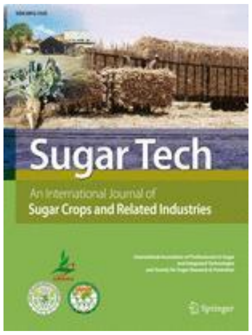

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Interrelationship Among Biomass Related Traits and Their Role in Sweet Sorghum Cultivar Productivity in Main and Ratoon Crops

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Interrelationship among biomass related traits and their role in sweet sorghum cultivar productivity in main and ratoon crops

Abstract

Increased global interest in biofuel feedstocks made sweet sorghum as one of the prominent energy crop suitable for both first and second generation biofuel production. An attempt has been made to critically identify the factors contributing to biomass yield and their interrelationship in sweet sorghum plant (main) and ratoon trials. The genotypes ICSSH 28, ICSSH 58, ICSA 749 x SPV 1411, B-24 and ICSV 93046 exhibited higher ratooning efficiency. It was observed that higher the ratooning efficiency lower will be the difference between the growing degree days (GDD) of main and ratoon crop. GDD

can be used as one of the selection criteria in breeding programs aiming for enhanced biomass and ratooning efficiency.

Key words Sweet sorghum, main crop, ratoon crop, biomass, growing degree days and photo thermal units

Introduction:

Sorghum [*Sorgh um bicolor* (L.) Moench], based on the use can be broadly classified as grain, sweet (sorgos) and fodder (high biomass). Three distinctly different types of sorghum can be used as ethanol feedstocks and they supply three different ethanol conversion systems-grains produce starch, sweet sorghum produce simple sugars, and high biomass energy sorghum for lignocellulosic conversion to ethanol (Rebecca 2009). Recently, global emphasis is focused on the development of these renewable energy sources so as to replace conventional fossil fuels due to depletion of petroleum reserves and increase in demand of petroleum products. Sweet sorghum is most important and excellent energy source for liquid fuels such as ethanol, which is used as biofuel. The improved varieties of this crop can be used as dedicated bioenergy crop, where both the sugars, and the grain, and the bagasse are used for ethanol production (Vermerris 2011), also animal feed or fertilizer after composting with agro-wastes (Rao et al. 2011). Sorghum yields a better energy output/input ratio compared to other feedstocks such as sugar cane, sugar beet, maize and wheat (Almodares and Hadi 2009). In order to meet this, sorghum cultivars are developed with potential to use for ethanol production along with increase in yields. Being an annual and a C4 plant with efficiency in photosynthesis, short duration dry land adaptation with food, fodder usage with high fermentable sugar content and ability to come up well in marginal soils with low input growth makes it an ideal feedstock (Almodares et al. 1994; Reddy et al. 2005; Rao et al. 2009). Thus commercial cultivation of sweet sorghum will play an important role in promoting the development of agricultural production, livestock husbandry (Fazaeli et al. 2006), and livelihood opportunities (Rao et al. 2012). In the United States, sorghum is the second most commonly used grain in ethanol production most ethanol is produced from maize grain starch, which is enzymatically converted to glucose and then fermented. The same process is used for grain sorghum (Renewable Fuels Association 2007). Ethanol produced from sucrose extracted from sugarcane is simpler, as it eliminates the need for enzymatic degradation of starch and requires less processing as is done in Brazil. Sweet sorghum juice could certainly be used in a similar system as sugarcane provided inhibiting substances such as starch, aconitic acid must be addressed (Rao et al. 2012). The presence of reducing sugars in sweet sorghum prevents crystallization and sweet sorghum cultivars have 90% fermentation efficiency (Ratnavathi et al. 2004).

Sweet sorghum has a rapid growth rate and matures in 90-120 days (Prasad et al. 2006) and can produce a ratoon crop in subtropical environments. Ratoon cropping *i.e.*, harvesting of the crop twice or more times from a single planting during the growing season. Ratooning does not involve sowing since it utilizes the regeneration stems, which involve the harvesting of the crop twice or more number of times from a single planting during the growing season (Duncan and Gardner 1983). This facilitates the supply of raw material *i.e* sweet stalks to fulfill the need of biofuel distillers and be commercially viable. Different varieties of sorghum have different ratooning potential. This should be considered in the evaluation of promising varieties especially in areas where ratooning is practiced (Pamplona 1986). Certain sorghum varieties have been reported to ratoon well, and the ratoon crop has in some cases been reported to yield more than the planted one (KARI 1992; 2005). Ratoon capability is dependent upon genotype and environment (Rooney et al. 2007) can be adopted in sweet sorghum especially in tropical conditions will not only extend the raw material supply to the distillery but also reduce the cost of feedstock production as well and also facilitate relay cropping to maximize the returns on land and labour (Rao et al. 2009; 2012).

