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Productivity-based evaluation of elite sugarcane cultivars for sustainable sugar production

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Abstract

This study was aimed at screening out local and exotic sugarcane clones based on productivity. Twenty-three early sugarcane varieties cultivated at model farms of Sugar Research Institute Shakkarganj (Pakistan) on September 2008 were examined periodically for juice extract, Brix, Pol, purity and sucrose recovery during the October to March crushing season of 2009-2010. A steady rise in quality was seen from the 11-12 month growth period until maturity with a clear decline afterwards to follow a quadratic equation given a strong correlation coefficient $r^2 \approx 1$. A highly significant difference ($P<0.01$) was observed within varieties and harvest period for all quality parameters. Juice extract (75.60%) and purity (87.65%) were recorded at a maximum in CP-77-400 and CP-80-1827 cultivars, respectively, whereas Brix (20.44%), Pol (17.10%) and sucrose recovery (11.03%) were highest in the CSSG-676 variety. Screening of cultivars was implemented on the basis of a logically developed productivity scale based on high sucrose recovery (≥9.5%). The validity of the technique was ascertained by comparing varietal potentials on a productivity scale with those at 'full maturity' and from 'mean estimates'. Based on productivity, CSSG-676, HoSG-2875, HSF-240, CP-77-400 and CP-87-1628 were demonstrated to be outstanding cultivars resistant to climatic stresses giving 7.69-9.78% excessive sucrose recovery. The CP-65-357, CPF-243, CP-85-1491, HoSG-1257, CP-72-2086, CP-80-1827, HoSG-104 and CPF-237 were also shown to be promising varieties with a high excessive sugar yield. Ganjbakhsh, Hoth-127 and SPSG-26 varieties did not perform well, and the cultivar GT-11 could not even reach the established minimum sucrose recovery level. The study would certainly be helpful in improving the gloom scenario of the sugar industry worldwide.

Keywords: efficient production period, excessive sucrose recovery, maturity stage, quality indices, sugarcane varietal performance

1. Introduction

Sugarcane (*Saccharum officinarum*, L.) is an important cash crop in Pakistan. However, low cane yield, reduced sucrose recovery and high production costs are major challenges confronting this crop (Tahir *et al.*, 2014). The farming community and industry are striving hard for sustainability and increased production of the crop (Anonymous, 2011a; Eggleston and Lima, 2015). Pakistan is ranked 6th in terms of sugarcane acreage yielding 48 to 50 tonne per hectare (T/ha) cane compared to 63.7 T/ha from 120 cane-growing countries (Anonymous, 2012; Junejo *et al.*, 2010). Based on sugar production the country stands in 15th position, producing 4 T/ha sugar with 8-9% sucrose recovery as against 6-13 T/ha sugar with 12-14% recovery the world over (Anonymous, 2013; Bahadar *et al.*, 2012).

One of the major tasks given by the sugar industry is to explore prospective varieties with high cane and sugar yield. Several factors are thought to be responsible for affecting sugarcane quality profile and yield. Workers in Pakistan (Bahadar *et al.*, 2012; Junejo *et al.*, 2010) also believe that the reason for low sugar and cane yield in the country is mainly due to the cultivation of sugarcane varieties with poor genetic potential. The late varieties, though having greater sugar potential, are becoming scarce due to severe climatic stresses particularly in subtropical world regions like Pakistan (Nayamuth *et al.*, 1999). In this situation the early varieties are being cultivated and to ensure better performance are passing through screening stages to substitute late cultivars. The quality of cane juice and other cane parameters are also highly depending upon the maturity stages of the crop (Saxana *et al.*, 2010; Scarpari and Beauclair, 2004). Gilbert *et al.* (2006) stressed that a promising cultivar loses value if it is not harvested at the right maturity time. Varietal performance has also shown to be influenced by the environment of the region (Zhao and Li, 2015). The consensus, however, is that the inherent characteristics of a variety play a major role in enhancing acreage and sugar yield (Tahir *et al.*, 2014). Arain *et al.* (2011) recommended screening out varieties that have lost yield and other qualities over the years.

A variety is normally evaluated based on its performance for cane and/or sugar yield estimated at full maturity stage (Hussain *et al.*, 2008). The increase in cane quality and sucrose content initially reaches a maximum at peak maturity followed by a certain decline depending upon the potential of the variety (Ongin'jo and Olweny, 2011).

The practice of assessing sugarcane variety at single maturity stage or taking mean values is likely to undermine the credibility of a variety if due consideration is not given to the entire crushing period aimed by the cultivar. Very little work has been reported worldwide on the screening of sugarcane varieties based on actual performance displayed throughout the harvesting period. The aim of the present investigation is to screen out imminent national and exotic sugarcane cultivars introducing a productivity-based evaluation. Due consideration is paid to cultivar performance derived from the amount of sucrose recovered over the entire efficient production period of a crushing season. Furthermore, a schedule for harvesting the varieties will be recommended accordingly. The study is considered highly productive and beneficial to the industry as well as to the farming community at national and international levels.

2. Materials and methods

Research was carried out during 2008-10 at the model research farms of Sugarcane Research Institute, Shakkarganj Sugar Mills Jhang, Punjab (Pakistan). The site is located above 560 feet sea level at 31.30677° N latitude and 72.32814° E longitude. The soil of the sampling site is characterised by pH (KCl) 7.94, organic matter 10 g/kg, sandy texture, electrical conductivity 1.22-1.7 d. S/m and TSS 768-1,024 mg/kg. Metrological data of the location is taken from the official website of the Pakistan government (Anonymous, 2011b). Twenty-three early sugarcane cultivars comprised of national and exotic clones were planted in September 2008. The cultivars were planted using a randomised complete block design (thrice replicated) on 69 plots of 180 m^2 each (eight rows of 15 m length with 1.5 m inter-row spacing) covering a total area of 12,420 m^2. All the agronomic practices like fertilisation, irrigation, and weed/pest management were maintained in an appropriate and uniform manner.

