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RESCHEDULING OF CONVENTIONAL CROP HARVEST PROGRAM BASED ON THE PERFORMANCE OF NATIONAL ELITE AND EXOTIC SUGARCANE CULTIVARS IN PAKISTAN

MUHAMMAD MUNIR[1]*, FARZANA AHMAD[2], MUSA K. BALOCH[3], AHMAD K. BALOCH[1], SHAHID AFGHAN[4], MALIK M. HASHIM[1] AND SALMA SHAHEEN[5]

[1]*Institute of Food Science & Nutrition, Gomal University, Dera Ismail Khan, KPK, Pakistan*
[2]*Department of Chemistry, Konkuk University, Seoul 05029, Korea*
[3]*Qurtaba University of Science & Information Technology, Dera Ismail Khan, KPK, Pakistan*
[4]*Sugarcane Research & Dev. Board (Punjab) Pakistan*
[5]*Department of Soil Science, Gomal University Dera Ismail Khan*
**Corresponding author's email: mmunir92@gmail.com*

Abstract

Despite occurring at suitable latitude for sugarcane cultivation a significant improvement in sucrose recovery and sugar yield has yet to be achieved in Pakistan. Owing to shortages of sugar and the high cost of production, the country is currently facing a severe sugar crisis. In this study sugarcane genotype and the conventional milling schedule appear largely responsible. Elite as well as exotic cultivars available in the country were cultivated in September 2016 and February 2017 under CRB Design at Chashma Right Bank Canal command area of Dera Ismail Khan KPK, Pakistan. Initially September and February plant crops were evaluated for varietal performance. Juice quality indices that are commonly appraised were measured every two weeks between October to March. Parameters with commercial implications such as varietal productivity, efficient production period (EPP) and cane/sugar yield were also determined. Based on their superior performance, fourteen cultivars were further studied during two subsequent ratoons in 2018-2020. The trend in sucrose recovery was examined from October to March encompassing the period of conventional harvest schedule. The average sucrose recovery was $\geq$ 9.5% for plant to ratooned crops of all the cultivars covering the period from mid October to mid February. Cultivars HSF-240, CSSG-676, MCP-421, CP-87-1628, CP-77-400, HoSG-2875, CP-72-2086, HoSG-1257 and CP-85-1491 exhibited high EPPs (3.79 to 4.84 months), productivity (11.57-16*10^{-1}) and sugar yields (11.30-13.71 tons/ha) at commendable ranges. Cultivars like CP-80-1827, CPF-243, CP-65-357, Mardan-92 and CPF-246 were less productive and were screened out. The delay in milling is responsible for huge financial loss to farmers, industry and the country at large. Under the conventional harvest schedule (late December to March), only 50% of the crush duration was utilized economically even with outstanding cultivars. The sugar production could double by rescheduling the milling session much earlier. This magnitude could also be enhanced many folds by cultivating superior sugarcane varieties and harvesting them during the most productive period from October to February ending. The study also applies to sugar producing countries, particularly of those locating at subtropical regions worldwide.

Key words: Sugarcane cultivars, Harvest time, Cane and sugar yields, Farmers, Industry, Pakistan.

Introduction

Pakistan ranks 5th in the world with respect to sugarcane cultivation area but only holds the 15th position in sugar production (Anon., 2022) because of low sucrose recovery of 9% when compared to 12-14% to most of the rest of the world (Soomro *et al*., 2006; Junejo *et al*., 2010; Bahadar *et al*., 2012; Munir *et al*., 2017). In spite of several elite and exotic sugarcane cultivars being grown in Pakistan for the last few decades, no significant improvement in sugar recovery has been observed (Shehzad *et al*., 2017; Khan *et al*., 2019). Owing to the low sucrose recovery and high cost of sugar production in the country, Pakistan is currently facing severe sugar crisis (Tahir *et al*., 2014; Khan *et al*., 2020). The farmers and industrialists are suffering badly and consider this a substantial threat to their viability.

Worldwide studies particularly those under subtropical regions (Chen & Chou, 1993; Salassi *et al*., 2004; Scarpari & Beauclair, 2004; Wagih *et al*., 2004; Singh *et al*., 2008; Ramos *et al*., 2010; Sandhu *et al*., 2017; Ruan *et al*., 2018; Singels *et al*., 2021) showed serious concerns over a prolonged cane harvesting season leading to significant loss in juice and sucrose recovery by chilling temperatures followed by further deterioration in subsequent delay in crop processing.

Since harvesting and milling of cane occur over a prolonged period, the entire crop in a milling zone cannot necessarily be harvested at the time of maximum quality, causing only a limited amount of the crop's value to be harnessed. Demarcation of defective crop harvest maturity added with climatic stresses are crucial factors often overlooked nationally as well as globally that wreak the profitability of the stakeholders. Hence there is a genuine need to review our national harvest program based on sugarcane cultivars with suitable maturity index under variable environments. In our previous study, several sugarcane cultivars were cultivated under the Jhang environment (Punjab, Pakistan) and potential cultivars gave acceptable productivity levels based on sucrose recovery and efficient production period (Munir *et al*., 2017). The aim of the present investigation was to assess performance of sugarcane cultivars grown under CRBC command area of Dera Ismail Khan and to evaluate thoroughly the conventional harvesting cum milling schedule in the light of commercially important industrial parameters so as to achieve maximum sugar recovery at national level. The appraisal is based on overall performance of two plantings from productive cultivars with subsequent two ratoon crops at different maturity stages to ensure cost-effective processing.

Material and Methods

Twenty-one (21) sugarcane cultivars comprised of elite and exotic clones were available in Dera Ismail Khan. The research site of the CRBC at Model Research farms of Chashma Sugar mills (Unit-1) Dera Ismail Khan is situated at 31°N latitude with extreme summer and winter season with annual temperature 0°-50°C and average rainfall 35 mm. The soil is characterized by pH 8.27, organic matter 0.52% and electrical conductivity of 1.09 d. s /m.

The crop was planted within sixty-three (63) plots of 180 m^2 each comprising of 8 rows of 15 m length with 1.5 m inter row spacing covering a total area of 11,340 m^2. All the agronomical practices were maintained in appropriate manner (Munir *et al*., 2017).

The cultivars were grown in September 2016 and February 2017, and the plants (SPC, FPC) as well as two subsequent ratoon crops (SR1, FR1, SR2, FR2) were harvested after attaining crop maturity, and harvesting continued until the end of the conventional milling program in March.