The present study was conducted to assess ratoonability of different sweet sorghum cultivars and the inter-relation between various candidate traits effecting biomass yield in main and ratoon crops.

Materials and Methods

A sweet sorghum ratoon trial was planted at International Crop Research Institute for semi-Arid Tropics (ICRISAT), Patancheru research farm (latitude: 17.53^{o}N; longitude: 78.27^{o}E; altitude: 545m) with ten varieties and six experimental hybrids along with four standard checks *viz.*, SSG 59-3 (forage line); ICSV 93046 and RSSV 9 and CSH 22 SS in rainy season, 2011. The experiment was conducted in a randomized complete block design (RCBD) in three replications. The planting was done on ridges with a plant stand of about 80,000 plants ha^{-1}. Each cultivar was planted in 4 rows of 4 m length in 12 m^{2} plots with a spacing of 75 x 15 cm in second week of June. A fertilizer dosage of 80N, 40P ha^{-1} were applied with 50% N as basal (DAP) and the balance 50% as urea after 35 days after emergence as top dressing for the main crop and for ratoon crop 50% N and total P (DAP) was applied during intercultivation (about 10 days after harvest of main crop) and remaining 50% N (urea) as top dressing 25 days after first dosage application. Hand weeding was done twice followed by hoeing and inter-cultivation for both the crops. Standard agronomic practices and crop protection measures were followed throughout the crop growth. The main crop (June to October, 2011) was entirely grown as rain-fed crop while minimal irrigation was applied (November to February, 2011) for the ratoon crop. Data was recorded at flowering stage for the traits *viz.*, days to 50% flowering (DF), plant height (PH) (m), number of tillers (NT), number of leaves (NL) at flowering, leaf weight (LW) (g), stalk weight (SW) (g), stripped stalk weight (SSW) (g), and Brix (%). The ratooning efficiency (RE) and tillering capacity (TC) (Duncan and Gardner 1983) was estimated. For each cultivar data was recorded in the middle two rows for the first half 2 m, and the stalks were cut 2 inch above the ground level for the plant sap and at the ground level for the ratoon. Juice extraction was done after removal of panicles along with peduncles and leaves were completely stripped by hand from each plant. The stripped stalks were squeezed using a three-roller cane press mill. Brix (%) was estimated using a hand held pocket refractometer (Atago, Japan) based on the extracted juice samples taken from each plot. Growing degree days (GDD) were calculated from daily maximum (T_{max}) and minimum (T_{min}) air temperature measured at 2m height for 24 hours, mid-night to mid-night, as follows:

$$GDD = [\text{Average } (T_{max}+T_{min})]-T_b$$

Where T_b, base temperature, is 10^0C.

Photothermal units (PTU) (Nuttonson 1948) are the product of degree-days and daylight hours. Daylight is defined as the period between sunrise and sunset. In this experiment we considered bright sunshine hours which are the active period for photosynthetic activity.

General linear model (GLM) was used for analysis of variance and to calculate significant differences among improved varieties (SAS computer program 1988).

Results and Discussion

The analysis of variance (ANOVA) reveals that there is a significant difference among the twenty sweet sorghum genotypes for traits like days to 50% flowering, tillering capacity, plant height, stalk yield, no. of leaves, leaf weight and Brix (%) (Table 1). In the ratoon crop there was no significant difference in days to 50% flowering, probably due to the observational bias in recording flowering data due to profuse tillering. All the genotypes exhibited very high level of uniformity as indicated by low CV% except for no. of tillers in both main and ratoon crops.

