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Effects of spatial and genotypic variability on heat and energy use efficiency in sugarcane under Tropical Indian conditions

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ABSTRACT

The field experiment on effects of spatial and genotypic variability on heat use efficiency, energy use efficiency and sugarcane productivity was conducted during 2018 at ICAR- Sugarcane Breeding Institute, Coimbatore, Tamil Nadu, India.The results revealed that planting sugarcane at 120 cm row spacing recorded numerically higher cane yield (137.09 tha^{-1}), heat use efficiency and energy use efficiency than 150 cm row spacing.The sugarcane genotype Co 12012 with 129460 NMC/ha registered significantly highest number of millable cane (NMC) than ruling Co 86032 (89670 NMC/ha) variety. Amongst sugarcane genotypes under study, highest values of 22.37, 22.05 and 98.55 for brix, sucrose per cent and purity per cent, respectively, were exhibited by CoC 671 sugarcane genotype. However, with 22.91 and 20.85 t/ha of CCS yield, VSI 12121 and Co 12012 showed better agronomic response and in addition to this there also recorded better heat use efficiency and energy use efficiency than the standard check sugarcane varieties Co 86032 and CoC 671. The present field experiment revealed the climate resiliency of VSI 12121 and Co 12012 sugarcane genotypes in terms of better juice qualities, superior heat use efficiency, energy use efficiency and enhanced cane productivity under wider row planting system in 120 cm row spacing under tropical Indian conditions.

Keywords:Cane yield, **e**nergy use efficiency,growing degree days, heat use efficiency, sugarcane

Internationally, sugar is well-known as a staple food by numerous clienteles. Sugar usage, refined or otherwise, in most of the processed foods is currently in vogue globally. The FAO of the United Nation recognises 103 countries that produce sugarcane (*Saccharum* hybrids L.). Worldwide, sugarcane cultivation is taken up on 24.5 million hectares mostly in tropical lowland climates (OECD/FAO, 2019). Sugarcane is grown entirely in the middle of 30^0 S and 30^0 N latitudes and most precisely it is concentrated between 20-degrees (Bull and Glasziou, 1979). After Brazil, India holds conspicuous place for highest sugarcane acreage (5.06 million ha) and produced annually 405.30 million tonnes of cane. More recently, in India, a quantum jump in sugar demand was observed, and furthermore it is projected that by the year 2050 it will closely upswing to 48 million tonnes (ICAR-SBI, 2015). To cope up with escalating sugar demand of the country, planting climate resilient sugarcane genotype under optimal crop geometry is indispensable in the present-day context of climate change. In the context of changing climate scenario, global surface temperature change for the end of the 21st century is likely to exceed 1.5°C relative to 1850 to 1900 for all RCP scenarios except RCP2.6. It is likely to exceed 2°C for RCP6.0 and RCP8.5, and more likely than not to exceed 2°C for RCP4.5 (IPCC,2013). As far as sugarcane is concerned, a minimum mean temperature of 20°C is congenial during active growth phase. Temperatures both below 5°C and above 35°C are not suitable as previous may be harmful for young leaves and buds (Srivastava and Rai, 2012). Temperatures above 38°C reduce the rate of photosynthesis and increase respiration. This revealed that temperature is a crucial environmental factor that impacts the growth and development, phenology, cane yield and sugar recovery. Sugarcane has a definite temperature requirement to accomplish phenological stages, wherein, an optimum temperature for germination is 32-38°C and it slows down below 25°C. Germination of buds reaches plateau between 30-34°C, and reduced above 35°C, whereas practically stops when the temperature is above 38°C. Under the tropical climates the excessive radiations and elevated temperatures are major limiting factor to plant growth and development. The Indian northern subtropical region experiences extreme summer temperatures as well as severe cold in winter, whereas the tropical region in south of Vindhyans, the temperature shoots up to 47°C in comparatively prolonged summer season (Srivastava and Rai, 2012). Several researchers, viz. Ashraf and Hafeez (2004), Wahid and Close (2007) reported a significant reduction in the growth and net assimilation rate in maize and sugarcane (*Saccharum officinarum* L.) under heat stress. Whereas Ebrahim *et al.* (1998)reported a substantial decline in the inter-nodal length and biomass accumulation along with early leaf senescence in sugarcane under heat stress. Impact of temperature on phenology and yield of crop plants can