Sample preparation

Six mature stalks were harvested serially along the centre row of each plot starting on 15th of each month from October to March during 2009-10 (1st year/plant crop). The samples were prepared by randomly taking four out of the six stalks from each replicate, giving a total of twelve millable canes for each cultivar. The clean canes were cut into 6-8 cm pieces with the help of a mechanical shredder. The shreds were mixed thoroughly and disintegrated using a Jaffico cutter-grinder equipped with sharp blades to obtain a homogeneous mass. Juice was extracted soon after harvesting the sugarcane crop and analysed for juice extract (%), Brix (%), Pol (%), purity (%) and sucrose recovery (%). Cane yield (T/ha) was recorded in December 2009 after weighing the fresh millable stalks harvested from two inner rows of each plot. Excessive sugar yield of the crop (T/ha) was calculated by multiplying cane yield (T/ha) and excessive sucrose recovery (%). The samples from each variety were taken in triplicate for analysis, and the mean values were recorded.

Sucrose recovery (%)

The parameter was estimated using the sugar, juice, and molasses formula (Hussain *et al.*, 2010):

$$\text{Sucrose recovery (\%)} = \frac{\text{BHE} \times \text{BHR} \times \text{Pol (\%)} \times \text{juice (\%)}}{100} \quad (1)$$

Where BHE = boiling house efficiency ≈ 0.98; BHR = boiling house recovery ≈ S (J-M) / J (S-M); S = sugar purity ≈ 100; J = juice purity; M = molasses purity ≈ 40; and juice purity (%) = (Pol% × 100) / (Brix%).

The extraction and estimation of juice, Brix and Pol was done as per Chen and Chou (1993) technique. A triplicate 500 g fibrated cane sub-sample taken in a cylindrical cage of Smith Craft Sugarcane Hydraulic press made in Gujranwala (Pakistan) was pressed at 3,625 psig for 5 minutes. The fibre cake (bagasse) was removed from the press and weighed accurately. The juice (g / 100 g) was calculated subtracting the weight of the bagasse from the sample weight.

The Brix (%) was determined using automatic temperature compensated (20 °C) Brix Hydrometer (Atago Pty, Tokyo, Japan). The 'observed' Pol (%) in juice was recorded using a polarimeter (AA-15; Optical Activity, Huntingdon, UK).

Pol (%) was then determined by comparing the 'observed' Pol with Brix using a Schmitz table (Chen and Chou, 1993).

Efficient production period

The efficient production period (EPP) is a crushing duration in which there is at least 9.5% sucrose recovery from a crop. The EPP range for any sugarcane variety was precisely determined substituting 9.5 to its quadratic equation. A polynomial equation obtained for CSSG-676 as an example is given below:

$$y = -0.41x^2 + 11.942x - 74.653 \quad (2)$$

Equation 2 is advanced plotting percentage sucrose recovery against respective harvest period starting from October 15 to March 15, i.e. 12.5-17.5 month after planting.

Now inserting 9.5% sucrose recovery, Equation 2 becomes:

$$9.5 = -0.41x^2 + 11.942x - 74.653 \quad (3)$$

After rearranging Equation 3, it becomes:

$$-0.41x^2 + 11.942x - 84.153 = 0 \quad (4)$$

Solving the quadratic Equation 4 for x, we use a general equation of the type:

$$X = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a} \quad (5)$$

Where 'a' is the coefficient of 'x^2', 'b' is the coefficient of 'x' and 'c' is the equation constant.

Two values of 'x' 11.95 and 17.18 months were obtained, which correspond to the start and terminal productive period having at least 9.5% sucrose recovery. Therefore, the EPP for CSSG-676 ranged from 11.95 and 17.18 months, giving a net EPP of 5.23 months (Table 4).

Productivity

The productivity of a variety is defined as the 'gross amount of sucrose recovery above 9.5% per unit EPP'. The magnitude of productivity was estimated by integrating quadratic Equation 4 of a variety CSSG-676 for example, within the respective EPP range varying from 11.95 to 17.18 and dividing the value by EPP of 5.23.

$$\text{Productivity} = \frac{\int_{11.95}^{17.18} (-0.41x^2 + 11.942x - 84.153)dx}{5.23} \quad (6)$$

Therefore, productivity for CSSG-676 ≈ 18.70×10^{-1}.

Statistical analysis

The experiment was carried out in a randomised complete block design with an interacted factor of analysis, i.e. variety 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) taking replications as fixed factors, and variety and time (months) of harvest as random factors. Treatment means were separated applying the post-hoc Duncan test ($P<0.01$). The Microsoft Excel software programme (2007; Microsoft Corporation, Redmond, WA, USA) was used for regression and correlation analysis, drawing graphs and quadratic equations for estimating EPP and productivity.

3. Results and discussion

Twenty-three renowned sugarcane cultivars comprising early clones were used for the investigation. These varieties originate from diverse regions of the world, i.e. Canal Point (Florida), Houma (Brazil), Coimbatore (India), Natal (South Africa), Guang Tong (China), Sau Paulo (Brazil) and Commonwealth sugars (New Zealand), etc., and are adopted in Pakistan. The crops were harvested after reaching 11-12 months' maturity.

Juice was extracted soon after harvesting the sugarcane crop on 15th of each month, and analysed for juice extract (%), Brix (%), Pol (%) and purity (%).The mean data value for each quality is given in Table 1, and whole data points for each quality collected every month were used for the calculation of sucrose recovery (%) as per Table 2. The level of quality parameters increased from October to December and then gradually decreased till harvest termination. A similar trend in crop potential during the whole harvest period was found previously (Ongin'jo and Olweny, 2011; Qudsieh *et al.*, 2001). The extent of variation in each quality parameter followed almost the same pattern in the harvesting period as for sucrose recovery (Table 2).

