ARTICLE

Flooding tolerance of sugarcane genotypes under recurring floods in plant and ratoon crops

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Crop Breeding and Applied Biotechnology
24(2): e46712422, 2024
Brazilian Society of Plant Breeding.
Printed in Brazil
http://dx.doi.org/10.1590/1984-70332024v24n2a15

Abstract: *The goal of this research was to evaluate the flooding tolerance of sugarcane genotypes under recurring floods of both plant and ratoon canes. Control and recurring flood conditions were compared using 10 sugarcane genotypes. As a result of the flooding, cane height increased and tillering decreased. Flooding reduced cane yield and commercial cane sugar (CCS) yield, as well as the percentage of polarization (POL), purity, and CCS in sugarcane juice. Sugarcane flood tolerance varied by genotype, with KPS01-4-29 and SP94-2-483 having the highest flooding tolerance index and KK07-037, K95-84, and KK07-599 having the highest yield under flooded conditions. Furthermore, under flooded conditions, a relationship between yield traits, cane height, and cane number was observed in sugarcane (r = 0.45* to 0.92**). As a result of our research, flood-tolerant sugarcane genotypes could be selected. Sugarcane genotype selection for flooding tolerance could include cane height and cane number as indirect traits.*

Keywords: *Flooding stress, growth traits, juice quality, tolerance index*

INTRODUCTION

Flooding is a natural problem that affects crop production in agricultural areas all over the world. Flooding is also a major issue for sugarcane cultivation in tropical and subtropical regions prone to climate change and fluctuating rainfall (Sanghera and Jamwal 2019). Sugarcane is an important economic crop in many countries worldwide. Particularly in Thailand, it is used as the primary raw material in the sugar industry, which is not only used for domestic consumption but also as an important export product (Pipitpukdee et al. 2020). As a result, farmers plant more sugarcane in lowland areas where rice has previously been grown. Sugarcane grown in lowland and lowland areas are at high risk of flooding as the rainy season approaches, affecting sugarcane growth and yield (Jaiphong et al. 2016, Jaiphong et al. 2017).

Flooding reduces plant growth and productivity. It can result in lower sugarcane growth and yield, as well as lower sugar yield, in both plant and ratoon crops (Gomathi et al. 2015). The extent of flooding damage to sugarcane depends on the environment, the sugarcane growth stage, the height of the water level, and the time it flooded, as well as the sugarcane genotypes' level of flooding tolerance (Glaz and Lingle 2012, Fazle et al. 2015, Jain et al. 2017).

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Received: 06 September 2023
Accepted: 11 January 2024
Published: 06 February 2024

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Flooding causes water to fill gaps in the soil, resulting in a lack of oxygen. Sugarcane roots are then oxygen-deprived, resulting in decreased root respiration. The ability of roots to absorb water and nutrients is diminished due to a lack of energy. Until either the roots are damaged or die (Gomathi et al. 2015, Maitreemitr et al. 2023). Other physiological abnormalities occur as a result, affecting sugarcane growth and yield.

Compared to other stages of development, sugarcane is the most susceptible to flooding during the early stages. Furthermore, flooding during the tillering and vegetative stages of the growing season can affect the quantity and quality of sugarcane yield at the end of the season (Sanghera and Jamwal 2019). Sugarcane cultivation in Thailand's lowland and irrigated areas typically begins before the rainy season and continues until the rainy season begins. As a result, as the rainy season approaches, sugarcane plantations may be flooded due to strong monsoons causing heavy rainfall. Lowland sugarcane cultivation is thus vulnerable to flooding during the early stages of annual growth (Jaiphong et al. 2016, Jaiphong et al. 2017). This is because ratoon is usually left over from the previous year's sugarcane cultivation. As a result, the flooding problem in ratoon cane is very likely to recur.