Sample preparation, juice extraction and quality measurement: Collection and preparation of sugarcane samples, juice extraction and measurement of juice quality parameters were conducted according to previously adopted procedures (Munir *et al*., 2017). Sugarcane samples were collected from each cultivar (in triplicate) on 15th of each month from October to March for all crops. The harvested canes after proper cleaning were immediately used for juice extraction and quality measurements. A 500 g fibrated cane sub-sample taken in a cylindrical cage of sugarcane hydraulic press (Gujranwala, Pakistan) was squeezed at 3,625 psig for 5 minutes to get fresh juice. The research laboratory of Chemistry Department, Gomal University Dera Ismail Khan was used for the analysis of juice quality parameters like Brix, Pol and purity of each variety to ultimately estimate sucrose recovery percentages (Munir *et al*., 2017).

The ranking of each cultivar was precisely assessed in terms of productivity and cane yield measures. The efficient production period (EPP) of a specific variety is a productive span during which a variety maintains sucrose recovery of ≥ 9.5%. The EPP range and span was precisely determined by plotting sucrose recovery (%) against harvest period of the cultivar and substituting 9.5% sucrose recovery to a quadratic equation evolved. The excessive sugar recovery was calculated integrating respective polynomial equation within the stipulated EPP limits, and varietal productivity expressed as excessive sugar recovery per unit EPP (Munir *et al*., 2017).

Statistical analysis

The cultivation of plot experiment was carried out in a randomized complete block design with an interacted factor of analysis i.e. crop and time of harvest, and the experiment for treatments repeated thrice. The analyses were performed in SPSS version 16.0 (SPSS Inc., Chicago, IL, USA). Average effects of treatments were compared applying post-hoc Duncan test (p<0.01). Microsoft Excel software program (2007; Microsoft Corporation, Redmond, WA, USA) was used for correlation analysis, drawing graphs and quadratic equations for EPP estimates.

Results and Discussion

Performance of 21 sugarcane cultivars including nationally popular and environmentally adopted foreign cultivars was investigated at Dera Ismail Khan. The exotic varieties originated from diverse regions of the world: (New Zealand), Canal Point (Florida), Houma (Brazil), Coimbatore (India), Natal (South Africa) and Sau Paulo (Brazil). The results presented are based on results after 5 years continuous study from 2016 to 2020 on September and February cultivated crops with two subsequent ratoons.

Preliminary variety screening: Preliminary screening of 21 cultivars was performed after cultivating plant crops from September (2016) and February (2017). The sucrose recovery (an overall index of cane juice, Brix, Pol and juice purity) was estimated for each variety from October to March next year in case of September planted crop, while during the same year for the February planted crop. Averaged sucrose recovery values from both the crops are reported in (Table 1). A highly significant increase in overall sucrose recovery of 9.17 to 11.05% was observed during the maturity periods from October to December. Beyond that stage the value decreased to 10.77%, 9.35% and 7.41% during January, February and March, respectively. The overall sucrose recoveries covering maturity and decay periods of the cultivars in both crops followed a polynomial trend of the form:

$$y = -0.4295x^2 + 12.415x - 78.113, (R^2 \approx 1).$$

Since sucrose accumulation is a very important quality in sugarcane the varietal worth was assessed using this parameter. After analysis of variance a highly significant variation (p<0.01) in overall sucrose recovery was observed within the cultivars (Table 1). From the present study it became quite clear that the cultivar differs in their sugar production depending upon their potential, maturity and worth to stand against the adverse environmental stresses. Based on sucrose recovery levels the varieties were separated into groups for ease in discussion. The cultivars HoSG-1257, CP-72-2086, CP-87-1628, CP-77-400, MCP-421, HSF-240, HoSG-2875 and CSSG-676 possessing more than 10% sucrose recovery (10.02-10.83%) were considered outstanding (Table 1). The cultivars Mardan-92, CP-80-1827, CPF-243, CP-65-357, CPF-246 and CP-85-1491 also held high sucrose recovery (9.60-9.91%) and hence regarded as commercially acceptable. The remaining seven genotypes (CO-1148, SPF-238, BF-129, NIA-98, SPF-213, NSG-555 and HSF-242) yielded lower recovery below 9.5% (7.41-9.40%), a level previously considered substandard for varietal evaluation in Pakistan (Munir *et al*., 2017). These cultivars were assumed as non-productive. Therefore, 14 out of 21 cultivars were regarded appropriate for further evaluation to successive two ratoon crops from both the cropping seasons.

Table 1. Overall sucrose recovery* (%) of Sep/Feb cultivated sugarcane varieties on plant crop harvest.

Variety	Oct		Nov		Dec		Jan		Feb		Mar		Overall
	Sep	Feb	Sep	Feb	Sep	Feb	Sep	Feb	Sep	Feb	Sep	Feb	
CP-72-2086	9.96	9.67	10.90	10.62	11.74	11.42	10.93	10.70	9.74	9.52	8.21	7.98	**10.12 e**
CP-80-1827	9.90	9.73	10.71	10.53	11.63	11.44	10.57	10.48	8.96	8.78	6.68	6.58	**9.67 i**
SPF- 213	8.25	8.14	9.08	8.95	9.86	9.73	11.12	11.05	9.35	9.32	7.37	7.32	**9.13 k**
HSF-242	9.35	9.34	10.35	10.33	11.66	11.54	10.22	10.25	8.64	8.35	6.39	6.35	**9.40 j**
HoSG-1257	9.96	9.82	11.03	10.92	11.97	11.83	11.02	10.77	9.13	9.11	7.39	7.33	**10.02 f**
CPF-243	9.80	9.60	10.86	10.64	11.94	11.66	10.55	10.64	8.97	8.86	6.86	6.90	**9.77 h**
SPF-238	6.93	6.88	7.80	7.68	8.63	8.59	9.59	9.51	7.74	7.72	5.67	5.64	**7.70 n**
CSSG-676	10.30	10.20	11.50	11.20	12.39	12.27	11.76	11.58	10.62	10.65	8.72	8.73	**10.83 a**
BF-129	7.59	7.48	8.27	8.21	9.09	8.96	9.89	9.81	7.99	7.94	6.03	6.03	**8.11 m**
CP-77400	10.05	9.81	11.08	10.94	12.21	11.98	11.26	11.24	10.54	10.42	8.59	8.62	**10.56 c**
Mardan-92	8.66	8.45	9.52	9.38	10.45	10.31	11.35	11.26	9.98	9.95	7.97	7.95	**9.60 i**
CP-85-1491	9.52	9.29	10.61	10.52	12.11	11.75	10.62	10.54	9.36	9.49	7.49	7.59	**9.91 g**
NIA-98	7.75	7.61	8.53	8.39	9.44	9.22	10.41	10.28	8.83	8.83	6.82	6.94	**8.59 l**
HSF-240	10.47	10.23	11.45	11.27	12.42	12.38	11.42	11.46	10.23	10.18	8.51	8.50	**10.71 b**
NSG-555	8.67	8.51	9.42	9.33	10.16	10.10	11.07	10.93	9.53	9.42	7.51	7.51	**9.35 j**
HoSG-2875	10.56	10.56	11.53	11.29	12.45	12.20	11.33	11.24	10.22	10.25	8.52	8.41	**10.71 b**
CO-1148	6.61	6.49	7.27	7.24	8.03	7.98	8.87	8.80	7.67	7.66	6.16	6.11	**7.41 o**
CP-87-1628	10.33	10.22	11.35	11.30	12.39	12.19	11.19	11.00	10.02	9.90	7.76	7.84	**10.46 d**
MCP-421	9.91	9.86	10.80	10.66	11.85	11.77	12.79	12.65	10.55	10.61	8.29	8.21	**10.66 b**
CPF-246	9.52	9.31	10.41	10.26	11.38	11.15	10.74	10.55	9.75	9.61	8.01	7.87	**9.88 g**
CP-65-357	9.97	9.79	11.00	10.80	11.97	11.72	10.49	10.26	9.16	9.01	6.94	6.85	**9.83 gh**
Mean	**9.24**	**9.09**	**10.17**	**10.02**	**11.13**	**10.96**	**10.82**	**10.71**	**9.38**	**9.31**	**7.42**	**7.39**	
Grand means	**9.17 e**		**10.09 c**		**11.05 a**		**10.77 b**		**9.35 d**		**7.41 f**		