Maturity as well as ageing period was noted to have a great impact on sucrose recovery of all the cultivars (Scarpari and Beauclair, 2004). Analysis of variance for sucrose recovery and other quality parameters revealed a highly significant variation ($P<0.01$) within the cultivars and the harvest period. A highly significant increase in mean sucrose recovery varying from 9.64 to 11.63% was observed during October to December. The level, however, decreased significantly thereafter from 10.45 to 9.17% reaching a minimum of 7.22% in March with a fall in recovery of 1.18, 1.28 and 1.95% in January, February and March respectively (Table 2). Similar quality changes during crop maturation and decaying have been reported previously (Gilbert *et al.*, 2006; Habib *et al.*, 1992).

Table 1. Overall mean cane juice quality parameters of various sugarcane cultivars.[1]

Variety	Juice (%)	Brix (%)	Pol (%)	Purity (%)
HoSG-104	74.26 d	18.99 l	15.89 hi	83.63 g
HoSG-1257	74.10 e	19.26 i	16.03 fg	83.15 i
HoSG-2875	74.62 cd	20.00 cd	16.90 b	84.42 e
CP-72-2086	72.89 f	19.55 gh	16.40 e	83.87 f
CPF-237	72.30 h	19.09 k	15.80 i	82.69 j
HSF-240	74.83 c	19.75 f	16.75 c	84.79 d
HSF-242	71.29 k	19.92 de	16.09 f	80.71 q
SPF-234	71.88 i	18.99 l	15.57 k	81.90 l
CPF-243	71.81 j	20.28 b	16.59 d	81.70 m
CP-65-357	71.34 k	18.77 m	15.98 gh	85.06 c
CP-85-1491	74.41 d	19.62 g	16.11 f	82.04 k
LRK-2003	68.11 o	19.21 ij	15.68 j	81.48 n
CP-80-1827	71.80 j	17.45 o	15.31 l	87.65 a
CP-87-1628	71.73 j	20.03 c	17.07 a	85.19 b
CPF-246	72.61 g	18.75 m	15.98 gh	85.17 bc
CSSG-676	75.48 b	20.44 a	17.10 a	83.61 h
CSSG-668	70.82 l	19.87 e	16.09 f	80.90 p
SPSG-394	72.58 g	19.48 h	15.83 i	81.19 o
GT-11	69.86 m	16.85 p	13.56 o	80.35 r
HoTh-127	71.80 j	18.63 n	14.89 n	79.82 s
SPSG-26	69.27 n	19.20 ij	15.18 m	78.95 t
CP-77-400	75.60 a	20.00 cd	16.64 d	83.13 i
Ganjbakhsh	71.17 k	19.15 jk	14.85 n	77.77 u
Mean	72.37	19.27	15.92	82.57

[1] Response of three replicates. Different letters in a column indicate significant difference (P<0.01). Mean square (error) for juice (6.3%, LSD = 0.529), Brix (1.1%, LSD = 0.221), Pol (1.2%, LSD = 0.231) and purity (1.7%, LSD = 0.275).

When plotting the overall data of each quality profile against respective harvesting period, a polynomial relationship was displayed and the data fitted well as per high coefficient of correlation $R^2 \approx 1$ (Figure 1). Sucrose recovery in total, for example, which is in fact an accumulative index of cane juice, Brix, Pol and purity had followed a quadratic equation of the type $Y = -0.4143x^2 + 11.928x - 74.591$ (R^2=0.9797). Each of the cultivars however presented a distinct set of quadratic parameters for each quality. The decline in quality after reaching full maturity is attributed to crop ageing as well as to the change in prevailing climate (Zhao and Li, 2015). According to meteorological data the climate in Pakistan became harshly cold with frost onset after the December crushing stage (Anonymous, 2011b). Owing to complex physiological changes initiated therein, the crop started drying off and weight loss resulted (Eggleston *et al.*, 2008). The simultaneous reduction in pH of the juice also caused a significant decrease in Brix, Pol and purity of the juice. The sucrose reserves became depleted, converting into low molecular weight sugars and their degraded components (Nayamuth *et al.*, 1999; Saxana *et al.*, 2010; Solomon *et al.*, 2011; Wang *et al.*, 2014). With the rise in temperature again at the beginning of March, the crop started sprouting with dextran accumulation (Eggleston *et al.*, 2008; Wojtczak, 2011; Wojtczak *et al.*, 2014). Moreover, the microbes and inherent enzymes sparked off sucrose fermentation/degradation at a rapid rate (Singh *et al.*, 2008). In the end, such adverse changes considerably damaged sucrose recovery of the crop. However, the sucrose build-up during crop maturation and that of depletion on ageing varied from one variety to another, and is considered specific to varietal clones (Table 2).

Productivity-based evaluation

Sugarcane cultivars are frequently screened for levels of quality like Pol, Brix or other similar parameters observed on full maturity or on mean estimates throughout the harvesting period. Both of the estimates appear to be reasonable and have been largely adopted in the past (Das *et al.*, 1997; Gilbert *et al.*, 2006; Habib *et al.*, 1992; Tejera *et al.*, 2007; Wagih *et al.*, 2004) yet give quite erroneous results. Looking at the data based on 23 varieties (Table 1 and 2), there appeared to be a steady rise in quality with time until it reached a peak, then started declining immediately or after a pause till the end of harvest. The

Table 2. Sucrose recovery of various sugarcane cultivars during the harvesting period.[1]