Flood-tolerant sugarcane genotypes can effectively address the issue of the effect of flooding on sugarcane production. Research into the effects of recurring flooding on sugarcane genotypes and assessing sugarcane flood tolerance is therefore critical. Furthermore, sugarcane breeding for flooding tolerance necessitates knowledge of the indirect traits that can be used for breeding selection. The relationship between flooding tolerance and sugarcane growth traits can help identify traits that can be used to effectively select sugarcane genotypes for flooding tolerance. Previous research on sugarcane flooding tolerance has shown a significant and positive relationship between the tolerance index for whole clump dry weight, stalk dry weight, leaf dry weight, leaf sheath dry weight, and root dry weight (Jain et al. 2017). Similarly, the tolerance index for total chlorophyll correlated positively with the levels of chlorophyll a, b, and carotenoids (Jain et al. 2017). Furthermore, a significant positive correlation was found between flooding tolerance and the stalk growth rate during flooding (Singh et al. 2019). As a result, the goal of this study was to investigate the effects of recurring floods on growth and yield in plant and ratoon canes, to assess sugarcane genotype tolerance to flooding, and to evaluate the relationship between sugarcane growth traits and yield under normal and flooded conditions.

MATERIAL AND METHODS

Experimental design and treatments

This experiment was carried out at Kasetsart University Kamphaeng Saen Campus, Nakhon Pathom Province, Thailand, in the Department of Agronomy. The experimental site was located at lat 14° 01' 21.97'' N, long 99° 58' 42.04'' E, alt 7.25 m asl. The soil had the following properties: clay; pH 6.31; electrical conductivity, 1.00 dS/m; organic matter, 0.90%; total nitrogen, 0.06%; phosphorus, 89.69 mg kg^{-1}; potassium, 120.42 mg kg^{-1}; magnesium, 460.98 mg kg^{-1}; and calcium, 1887.14 mg kg^{-1}. Plant cane was evaluated from April 2019 to March 2020, and ratoon cane was evaluated from April 2020 to March 2021. The split plot was used in a randomized complete block design (RCBD) for four replicates. The main plot was the state of watering at two different levels: control and flooding. The subplot contained 10 sugarcane genotypes. Genotypes KK07-037, KK07-250, and KK07-599 were introduced by the Khon Kean Field Crops Research Center, Department of Agriculture, Thailand. Suphan Buri Field Crops Research Center, Department of Agriculture, Thailand, provided UT15 (U Thong 15) and UT17 (U Thong 17). KPS01-4-29 was obtained from the Kamphang Saen Sugarcane Genotypes of the Cane and Sugar Research and Development Center in Thailand. K95-84, KK3, LK92-11, and SP94-2-483 (Suphanburi 80) were commercial cultivars in Thailand; although they are recommended for planting in the central and northeast regions of Thailand, where flooding is possible, there are no reports of their flooding tolerance.

In April 2019, sugarcane cuttings were planted in cylindrical cement pots 80 cm in diameter. The pot was filled to a height of 45 cm with soil. If the soil collapsed, more soil was added to reach 45 cm in height. Before transplanting, 200 g of manure per clump and 15 g of 15-15-15 (N-P_2O_5-K_2O) fertilizer per clump were added twice a year, at 1 and 4 months. The sugarcane was watered on a regular basis after planting. When the sugarcane was 5 months old, the flooding simulation was performed by adding water 45 cm above the soil surface to compare it to the control condition. Water was added to compensate for the evaporated portion, keeping the flood level constant throughout the flood simulation. The sugarcane was flooded for 30 days before being drained to assess recovery. Subsequently, the sugarcane was given adequate water until harvesting in March 2020, 12 months after planting. Ratoon cane was then grown in the second year for the April 2020 ratoon cane study. After 5 months, the ratoon cane again underwent flooding simulation. Water was added 45 cm above the soil. Flooding occurred for 30 days, and then the water was released from the cement pots to allow sugarcane to recover. Sufficient watering was performed during sugarcane recovery until harvesting in March 2021, when the ratoon cane had grown for one year.

Measurement of growth and yield traits

Plant and ratoon cane growth data were collected 0, 15, and 30 days after flooding (DAF), as well as at 30, 60, 90, and 120 days after recovery (DAR), including data collection at harvest. Data were collected from 5 canes per clump at random. To determine the diameter of the cane, a vernier caliper was used to measure the cane's center. The cane length was measured from the ground level to the first node of the visible dewlap. In addition, the number of canes per clump was recorded. After 12 months, both the plant and ratoon cane were harvested. Cane yield (kg clump^{-1}) and cane weight (kg cane^{-1}) were measured. At the Suphanburi Field Crops Research Center's laboratory, 5 canes were randomly sampled per clump to be analyzed for sugarcane juice quality, specifically Brix, polarization (POL), purity, fiber, and commercial cane sugar (CCS). The CCS yield (t ha^{-1}) was calculated as follows (Mahadevaiah et al. 2021):

