 0.04 °C and 1.46 ± 0.03 °C during the day and night, respectively.

Relative humidity (RH%) inside all OTCs was greater than that in the open field throughout the day (Table 1). Compared to C_aT_a, ECO_2, and ET_a, both individually and in combination, RH% decreased within the OTCs. The highest depletion of RH% was in C_aT_e, whereas the lowest was in C_eT_a during the day and in C_eT_e during the night. The reduction of RH% was lower in the two ECO_2 treatments compared to the C_aT_e treatment because the ECO_2 retained more water vapor than ambient CO_2. This data agrees with the atmospheric processes taking place on a global scale (Houghton, 2009).

Number of shoots per hill (N_{sh})

Significant ($p<0.05$) effects of treatment, variety, and treatment × variety interaction on the number of shoots per hill (number of shoots emerged from a one-budded sett planted) were observed at 121, 156, and 187 DAP (Table 2, Figure 2).

Separate analyses of variance for different varieties showed significant ($p<0.05$) treatment effects on N_{sh} in some of the varieties. In comparison to the ambient (C_aT_a), elevated T_a increased N_{sh} in the majority of varieties (*e.g.* Co775, SL7130, SL924918, and SL96328) at 121, 156, and 187 DAP. As such, the data suggest higher temperatures stimulated tillering and the population density of sugarcane. Similarly, Inman-Bamber (1994) showed that temperature is a major factor influencing the tiller and leaf appearance of sugarcane, and it is more important for efficient canopy light interception of sugarcane.

Elevated CO_2 and the combination ECO_2 and ET_a increased N_{sh} relative to C_aT_a in a minority of varieties (Figure 2). It showed that when elevated T_a combined with ECO_2, the observed stimulation of tillering and population density have been further enhanced in some varieties (*ex.* SL7130 and SL96128) but not in others. However, encouraging good tillering is vital to building an adequate plant population in the field (Robertson *et al*., 1996; van Heerden *et al*., 2010), and it provides the crop with the sufficient number of stalks required for a good plant and ratoon cane yields (Vasantha *et al*., 2010; Matsuoka and Stolf, 2012; Bonnett, 2014.

Table 1: The average air temperatures, air CO_2 concentration ($[CO_2]$) and relative humidity (RH%) in the main treatments from 07:00 to 17:00 hours in open top chambers and open field conditions

Environmental variables	Main treatments				
	C_aT_a	C_eT_a	C_aT_e	C_eT_e	Open
Air $[CO_2]$ ppm	344	777	352	779	368
Air temperature (°C)	34.9	35.6	36.6	38.3	33.3
RH%	55.9	53.3	50.5	52.4	47.9
VPD (kPa)	2.47	2.72	3.05	3.21	2.67

Note: C_aT_a: ambient CO_2 + ambient T_a; C_eT_a: elevated CO_2 + ambient T_a; C_aT_e: ambient CO_2 + elevated T_a; C_eT_e: elevated CO_2 + elevated T_a; Open: open field conditions under the sugarcane canopy; RH%: relative humidity; VPD: Vapour Pressure Deficit

Table 2: Statistical significance of variety, treatment and variety × treatment interaction on number of shoots per hill at different stages

Source	121 DAP	156 DAP	187 DAP
Variety	0.0001	0.0001	0.0065
Treatment	0.0004	0.0126	0.0020
Variety × treatment	0.0579	0.0007	0.0054

