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Harvest index and the components of biological yield in sugarcane

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Abstract

Sugarcane has emerged as a new and potential source of power and bioethanol. Harvest index is a useful parameter to assess the suitability of different varieties for various end-uses. Field studies on harvest index were carried out involving sugarcane varieties and elite genotypes representing the varietal spectrum of subtropical India. The relative contribution of various components of biological yield, such as leaf, stalk and root biomass showed substantial differences among varieties. Harvest index for cane yield was found to vary between 66-81% for the commercial hybrids. The harvest index for sugar yield followed more or less a similar trend. Results highlighted the positive impact of inter-specific hybridization, as the current varieties had higher harvest index than the accessions of the parental cultivated species, namely, *Saccharum officinarum, S. barberi* and *S. sinense* and the wild species, *S. spontaneum*. The extent of variability for this important parameter provides scope for further improving the assimilate partitioning without jeopardizing the adaptability of sugarcane varieties under North Indian agro-climates.

Key words: Harvest index, sugarcane varieties, components of biological yield, cane yield, sugar yield, bagasse yield

Introduction

Harvest index (HI) is the measure of economic yield in relation to total biological yield. Depending on the economic product, harvest index varies widely. In grain crops with improved plant types, high harvest index is common, touching 0.6 [1, 2], whereas in sugarcane, the economic product is the vegetative cane stalk from which sugar is extracted. The harvest index ranges from 0.6 to 0.8 for sugarcane stalk and 0.06 to 0.10 for sugar yield [3, 4]. Potato, another crop where the vegetative underground stem is the plant part of economic importance, has a harvest index of about 0.9, since at harvest, the rest of the aerial portion of the plant has dried up [5].

However, it may not generally be realized that sugarcane and sugar revolution took place much earlier than the green revolution in grain crops in 1920s in India. Due to the advantage of clonal propagation, hybrid varieties have become the mainstay of cane cultivation. Sugarcane breeding pioneered the use of hybrid varieties and ushered in the unsung quantum jumps in cane yield with the successful interspecific crossing of *Saccharum officinarum* and *Saccharum spontaneum*. The first commercial hybrid Co 205 was released in 1918 and in no time it replaced the cultivated clones of *Saccharum barberi* in the subtropical region [6, 7]. The hybrids that followed improved upon the performance of the original hybrid and spread not only in India but also to other sugarcane producing countries. The current sugarcane varieties are generally derived from intervarietal crossing and are several generations removed from the original interspecific hybridization. At present, except for small pockets of pure *S. officinarum* accessions cultivated around the cities to meet the specific requirement of these canes in religious festivities, the hybrids have proved much more hardy, adaptable and productive [8].

Sugarcane breeding has come a long way from the era of early hybrids. Being a polyploid and interspecific hybrid, inter-varietal crosses have yielded most of the subsequent varieties. Consequently and indirectly, the partitioning of photosynthates in favour of the economic plant part i.e., cane stalk, has increased as a result of breeding. The fact that the steady enhancement of cane yield in India has been unaccompanied by any decline in juice quality is no

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small achievement [9]. This has led to indirect increase in sugar yield per unit area and time. Despite the remarkable breeding achievements in sugarcane, the harvest index has been studied rarely [10, 3, 4]. The present study was, therefore, undertaken to make a comparative assessment of the efficiency of subtropical sugarcane varieties in terms of harvest index, and to see if viewed in this light, any new conceptual as well as feasible breeding strategies could be identified.

Materials and methods

The material for this study comprised of seventeen sugarcane varieties bred at different sugarcane research stations of north India, such as Jalandhar (Punjab), Karnal (Haryana), Shahjahanpur and Lucknow (Uttar Pradesh), Pantnagar (Uttrakhand) and Motipur and Pusa (Bihar). These varieties served the sugar industry for nearly three decades and included some of the latest elite genotypes and advance selections (Table 1). These were planted in spring season (Feb-Mar) in rows 90 cm apart using the conventional three-bud setts. Experiments on sugarcane plant type, including the ones reported here, were carried out from 1999 to 2004. The recommended packages of practices were followed to raise a good crop both in field and in pots. Sampling for juice brix (*TSS: Total Soluble Solids*) and fibre content was done in the following January. For fibre estimation, a sample of bagasse was taken at the time of juice extraction from each genotype. Fibre content was estimated as per the method used by Henderson *et al*. [11]. In February, clumps were dug out to estimate different components of biological yield as described earlier [12].

In the following year, one representative accession each of *Saccharum officinarum, S. barberi, S. sinense* and *S. spontaneum* (Table 1) was grown to maturity in big metallic pots from sprouted single buds, along with a few representative commercial varieties. Data were recorded on the number and weight of millable canes, brix and weight of green leaves, the dry leaves and the roots in order to estimate biological yield and work out the harvest index as follows:

$$\text{Harvest Index for cane yield} = \frac{\text{Weight of millable canes}}{\text{Total biological yield}} \times 100$$

$$\text{Harvest Index for sugar yield} = \frac{\text{Brix \% juice} \times \text{Juice \% cane} \times \text{weight of millable canes}}{\text{Total biological yield}} \times 100$$

$$\text{Harvest Index for bagasse yield} = \frac{\text{Fibre \% cane} \times \text{weight of millable canes}}{\text{Total biological yield}} \times 100$$