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

Statistical analysis

A combined analysis of variance (ANOVA) was performed for each variable across years (plant and ratoon canes) and water stress conditions. The combined ANOVA for plant and ratoon canes was then examined separately for the control and flooded conditions. Duncan's Multiple Range Test (DMRT) was used to compare the means. The flood tolerance index (FTI) was calculated for each genotype using a formula modified from Jain et al. (2017) and Maitreemitr et al. (2023): FTI = (measured plant parameter under flooded conditions/measured plant parameter under control conditions). The FTI formula was applied to the cane yield and CCS yield. To compare the control and flooded conditions in the plant and ratoon canes, the mean and standard error for each genotype were computed. Furthermore, by analyzing the correlation across plant and ratoon cane (n = 20), the simple correlation between growth, yield, and juice quality was calculated.

RESULTS AND DISCUSSION

Effects of flooding on the growth of plant canes and ratoon canes

A combined ANOVA for two years of data (Table 1) revealed a significant difference in growth traits at 30 DAF and harvest date between plant and ratoon crop years. A flooding effect and genotype variation were also observed for growth traits. Sugarcane growth was monitored continuously from flooding to harvest. When flooded, the sugarcane adapted by growing taller (Figure 1a). The harvesting period was also affected by increasing cane height at that time. Flooded sugarcane was taller than unflooded sugarcane. However, flooding had no discernible effect on cane diameter in either the plant or ratoon cane (Figure 1b), except when the plant cane was harvested. Under flooded conditions, the plant cane had a larger cane diameter than under control conditions. Tillering stopped or was reduced when sugarcane was flooded (Figure 1c). However, minor correction normalcy was restored, and sugarcane tillering resumed until the cane number at harvest was no different from the sugarcane in the control conditions.

Flooding affects the growth of plant and ratoon canes. Previous research found that flooding inhibited sugarcane tillering, as well as cane and leaf growth (Gomathi et al. 2015, Jaiphong et al. 2017). Tavares et al. (2018) found that sugarcane flooded for 12 days at 210 days of age, increasing cane growth, leaf number, leaf area, and leaf area index. In our study, the ratoon cane grew faster than the plant cane, likely because the ratoon cane had already adapted to the growing conditions and thus grew faster. The effects of flooded conditions were more pronounced in plant cane than in ratoon cane, possibly because ratoon cane had already adapted to being flooded in the first year. Additionally, a comparison of growth traits for plant and ratoon cane genotypes revealed that cane height, cane diameter, and cane number differed significantly between genotypes in both control and flooded conditions (data not shown).

Table 1. Statistics F from the combined analysis of variance for growth, yield and juice quality of sugarcane

Source of variation	30 DAF			Harvest date				
	Cane height	Cane diameter	Cane number	Cane height	Cane diameter	Cane number		
Year (Y)	205.40 **	23.80 **	516.97 **	168.16 **	0.89	202.18 **		
Reps. within Year								
Water stress condition (W)	81.99 **	0.49	43.73 **	34.11 **	11.60 *	0.17		
Y × W	0.96	0.87	18.56 *	5.51	24.42 **	32.94 **		
Error A								
Genotype (G)	15.85 **	8.96 **	5.99 **	20.47 **	12.70 **	8.32 **		
G × Y	6.00 **	1.36	1.64	1.80	4.36 **	1.00		
G × W	1.35	0.52	0.73	1.48	2.25 *	2.16 *		
Y × W × G	0.26	0.69	1.29	1.04	2.41 *	0.57		
Error B								
	Harvest date							
	Cane weight	Cane yield	CCS yield	Brix	POL	Purity	Fiber	CCS
Year (Y)	38.96 **	827.70 **	620.72 **	433.62 **	392.86 **	84.40 **	0.80	299.44 **
Reps. within Year								
Water stress condition (W)	0.26	25.09 **	41.47 **	1.25	41.02 **	47.43 **	3.64	42.94 **
Y × W	0.14	1.36	6.60 *	7.78 *	0.92	1.07	9.06 *	0.00
Error A								
Genotype (G)	7.47 **	9.11 **	5.88 **	5.67 **	9.06 **	11.32 **	3.73 **	11.16 **
G × Y	1.71	3.64 **	3.85 **	10.10 **	4.53 **	3.73 **	4.42 **	2.57 *
G × W	1.55	0.76	0.56	0.96	1.06	1.69	1.73	1.20
Y × W × G	1.30	1.35	2.45 *	2.48 *	3.82 **	3.31 **	2.68 **	3.77 **
Error B								