Note: DAP: days after planting

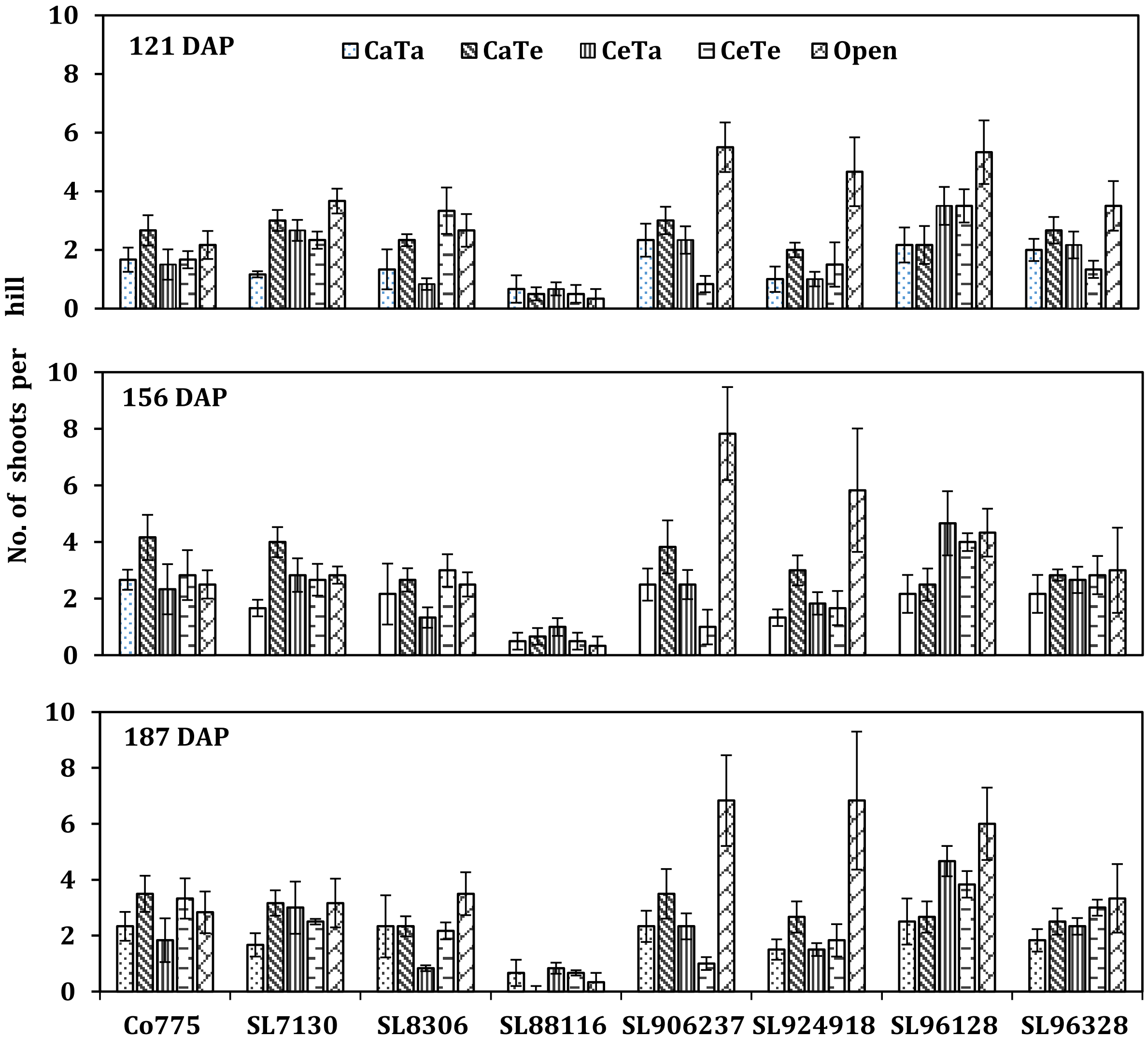

Figure 2: Number of shoots per hill (N_{sh}) in different sugarcane varieties at ambient CO_2 and ambient temperature (C_aT_a), ambient CO_2 and elevated temperature (C_aT_e), elevated CO_2 and ambient temperature (C_eT_a), elevated CO_2 and elevated temperature (C_eT_e) and in open field conditions (Open) at 121, 156 and 187 DAP. Each bar represents a mean of 6 data points. Error bars denote standard errors of mean

Biomass accumulation of sugarcane

Biomass in the individual stalks (W_{st})

Biomass per stalk (dry weight basis) showed significant ($p<0.05$) treatment effects at 121, 156, and 370 DAP (Figure 3). The variety × treatment interaction effect on W_{st} was not significant ($p>0.05$). Elevated CO_2 increased W_{st} by 27% relative to C_aT_a at 156 DAP. However, at 370 DAP, W_{st} was decreased by 7% and 6%, respectively, in ET_a and the combination of ECO_2 and ET_a in comparison to C_aT_a. Elevated CO_2 did not show significant ($p>0.05$) effects on W_{st} at 370 DAP. It could be due to the low response of C_4 photosynthetic process to ECO_2 (Long, 1999; Ghannoum *et al.*, 2000; von Caemmerer and Furbank, 2003; Long *et al.*, 2004; Leakey *et al.*, 2009; Stokes *et al.*, 2016; De Silva *et al.*, 2021).