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Short communication

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be studied under field condition through accumulated heat units (Bishnoi *et al.,* 1995;Chakravarty and Sastry, 1984; Rajput *et al*.,1987) and suitable crop genotypes performing well can be advised under such abiotic stresses. More recently, Rane and Nagarajan (.2004) underlined the need of screening the genotypes across space and time under field conditions by choosing sites, which are showcased by high temperature ("hot spots") regime. Similarly, Bacchi and Sousa (1977) also suggested the excellent prospects for utilizing GDD concept with sugarcane culture due to existence of large genetic variability amid the sugarcane varieties. If the thermic requirements of the varieties in degree-days are known, it is possible to schedule a planting program so that mature cane can be obtained at different times, which increases the useful period of cane processing. On the other hand, by knowing the thermic values of new growing regions, we can indicate the most promising varieties for introduction. Various genotypes perform differently due to their plant architecture particularly under different crop geometries. Bonnett *et al.*(2006) noticed that sugarcane varieties with thick cuticles and leaf wax can reflect solar radiation and thereby moderate the adverse effects of heat stress. Differential cultivar response to water deficit was noted by Inman-Bamber *et al.*(2012) as well. Under deficit irrigation scheduling in sugarcane at ICAR-SBI, Coimbatore, India, Tayade *et al.* (2020) recommended Co 10026, Co 13006, Co 85019, Co 62175, Co 86010, and Co 1148 sugarcane genotypes. In the above context, it was felt necessary to screen high quality, elite climate resilient sugarcane genotypes for better heat use efficiency and sugarcane productivity under suitable wider row planting techniques.

Field experiment was conducted during 2018 at ICAR-Sugarcane Breeding Institute, Coimbatore (11^{0}N, 77^{0}E with an altitude of about 427 m from mean sea level), India. Eleven elite sugarcane genotypes *viz*. Co 12007, Co 12008, Co 12009, Co 12012, Co 12019, Co 12024, Co 86032, CoC 671, CoM 12085, CoSnk 05103, and VSI 12121 in main plot and two inter row spacing (120 and 150 cm) in sub plot were accommodated in a replicated split plot design. The soil of the experimental site was typic haplustalf with clay loam texture, neutral in reaction, non saline in electrical conductivity, low in nitrogen, high in phosphorus and potash. Sugarcane planting was done during February 2018, by using two budded setts @ 40 setts per six-meter furrow length. In all, four rows of sugarcane were accommodated in plot size of 6 × 4.8 m and 6 × 6.0 m for 120 and 150 cm inter row spacing, respectively. Standard nutrient management scheduling was followed, wherein, basal applications of P (62.5 kg ha^{-1}) and split N (280 kg ha^{-1}) and K(120 kg ha^{-1}), at partial and full earthing up respectively. Harvesting of cane was done manually at full maturity at 12 months *i.e*., February 2019. Close harvesting (2 to 3 cm below ground level) was performed using a hand axe. The cane yield per plot was recorded at the time of harvesting. The yield per hectare was then determined using the cane yield per plot and expressed in t ha^{-1}. The standard protocol as suggested by Meade and Chen (1977) was followed for studying the sugarcane quality parameters such as Brix, Pol (%), and Purity %. The total recoverable sugar % (sucrose) in the cane *i.e*., commercial Cane Sugar and CCS yield (t ha^{-1}) were estimated by using the following formula

$$\text{Commercial cane sugar \%} = [(\text{Sucrose\% x } 1.022) - (\text{Brix x } 0.292)] \qquad \ldots\ldots\ldots\ldots\ldots(1)$$

CCS yield (t ha^{-1}) was calculated by following the formula.

$$\text{CCS Yield (t ha}^{-1}) = \frac{\text{CCS \% x Cane yield (t ha}^{-1})}{100} \qquad \ldots\ldots\ldots\ldots\ldots(2)$$

Daily maximum temperature (T_{max}), minimum temperature (T_{min}), rainfall and other meteorological observations were recorded at Agro-meteorological observatory installed at ICAR-SBI, Coimbatore. The growing degree days (GDD), and heat use efficiency (HUE) for different phenophases of sugarcane were calculated using 18 °C base temperature (Tb) as per following formula (3) and accumulated from the date of sowing (*i.e*., 7th February, 2018) to date of harvesting (6th February, 2019).

$$\text{GDD}(^{o}Cd) = \frac{\sum(\text{T max} + \text{T min})}{2} - \text{Tb} \qquad \ldots\ldots\ldots(3)$$