* significant for P < 0.05; ** significant for P < 0.01. DAF = days after flooding

Effects of flooding on the yield and juice quality of plant cane and ratoon cane

A two-year combined ANOVA revealed differences in yield traits and juice quality between plant and ratoon cane and an effect of flooded conditions and genotype (Table 1). Plant and ratoon canes had statistically significant ($P < 0.01$) differences in cane weight, cane yield, CCS yield, Brix, POL, purity, and CCS, excluding fiber (Table 2). Ratoon cane produced more and had a higher juice quality than plant cane. Ratoon cane yield and juice quality were higher in this study because ratoon cane growth was greater than plant cane growth. There was also a statistically significant difference ($P < 0.01$) between water stress conditions for cane yield, CCS yield, POL, purity, and CCS, but not for cane weight, Brix, or fiber. Sugarcane yielded 9.25 kg clump^{-1} under flooded conditions, which was less than the cane yield under control conditions of 10.99 kg clump^{-1}. Flooded sugarcane had a CCS yield of 1.17 kg clump^{-1}, which was less than sugarcane in the control, with a CCS yield of 1.50 kg clump^{-1}. Sugarcane grown under flooded conditions had a POL of 68.56% lower than sugarcane grown under control conditions, which had a POL of 71.89%. Flooded sugarcane had a lower purity (81.04%) and CCS (11.82) than sugarcane in the control (84.60% and 12.83, respectively). Flooding can affect sugarcane growth and yield, as well as yield quality (Gomathi et al. 2015, Sanghera and Jamwal 2019). Flooded conditions affected both sugarcane yield and juice quality, lowering cane yield and CCS yield, as well as POL, purity, and CCS.

Flooding tolerance of sugarcane genotypes

The tolerance index of sugarcane genotypes was used to assess flooding tolerance. The ANOVA for the tolerance index revealed the difference between plant cane and ratoon cane, as well as genotype variation (data not shown). The sugarcane FTI differed between genotypes. In plant cane, the FTI for cane yield ranged from 0.63 to 0.95 (Figure 2a), with KPS01-4-29, LK92-11, and KK07-599 having the highest FTI for cane yield. The FTI of cane yield ranged between 0.83 and 1.02 in ratoon cane, which was higher than in plant cane. KK3, SP94-2-483, and KK07-599 had the highest FTI for cane yield. Surprisingly, the KK3 genotype had the highest FTI for cane yield in ratoon cane, despite having the lowest FTI for cane yield in plant cane, indicating that the KK3 genotype had the best adaptation to repeated flooded conditions after the first year of flooding. Furthermore, KK07-599 had a high FTI for cane yield in both plant and ratoon cane. The FTI for CCS yield ranged from 0.54 to 1.06 in plant canes (Figure 2b), with KPS01-4-29, KK07-599, and K95-84 having the highest values. Most sugarcane genotypes had a higher FTI for CCS yield in ratoon cane than in plant cane. The FTI for CCS yield in ratoon cane ranged from 0.69 to 0.93, with SP94-2-483, KK3, and UT15 having the highest.

The tolerance index measures the ability of sugarcane genotypes to withstand flooded conditions, with genotypes with a high FTI describing sugarcane traits that do not change or decrease significantly when exposed to flooded conditions compared to non-flooded conditions (Jain et al. 2017, Maitreemitr et al. 2023). Previous research has used the tolerance index of biomass to indicate sugarcane tolerance to flooded conditions, and a relationship between the tolerance index of biomass and cane dry weight, leaf dry weight, root dry weight, and cane growth rate has been found in sugarcane (Jain et al. 2017, Singh et al. 2019). According to our findings, the FTI of sugarcane differed between genotypes in both plant and ratoon cane. Most sugarcane genotypes had a higher FTI in ratoon cane than in plant cane, indicating that they adapted after being flooded in the first year. Furthermore, our research discovered that KPS01-4-29 had the highest FTI for cane yield and CCS yield in plant cane, and SP94-2-483 had the highest FTI for cane yield and CCS yield in ratoon cane, indicating that they were the sugarcane genotypes with the best flooding tolerance.