Variety	October	November	December	January	February	March
HoSG 104	9.90	10.91 o-s	11.48 h-k	10.73 p-v	9.70	7.84
HoSG-1257	10.14	11.10 m-p	11.93 d-f	10.67 r-x	9.32	7.58
HoSG-2875	10.75 p-v	11.52 g-k	12.52 a	11.46 h-l	10.37	8.62
CP-72-2086	9.99	10.85 p-t	11.78 e-g	10.92 o-s	9.70	8.25
CPF-237	9.87	10.78 p-u	12.26 b	10.15	8.57	6.68
HSF-240	10.57 u-y	11.47 h-k	12.39 ab	11.39 j-m	10.42	8.83
HSF-242	9.57	10.38	11.98 c-e	10.00	8.68	6.57
SPF-234	9.39	10.40	11.33 k-m	10.32	8.62	6.50
CPF-243	10.09	10.94 o-r	12.38 ab	10.31	9.18	7.10
CP-65-357	10.01	10.95 o-q	11.90 d-f	10.45	9.58	7.03
CP-85-1491	9.37	10.49 v-z	12.23 bc	10.69 q-w	9.65	8.00
LRK-2003	9.32	10.13	11.52 g-k	9.96	7.69	5.44
CP-80-1827	10.14	10.92 o-s	11.75 e-g	10.43	9.04	6.76
CP-87-1628	10.38	11.30 k-m	12.15 b-d	11.20 l-n	10.13	8.66
CPF-246	9.74	10.58 t-y	11.60 g-j	10.77 p-u	9.65	8.15
CSSG-676	10.59 t-y	11.67 f-i	12.58 a	11.85 ef	10.67 r-x	8.83
CSSG-668	9.18	10.29	11.73 e-h	9.88	9.09	6.67
SPSG-394	9.52	10.25	11.29 k-m	10.21	9.23	6.95
GT-11	7.54	8.55	9.43	9.09	7.22	5.46
HoTh-127	8.67	9.56	10.47 v-z	9.69	8.07	6.17
SPSG-26	8.28	9.31	10.18	9.53	7.92	5.98
CP-77-400	10.08	11.14 m-o	12.25 b	11.30 k-m	10.66 s-x	8.70
Ganjbakhsh	8.68	9.54	10.41	9.73	7.82	5.37
Mean	9.64 d	10.56 b	11.63 a	10.45 c	9.17 e	7.22 f

[1] Response of three replicates. Different letters in a column or row indicate significant difference (*P*<0.01). Mean square (error) for recovery (%) 1.2% (LSD=0.231).

trend over 6 months' harvest period followed a quadratic regression and is variety specific (Figure 1). No attention is paid to these effects for the variety evaluation at single full maturity, though the activity continues beyond this stage. Evaluation of the overall mean values show several varieties with low quality during the entire crushing season and are included in the assessment. It is therefore highly likely that an evaluation on these grounds will result in defective inferences. By comparing the varietal worth based on full maturity (December values) with that of the mean amounts, there will be an obvious difference in potential order between the two groups (Table 3).

Varieties like CPF-243, CPF-237 and HSF-242 are worth mentioning. Their potential decreased from 4th, 5th and 9th at full maturity to 11th, 14th and 16th in overall mean, respectively. Whereas the cultivars HoSG-104, CP-72-2086 and CPF-246 were upgraded from 17th to 8th, 12th to 6th and 15th to 9th position, respectively. A similar change in performance order was also seen in other cultivars (Table 3). The change in potential, which is normally considered a genotypic phenomenon, could possibly lead to the wrong assumption for any estimate. In our opinion the selection

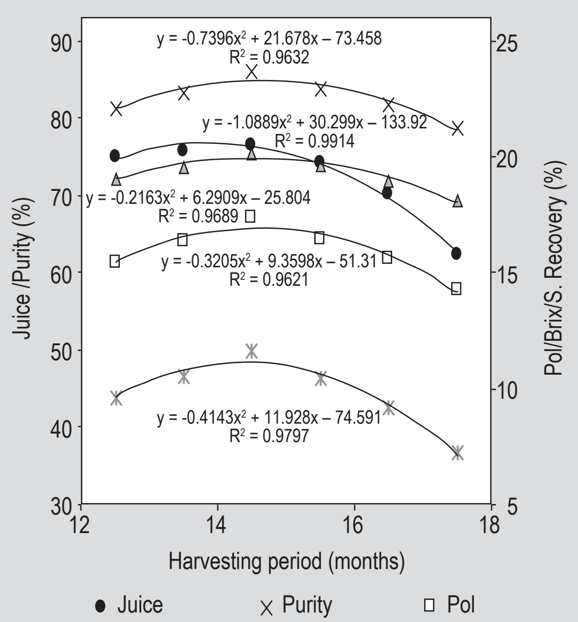

Figure 1. Overall quality changes in sugarcane cultivars during the harvesting period.

Table 3. Potential order of sugarcane varieties assessed as sucrose recovery at full maturity and six months' overall mean, and as productivity score.[1]

Full maturity (December)			Overall mean			Productivity (10^{-1})		
Variety	Magnitude	Order	Variety	Magnitude	Order	Variety	Magnitude	Order
CSSG-676	12.58 a	1	CSSG-676	11.03 a	1	CSSG-676	18.70 a	1
HoSG-2875	12.52 ab	2	HoSG-2875	10.87 ab	2	HoSG-2875	17.22 a	2
HSF-240	12.39 abc	3	HSF-240	10.85 b	3	HSF-240	16.41 b	3
CPF-243	12.38 abc	4	CP-77-400	10.69 c	4	CP-77-400	15.72 c	4
CPF-237	12.26 bcd	5	CP-87-1628	10.64 c	5	CP-87-1628	15.08 c	5
CP-77-400	12.25 bcd	6	CP-72-2086	10.25 d	6	CP-65-357	13.52 d	6
CP-85-1491	12.23 cd	7	HoSG-1257	10.12 e	7	CPF-243	13.40 de	7
CP-87-1628	12.15 cde	8	HoSG 104	10.09 ef	8	CP-85-1491	13.00 de	8
HSF-242	11.98 def	9	CPF-246	10.08 ef	9	HoSG-1257	12.98 ef	9
HoSG-1257	11.93 ef	10	CP-85-1491	10.07 ef	10	CP-72-2086	12.79 ef	10
CP-65-357	11.90 ef	11	CPF-243	10.00 f	11	CP-80-1827	12.33 fg	11
CP-72-2086	11.78 fg	12	CP-65-357	9.99 f	12	HoSG 104	12.07 g	12
CP-80-1827	11.75 fgh	13	CP-80-1827	9.84 g	13	CPF-237	12.07 g	13
CSSG-668	11.73 fgh	14	CPF-237	9.72 h	14	CPF-246	10.98 h	14
CPF-246	11.60 ghi	15	SPSG-394	9.58 i	15	HSF-242	10.85 h	15
LRK-2003	11.52 g-j	16	HSF-242	9.53 ij	16	CSSG-668	9.78 i	16
HoSG 104	11.48 hij	17	CSSG-668	9.47 jk	17	SPF-234	9.72 ij	17
SPF-234	11.33 ij	18	SPF-234	9.42 k	18	SPSG-394	9.22 ij	18
SPSG-394	11.29 j	19	LRK-2003	9.01 l	19	LRK-2003	9.08 j	19
HoTh-127	10.47 k	20	HoTh-127	8.77 m	20	Ganjbakhsh	5.08 k	20
Ganjbakhsh	10.41 kl	21	Ganjbakhsh	8.59 n	21	HoTh-127	4.79 k	21
SPSG-26	10.18 l	22	SPSG-26	8.53 n	22	SPSG-26	3.01 l	22
GT-11	9.43 m	23	GT-11	7.88 o	23	GT-11	0	23