Where T_{max} and T_{min} represents the daily maximum and minimum temperatures and T_b is the base temperature for sugarcane T_b considered as 18°C (Bacchi and Sousa, 1977). The heat use efficiency (HUE: kg ha^{-1} ^{0}C^{-1} day^{-1}) was calculated based on the formula:

$$\text{HUE} = \frac{\text{Sugar yield(kg ha}^{-1})}{GDD} \qquad \ldots\ldots\ldots(4)$$

The energy use efficiency (E_μ) was calculated as :

$$\text{E}\mu = \frac{\text{Chemical energy captured by crop}}{\text{Solar energy received}} \qquad \ldots\ldots(5)$$

Where chemical energy captured by crop is represents 3940 calories g^{-1} for sugar and solar energy captured represents the photosynthetically active radiation (cal^{-1}cm^{2}day^{-1}) received during the crop duration. The EUE was calculated based on the CCS and PAR received during the experimentation period.The data was analysed statistically by standard procedures given by Gomez and Gomez (1984) and comparison of means test was carried out using least significance difference (LSD) at the 5% probability level.

The prevailing climatic conditions during experimentation represented tropical Indian condition, wherein mean temperature was ranging between 17.4 to 34.3^{0}C, with relative humidity of 56.75 to 76.35 per cent (Fig. 1). The annual rainfall deviated from sixty years of normal rainfall (674.2 mm) and substantially higher rainfall was recorded (828.2 mm) in 65 rainy days. With no rains in the February month of 2018, monthly rainfall distribution showed exceedingly erratic pattern and May month of 2018 recorded the highest rainfall of 214.3 mm in 13 rainy days. From BSSH data depicted in Fig. 1, it can be observed that February month of 2018 recorded highest (8.90 hrs) monthly average BSSH, and June month of 2018 recorded lowest (4.05 hrs) monthly average BSSH.

The overall effect of temperature on sugarcane growth, development, and cane yield was quite apparent and it influenced the phenological development process of sugarcane *viz*. germination phase (0-60 DAP), formative phase (60-150 DAP), grand growth phase (150-240 DAP) and ripening phase (240-365 DAP) in terms of consumption of degree days to attain the respective phenophase.The GDD recorded during different phenophase of sugarcane is represented in Fig.2 wherein, highest GDD *i.e*., 870-degree days was observed during 240-365 days after planting followed by 60-150 DAP (766.5). Higher amount of solar radiation and higher daily mean temperature recorded during 240-365 DAP and 60-150 DAP might have resulted in accumulating the more degree day than 150-240 DAP (547.8-degree days).The lowest GDD consumed during150-240 DAP was primarily attributed to the moderate temperature (25-26^{0}C) recorded in the month of July 2018 to October 2018. *Per se* sugarcane grows slowly during the early part of its growth period (Bull and Glasziou, 1975; Thompson, 1991; Robertson *et al*.,1996) further more accumulated dry mass slowly in the late part of the growth phase too (Lingle, 1997; Allison and Pammenter, 2002).Thus, GDD could be a good weather-based indicator for evaluating sugarcane development as it measures heat accumulation during the ontogeny of sugarcane crop. Under tropical Indian conditions at ICAR-Sugarcane Breeding Institute, Coimbatore, a 12-month *suru* sugarcane plant crop accumulated a total of 2766.5-degree days.

Better heat use efficiency (HUE) and energy use efficiency (EUE) were noticed in 120 cm spacing compared to 150 cm row spacing (Fig. 3). The higher HUE (sugar yield per degree day) values in 120 cm crop geometry could be attributed to more photosynthetic efficiency, greater number of millable cane and finally the higher sugar yield. As the temperature and solar radiation were optimum throughout the growing period it utilized heat more efficiently and increased biological activities that confirms higher sugar yield. Also, among the explored clones the Co 12012 and VSI 12121 registered substantially improved HUE and EUE compared to Co 86032, CoC 671.

The better HUE and EUE exhibited by Co 12012 and VSI 12121 sugarcane genotypes primarily ascribed to greater tillers, NMC, improved yield attributing characters (129.46 × 10^3 NMC in Co 12012), highest single cane weight (2.06 kg in VSI 12121), more cane yield and CCS yield recorded by these genotypes. The improved cane yield of sugarcane crop is the final outcomes of the positive impacts of optimal environmental factors such as rainfall, relative humidity, solar radiation and temperature. Temperature played an important role in crop growth and biomass production and it looks as if that Co 12012 and VSI 12121 genotypes exploited the various environmental factors more efficiently than the rest of the sugarcane genotypes. Similarly, Bonnett *et al.* (2006) observed that sugarcane varieties with thick cuticles and leaf wax could reflect solar radiation and thereby moderate the adverse effects of heat stress. Similar differential cultivar response to water deficit was also witnessed by Inman-Bamber *et al.* (2012) and Tayade *et al.* (2020). In the present investigation, spatial × genotypic interaction effects were found non-significant for heat use efficiency and energy use efficiency.