Sugarcane yield and juice quality from combined plant and ratoon cane analysis revealed significant differences between sugarcane genotypes ($P < 0.01$) in all traits studied in both control and flooded conditions (Table 3), except for fiber values, which showed no difference between genotypes under flooding. Under control conditions, SP94-2-483 and KK07-599 had the highest cane weights, at 1.28 and 1.26 kg cane^{-1}, respectively. Under flooded conditions, KK07-599, KK3, and K95-84 had the highest cane weights, at 1.49, 1.32, and 1.31 kg cane^{-1}, respectively. Under control conditions, KK07-037 and UT15 had the highest cane yields, at 12.43 and 11.83 kg clump^{-1}, respectively. Under flooded conditions, KK07-037, KK3, and UT15 had the highest cane yields of 10.07, 9.97, and 9.73 kg clump^{-1}, respectively. Furthermore, K95-84 and KPS01-4-29 had the highest CCS yields in the control condition, at 1.65 and 1.64 kg clump^{-1}, respectively. Under flooded conditions, the CCS yields of KK3, UT15, and K95-84 were 1.32, 1.30, and 1.29 kg clump^{-1}, respectively. In terms of juice quality traits, K95-84 had the highest quality under both control and flooded conditions, with the highest Brix values of 21.27% and 21.35%, the highest CCS of 14.09% and 13.90%, the highest POL values of

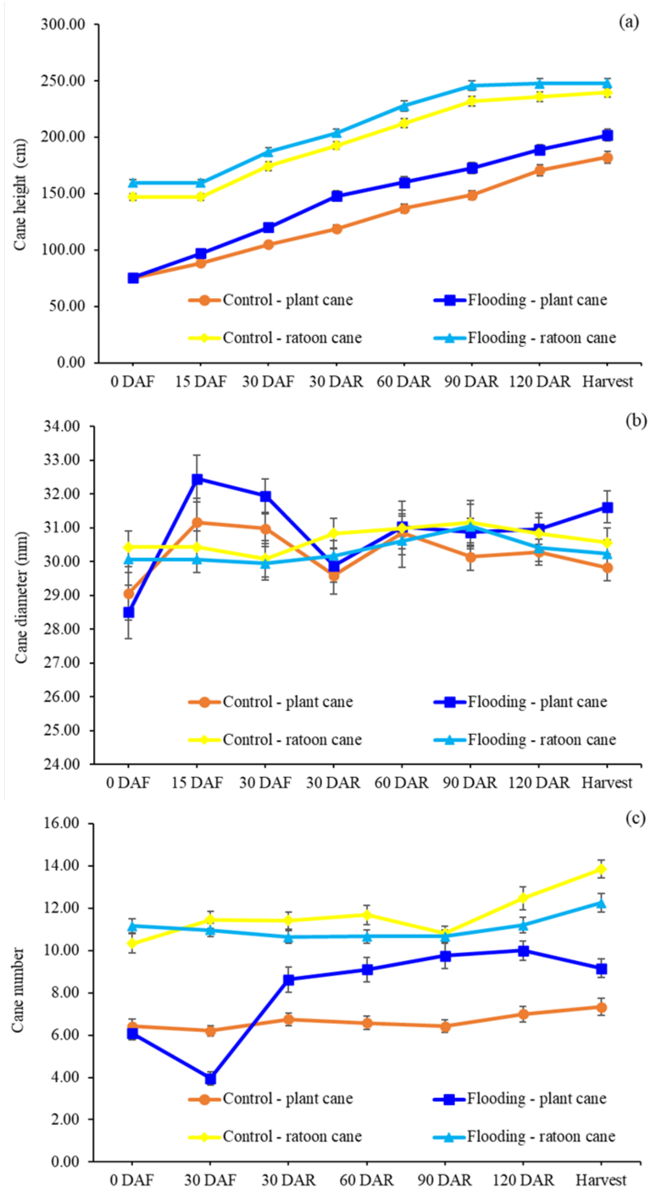

Figure 1. Cane height (a), cane diameter (b), and cane number (c) under control and flooding conditions in plant cane and ratoon cane. Error bars represent ± SE. DAF = days after flooding, DAR = days after recovering.