[1] Magnitudes are response of three replicates. Means in the same column with different letters differ significantly ($P<0.01$).

of defective maturity demarcation as well as counting inappropriate levels of quality rendered both the appraisals unreliable.

Let us now consider the potential of a cultivar based on productivity score. Before evaluating the cultivars on productivity, EPP over the entire harvesting stage for each variety has to be identified. For this purpose, it was considered appropriate to fix sucrose recovery (%) at a productive level that would also be acceptable to the country. The recovery yield is normally taken by examining juice extracts, Pol, Brix and purity of cane juice (Chen and Chou, 1993), the parameters varying with growth and maturity level of a crop. A Pol ≥16% and purity ≥80% are commercially acceptable levels for this purpose (Wagih *et al.*, 2004). In the light of the above assumptions together with presently available overall juice levels of 72.37%, Pol 15.92% and purity 82.57% (Table 1) a calculated sucrose recovery of 9.5% is assumed to be a productive and valid level for variety evaluation. The adopted amount is more than 9.0% reported maximum recovery in Pakistan (Khushk *et al.*, 2011). Now it is necessary to calculate the EPP over which at least 9.5% baseline sucrose recovery is maintained by a variety (Figure 2). The EPP range (month) was calculated by inserting 9.5 in a quadratic equation of each variety (Table 4). The total sucrose recovery above 9.5% is calculated by integrating a respective polynomial equation for each variety within the stipulated EPP limits, and productivity (total sucrose recovery ≥9.5% per unit EPP) determined (Table 3 and 5).

Most of the varieties differed significantly ($P≤0.01$) from each other based on productivity scores, however these were grouped into 4 categories. CSSG-676, HoSG-2875, HSF-240, CP-77-400 and CP-87-1628 cultivars have a productivity score ranging from 18.70 to $15.08×10^{-1}$ and are placed in the top position (group 1). It is pertinent to note that these varieties produced 9.78 to 7.69% excessive sucrose recovery above 9.5% during the EPP range of 5.00-5.35 months. A larger group of cultivars including CP-65-357, CPF-243, CP-85-1491, HoSG-1257, CP-72-2086, CP-80-1827, HoSG-104 and CPF-237 had a 13.52 to $12.07×10^{-1}$ productivity score and are also considered very productive (group 2). CPF-246, HSF-242, CSSG-668, SPF-234, SPSG-394 and LRK-2003

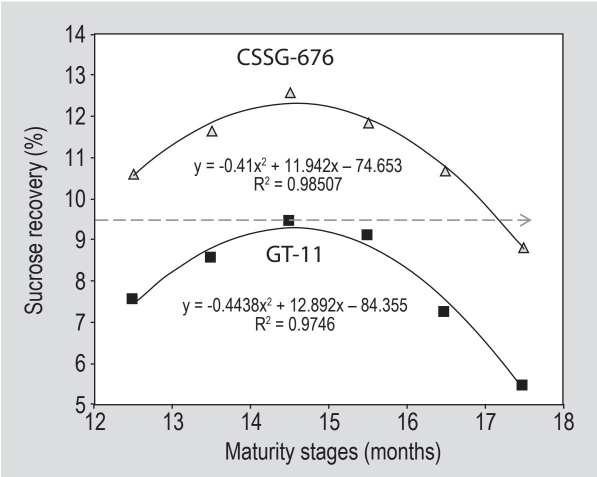

Figure 2. Two typical sugarcane cultivars crossing the minimum standard of 9.5% sucrose recovery.

cultivars had productivity in the range of 10.98 to 9.08×10^{-1} of low profile (group 3). A minimum productivity score of 5.08 to 3.01×10^{-1} was assigned to Ganjbakhsh, HoTh-127 and SPSG-26 cultivars which presented a poor performance (group 4). Comparing the potential of cultivar CP-87-1628 occupying a bottom score (15.08×10^{-1}) within the 1st group was found to have 1.12-1.25, 1.37-1.66 and 2.97-5.01 times higher productivity score than those in group 2, 3 and 4, respectively. The phenomenon of diversified performance is considered to be genotypic and variety-specific for having its own ageing process and ability to withstand adverse environmental stresses (Arain *et al.*, 2011).The variety GT-11 could not meet the requisite baseline criterion of 9.5% sucrose recovery (Table 3 and 4), and is considered the most inferior variety.