A total of three genotypes (Table 2) *viz*., sokoykaba (152.9 t ha^{-1}), D 10-A (143.3 t ha^{-1}) and (DSV 4 x SSV 84)-1-2-1-5-1-1-2 (141.7 t ha^{-1}) produced higher stalk yields than the best performing check CSH 22 SS (140.1 t ha^{-1}) in the main crop. In the ratoon crop, six genotypes were high yielding than the check RSSV 9 (36.6 t ha^{-1}). The highest stalk yield in ratoon was recorded by safed moti (56.3 t ha^{-1}) followed by ICSA 749 x

SPV 1411 (46.0 t ha^{-1}) and ICSSH 28 (45.6 t ha^{-1}). Stalk yields ranged from 5 to 53% in ratoon when compared with the main crop. Similar results in decrease in stalks yield was observed in sweet sorghum variety ICSV 93046 under tropical conditions (Rao et al. 2012). Ratoon efficiency (RE) was highest in safed moti (35) and ICSA 502 x ICSV 93046 (34). The best performers of main crop, sokoykaba and D 10-A showed poor ratooning efficiency while, the genotypes ICSSH 28, ICSSH 58, ICSA 749 x SPV 1411, B-24 and ICSV 93046 showed higher stalk yields in ratoon crop due to their high RC. It is noteworthy that the higher ratoon efficiency was recorded for hybrids. In all the tested genotypes the RE ranged from 5 to 35%. The ratoon crop flowered (61 days) 19 days earlier than the main crop (80 days). There was a sharp reduction in average plant height in ratoon crop (2.3 m) compared to main crop (3.6 m). The plant height was highest in D10-A (4.7 m), sokoykaba (4.5 m) and S2-9 (4.4 m) in the main crop and in the ratoon ICSSH 28, ICSA 749 x SPV 1411, B-24 and ICSV 93046 (2 m) were best. The ratoon crop height ranged from 32 to 82% of the main crop's height. There was an increase of 21 to 341% in the no. of tillers in the genotypes tested in ratoon *vis* a *vis* main crop. However, no. of leaves, leaf weight and stalk weight decreased from main to ratoon crop, by about 25, 58 and 75%, respectively. The decrease of biomass may be attributed to a significant decrease in plant height on ratooning which is vindicated by a significant correlation between plant height and stalk weight (r=0.78**).

The number of PTU accumulated by ratoon crop were more for heading than for the main crop indicating greater degree of photosensitivity in the genotypes tested. The genotypes S2-9, D10-A, sokoykaba and ICSR 93034 required relatively similar PTU in both the crops probably due to their photoinsensitivity (Fig.1). The number of GDD (Table 1) required for the genotypes for heading varied significantly in all the genotypes and wide variation was noted in the GDD in all the genotypes in both main and ratoon crops. In the main crop GDD varied between 787 to 1572 and in the ratoon crop it ranged between 820 to 1053 (Fig. 2) (Rao et al. 2012).

Correlations of biomass yield with its related parameters in main crop and ratoon are shown in the Tables 3 and 4. The degree of correlation differed for different traits under study in both main and ratoon crop, but the direction of correlation was same for biomass related traits like DF, GDD, NT, PH, SW, NL, LW and SSW. Selection for different biomass related traits with positive correlation will aid for biomass improved yield in the breeding program. SW exhibited a significant and positive correlation with traits like GDD (r=0.49*), NT (r=0.58**) and PH (r=0.66**) in the main crop and similarly the relation of SW had significant and positive correlation with GDD (0.47*), NT (r=0.46*) and PH (r=0.78**) in ratoon crop as well. The PH had a significant positive correlation with DF (r=0.85**) and GDD (r=0.86**) in the main crop whereas the correlation among them was non-significant in ratoon crop. SSW showed a significant positive correlation with GDD (r=0.48*), PH (r=0.67**), and LW (r=0.71**). Similar trend was noted in ratoon crop.

Conclusion

Sweet sorghum genotypes differed significantly in their ability to produce biomass in main and ratoon crops. So in a cropping system where ratoon crop is chosen a variety with good ratoonability is very useful. High stalk yielding genotypes do not always necessarily produce good yields in a ratoon crop. Therefore, it is always advisable to test various genotypes for ratoonability. In a ratoon crop biomass influencing traits like plant height, number of leaves, leaf weight and stalk yield decrease as compared to main crop. Though, the number of tillers increase significantly they don't seem to be contributing to biomass, so selection for plant type with biomass in tillers would be effective to develop sweet sorghum varieties suitable for ratooning. To be able to breed sweet sorghum varieties for ratooning one of the important criterions should be to select lines with photoinsensitivity, especially for SAT areas where there is greater variation in the GDD during different crop growing seasons. Sweet sorghum varieties selected with narrow range of GDD in main and ratoon crops expected to possess high ratoonable capacity as observed in ICSSH28, ICSSH 58, ICSA 749 x SPV 1411, B-24 and ICSV 93046. Higher ratoonability could be useful selection criteria for breeding sweet sorghum materials when aiming for continuous supply of feedstock for enhancing period of distillery operation.