Table 2. Comparisons of plant cane and ratoon cane under control and flooding conditions in cane yield and juice quality of sugarcane

	Cane weight (kg cane^{-1})		Cane yield (kg clump^{-1})		CCS yield (kg clump^{-1})		Brix (%)		POL (%)		Purity (%)		Fiber (%)	CCS (%)	
Year															
Plant cane	0.91	B	4.85	B	0.52	B	18.62	B	61.92	B	80.17	B	12.39	10.67	B
Ratoon cane	1.23	A	15.40	A	2.16	A	21.90	A	78.53	A	85.47	A	12.22	13.97	A
F-test	**		**		**		**		**		**			**	
Water stress condition															
Control	1.08		10.99	a	1.50	a	20.32		71.89	a	84.60	a	12.19	12.83	a
Flooding	1.05		9.25	b	1.17	b	20.20		68.56	b	81.04	b	12.42	11.82	b
F-test			**		**				**		**			**	
CV (%)	29.93		21.67		23.93		3.30		4.68		3.95		6.13	7.85	

Mean with different uppercase letters denote significant differences between years; different lowercase letters denote significant differences between water stress conditions.
* significant for P<0.05; ** significant for P<0.01.

77.99% and 77.19% (data not shown), and the highest purity of 87.36% and 86.23%, respectively.

In general, conventional plant breeding for water stress tolerance involves selecting tolerant genotypes based on biomass or yield traits under water stress conditions (Krishna et al. 2018, Arunyanark et al. 2022a, Chutteang et al. 2023). The current study selected sugarcane-tolerant genotypes for flooded conditions by evaluating their ability to produce average yields for both plant and ratoon cane under flooded conditions. Sugarcane genotypes differed in their tolerance to flooding, with KK07-037, K95-84, and KK07-599 having the highest cane yield, CCS yield, and cane weight under flooded conditions. Furthermore, K95-84 had the best juice quality under both control and flooded conditions.

Relationship between growth traits, sugarcane yield, and juice quality

Sugarcane yield traits and juice quality were highly correlated under both control and flooded conditions (Supplementary table). There was no correlation between fiber values and yield traits or other juice qualities. The correlation between yield traits and juice quality was lower under flooded conditions (r = 0.44* to 0.99**) than under control conditions (r = 0.61** to 0.99**), indicating that flooded conditions affected the relationship between yield traits and juice quality.

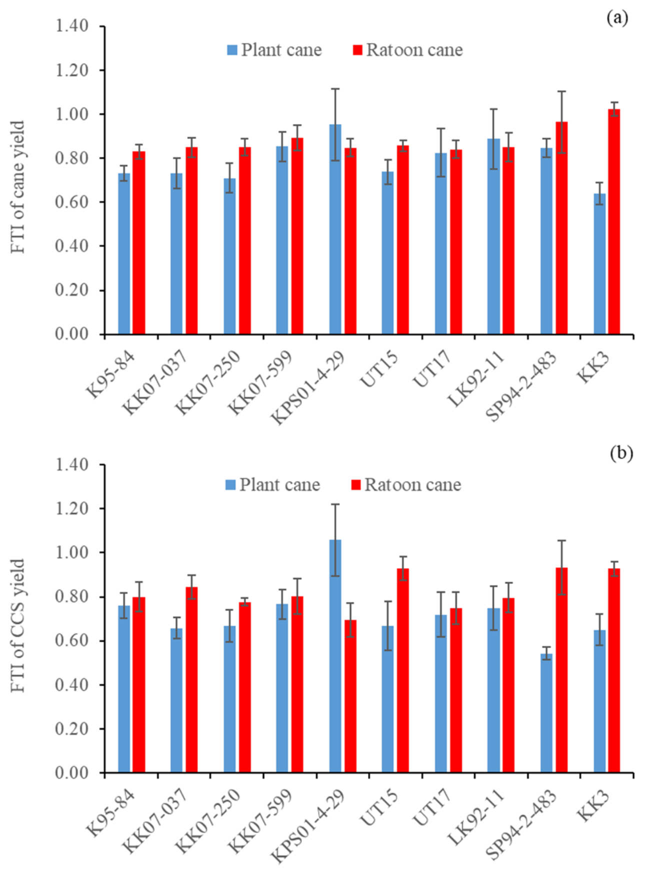

Figure 2. Flooding tolerant index (FTI) of cane yield (a) and CCS yield (b) of sugarcane genotypes in plant cane and ratoon cane. Error bars represent ± SE.