Significant ($p<0.05$) genotypic variation was observed in the variation of W_{st} of sugarcane at different growth stages (Figure 4). Varieties Co775, SL7130, and SL8306 recorded higher values, and SL88116 and SL906237 recorded lower values of W_{st} on a majority of measurement days. Inman-Bamber *et al.* (2011) revealed that increasing biomass content in stalks through breeding and selection may not necessarily result in reduced sucrose content and increased fiber content.

Biomass per hill (W_h)

Biomass per hill (W_h) in the majority of days of measurement was not affected by ECO_2 or ET_a or their combination (Figure 5), despite the increase in the number of shoots (N_{sh}) in the majority of days of measurements, especially in ET_a (Figure 2). Therefore, the absence of a response in the biomass per stalk (Figure 3) has had a dominant influence in controlling W_h under elevated CO_2 and elevated T_a, which simulated future climates. In agreement with these results, previous studies of sugarcane (Stokes *et al.*, 2016) and C_4 species such as maize (Leakey *et al.*, 2006) did not show stimulation of biomass at ECO_2 under well-watered conditions. In contrast, at 156 DAP, the individual effects of both ECO_2 and ET_a and their combination caused a significant ($p<0.05$) increase in W_h relative to C_aT_a. In ECO_2, this has occurred because of an increase in both N_{sh} and W_{st}. De Souza *et al.* (2008) and Allen *et al.* (2011) observed similar patterns, where sugarcane was grown at ECO_2.

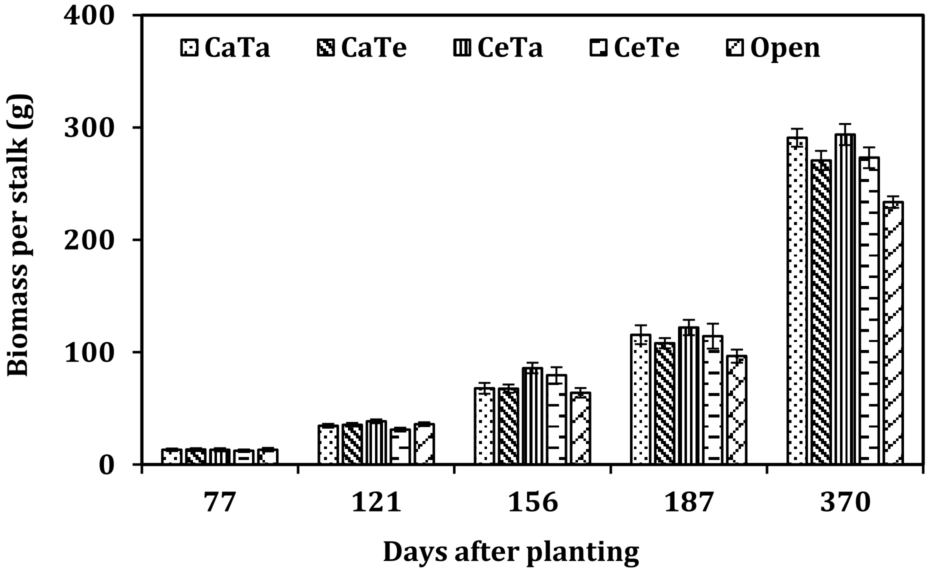

Figure 3: Dry weight basis biomass per stalk (W_{st}) of sugarcane at ambient CO_2 and ambient temperature (C_aT_a), ambient CO_2 and elevated temperature (C_aT_e), elevated CO_2 and ambient temperature (C_eT_a), elevated CO_2 and elevated temperature (C_eT_e) and in open field conditions (Open) at different stages. Each bar represents a mean of 48 data points across eight varieties and six replicates. Error bars denote standard errors of mean