*Response of three replicates, different superscripts in a column or row indicate significant difference (p<0.01)

Table 2. Overall sucrose recovery* (%) of Sep/Feb cultivated potential sugarcane varieties in plant and ratoon crops.

Cultivar	SPC	FPC	SR1	FR1	SR2	FR2	Overall
CP-72-2086	10.25	9.99	10.42	10.3	10.03	9.76	**10.12 a-e**
CP-80-1827	9.74	9.59	9.97	9.9	9.06	8.9	**9.53 de**
HoSG-1257	10.08	9.96	10.35	10.21	8.87	8.73	**9.70 c-e**
CPF-243	9.83	9.72	10.2	9.99	8.55	8.43	**9.45 e**
CSSG-676	10.88	10.77	11.07	10.86	9.8	9.7	**10.51 ab**
CP-77-400	10.62	10.50	10.8	10.91	10.09	9.98	**10.48 ab**
Mardan-92	9.66	9.55	9.85	9.62	9.37	9.22	**9.54 de**
CP-85-1491	9.95	9.86	10.2	10.16	9.45	9.33	**9.83 b-e**
HSF-240	10.75	10.67	11.05	11.02	10.12	9.99	**10.60 a**
HoSG-2875	10.77	10.66	11.01	10.61	9.49	9.38	**10.32 a-c**
CP-87-1628	10.51	10.41	10.74	10.78	9.65	9.56	**10.27 a-d**
MCP-421	10.70	10.63	10.83	10.67	9.12	9.06	**10.17 a-e**
CPF-246	9.97	9.79	10.19	10.09	8.91	8.73	**9.61 c-e**
CP-65-357	9.92	9.74	10.09	10.04	8.55	8.37	**9.45 e**
Mean	**10.26 a**	**10.13 a**	**10.48 a**	**10.37 a**	**9.36 b**	**9.22 b**	

*Response of three replicates, different superscripts in a column or row indicate significant difference (p<0.01)
SPC= September cultivated plant crop, SR1= September cultivated 1st ratoon, SR2 = September cultivated 2nd ratoon, FPC = February cultivated plant crop, FR1 = February cultivated 1st ratoon, FR2 = February cultivated 2nd ratoon

Impact of ratooning on crop performance: The 14 screened cultivars were then further investigated for performance during their subsequent two ratooning periods. The primary quality parameters like cane juice, Brix, Pol and juice purity as well as cane biomass were determined from October to March each year for the 1st and 2nd ratoon crops during 2018-19 and 2019-20 respectively. A sucrose recovery was calculated each month for each crop and the mean values from September/February plant cops and subsequent two ratoons were recorded for each cultivar. Irrespective of the genotype examined and season of the ratoon crop cultivation, overall sucrose recovery remained statistically at par in 1st ratoon compared to respective plant crops followed by a significant decline (p<0.01) in the 2nd ratoon (Table 2).

Previously, a sucrose recovery above 9.5% was considered a productive level for the evaluation of sugarcane cultivars. From this productive sucrose recovery level, the other commercially important quality parameters like EPP, productivity and sugar yield were derived (Tables 3-5). The EPP is a crushing duration (month) during which at least 9.5% sucrose recovery is retained by the cultivar. Productivity is the total amount of the productive sucrose level per unit EPP which was previously demonstrated by Munir *et al*., (2017) as a reliable quality parameter for comparing the worth of a variety. In comparison, the sugar yield implies total sugar produced by a cultivar taking cane biomass per unit area into account (Jackson *et al*., 1995). The selected parameters are the commercially important quality indices manifesting an actual varietal worth for maximum crop performance from plant crops till ratooning. Furthermore, the measures are indispensable for the stakeholders including farmers and industry in crop procurement and product quality standardization.

Regardless of the genotype and planting season, overall EPP remained statistically at par in 1st ratoon compared to respective plant crops followed by a significant decline (p<0.01) in the 2nd ratoon (Table 3). In contrast, overall trends in varietal productivity and sugar yield were enhanced significantly in first ratoon as compared to plant crops followed by a significant decline in second ratoon for both the cropping seasons (Tables 4, 5).

Examination of overall genotype performance: Sucrose recovery is a well-known parameter for the evaluation of sugarcane cultivars. The higher the sucrose yield then the greater is the varietal merit. Previously some sugarcane experts also compared the varietal performance on sucrose/ sugar yield (Aceland, 1971; Wagih *et al*., 2004). But in this study the worth of each cultivar was ascertained by examining the cumulative magnitude of commercially important parameters like EPP, productivity and sugar yield of the plant crops and subsequent two ratoons. Most of the cultivars differed statistically (p≤0.01) from each other for these indicators (Tables 3-5) and on the basis of overall output, the fourteen cultivars were separated into two distinctive groups (Table 6). The first group was considered highly productive and consisted of 9 cultivars: CP-85-1491, HoSG-1257, CP-72-2086, HoSG-2875, CP-77-400, CP-87-1628, MCP-421, CSSG-676 and HSF-240. This group of cultivars exhibited the highest overall sugar yields varying from 11.30 to 13.71 tons/ha from both plant and ratoon crops. Such cultivars also had a 11.57 -16 x 10^{-1} productivity score with exceptionally high EPP of 3.79 to 4.84 months out of 6 months covering 63.16 to 80.67% of the crushing period. The remaining 5 cultivars CP-65-357, Mardan–92, CPF-243, CPF-246 and CP-80-1827 were less productive on account of delivering unsatisfactory performances and did not meet the minimum criterion of 10 tons/ha sugar yields (Aceland, 1971; Wagih *et al*., 2004).