A separate correlation analysis of yield traits and sugarcane growth was performed for each water stress condition. Under the control conditions, cane weight, cane yield, CCS yield, and CCS were all positively correlated with cane height at 30 DAF and harvest date, with r = 0.57** to 0.90** (Table 4). Furthermore, at 30 DAF and harvest date, cane yield, CCS yield, and CCS were positively correlated with cane number (r = 0.74** to 0.88**). Except for r = 0.62** between cane weight and cane number at the harvest date, no correlation was found between yield traits and cane diameter. Under flooded conditions, cane weight, cane yield, CCS yield, and CCS were all positively correlated with cane height, with r ranging from 0.47* to 0.90** at 30 DAF and harvest. Furthermore, cane yield, CCS yield, and CCS were positively correlated with cane number at 30 DAF and harvest (r = 0.45* to 0.92**), but no correlation was found between yield and cane diameter. When both water stress conditions were combined, cane weight, cane yield, CCS yield, and CCS were all positively correlated with cane height and cane number, with r = 0.34** to 0.89**. There was no correlation between yield traits and cane diameter, except for r = 0.46** between cane weight and cane number at harvest.

Genotype selection is an important and difficult process in plant breeding. Plant yield traits are quantitative traits governed by multiple pairs of genes. Furthermore, environmental effects and genotype-by-environment interactions are frequently involved, posing a significant barrier to plant breeding (Oliveira et al. 2020). As a result, the relationship

Table 3. Combined analysis of two years for comparison of cane yield and juice quality of sugarcane genotypes between control and flooding conditions

Genotype	Cane weight ($kg\ cane^{-1}$)				Cane yield ($kg\ clump^{-1}$)				CCS yield ($kg\ clump^{-1}$)				Brix (%)				CCS (%)			
	Control		Flooding		Control		Flooding		Control		Flooding		Control		Flooding		Control		Flooding	
K95-84	1.08	abc	1.31	ab	11.06	bc	8.87	b	1.65	a	1.29	ab	21.27	a	21.35	a	14.09	a	13.90	a
KK07-037	0.99	c	0.93	cd	12.43	a	10.07	a	1.58	a	1.25	abc	19.34	c	20.39	abc	12.35	bcd	11.70	cd
KK07-250	1.08	abc	1.10	bc	11.33	abc	9.03	ab	1.52	a	1.13	b-e	19.60	bc	19.23	d	12.63	bcd	11.70	cd
KK07-599	1.26	ab	1.49	a	10.57	c	9.26	ab	1.51	a	1.19	a-d	20.31	abc	19.98	cd	13.27	abc	11.88	bc
KPS01-4-29	1.07	abc	0.95	cd	11.24	abc	9.57	ab	1.64	a	1.19	a-d	19.47	bc	19.39	cd	12.58	bcd	11.64	cd
UT15	1.06	bc	0.86	cd	11.83	ab	9.73	ab	1.52	a	1.30	ab	20.52	ab	20.19	bcd	12.03	d	11.89	bc
UT17	1.13	abc	0.96	cd	11.42	abc	9.48	ab	1.46	ab	1.07	cde	20.47	ab	20.31	abc	12.15	cd	10.63	de
LK92-11	0.69	d	0.64	d	8.62	d	7.18	c	1.28	b	0.99	e	21.01	a	20.35	abc	13.91	a	12.44	bc
SP94-2-483	1.28	a	0.99	bc	10.45	c	9.38	ab	1.27	b	1.01	de	20.33	abc	19.61	cd	11.75	d	9.66	e
KK3	1.20	abc	1.32	ab	10.96	bc	9.97	ab	1.55	a	1.32	a	20.86	a	21.20	ab	13.49	ab	12.80	b
F-test	**		**		**		**		**		**		**		**		**		**	
CV (%)	20.05		32.35		11.05		12.20		13.58		16.44		5.17		5.28		9.10		9.29	
Mean	1.08		1.05		10.99		9.25		1.50		1.17		20.32		20.20		12.83		11.82	

Mean with different lowercase letters denote significant differences among genotypes. ns, not significant at P<0.05; * significant for P<0.05; ** significant for P<0.01.