In order to justify the technique developed, the varietal potential in the form of 'productivity score' is compared with those from the 'estimates at full maturity' and 'overall means'. The cultivars HSF-240 (12.39%) and CPF-243 (12.38%) had the same sucrose recovery level at full maturity (Table 3). Based on productivity the variety HSF-240 with 16.41×10^{-1} score is far superior to CPF-243 of 13.40×10^{-1}. Similarly, comparing CPF-237 and CP-77-400 with an equal maximum sucrose recovery (12.25), there was a highly significant different level on productivity scale of 12.07×10^{-1} and 15.72×10^{-1} respectively. The cultivars CPF-243 (12.38), CPF-237 (12.26) and CP-85-1491 (12.23), though quite promising and superior in terms of sucrose recoveries

Table 4. Efficient production period, efficient production period (EPP) range and crushing span covered by various sugarcane varieties.[1]

Variety	EPP range	EPP (month)	EPP span	Crushing span (%)
HoSG 104	12.20-16.60	4.40 def	Oct 06-Feb 18	73.33
HoSG-1257	12.05-16.55	4.50 de	Oct 01-Feb 17	75.00
HoSG-2875	11.80-17.05	5.25 ab	Sep 24-Mar 02	87.50
CP-72-2086	12.20-16.75	4.55 d	Oct 06-Feb 23	75.83
CPF-237	12.20-16.25	4.05 hi	Oct 06-Feb 08	67.50
HSF-240	11.85-17.20	5.35 a	Sep 26-Mar 06	89.17
HSF-242	12.50-16.15	3.65 jk	Oct 15-Feb 05	60.83
SPF-234	12.50-16.10	3.60 k	Oct 15-Feb 03	60.00
CPF-243	12.10-16.40	4.30 efg	Oct 03-Feb 12	71.67
CP-65-357	12.40-16.50	4.10 gh	Oct 12-Feb 15	68.33
CP-85-1491	12.60-16.70	4.10 gh	Oct 18-Feb 21	68.33
LRK-2003	12.65-15.90	3.25 l	Oct 20-Jan 27	54.17
CP-80-1827	12.10-16.30	4.20 fgh	Oct 03-Feb 09	70.00
CP-87-1628	11.90-17.00	5.10 bc	Sep 27-Mar 01	85.00
CPF-246	12.25-16.75	4.50 de	Oct 08-Feb 23	75.00
CSSG-676	11.95-17.18	5.23 ab	Sep 29-Mar 05	87.17
CSSG-668	12.65-16.25	3.60 k	Oct 20-Feb 08	60.00
SPSG-394	12.55-16.40	3.85 ij	Oct 17-Feb 12	64.17
GT-11	–	–	–	–
HoTh-127	13.25-15.65	2.40 m	Nov 08-Jan 20	40.00
SPSG-26	13.50-15.50	2.00 n	Nov 15-Jan 15	33.33
CP-77-400	12.20-17.20	5.00 c	Oct 06-Mar 06	83.33
Ganjbakhsh	13.20-15.60	2.40 m	Nov 06-Jan 18	40.00

[1] Magnitudes are the response of three replicates. Means in the same column with different letters differ significantly (P<0.01).

Table 5. Cane yield and sugar yield*data of the selected sugarcane varieties.[1]

Variety	Cane yield (T/ha)	Excessive sucrose recovery (%)	Excessive sugar yield (T/ha)	Potential order
CSSG-676	126.21 ef	9.78 a	12.34	1
CP-77-400	148.30 a	7.86 b	11.66	2
HSF-240	126.09 ef	8.78 ab	11.07	3
CP-87-1628	139.47 b	7.69 b	10.73	4
HoSG-2875	95.80 no	9.04 a	8.66	5
CP-80-1827	137.27 b	5.18 c	7.11	6
CP-85-1491	127.46 def	5.33 c	6.79	7
CPF-243	114.98 hi	5.76 c	6.62	8
CPF-246	126.26 ef	4.94 cd	6.24	9
HoSG 104	102.21 lm	5.31 c	5.43	10
CP-72-2086	90.74 p	5.82 c	5.28	11
HoSG-1257	88.41 p	5.84 c	5.16	12
CPF-237	99.49 mn	4.89 cd	4.87	13
SPSG-394	133.39 c	3.55 e	4.74	14
CSSG-668	130.29 cd	3.52 e	4.59	15
CP-65-357	80.53 p	5.54 c	4.46	16
SPF-234	125.54 ef	3.50 e	4.39	17
HSF-242	108.20 jk	3.96 de	4.28	18
LRK-2003	119.51 g	2.95 e	3.53	19
Ganjbakhsh	100.45 m	1.22 f	1.23	20
HoTh-127	105.83 kl	1.15 f	1.22	21
SPSG-26	95.51 o	0.60 f	0.57	22
GT-11	128.36 def	–	–	–

[1] Response of three replicates. Different letters in a column indicate significant difference (P<0.01).

(%) at full maturity from HoSG-1257 (11.93), CP-72-2086 (11.78) and HoSG-104 (11.48), remained statistically at par as per productivity-based evaluation (Table 3). Similarly comparing productivity scores of HSF-242 (10.85×10^{-1}) with HoSG-1257 (12.98×10^{-1}), and CSSG-668 (9.78×10^{-1}) with CP-72-2086 (12.79×10^{-1}), a significant difference was observed within these groups of cultivars although they occupied the same group at full maturity. It is interesting to note that LRK-2003 (11.52%) had a greater sucrose recovery in December than that of HoSG-104 (11.48%), even though it is absolutely inferior in terms of productivity (Table 3).

When comparing overall mean estimate with productivity score, the 5 leading varieties had the same potential order under both the scales. A potential discrepancy does however exist for several other varieties of relatively lower potential order. Notable examples are referred to here. HoSG-104 variety in overall mean had changed its potential order with respect to CP-85-1491, CPF-243 and CP-65-357 from top to bottom on the productivity scale. CP-80-1827, a statistically inferior cultivar to HoSG-104, CPF-243 and HoSG-1257 in mean estimate, did however gain a statistically similar position on the productivity scale. Several other obvious inconsistencies did exist between overall mean estimates and productivity score (Table 3). From these studies it became quite clear that productivity-based scoring gives the true potential of a variety and delivers dependable results. The scale is framed on rational grounds taking the real value of a variety in terms of sucrose recovery per unit of productive period.