Table 3. Overall efficient production period*(months) of potential sugarcane cultivars during plant and ratoon crops.

Cultivar	SPC	FPC	SR1	FR1	SR2	FR2	Overall
CP-72-2086	4.56	4.24	4.72	4.54	4.37	3.93	**4.39 a-e**
CP-80-1827	3.97	3.8	4.26	4.09	3.14	2.87	**3.69 ef**
HoSG-1257	4.28	4.17	4.66	4.42	2.75	2.45	**3.79 d-f**
CPF-243	4.01	3.87	4.48	4.26	2.25	1.92	**3.47 f**
CSSG-676	5.04	4.98	5.19	4.99	3.94	3.8	**4.66 ab**
CP-77-400	4.84	4.71	5.03	5.1	4.3	4.13	**4.69 ab**
Mardan-92	3.62	3.49	3.84	3.56	3.22	2.99	**3.45 f**
CP-85-1491	4.07	3.95	4.29	4.28	3.58	3.29	**3.91 c-f**
HSF-240	5.06	4.87	5.32	5.21	4.38	4.19	**4.84 a**
HoSG-2875	5.1	5.06	5.4	4.96	3.63	3.43	**4.60 a-c**
CP-87-1628	4.68	4.65	4.94	4.95	3.78	3.65	**4.44 a-d**
MCP-421	4.61	4.54	4.71	4.58	2.99	2.92	**4.06 b-f**
CPF-246	4.17	3.93	4.47	4.3	2.52	1.83	**3.54 f**
CP-65-357	4.17	3.98	4.34	4.31	2.4	1.9	**3.52 f**
Mean	**4.44 a**	**4.30 a**	**4.69 a**	**4.54 a**	**3.38 b**	**3.09 b**	

*Response of three replicates, different superscripts in a column or row indicate significant difference (p<0.01)
SPC= September cultivated plant crop, SR1= September cultivated 1st ratoon, SR2 = September cultivated 2nd ratoon, FPC = February cultivated plant crop, FR1 = February cultivated 1st ratoon, FR2 = February cultivated 2nd ratoon

Table 4. Overall productivity* of potential sugarcane varieties during plant and ratoon crops.

Cultivar	x (10^{-1})						Overall
	SPC	SR1	SR2	FPC	FR1	FR2	
CP-72-2086	12.70	14.24	10.89	12.89	14.53	11.13	**12.73 b**
CP-80-1827	12.00	13.36	7.32	10.92	13.57	5.99	**10.53 d**
HoSG-1257	13.8	14.94	5.64	14.00	15.19	5.83	**11.57 c**
CPF-243	12.7	15.36	3.87	11.71	13.45	2.66	**9.96 de**
CSSG-676	17.8	19.19	10.51	17.92	19.46	10.86	**15.96 a**
CP-77-400	15.60	16.66	11.93	15.85	17.87	12.26	**15.03 a**
Mardan-92	9.20	11.07	7.30	8.57	9.13	6.35	**8.60 ef**
CP-85-1491	12.70	14.45	9.13	12.89	14.93	9.42	**12.25 b**
HSF-240	16.80	18.52	12.37	16.94	18.83	12.53	**16.00 a**
HoSG-2875	16.70	18.28	8.26	16.87	18.52	8.53	**14.53 a**
CP-87-1628	16.50	17.75	10.45	16.72	18.32	10.61	**15.06 a**
MCP-421	18.30	18.96	7.63	18.45	19.27	7.86	**15.08 a**
CPF-246	10.80	12.42	4.09	9.57	11.77	1.91	**8.43 f**
CP-65-357	13.10	14.12	4.42	11.51	11.49	2.74	**9.56 de**
Mean	**14.19 b**	**15.67 a**	**8.13 c**	**13.92 b**	**15.45 a**	**7.76 c**	

*Response of three replicates, different superscripts in a column or row indicate significant difference (p<0.01)
SPC= September cultivated plant crop, SR1= September cultivated 1st ratoon, SR2 = September cultivated 2nd ratoon, FPC = February cultivated plant crop, FR1 = February cultivated 1st ratoon, FR2 = February cultivated 2nd ratoon

Table 5. Overall Sugar yield* (tons/ha) of potential sugarcane cultivars during plant and ratoon crops.

Cultivar	SPC	FPC	SR1	FR1	SR2	FR2	Overall
CP-72-2086	12.00	11.62	12.71	12.39	10.79	10.36	**11.64 de**
CP-80-1827	9.70	9.93	10.94	10.06	9.17	9.42	**9.87 f**
HoSG-1257	12.56	12.31	13.42	13.33	10.31	10.00	**11.99 de**
CPF-243	9.94	9.79	10.62	10.21	8.07	7.60	**9.37 f**
CSSG-676	12.48	12.28	13.32	12.89	9.77	9.70	**11.74 de**
CP-77-400	14.13	13.93	15.11	15.34	10.66	10.66	**13.30 ab**
Mardan-92	8.55	8.41	9.18	8.93	6.80	6.68	**8.09 g**
CP-85-1491	12.45	12.27	13.68	13.50	9.71	9.59	**11.87 de**
HSF-240	13.05	12.86	14.80	14.80	10.74	10.70	**12.83 bc**
HoSG-2875	11.97	11.69	12.77	12.33	9.67	9.39	**11.30 e**
CP-87-1628	13.90	13.75	15.81	15.98	11.56	11.28	**13.71 a**
MCP-421	13.27	12.17	13.81	13.12	10.77	10.43	**12.26 cd**
CPF-246	9.30	9.59	11.14	11.17	9.02	8.87	**9.85 f**
CP-65-357	8.27	8.05	8.99	9.06	6.12	6.06	**7.76 g**
Mean	**11.54 b**	**11.33 b**	**12.59 a**	**12.37 a**	**9.51 c**	**9.34 c**	

*Response of three replicates, different superscripts in a column or row indicate significant difference ($p<0.01$)
SPC= September cultivated plant crop, SR1= September cultivated 1st ratoon, SR2 = September cultivated 2nd ratoon, FPC = February cultivated plant crop, FR1 = February cultivated 1st ratoon, FR2 = February cultivated 2nd ratoon

Table 6. Overall performance in terms of productivity, Efficient production period and Sugar yield (tons/ha) of sugarcane cultivars during plant and ratoon crops.