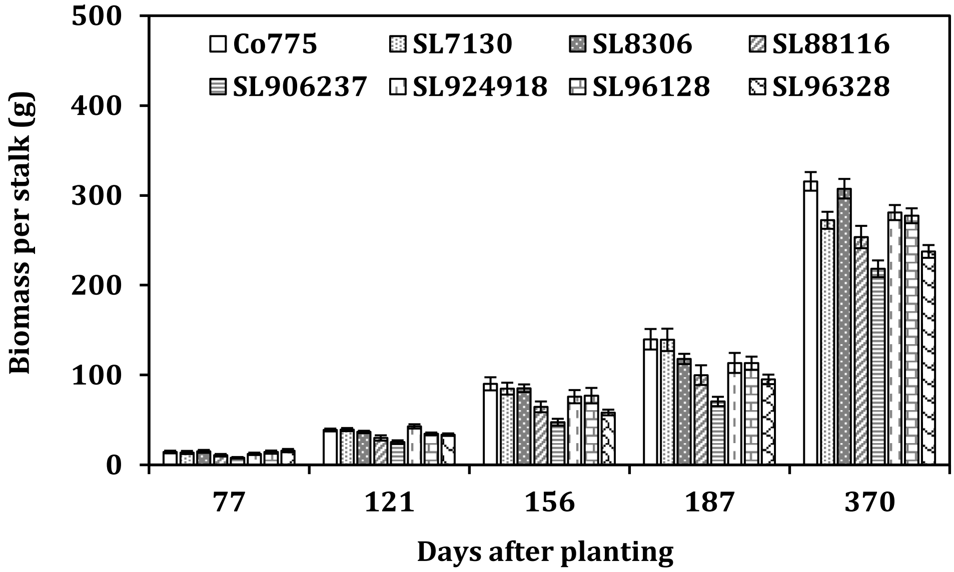

Figure 4: Dry weight basis biomass per stalk (W_{st}) in different sugarcane varieties at different stages. Each bar represents a mean of 30 data points across five treatments and six replicates. Error bars denote standard errors of mean

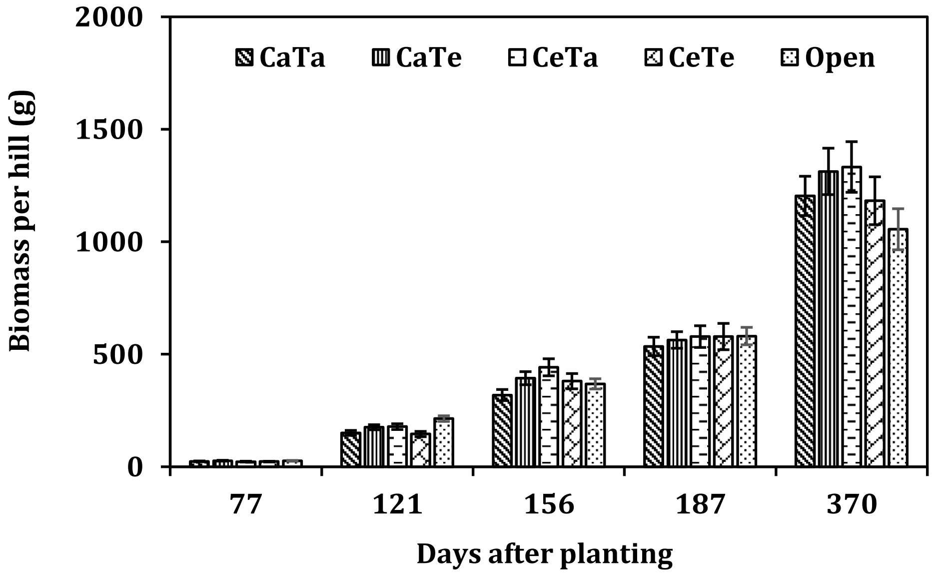

Figure 5: Dry weight basis biomass per hill (W_h) of sugarcane at ambient CO_2 and ambient temperature (C_aT_a), ambient CO_2 and elevated temperature (C_aT_e), elevated CO_2 and ambient temperature (C_eT_a), elevated CO_2 and elevated temperature (C_eT_e) and in open field conditions (Open) at different stages. Each bar represents a mean of 48 data points across eight varieties and six replicates. Error bars denote standard errors of mean