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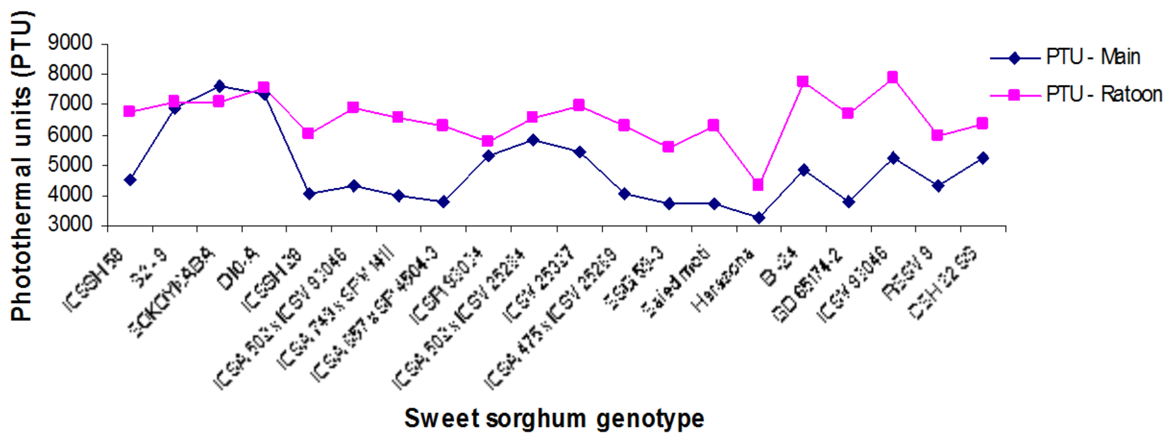

Fig. 1 Photothermal units (PTU) accumulated by main and ratoon sweet sorghum varieties and hybrids

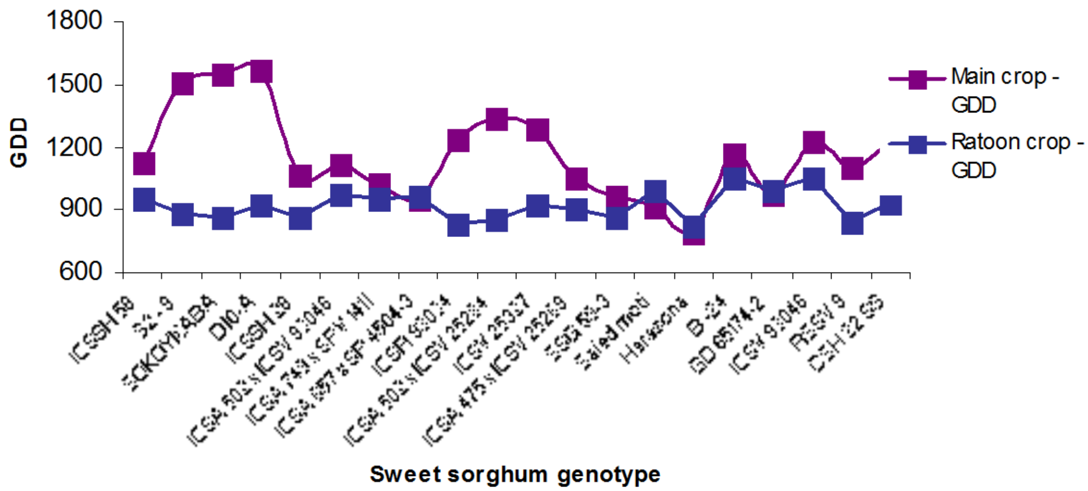

Fig. 2 Growing degree days (GDD) required for main and ratoon sweet sorghum varieties and hybrids

Table 1 ANOVA of sweet sorghum varieties and hybrids for biomass related traits in the trials conducted at ICRISAT-Patancheru 2011