Yield of crops is the results of the effects of various environmental factors. Temperature portrayed an crucial role in crop growth and biomass production. Effects of spatial variability on cane length, cane girth, number of internodes, single cane weight, number of millable cane and cane yield was not much more perceptible (Table 1), however, planting of sugarcane at 120 cm row spacing recorded numerically higher cane yield (137.09 t ha^{-1}) than 150 cm row spacing (120.71 t ha^{-1}). Moreover, commercial cane yield was numerically influenced due to inter-row distance. Overall, 13.57 and 12.68 per cent improvement in sugarcane yield and commercial sugar yield respectively was seen due to 120 cm over 150 cm row to row spacing. Higher cane yield in 120 cm row spacing may be ascribed to higher number of millable cane observed in it than planting sugarcane at row spacing of 150 cm. Similarly, studies on wide row spacing conducted at ICAR-SBI indicated yield decline when row spacing was widen to 150 cm from 90 cm Tayade *et al*. (2017). The interaction effects between genotypes and varied row spacings were absent.With regard to genotypes, Co 12012 with 129460 NMC ha^{-1} had registered significantly the highest NMC than ruling Co 86032 (89670 NMC ha^{-1}) variety. Amongst

Table 1: Effects of spatial and genotypic variability on cane length, cane girth, number of internodes, single cane weight (SCW), number of millabe canes (NMC) and sugarcane yield

Treatments	**Cane length (cm)**	**Cane girth (mm)**	**No of internodes**	**SCW (kg)**	**NMC (000/ha)**	**Cane yield (t/ha)**
Spacing						
120 cm	228.86	28.97	25.02	1.39	103.27	137.09
150 cm	241.97	29.95	26.90	1.58	84.59	120.71
SEm(±)	**9.61**	**0.75**	**0.72**	**0.04**	**4.15**	**2.36**
LSD (0.05)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**
Varieties						
Co 12007	236.67	26.92	25.16	1.32	92.72	106.85
Co 12008	219.16	30.52	25.33	1.24	83.05	97.03
Co 12009	264.167	33.83	24.83	1.86	80.99	142.57
Co 12012	242.49	25.68	26.83	1.29	129.46	164.94
Co 12019	172.08	27.23	25.08	0.98	103.01	111.75
Co 12024	215.00	30.17	30.58	1.38	89.18	117.68
VSI 12121	281.66	31.21	26.25	2.06	100.48	154.07
CoM 12085	287.08	32.72	28.50	2.20	67.03	125.12
CoSnk 05103	224.58	26.02	21.74	0.90	120.96	134.80
Co 86032	227.91	30.47	25.41	1.54	89.67	136.43
CoC 671	218.74	29.32	25.91	1.59	76.70	127.85
SEm(±)	**15.94**	**1.48**	**2.070**	**0.18**	**9.04**	**16.21**
LSD (0.05)	**33.26**	**3.10**	**4.319**	**0.38**	**18.86**	**33.81**
Interaction (V×S)						
SEm(±)	**22.55**	**2.10**	2.92	0.25	12.79	**16.19**
LSD (0.05)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**

Table 2: Sugarcane juice quality as influenced by row spacings and elite sugarcane genotypes

Treatments	**Brix (%)**	**Sucrose %**	**Purity %**	**CSS %**	**CCS yield (t/ha)**
Spacing					
120 cm	20.53	19.58	95.32	14.02	19.11
150 cm	20.42	19.58	95.79	14.05	16.96
SEm(±)	**0.068**	**0.20**	0.69	0.19	0.04
LSD (0.05)	**NS**	**NS**	**NS**	**NS**	**0.57**
Varieties					
Co 12007	20.02	19.46	97.22	14.05	15.02
Co 12008	22.17	21.13	95.30	15.12	14.71
Co 12009	20.22	19.22	95.01	13.74	19.68
Co 12012	19.57	18.01	92.01	12.70	20.85
Co 12019	20.32	19.17	94.31	13.66	15.40
Co 12024	19.52	19.18	98.27	13.90	16.17
VSI 12121	21.32	20.64	96.82	14.87	22.91
CoM 12085	20.89	20.37	97.52	14.71	18.41
CoSnk 05103	18.87	17.14	90.84	12.00	16.22
Co 86032	19.97	19.03	95.30	13.62	18.59
CoC 671	22.37	22.05	98.55	16.00	20.41
SEm(±)	0.62	0.65	1.16	0.50	1.93
LSD (0.05)	1.29	1.36	2.43	1.05	4.03
Interaction(V×S)					
SEm(±)	0.88	0.92	3.44	0.71	2.73
LSD (0.05)	**NS**	**NS**	**NS**	**NS**	NS