Potential order	Varieties	Potential order with respect to overall magnitude		
		Productivity x (10^{-1})	EPP (months)	Sugar yield (tons/ha)
1	HSF-240, CSSG-676, MCP-421, CP-87-1628, CP-77-400, HoSG-2875, CP-72-2086, CP-85-1491, HoSG-1257	11.57-16.00	3.79-4.84	11.30-13.71
2	CP-80-1827, CPF-243, CP-65-357, Mardan-92, CPF-246	8.43 to 10.53	3.45 to 3.69	7.76 to 9.87

Previously varietal performance was compared by experts (Habib *et al*., 1992; Das *et al*., 1997; Gilbert *et al*., 2004; Wagih *et al*., 2004; Tajera *et al*., 2007) on the basis of absolute amount of sucrose recovery by a cultivar at its peak maturity, no matter how much and how long it yielded. In our approach a limit on sucrose recovery of at least 9.5% was set describing a cultivar as worthwhile and productive. Since efficiency of the crop is affected by seasonal temperatures below normal, the cultivars were only considered beneficial so long as the sucrose yield was maintained at ≥9.5%. Hence besides sugar yield, credence was given to a cultivar for the period it continues yielding productive sucrose levels as measured using the EPP values. The parameter is desired by the sugar industry during which productive milling activity (EPP) is sustained by a cultivar for maximum period. Furthermore, the cultivar is succeeded in receiving a productive score based on total sucrose recovery above 9.5%. The data presented are from the results collected over 5 years of consistent study on varietal evaluation starting from plant crop cultivation on both cropping seasons until the end of two ratoon crops. Accordingly, the top group of the cultivars was regarded as outstanding for yielding sucrose recovery above 9.5% throughout the period commencing from October to January ending, delivering at least 41% higher sugar yield than the nonproductive varieties. These cultivars are not only suitable for the cultivation under agro climatic conditions of Dera Ismail Khan but are also widely grown in KPK. Most of these varieties had previously been reported equally productive and appropriate at Jhang (Punjab), Pakistan having similar agro environment (Munir *et al*., 2017).

Crush schedule analysis and modification: The sugar processing industry has a common practice to start the crushing season from mid-December or even later and continue the processing until crop the end of March/April. Factory management gives justification for commencement of late milling by maintaining the view that the sugarcane crop attains full maturity after mid-December. Further, there is another misplaced concept among processors that with increasing cold there is an increase in the sugar content of sugarcane. The industry also believes that cultivar ensure their profitable performance until process termination (March/April). To verify their claims, the data of the current study required thorough inspection.

The cumulative EPP range of 14 cultivars was plotted to find out the potential time period (specific date) during which a cultivar exhibited sucrose recovery of ≥ 9.5% (Fig. 1). The average productive period of all the cultivars from plant crop to ratoon ranged from mid-October to mid-February (4 months) and only a few cultivars remained productive beyond that limit and only for a week or so. The cumulative sucrose recovery level continued to increase from 9.4% in October to becoming maximum around December (11.35%) with a subsequent decline in January. The cumulative sucrose recovery beyond this period followed a rapid decline at least twice as fast in March (7.47%) and even faster in April (4.53%) before crop termination. Typically, in Pakistan the conventional crush program is only 50% worthwhile using EPP results (Fig. 1). Similarly, the same recovery data of plant and two subsequent ratoon crops collected monthly were plotted against crop harvest time (Fig. 2). Variation in quality levels is often regarded as being due to differences in metabolic activity with it being high during growth/ maturation of the sugarcane crop and low in decay periods. Bahadar *et al*., (2012) observed that frost injury in the month of January and onward affects thousands of hectares of the crop annually since the frost can damage the sugarcane and make it susceptible to microbial deterioration. Our findings are also evidenced by findings from researchers (Wagih *et al*., 2004; Zhao & Li, 2015; Pongpat *et al*., 2017; Ruan *et al*., 2018; Marin *et al*., 2019; Ayub *et al*., 2021; Marin *et al*., 2021) who regarded that the chilling temperatures badly damage the above-ground parts of sugarcane triggering changes in juice quality including sucrose content, purity and sugar yield on account of cane staling. Circulation of cold dry winds in late February further aggravate the situation (Scarpari & Beauclair, 2004; Siddhant *et al*., 2009; Wang *et al*., 2014). By March, the ambient temperature starts rising again which allows the growth of microbes responsible for cane deterioration which causes unwanted dextran formation (Singh *et al*., 2008). It is considered that increasing weather stresses during late crushing coupled with interactions from biotic factors cause enormous losses in sucrose recovery. Furthermore, the melassagenic components (dextran, etc.) possibly produced in standing as well as harvested cane stalks can interfere with the process of sugar crystallization (Eggleston *et al*., 2004) causing additional losses. Meanwhile sugarcane starts sprouting and a substantial portion of the sucrose reserve is consumed in raising the vegetative growth. In April, the temperature becomes high enough to dehydrate the sugarcane crop (Saxena *et al*., 2010). Since there is a weight-based payment for crop procurement in Pakistan, the millers pay no attention to the fact that less payment is being made to the farmers for their naturally dried crops. Additionally, the harvested crop undergoes biochemical changes hastening the process of inversion but the greatest contribution to sucrose losses is from microbial deterioration reactions. Eggleston *et al*., (2008) observed a drop in juice pH of the freeze deteriorated crop due to the associated formation of organic acids. It is possible that the over-aged crop could yield an increased acidity which caused an inversion in the juice quality depreciating its purity profile. Realizing the situation of the huge financial losses, the industrial management imposed a “katoty” (reduction) measure on the harvested crop on the farmers for providing dried crops. Additionally, the crop at this stage is more vulnerable to fire as a considerable part of it is burnt off causing a colossal loss to farmers every year. The industry also compels farmers to sell their crops at reduced rates after already suffering from natural disasters. Hence a tussle starts between farmers and industrial management to safeguard their own interests and recover material and financial losses. Both parties blame each other and thus harm mutual benefits. Consequently, a series of litigations can take place leading to strikes, traffic jams and even court cases. The weight-based payment system is a bone of contention between farmers and industry. Farmers are constantly sticking towards the mass cultivation and propagation of the high moisture/succulent varieties whereas the industry is harming the profit of farmers by undue tactics.