The performance of varieties is also presented in the form of a dendrogram (Figure 3). Cluster analysis based on the productivity of 22 sugarcane varieties showed that there are three main groups, referred to as A, B and C. Varieties CSSG-676, HoSG-2875, HSF-240, CP-77-400, and CP-87-1628 fall into group A of similarity. They have an average 90% coefficient of total productivity. The group A on the extreme left is linked to the group B containing three varieties (Ganjbakhsh, HoTh-127, SPSG-26). The analysis of group B revealed major differences in productivity compared to the other varieties. The group AB appeared linked to group C on the far right. Based on similarities group C had three sub groups in their productivity size consisting of a group of 14 varieties in this cluster. Furthermore, all of the 22 varieties could also be placed into several groups with statistically distinct letters of significance, yet there was extensive overlap in standard deviations and ranges in these groups. The most superior cultivars were CSSG-676, HoSG-2875, HSF-240, CP-77-400

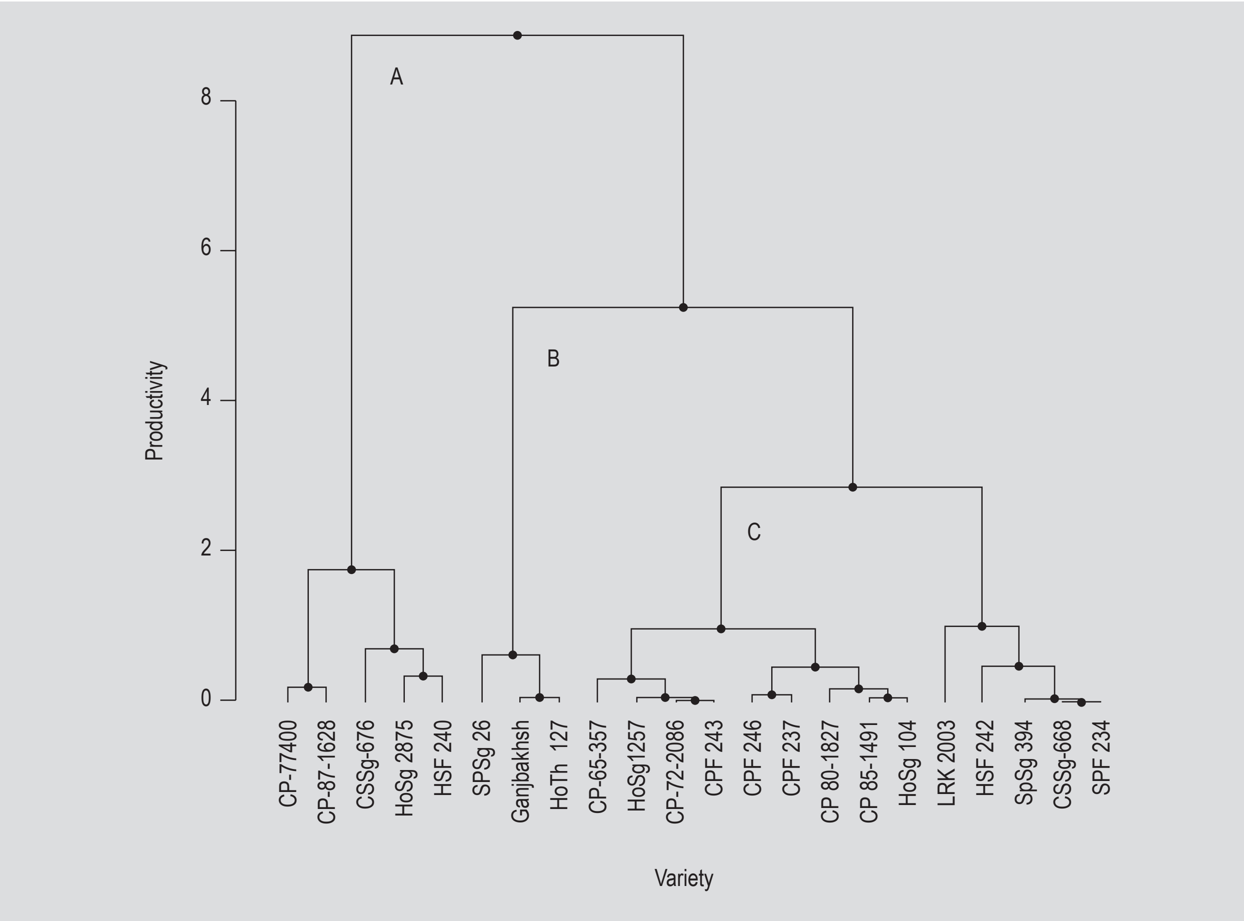

Figure 3. Dendrogram of 22 sugarcane cultivars.

and CP-87-1628, and the least productive varieties were SPSG-26, HoTh-127 and Ganjbakhsh. The variety GT-11 had no productivity and was thus discarded.

It is interesting to note that the productivity technique introduced in this study is unique in the sense that crop performance evaluation is based on the productive level of sucrose recovery estimates having commercial significance. The technique quantifies the precise magnitude of sucrose recovery over the entire efficient production period and displays the exact rationale of a variety. The methodology has never been worked out before as applied in the present format.

Crop crushing schedule

The data on EPP range (Table 4) of each cultivar were further plotted to find out the potential time period (specific date) during which a variety harnessed sucrose recovery of ≥9.5% (Figure 4). Based on EPP the cultivars could be grouped into 4 distinct classes. The cultivars CP-77-400, CP-87-1628, CSSG-676, HoSG-2875 and HSF-240 had 5.00 to 5.35 efficient production period (month) and cover 83.33% to 89.17% crushing span starting from late September till early March (ending February). Varieties of this group acquired harvesting maturity at the most 11 months after planting. These results correspond to the findings of other researchers reporting 8 to 11 months to ripening of early sugarcane varieties cultivated in Pakistan (Hussain *et al.*, 2004), India (Das *et al.*, 1997), Mauritius (Wagih *et al.*, 2004) and Indonesia (Indriani and Sumiarsih, 1995). The early maturing cultivars of the present study with a long production period had the capacity to support in late crushing periods and hence would serve in the event of a shortfall of late varieties, which are becoming insufficient to meet heavy industrial demands.