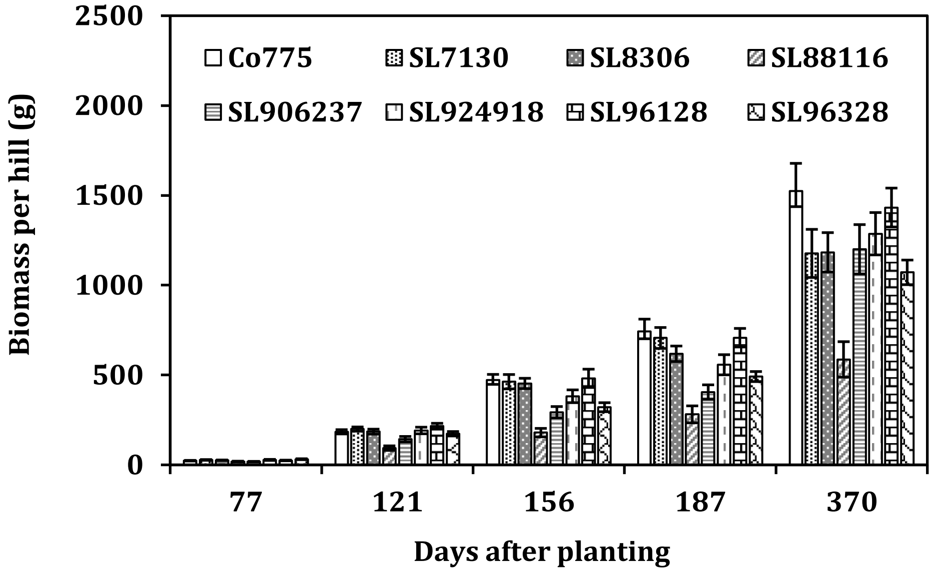

Figure 6: Dry weight basis biomass per hill (W_h) in different sugarcane varieties at different stages. Each bar represents a mean of 30 data points across five treatments and six replicates. Error bars denote standard errors of mean

In response to ET_a, the increase in W_h had occurred because of increased N_{sh} while W_{st} has remained unchanged. Similarly, Vu and Allen (2009) showed significant increases and genotypic variation in biomass accumulation of sugarcane in response to ET_a. In contrast, Allen *et al.* (2011) showed that ET_a caused a slight downward trend in sugarcane biomass accumulation regardless of genotypes or CO_2 elevation.

Significant ($p<0.05$) genotypic variation was shown in the responses of W_h at different growth stages (Figure 6). Varieties Co775 and SL96128 recorded higher W_h on a majority of measurement days. Notably, SL88116, which had higher Pol and POCS (Figure 7), recorded the lowest W_h than all other varieties at all measurement days (Figure 6).

Sucrose accumulation and quality characters

Percentages of Pol and POCS in cane juice showed significant ($p<0.05$) effects of treatment, variety, and variety × treatment interactions at 370 DAP (Figure 7). Separate analyses of showed significant ($p<0.05$) treatment effects on Pol and POCS in the majority of varieties.

SL96328 recorded the highest reduction of Pol and POCS by 20 and 25%, respectively, due to the effect of ECO_2 in C_eT_a. On the other hand, ECO_2 increased Pol and POCS by 9 and 14%, respectively, in SL924918. While SL96328 had the highest Pol and POCS in ambient conditions (C_aT_a), SL924918 had the lowest of the respective values in C_aT_a. Percentages of Pol and POCS in other varieties did not show responses to ECO_2. It indicated that the effect of ECO_2 in the absence of ET_a on sucrose accumulation varied among varieties. Previous studies using single variety have also shown that the sucrose content in sugarcane was increased by elevation of CO_2 (Vu *et al.*, 2006; De Souza *et al.*, 2008). They further showed that increased photosynthetic rates (+30%) and biomass accumulation (+40%) at ECO_2 enhanced biomass partitioning to sucrose. Inman-Bamber *et al.* (2011) and Lobo *et al.* (2015) showed that photosynthesis did not alter by a feedback mechanism induced by sucrose accumulation in stalks. Sink strength for sucrose storage in the upper internodes is stronger in both high fiber and high sucrose varieties. McCormick *et al.* (2006, 2008, and 2009) and Ribeiro *et al.* (2017) showed an increase in leaf photosynthetic capacity with a decrease in assimilating availability in young sink tissues.