Table 4. Correlation coefficients (r) between growth traits and cane yield of sugarcane across plant cane and ratoon cane under control and flooding conditions

	Cane height				Cane diameter				Cane number			
	30 DAF		Harvest date		30 DAF		Harvest date		30 DAF		Harvest date	
	Control (n = 20)											
Cane weight	0.76	**	0.84	**	0.20		0.62	**	0.34		0.27	
Cane yield	0.90	**	0.82	**	-0.19		0.21		0.88	**	0.86	**
CCS yield	0.86	**	0.79	**	-0.15		0.23		0.87	**	0.85	**
CCS	0.63	**	0.57	**	-0.14		0.12		0.74	**	0.74	**
	Flooding (n = 20)											
Cane weight	0.48		0.47	*	0.15		0.39		0.33		-0.10	
Cane yield	0.90	**	0.75	**	-0.40		-0.28		0.92	**	0.63	**
CCS yield	0.87	**	0.70	**	-0.36		-0.27		0.92	**	0.62	**
CCS	0.55	*	0.34		-0.07		-0.20		0.80	**	0.45	*
	Pooled (n = 40)											
Cane weight	0.56	**	0.59	**	0.16		0.46	**	0.34	*	0.08	
Cane yield	0.84	**	0.73	**	-0.31		-0.07		0.89	**	0.75	**
CCS yield	0.80	**	0.68	**	-0.26		-0.06		0.88	**	0.75	**
CCS	0.52	**	0.39	*	-0.12		-0.10		0.78	**	0.58	**

* significant at P<0.05; ** significant for P<0.01. DAF = days after flooding

between the traits of interest should be investigated so that they can be used as yield selection criteria. Some physiological and morphological traits have been identified as potentially useful in plant breeding for yield (Arunyanark et al. 2022b, Arunyanark et al. 2023a, Arunyanark et al. 2023b). The relationship between plant traits of interest and tolerance to water stress conditions has been investigated as a selection criterion, allowing these traits to be used as an effective indirect tool for plant breeding for water stress tolerance (Arunyanark et al. 2022a, Chutteang et al. 2023). Previous research has examined sugarcane traits associated with flood tolerance. Cane weight and chlorophyll FTI, as well as cane weight and potassium content of leaves in flooded sugarcane, have been found to be related (Singh et al. 2019). A positive relationship was also found between root traits, total dry weight, and FTI. Sugarcane flooding tolerance is also related to adventitious root traits (Maitreemitr et al. 2023). Sugarcane yield traits are positively related to cane height and cane number, according to our findings. Thus, these growth traits can be used to assess sugarcane yield traits. Under flooded conditions, a correlation was discovered between cane yield traits and cane height and cane number. As a result, cane height and cane number could be used as indirect traits to select sugarcane genotypes with flooding tolerance.

CONCLUSIONS

Flooded conditions affected both plant cane and ratoon cane growth, yield, and juice quality. Sugarcane adapted to flooding by increasing cane height and interrupting or reducing tillering, but there was no effect on cane diameter. When the sugarcane was harvested after recovering from flooding, the previously flooded sugarcane had a higher cane height and cane diameter than the never-flooded sugarcane. Furthermore, flooded sugarcane produced cane numbers comparable to non-flooded sugarcane. Flooding also reduced sugarcane cane yield and CCS yield, as well as sugarcane juice POL, purity, and CCS. Sugarcane genotypes differed in terms of growth traits, yield, and juice quality under both non-flooded and flooded conditions. Sugarcane genotypes differed in their tolerance to flooding, with KPS01-4-29 having the highest FTI in plant cane and SP94-2-483 having the highest FTI in ratoon cane. Furthermore, under flooded conditions, KK07-037, K95-84, and KK07-599 had the highest cane yield, CCS yield, and cane weight. As a result, these sugarcane genotypes were identified as being highly tolerant to flooding stress. Furthermore, under flooded conditions, a relationship was discovered between sugarcane yield traits and cane height and cane number. As a result, cane height and cane number could be used to select sugarcane genotypes for flooding tolerance.

ACKNOWLEDGEMENTS

The Center for Academic Excellence in Sugarcane at Kasetsart University's Kamphaeng Saen Campus provided financial support for this research. The authors gratefully acknowledge the Department of Agronomy, Faculty of Agriculture, Kasetsart University, Kamphaeng Saen, for their assistance.

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