		Mean squares								
		Main crop								
Source of variation	DF	Days to 50% flowering	Growing degree days	No. of tillers	Plant height (m)	Stalk yield (t ha^{-1})	No. of leaves at flowering	leaf yield (t ha^{-1})	stripped stalk yield (t ha^{-1})	Brix (%)
Replication	2	15.24	1980.7	216.22	0.07	68.36	2856.5	6.3	68.97	6.06
Genotype	19	557.21**	135165.8**	1196.86**	0.68**	1723.92**	246412**	85.77**	1167.59**	23.68**
Error	38	6.91	658.2	40.56	0.04	72.14	19984	8.15	49.3	1.38
		Ratoon crop								
Replication	2	18.95	2606	593.8	0.06	10.48	15762.0	1.31	9.54	3.22
Genotype	19	82.28	14407*	405.7**	0.33**	611.74**	126725**	65.07**	336.45**	10.08**
Error	38	48.25	5328	112.6	0.04	9.26	19287	1.84	7.11	1.30

DF degree of freedom, *Significant at $P \leq 0.05$, **Significant at $P \leq 0.01$

Table 2 Mean performance of sweet sorghum genotypes for agronomic parameters during rainy and post-rainy seasons, 2011 at ICRISAT, Patancheru,

Genotype	Days to 50% flowering		Growing degree days		No. of tillers		TC	Plant height (m)		Stalk yield (t ha^{-1})		RE	No. of leaves at flowering		leaf yield (t ha^{-1})		stripped stalk yield (t ha^{-1})		Brix (%)	
	Main	Ratoon	Main	Ratoon	Main	Ratoon		Main	Ratoon	Main	Ratoon		Main	Ratoon	Main	Ratoon	Main	Ratoon	Main	Ratoon
ICSSH 58	79	62	1128	957	18	30	172	3.3	2.4	113.7	45.0	28.4	770	576	30.0	17.0	84.7	28.6	8	10
S2-9	102	64	1504	883	17	31	188	4.4	2.4	109.7	11.6	9.6	1076	531	25.6	4.1	84.8	8.2	13	8
Sokoykaba	105	62	1547	866	16	19	121	4.5	2.0	152.9	7.5	4.7	1521	490	31.9	2.1	120.8	5.2	13	9
D10-A	106	67	1572	920	17	30	180	4.7	1.5	143.3	7.9	5.2	1428	394	29.4	2.4	114.4	6.3	13	7
ICSSH 28	74	55	1059	865	12	29	238	3.6	2.6	104.7	45.6	30.3	557	451	24.7	10.4	80.7	35.5	7	8
ICSA 502 x ICSV 93046	77	63	1112	971	14	26	186	3.2	2.1	64.7	33.4	34.1	244	319	10.6	5.9	53.9	27.6	8	10
ICSA 749 x SPV 1411	72	61	1023	957	14	47	338	3.7	2.6	113.6	46.0	28.8	662	576	27.2	10.5	86.9	36.1	7	8
ICSA 657 x SP 4504-3	67	61	953	962	17	37	218	3.0	2.1	101.3	23.6	18.9	669	322	26.6	8.6	76.2	15.4	4	6
ICSR 93034	85	54	1237	833	18	26	145	3.6	2.0	125.8	24.2	16.2	756	438	32.6	12.4	93.9	11.3	11	10
ICSA 502 x ICSV 25284	94	57	1332	852	15	26	172	3.5	1.6	83.8	9.8	10.5	761	689	26.8	7.2	58.1	4.4	12	9
(DSV 4 x SSV 84)-1-2-1-5-1-1-2	88	62	1285	921	16	38	245	3.7	2.1	141.7	18.0	11.2	740	588	30.3	7.1	112.0	12.2	10	10
ICSA 475 x ICSV 25269	74	57	1054	907	16	41	254	3.6	2.3	143.7	26.3	15.5	762	431	32.7	9.4	111.5	16.8	8	7
Safed moti	64	63	916	988	16	36	223	3.3	2.6	106.3	56.3	34.6	743	795	22.9	17.3	85.1	39.5	5	7
Harasona	56	52	787	820	12	33	276	3.1	2.0	99.2	28.8	22.5	623	430	18.2	10.5	81.0	18.8	6	5
B-24	81	71	1166	1050	18	43	235	3.4	2.3	120.8	42.9	26.2	1027	676	24.8	13.9	96.9	29.2	8	12
GD 65174-2	69	63	976	997	15	57	382	2.8	2.3	82.7	36.4	30.6	839	857	24.4	13.2	58.9	24.2	5	9
SSG 59-3	68	54	963	860	15	64	441	3.2	2.6	82.4	36.6	30.8	1094	1194	22.0	14.3	61.7	22.8	5	6
ICSV 93046	84	72	1224	1053	18	54	309	3.5	2.6	115.7	42.7	27.0	866	714	26.8	15.2	87.9	27.2	9	11