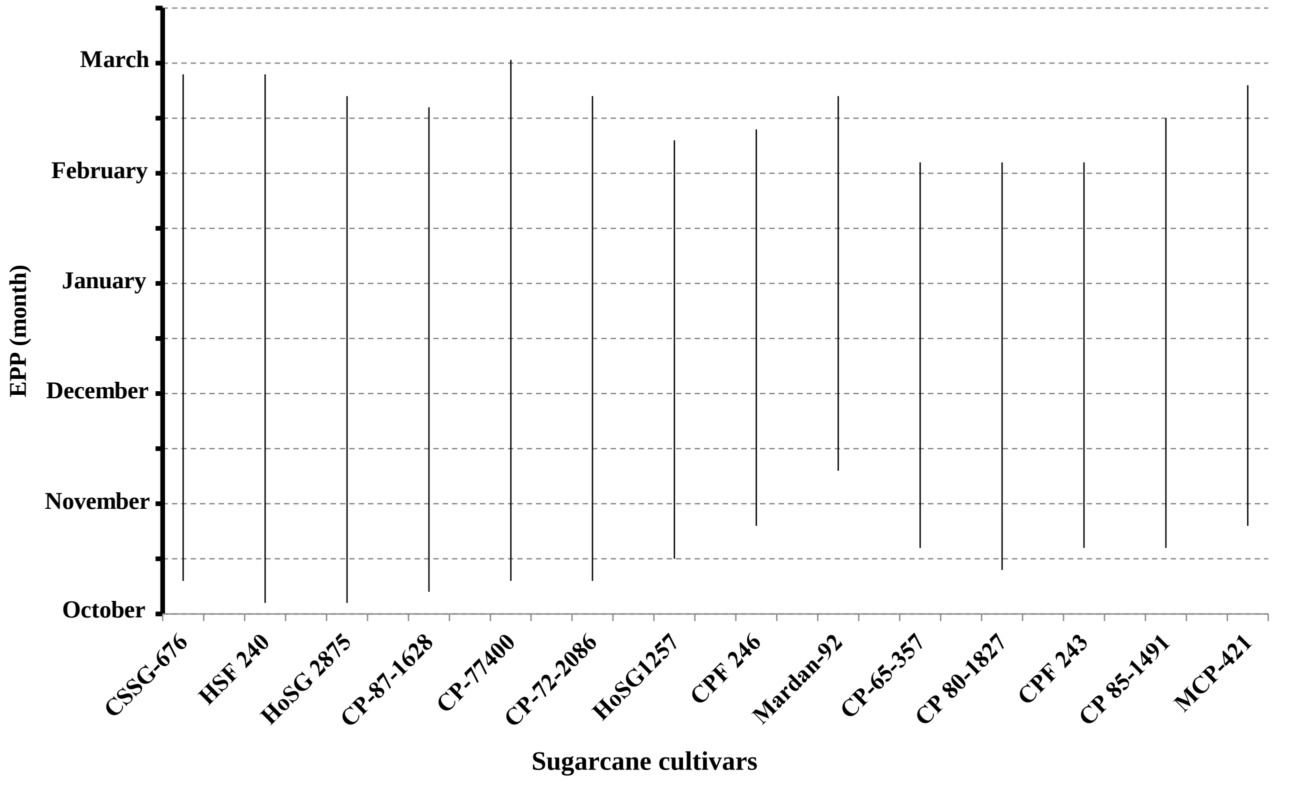

Fig. 1. Sugarcane cultivars with respective EPP range from plant as well as ratoon crops.

Weather plays a primary role and this coupled with interactions from associated biotic factors determine the rate of deterioration that eventually lead to enormous losses in sugar recovery. The delivery of consignments of the deteriorated sugarcane to factories can detrimentally affect multiple process units, and occasionally lead to a factory shutdown (Eggleston *et al.*, 2004). Since sugarcane processing is a seasonal and time-bound activity a struggle starts among the farmers each trying to complete harvesting as early as possible. The growers develop competition for the procurement of indents, harvesting labor and transportation facilities etc. As a result, the harvesting and transportation charges can increase (Khan *et al.*, 2020; Khushk *et al.*, 2011). The situation is the result of milling delay amounting to huge financial losses to farmers, industry and the government as well.

According to our present data the conventional milling practices afford profitable performance to only half of the crushing period (mid-December to mid-February at the most). On further processing the varieties registered a rapid decline in sucrose recovery and the installation runs on deficit. The industry receives even higher monitory losses if the milled cultivars are of lower productivity. The claim of the industrial authorities on profitable performance of sugarcane crop till harvest termination (until March/April) therefore seems inappropriate. There is no reality of producing sugar profitably beyond December.

Modification in the conventional crushing schedule: The quality of the sugarcane supply to the factory plays a key role in raw sugar production and processing costs. In our previous study it had been observed that sucrose recovery in cultivars furnished a steady rise with maturity period reaching a peak and then immediately, or after a pause depending upon cultivar, the recovery tended to decline at a rapid rate until harvest termination (Munir *et al.*, 2017). A few researchers' world over (Bond, 1982; Legendre, 1985; Mamet & Galwey, 1999; Elfadil & Mohammad, 2015; Ahmed & Awadalla, 2016; Sandhu *et al.*, 2017) have reported similar recovery trends and have developed maturity curves for individual cultivars to harvest a particular variety at a specific period undertaken a legal coverage. Although the proposal seems logical, it is probably non pragmatic in our country owing to a supply of blended stalks to the factory from diverse cultivars and varied plantings throughout the milling span. Moreover, due to inadequate number of late maturing varieties for covering the entire harvest period. Likewise, the maintenance of liaison between farmers and the industry is likely to develop further complications for catering specific varieties at particular times.

In this perspective the data collected over 5 years from February/September plant and two subsequent ratoon crops of 14 elite varieties were scrutinized objectively. The sucrose accumulation for the entire milling period under conventional harvest program is depicted in the form of cultivar performance curve (Fig. 2). The cumulative trend followed a quadratic regression ($y = -0.4226x^2+12.303x-78.433$) with high correlation coefficient (0.995). The period with a productive sucrose recovery (≥9.5%) is marked with an arrow line B to E. The rate of efficient sucrose recovery production starting as early as mid-October (B) reached a maximum around mid-December (C). The rate then dropped rapidly approaching a nonproductive level beyond mid-February (E). Keeping the conventional milling practices in view (late December - late April) the harvest process functions productively in only half of the period at the most. Moreover, carrying on crushing beyond February also encourages increased production of melassagenic components and deterioration products from the staled canes known to interfere with sucrose crystallization thus causing enormous reduction in sugar recovery (Eggleston *et al.*, 2004). The loss in sugar production becomes even greater when processing low productivity cultivars. It is interesting to note that under the conventional milling the processor not only fails to recover the expected financial gains on account of substantial reduction in product yield and expended time/ energy but could not even secure the input cost.