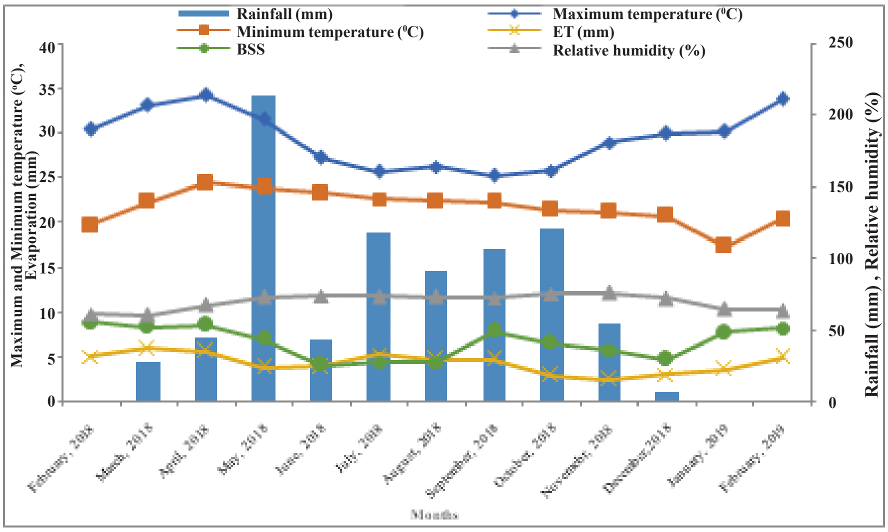

Fig. 1: Weather conditions prevailed during 2018-19

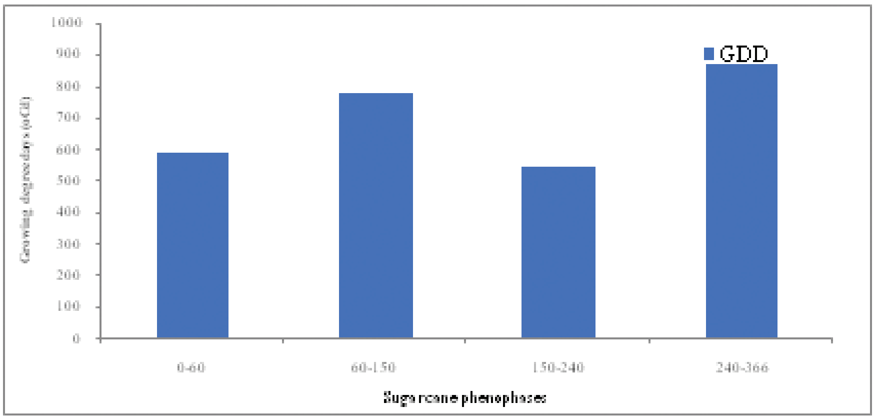

Fig. 2: GDD recorded during different sugarcane phenophase

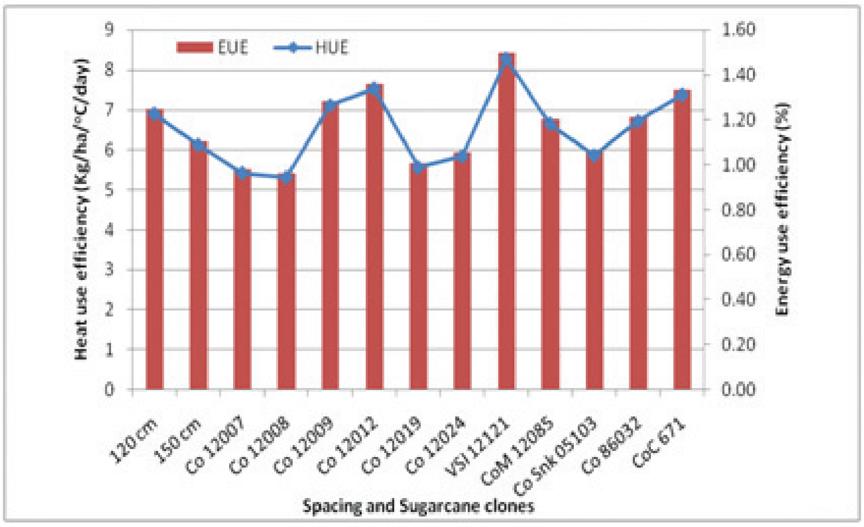

Fig. 3: Impact of spatial and genotypic variability on EUE and HUE

the 11 elite sugarcane genotypes, with 22.91 and 20.85 t ha^{-1} of CCS yield, VSI 12121 and Co 12012 showed better agronomic response than the check entries CoC 671(20.42 t ha^{-1}) and Co 86032 (18.60 t ha^{-1}). The higher CCS yield recorded by VSI 12121 and Co 12012 varieties was basically attributed to better juice qualities *i.e*., brix (%), sucrose (%), purity (%), CCS (%) and higher cane yield. Because commercial sugar yield in sugarcane is the product of cane yield and commercially recoverable cane sugar content (%) in cane. Commercially recoverable sugar content in sugarcane (CCS, expressed as a percentage) is a key selection criterion in sugarcane breeding programs. Studies revealed that CCS (t ha^{-1}) had positive and significant association with brix (%) 10 months, sucrose (%) 10 months, purity (%) 10 months and CCS (%) 10 months, brix (%) 8 months and cane yield (t ha^{-1}), indicating the weights of these traits while selecting for high quality genotypes in sugarcane (Sanghera *et.al.,* 2014).

Significant varietal differences were noticed with respect to juice quality parameters (Table 2) wherein, the sugarcane varieties CoC 671 and Co 12008 were found at par in terms of brix (%) and sucrose per cent in the juice. Amongst, elite sugarcane genotype, Co 12008 was found more promising and recorded significantly higher sucrose % (21.13%) than CoSnk 05103(17.14%) and Co 86032(19.03%). Quality of juice is primarily a varietal characteristic. A non-significant V x S *i.e*.,genotypes and spacing interactions were observed for brix and sucrose, purity and CCS percent. Higher sucrose values for CoC 671 (22.05), Co 12008 (21.13) and VSI 1221 (20.64%) varieties indicated higher genetic capability to build up more sucrose in juice. Similarly, CoC 671 also showed significantly higher purity percentage (98.55%) than the check