Elevated T_a in the absence of ECO_2 (C_aT_e) reduced Pol in SL7130, SL96128, and SL96328. The highest reduction of Pol and POCS by 20 and 19%, respectively, was recorded in SL96128. The increase in T_a may eliminate the benefits of the projected rise in CO_2 on sugarcane as lower temperatures are essential for enhancing sucrose accumulation (Verma, 2004). Our findings agree with the previous results of Ebrahim *et al.* (1998) and Verma (2004), who recorded decreasing sucrose accumulation in sugarcane with increasing the T_a. However, Pol and POCS in SL88116, SL906237, and SL924918 did not show significant ($p>0.05$) responses to elevated T_a. Notably, sugarcane varieties in Sri Lanka grow in high-temperature (33.3 °C) environments (Table 1). Furthermore, our study provides an indication that growth, stomatal anatomical features and photosynthesis of the variety SL88116 did not respond to the elevation of temperature up to 36.6 °C (De Silva, 2021; De Silva et al., 2021).

The combined effect of ECO_2 and ET_a decreased Pol in Co775, SL8306, and SL96328. The highest reduction of Pol by 13%, was recorded in SL8306 which had higher corresponding values in C_aT_a. Percentages of Pol and POCS in SL7130, SL88116, SL906237, SL924918, and SL96128 did not show a significant ($p>0.05$) response to the combination of ECO_2 and ET_a. Similar to these findings, Vu and Allen (2009) have observed significant varietal variation on sucrose productivity of sugarcane at ECO_2 and ET_a. However, the increased respiration rates due to ET_a (Hofstra and Hesketh, 1969; Atkin and Tjoelker, 2003; Heskel *et al*., 2016) could be the most probable reason for the reduction of sucrose accumulation in sugarcane.