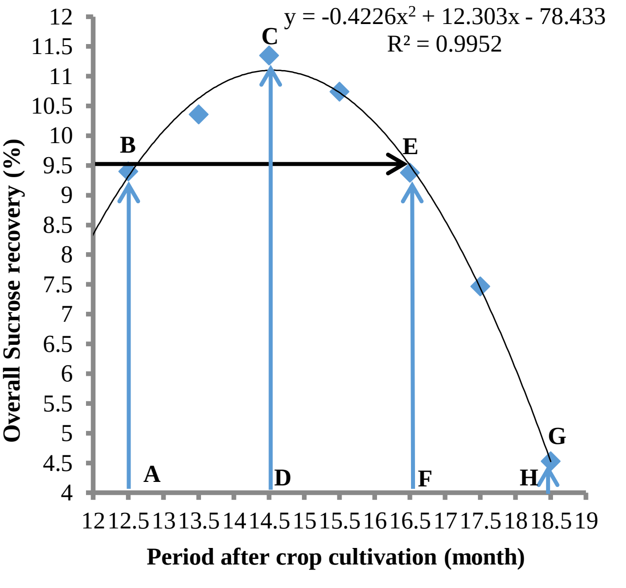

Fig. 2. Overall sucrose recovery of Sep./Feb. cultivated plant crops and subsequent two ratoons from 14 varieties.

The proposed shifting of the cane schedule in Pakistan is likely to recover at least 1.5 times greater amounts of sugar. Further the melassagenic components and deterioration products resulting from deteriorated cane in late crushing greatly add to the reduced sucrose recovery and could be easily avoided with the proposed new scheduling. Sugar production could even double cultivating more productive varieties as reported in Table 6 are used. A huge amount of additional sugar could be made available in the country cultivating such productive varieties on mass scale and shifting the crushing period to an earlier time. The farmers will not only get rid of the "katoty" imposed on their stale stalks supplied in the late season but additionally benefit from possibly increased cane yields on account of timely harvesting (McDonald & Lisson, 2001). Hopefully, it would bring more harmony between farmers and industrial managements. By adopting the proposed new practices, a much larger quantity of sugar will become available in the country for local consumption, and sugar prices could eventually get down to within the reach of the common people, a strong issue of concern. It may also be possible that a certain amount of the product could be exported to earn foreign exchange. Therefore, the milling practices should be modified accordingly within the productive range starting from mid-October to mid-February instead of mid-December until harvest termination (April).

Conclusion

In order to obtain maximum gains and avoid other undue liabilities faced by industry and the peasants a well-planned start and end of industrial process is recommended. The proposed shifting could cause at least 1.5 times higher amounts of sugar to be recovered. Sugar production is expected to become even greater when cultivating more productive varieties (Munir *et al.*, 2017). The farmers will not only get rid of "katoty" imposed on their stale stalks supplied in the late season they will additionally benefit from increased cane weight on account of timely harvesting. In addition to increased sugar yield the expected conflicts arising between industrial management and the farmers can be avoided if both parties benefit.

Many the same sugarcane varieties are under cultivation in other parts of Pakistan and are expected to produce similar recovery magnitude under comparable climatic conditions prevailing all over Pakistan, although studies will be needed to confirm this. There are 90 Sugar Mills currently operating in Pakistan with a total sugar production of about 6.8 million metric tonnes during crushing season 2021-2022 (Soomro *et al*., 2021). Production could be further enhanced to 10.2 million metric tonnes by adopting the proposed rescheduling. Besides less expensive with respect to the production rate a significant amount of the excessive sugar could become available in the country which may eventually help to reduce sugar prices within the reach of common people. Further some amount of the product would also be available for export in order to fetch foreign exchange earnings. Since the conventional harvesting of the crops requires occasional evaluation on account of climatic shifts as envisaged by our findings the reframing of harvest program is equally valid to other sugar producing countries especially for the subtropical ones, although each country will need to undertake their own studies due to varying soils, etc. in each country. It is pertinent to note that sugarcane harvesting is assumed from November to April and May to October in countries of Northern Hemisphere and Southern Hemisphere respectively (Chen & Chou, 1993). These countries may adopt their own harvest practices accordingly in order to safeguard the sugarcane crop from the adverse climatic stresses affecting in late harvest seasons.

References

Aceland, J.D. 1971. An introduction to the production of field and plantation crops in Kenya, Tanzania and Uganda. Published by *Longman Group Ltd.,* Singapore.

Ahmed, A.Z. and A.O. Awadalla. 2016. Effect of harvesting age on yield, yield components and quality of some promising sugarcane varieties. *J. Plant Prod*., 7: 1501-1507.

Anonymous. 2022. Crops and livestock products. https://www.fao.org/faostat/en/#data/QCL

Ayub, S., S. Huang and S.H. Raza. 2021. Effect of climatic vulnerabilities on sugarcane production in Punjab, Sindh and KPK: a case study from Pakistan. *J. Agri. Res.*, 59: 305-312.

Bahadar, K., M. Rashid and A. Quddoos. 2012. Response of new sugarcane genotypes in southern region of Khyber Pakhtoon Khah. *Pak. Sugar J.*, 27: 2-10.

Bond, R.S. 1982. Maturity differences between varieties in the selection program. *Proceed. Annual Congress S. Afr. Sugar Tech. Assoc.*, 56: 136-139.

Chen, J.C.P. and C.C. Chou. 1993. *Cane sugar handbook* (12th edn). New York: John Wiley.

Das, P.K., N. Nayak and S.S. Mahapatra. 1997. Performance of early maturing sugarcane genotypes in the coastal plains of Orissa. *Indian Sugar*, 16: 111-113.

Eggleston, G., B. Legendre and T. Tew. 2004. Indicators of freeze-damaged sugarcane varieties which can predict processing problems. *Food Chem.*, 87: 119-133.

Eggleston, G., D. Morel and S.N. Walford. 2008. A review of sugarcane deterioration in the United States and South Africa. *Proceed. S. Afr. Sugar Technol. Assoc.*, 81: 72-85.

Elfadil, A.D. and M.K. Mohamed. 2015. Effect of dry-off period and crushing and extracting delays on sugarcane quality and productivity. *Transact. Ind. Financ. Bus. Manag.*, 3: 67-72.

Gilbert, R.A., J.M. Shine, J.D. Miller, R.W. Rice and C.R. Rainbolt. 2004. The effect of year, cultivar and time of harvest on sugarcane yields in Florida. *J. Amer. Soc. Sugarcane Technol.*, 24: 165-184.

Habib, G., K.B. Malik and M.Q. Chatta. 1992. Preliminary evaluation of exotic sugarcane varieties for qualitative characters**;** II. *Pak. J. Agric. Res.*, 13 (4): 320-326.

http://www.plantmanagementnetwork.org/pub/cm/research/2004/sugarcane/.