sugarcane varieties CoSnk 05103 and Co 86032. In terms of CCS%, the CoC 671(16.0%) followed by Co 12008 (15.12%) genotypes significantly recorded the highest CCS % over rest of the varieties. This may be attributed to fact that juice quality parameters in sugarcane, by and large, are governed by the genetic constitution of varieties. Thus, outcomes of this experimentation corroborated the findings of Naga Madhuri *et al.* (2011) wherein, differential varietal responses were also found in terms of juice sucrose. Similarly, in sugarcane genotypes, Garside and Bell (2009) and Tayade *et al.* (2018) also observed the significant differential responses with respect to yield and quality. The impact of varied row spacing *i.e*., 120 cm and 150 cm on juice quality parameters was not apparent and both plant geometries recorded same juice qualities. This could be due to pervasiveness of similar type microclimate and specifically more uniform ambient temperature experienced during ripening phase by the crop due to planting sugarcane in varied row spacing. Temperature plays a decisive role in the process of ripening. During ripening period, a low temperature in the range of 12-14°C reduces vegetative growth rate and enrichment of sucrose in the cane (Fageria *et al.,* 2010).The other studies of Marafon (2012) have shown that sucrose accumulation in stems in the maturation phase is favored by relatively low temperatures, which reduce the absorption of nutrients and plant growth, and a period of water restriction, because the dehydration of plant tissues forces the conversion of reducing sugars into sucrose. During this process, sucrose content increases to reach extreme limits from 12 to 18%, as the other sugars such as glucose and fructose have their contents reduced by up to limits of 0.2%.

The present field experiment revealed the climate resiliency of VSI 12121 and Co 12012 sugarcane genotypes in terms of better juice qualities, superior heat use efficiency, energy use efficiency and enhanced cane productivity under wider row planting system in 120 cm row spacing in tropical Indian conditions.

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