The cultivars CPF-237, CP-85-1491, CP-65-357, CP-80-1827, CPF-243, HoSG-104, HoSG-1257, CPF-246 and CP-72-2086 had 4.05-4.55 months EPP and covered crushing tenure of 67.5-75.83% (early October to mid-February). These cultivars would also be helpful in running the crushing season smoothly. LRK-2003, SPF-234, CSSG-668, HSF-242 and SPSG-394 comprised on 3.25 to 3.85 months EPP with 54.17-64.17% crushing span (mid-October to early February). The potential of these varieties could be best utilised if harvested near the stipulated maturity period. SPSG-26, Ganjbakhsh and HoTh-127 varieties had a milling

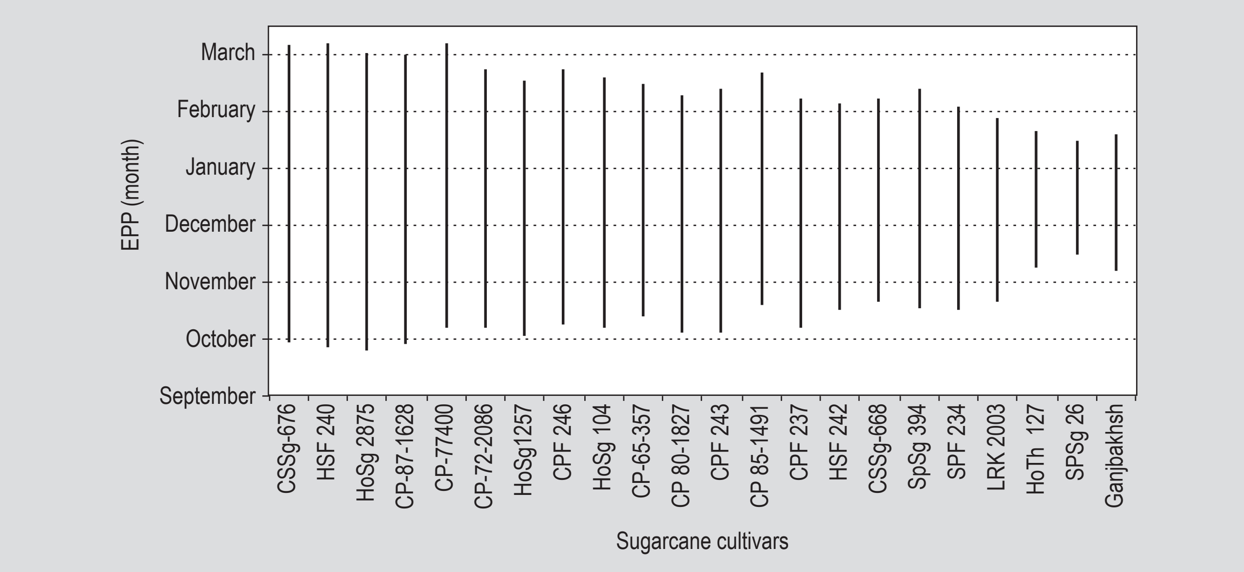

Figure 4. Sugarcane cultivars with respective efficient production period (EPP) range.

span of 2.0-2.4 months starting from mid-November to mid-January (Table 4). The cultivar GT-11 could not meet the minimum required sucrose recovery level of 9.5% and was therefore rejected.

Cane biomass and sugar yield data

Cane yield and excessive sugar yield data of twenty-three sugarcane cultivars are given in Table 5. Cane yield varied from 80.53 to 148.30 (T/ha) whereas excessive sucrose recovery ranged from 0.60 to 9.78% among sugarcane varieties. The CSSG-676, CP-77-400, HSF-240, CP-87-1628, HoSG-2875 and CP-80-1827 were found overall to be outstanding cultivars with respect to excessive sugar yield. The varieties CP-85-1491, CPF-243, CPF-246, HoSG-104, CP-72-2086, HoSG-1257, CPF-237 and CP-65-357 are also considered productive, with high excessive sugar yields. Ganjbakhsh, HoTh-27 and SPSG-26 varieties performed poorly and the cultivar GT-11 did not even meet the minimum standard of sucrose recovery level of 9.5% (Table 5).

Sugar processing is a seasonal and time-constrained activity, commencing in Pakistan normally from December, a period when most cultivars are no longer productive. Almost 50% material loss occurs upon initiation of late harvesting, which has a colossal impact on the national economy. The situation requires a restructuring of the crushing programme to earlier harvesting so as to fully utilise the national resources. Introducing new varieties and maintaining varietal diversification are highly desirable objectives for increased sugar yields from the beginning to the end of the season. Such provisions ensure that sugar and gur production is economical and sustainable (Muchow *et al.*, 1996). Bearing in mind the overall performance, 13 cultivars, namely CSSG-676, HoSG-2875, HSF-240, CP-77-400, CP-87-1628, CP-65-357, CPF-243, CP-85-1491, HoSG-1257, CP-72-2086, CP-80-1827, HoSG-104 and CPF-237 were screened and selected for further evaluation as regards ratoon cropping.

5. Conclusions

Twenty-three sugarcane genotypes (1^{st} year/plant crop) grown at Model Research Shakkarganj Farms (Pakistan) during 2008-10 were screened for their performance in terms of juice extract, Brix, Pol, purity and sucrose recovery on a monthly basis. Cane juice quality was seen to rise after 11-12 months till maturity with a decline thereafter via a quadratic equation with strong correlation coefficient ($r^2 \approx 1$). The LRK-2003, Ganjbakhsh, SPSG-26 and HoTH-127 performed poorly, while GT-11 failed to meet a minimum productivity criterion of ≥9.5% sucrose recovery. CSSG-676, HoSG-2875, HSF-240, CP-77-400, CP-87-1628, CP-65-357, CPF-243, CP-85-1491, HoSG-1257, CP-72-2086, CP-80-1827, HoSG-104 and CPF-237 proved to be potentially viable varieties. Such varieties displayed outstanding productivity by delivering excessive sucrose recovery and extended efficient production period (EPP) under adverse climatic stresses. Although the selected cultivars are still of early maturity, they are likely to cover the shortfall in late varieties. It is worth mentioning that the cultivars were screened developing a rationale technique of productivity based on total sucrose recovery in excess of 9.5%.

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Conflict of interest

The authors have no conflict of interest among them on any issue regarding the publication of this research article.

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