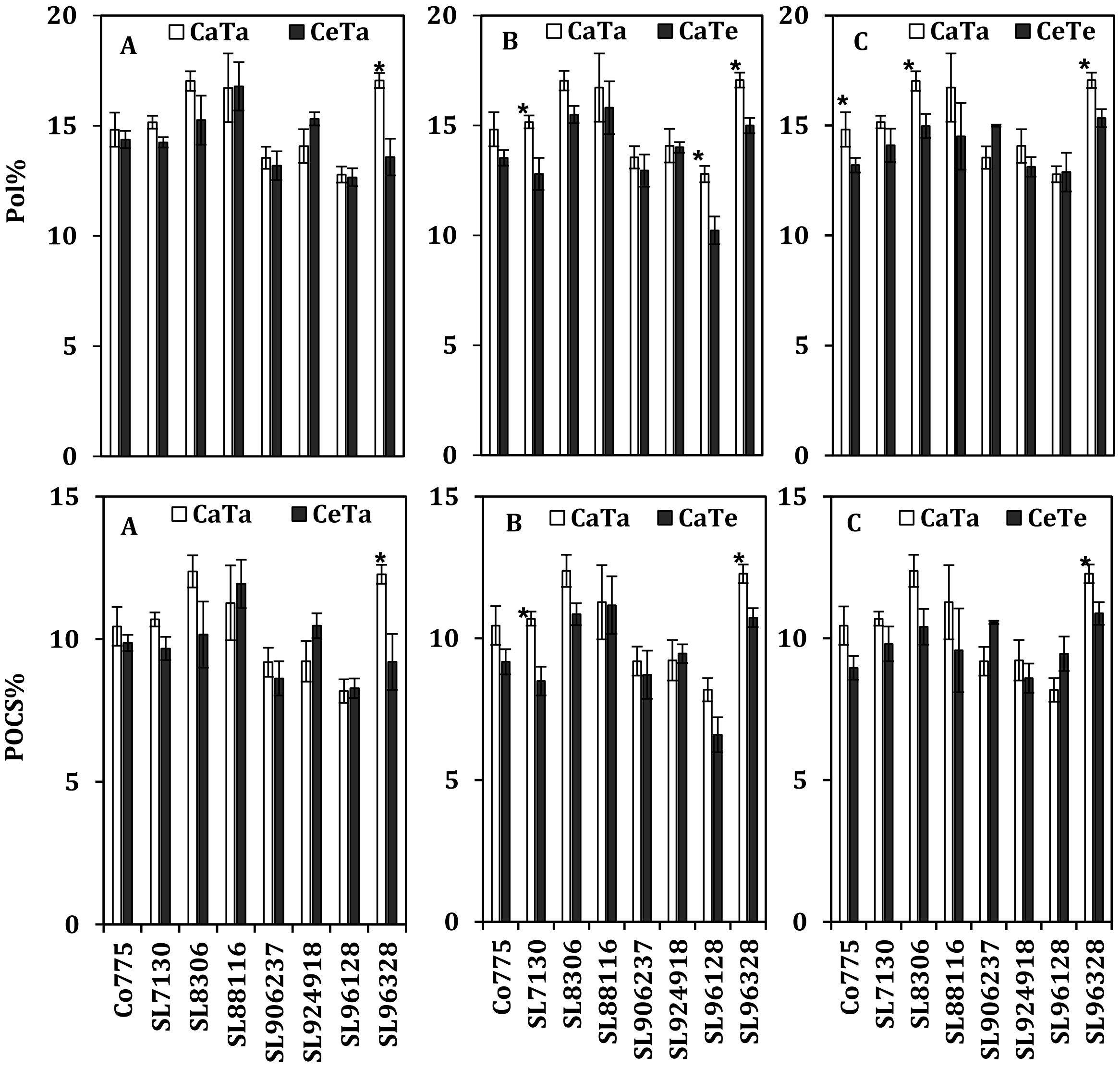

Figure 7: Responses of Pol and pure obtainable cane sugar (POCS) in cane juice to elevated CO_2 at ambient temperature (A), elevated temperature at ambient CO_2 (B) and the combination of elevated CO_2 and temperature (C). C_aT_a: ambient CO_2 and ambient temperature; C_eT_a: elevated CO_2 and ambient temperature; C_aT_e: Ambient CO_2 and elevated temperature; C_eT_e: elevated CO_2 and temperature. Each bar is a mean of 6 replicate measurements. Error bars show the standard errors of means. Within each variety, significant ($p<0.05$) responses, based on pre-planned mean contrasts, are shown by '

Notably, Pol and POCS in SL96328, which had higher respective values, were affected by the ECO_2 and ET_a individually and in combination. The significant ($p<0.05$) genotypic variation in the response of sucrose accumulation in sugarcane to ECO_2 and ET_a is further demonstrated by the observation of SL88116 not showing a significant ($p>0.05$) response in its already higher Pol and POCS to both ECO_2 and ET_a individually or in combination. Therefore, unresponsiveness of higher Pol and POCS in SL88116 to ECO_2, ET_a, and the combination of ECO_2 and ET_a could be vital in a future climate to ensure the stability of sugar recovery of sugarcane at milling.

CONCLUSIONS

As increasing atmospheric [CO_2] and the resulting increase in air temperature (T_a) are clear features of future climate change, the current results provide indications and insights into the impacts of future changes in climate on sugarcane. Biomass production of sugarcane was not affected by ECO_2 or ET_a or their combination. The combinations of ECO_2 and ET_a reduced sucrose accumulation in 3 out of 8 varieties (Co775, SL8306 and SL96328) at the end of the growing season. However, sucrose accumulation in the variety SL88116, which had higher respective values at ambient and simulated future climatic conditions, was not affected by either ECO_2 or ET_a individually or in combination. The responses and the significant genotypic variation observed in sucrose accumulation to ECO_2 and ET_a, both individually and together could be utilized to maintain the stability of sugar production in CO_2-rich warm climates.

ACKNOWLEDGEMENTS

This research was funded by the Sugarcane Research Institute (SRI) of Sri Lanka. Assistance given by Dr. A.P. Keerthipala (Former Director), Mr. L.M.J.R. Wijayawardhana (RO/Water Management), Mr. I.P. Manawadu (TO) and Mr. G.S. Udawatta (STO) of SRI are gratefully appreciated.

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