Jackson, P., M.R. Tony and M. Hogarth. 1995. Selection of sugarcane families across viable environments 1. Sources of variation and an optimal selection index. *Field Crops Res.*, 43: 109-118.

Junejo, S., G.M. Kaloi, R.N. Panhwar, M. Chohan, A.A. Junejo and A.F. Soomro. 2010. Performance of some newly developed sugarcane genotypes for some quantitative and qualitative traits under Thatta conditions. *J. Anim. Plant Sci*., 20(1): 40-43.

Khan, M.T., N. Seema, I.A. Khan and S.H. Yasmine. 2019. Exploitation of somaclonal variations for improvement of sugar recovery in sugarcane. *Zuckerind.*, 144: 194-203.

Khan, M.T., S.H. Yasmeen and I.A. Khan. 2020. Comparative analysis of sugarcane genotypes for post-harvest deterioration under natural conditions. *Pak. J. Bot.*, 52: 81-95.

Khushk, A.M., A. Memon and I. Saeed. 2011. Analysis of sugar industry competitiveness in Pakistan. *J. Agric. Res.*, 49: 137-151.

Legendre, B.L. 1985. Changes in juice quality of nine commercial sugarcane varieties grown in Louisiana. *J. Amer. Soc. Sugarcane Technol.*, 4: 54-57.

Mamet, L.D. and N.W. Galwey. 1999. A relationship between stalk elongation and earliness of ripening in sugarcane. *Exp. Agric.*, 35: 283-291.

Marin, F.R. J.I.R. Edreira, J.F. Andrade and P. Grassini. 2021. Sugarcane yield and yield components as affected by harvest time. *Sugar Tech.*, 23: 819-826.

Marin, F.R., J.I.R. Edreira, J.F. Andrade and P. Grassini. 2019. On-farm sugarcane yield and yield components as influenced by number of harvests. *Field Crops Res.*, 240: 134-142.

McDonald, L.M. and S.N. Lisson 2001. The effect of planting and harvest time on sugarcane productivity. In: *Proceed. 10th Austral. Agron. Conf., Hobart*.

Munir, M., M.K. Baloch, S. Afghan, A.K. Baloch and M.M. Hashim. 2017. Productivity based evaluation of elite sugarcane cultivars for sustainable sugar production. *Quality Assur. Safety Crops Foods*, 9(3): 323-334.

Pongpat, P., S.H. Gheewala and T. Silalertruksa. 2017. An assessment of harvesting practices of sugarcane in the central region of Thailand. *J. Cleaner Prod.*, 142: 1138-1147.

Ramos, N.M., V.E. Ruvalcaba, M.B. Carado, P.O. Brahana, J.L. Sarquis and A.H. Solana. 2010. Environmental effects on yield and quality in three sugarcane varieties grown in Veracruz, Mexico. *Int. J. Bioresour. Stress Manag.*, 1: 198-203.

Ruan, H., P. Feng, B. Wang, H. Xing, G.J. O'Leary, Z. Huang and D.L. Liu. 2018. Future climate change projects positive impacts on sugarcane productivity in southern China. *Europ. J. Agron.*, 96: 108-119.

Salassi, M.E., M.J. Garcia, B. Breaux and C.N. Sung. 2004. Impact of sugarcane delivery schedule on product value at raw sugar factories. *J. Agribus.*, 22: 61-75.

Sandhu, H.S., M.P. Singh, R.A. Gilbert, F. Subiros-Ruiz, R.W. Rice and Jr, J.M. Shine. 2017. Harvest management effects on sugarcane growth, yield and nutrient cycling in Florida and Costa Rica. *Field Crops Res.*, 214: 253-260.

Saxena, P., R.P. Srivastava and M.L. Sharma. 2010. Impact of cut to crush delay and bio-chemical changes in sugarcane. *Aust. J. Crop Sci.*, 4(9): 692-699.

Scarpari, M.S. and E.G.F. Beauclair. 2004. Sugarcane maturity estimation through Edaphic-Climatic parameters. *Sci. Agric.*, 61: 486-491.

Shehzad, S., S. Shokat and N. Fiaz. 2017. Impact of yield and quality-related traits of sugarcane on sugar recovery. *J. Crop Sci. Biotechnol.*, 20: 1-7.

Siddhant, S., R.P. Srivastava, S.B. Singh and M.L. Sharma. 2009. Post harvest sugar losses in sugarcane varieties at high ambient temperatures under subtropical conditions. *Sugar Tech*., 10: 350-354.

Singels, A., P. Jackson and G. Inman-Bamber. 2021. Sugarcane. In: *Crop Physiology Case Histories for Major Crops* (pp. 674-713). Academic Press.

Singh, P., S. Solomon, A.K. Shrivastava, C.P. Prajapati and R.K. Singh. 2008. Post-harvest deterioration of sugarcane and its relationship with the activities of invertases and dextransucrases during late-crushing season in sub-tropics. *Sugar Tech*., 10(2): 133-136.

Soomro, A.F., S. Tunio, M.I. Keerio, I. Rajper, Q. Chachar and M.Y. Arain. 2021. Effect of inorganic NPK fertilizers under different proportions on growth, yield and juice quality of sugarcane (*Saccharum officinarum* L). *Pure Appl. Biol.*, 3: 10-18.

Soomro,A.F., A. Junejo and M. Aslam. 2006. Evaluation of Different Promising sugarcane varieties for some quantitative and qualitative attributes under Thatta (Pakistan) conditions. *Int. J. Agric. Biol.*, 8 (2): 195-197.

Tahir, M., I.H. Khalil and H. Rahman. 2014. Evaluation of important characters for improving cane yield in sugarcane (*Saccharum* sp.). *Sarhad J. Agric.*, 30(3): 319-323.

Tajera, N.A., R. Rodés, E. Ortega, R. Campos and C. Luch. 2007. Comparative analysis of physiological characteristics and yield components in sugarcane cultivars. *Field Crops Res.*, 102: 64-72.

Wagih, M.E., A. Ala and Y. Musa. 2004. Evaluation of sugarcane varieties for maturity earliness and selection for efficient sugar accumulation. *Sugar Tech*., 6(4): 297-304.

Wang, M.L., M. Cole, B. Tonnis, D. Pinnow, Z. Xin, J. Davis, Y.C. Hung, J. Yu, G.A. Pederson and G. Eggleston. 2014. Comparison of stem damage and carbohydrate composition in the stem juice between sugarcane and sweet sorghum harvested before and after late fall frost. *J. Sustain. Bioen. Syst.*, 4: 161-174.

Zhao, D. and Y.R. Li. 2015. Climate change and sugarcane production: Potential impact and mitigation strategies. *Int. J. Agron.*, http://dx.doi.org/10.1155/2015/547386.

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