RSSV 9	77	63	1107	844	17	45	271	3.4	2.5	126.4	36.6	22.4	769	612	30.5	14.4	96.8	22.5	8	9
CSH 22 SS	84	61	1216	928	16	47	289	3.9	2.5	140.1	35.4	20.2	778	551	31.0	15.4	109.0	20.8	10	6
Mean	**80**	**61**	1158	922	**16**	**38**	**244**	**3.6**	**2.3**	**113.6**	**30.7**	**21.3**	**834**	**582**	**26.4**	**10.6**	**87.7**	**20.6**	**8**	**8**
lsd (p<0.005)	4.35	11.48	42.48	120.65	10.53	17.54		0.36	0.36	14.04	5.03		233.7	229.60	4.72	2.24	11.60	4.40	1.94	1.88
CV%	3.3	11.3	2.2	7.9	34.0	28		6.1	9.8	7.5	9.9		16.9	23.9	10.8	12.9	8.0	12.9	13.9	13.8

*Ratoon efficiency (RE) = stalk yield in ratoon/stalk yield in main crop x 100; Tillering capacity (TC) = tiller number in ratoon crop/ tiller number in main crop x 100

Table 3 Correlation between different biomass related traits in sweet sorghum main crop during rainy season, 2011 at ICRISAT, Patancheru

	DF	GDD	NT	PH	SW	NL	LW	SSW	Bx
DF	1.00	*	*	*	*	*	*	*	*
GDD	0.99**	1.00	*	*	*	*	*	*	*
NT	0.28	0.28	1.00		*	*	*	*	*
PH	0.85**	0.86**	0.25	1.00	*	*	*	*	*
SW	0.48*	0.49*	0.58**	0.66**	1.00	*	*	*	*
NL	0.63**	0.64**	0.57**	0.66**	0.52*	1.00	*	*	*
LW	0.44*	0.43	0.79**	0.45*	0.81**	0.46*	1.00	*	*
SSW	0.46*	0.48*	0.49*	0.67**	0.98**	0.51*	0.71**	1.00	*
Bx	0.94**	0.94**	0.21	0.84**	0.50*	0.51*	0.42	0.48*	1.00

DF: days to 50% flowering, GDD: Growing degree days, NT: No. of tillers, PH: Plant height, SW: Stalk weight, NL: No. of leaves, LW: Leaf weight, SSW: Stripped stalk weight, Bx: Brix%

*Significant at $P \leq 0.05$, **Significant at $P \leq 0.01$

Table 4 Correlation between different biomass related traits in sweet sorghum ratoon crop during postrainy season 2011 at ICRISAT, Patancheru

	DF	GDD	NT	PH	SW	NL	LW	SSW	Bx
DF	1.00	*	*	*	*	*	*	*	*
GDD	0.78**	1.00	*	*	*	*	*	*	*
NT	0.16	0.36	1.00	*	*	*	*	*	*

PH	0.09	0.29	0.57**	1.00	*	*	*	*	*
SW	0.11	0.47*	0.46*	0.78**	1.00	*	*	*	*
NL	0.03	0.14	0.70**	0.42	0.35	1.00	*	*	*
LW	0.02	0.32	0.57**	0.66**	0.83**	0.51*	1.00	*	*
SSW	0.13	0.49*	0.39	0.75**	0.97**	0.26	0.68**	1.00	*
Bx	0.55*	0.43	-0.11	0.00	0.09	0.03	0.07	0.09	1.00

DF: days to 50% flowering, GDD: Growing degree days, NT: No. of tillers, PH: Plant height, SW: Stalk weight, NL: No. of leaves, LW: Leaf weight, SSW: Stripped stalk weight, Bx: Brix%

*Significant at $P \leq 0.05$, **Significant at $P \leq 0.01$