Table 1. Details of the experimental material

S.No.	Variety/ accessions	Parentage	Year of release/ status
1	Co 1148	P 4383 x Co 301	1965
2	CoLk 9606	Co 7224 PC	NR
3	CoLk 9617	Co 62399 x BO 91	NR
4	Co 87263	Co 312 x Co 6806	1999
5	Co 1158	Co 421 GC	1963
6	CoLk 8901	Mutant of CoJ 64	NR
7	CoLk 8001	Co 62174 x Co 1148	1988
8	CoS 687	Co 976 x Co 312	1976
9	CoS 95255	Co 1158 x Co 62198	1996
10	LG 95056	Co 89003 x CoC 671	NR
11	R 1-40-8	Co 85007 x CoC 671	NR
12	BO 91	BO 55 x BO 43	1978
13	CoJ 64	Co 976 x Co 617	1975
14	CoPant 90223	BO 91 GC	2000
15	CoS 94257	BO 91 x Co 62198	1995
16	CoS 91269	BO 91 x Co 1158	1992
17	CoPant 90222	NA	NR
18	Rayada	*Saccharum officinarum*	Cultivated
19	WB-1	*Saccharum spontaneum*	Wild
20	Saretha	*Saccharum barberi*	Cultivated
21	Khelia	*Saccharum sinense*	Cultivated

NA: Not available NR: Not released for cultivation
Source: *Amalraj *et al*. [13]; *Srivastava and Srivastava [14].

Results and discussion

In the first experiment, on account of the conventional planting, it was not easy to tell apart different clumps. Therefore, the various components of harvest index were expressed on per cane basis (Table 2). Of the seventeen varieties evaluated, BO 91 was the leading variety for biological yield (a robust variety of the North Central zone with a well developed root system accounting for its tolerance to drought and water-logging), followed by CoLk 9617, R 1-40-8 and Co 87263. Based on the proportion of green leaves, CoLk 9617, CoS 91269, CoS 94257 and CoJ 64 were among

Table 2. Proportion of different components in biological yield

S.No.	Variety/accession	Biological yield/cane (kg)	% green leaves	% dry leaves	% root mass	% cane stalk
1	Co 1148	0.76	11.85	10.47	4.41	73.20
2	CoLk 9606	1.01	13.37	2.48	6.93	77.23
3	CoLk 9617	1.41	17.70	7.08	8.85	66.37
4	Co 87263	1.21	7.67	6.19	4.72	79.08
5	Co 1158	0.61	13.26	4.08	11.22	71.43
6	CoLk 8901	0.88	5.18	6.22	5.18	73.06
7	CoLk 8001	1.19	12.18	4.68	10.30	72.83
8	CoS 687	0.63	13.16	4.21	4.21	78.42
9	CoS 95255	1.10	14.41	4.20	14.11	67.27
10	LG 95056	0.99	9.64	6.09	3.04	81.22
11	R 1-40-8	1.24	10.55	3.02	7.54	78.89
12	BO 91	1.43	11.81	4.20	10.50	73.49
13	CoJ 64	0.87	16.04	7.40	6.72	69.84
14	CoPant 90223	1.06	7.55	1.89	9.43	81.13
15	CoS 94257	0.92	17.05	4.65	10.08	68.22
16	CoS 91269	1.00	17.61	1.66	10.63	70.10
17	CoPant 90222	0.80	10.42	4.69	11.98	72.92
	Mean	1.01	12.32	4.89	8.23	73.81
	Max	1.43	17.70	10.47	14.11	81.22
	Min	0.61	5.18	1.66	3.04	66.37
	SD	0.24	3.62	2.21	3.18	4.76
	CV(%)	23.97	29.40	45.13	38.65	6.45

the leafy genotypes. The percent of dry leaves in the total biomass could be an indication of the relative self de-trashing nature of sugarcane. On that score, Co 1148, CoJ 64, CoLk 9617, CoLk 8901, Co 87263 and LG 95056 are desirable genotypes. CoS 95255 is leafier coupled with a bulky root mass, yet it does not translate into a good harvest index. Another interesting pair is CoJ 64 and its mutant CoLk 8901 wherein the latter recorded a higher harvest index just because of a smaller proportion of green leaves. CoS 91269 is a late maturing variety attributable perhaps to the high proportion of its persistent green leaves. It is interesting to observe that maximum variation was for % dry leaves, followed by % root mass and % green leaves. The fact that minimal variation was observed for % cane stalk or the HI, points to the more or less efficient route various clones take for their sink development.

The most significant revelation is the proportion of root mass wherein the range is from 3 to 14%. It is interesting to note that genotypes with much smaller proportion of roots happen to have a high or at least intermediate HI. The proportion of root mass to the total biomass is an indication of '*root efficiency*' [12]. The efficient genotypes from this perspective were LG 95056, Co 1148, CoS 687 and Co 87263. With the exception of Co 1148, the rest are early maturing varieties, which are known to be poor ratooners. May be these have more superficial root spread. On the contrary, Co 1148 had been a reigning variety for a very long time due to its good ratooning and wide adaptability in the subtropical belt. On the other extreme were varieties such as CoS 95255, Co 1158, CoPant 90222, CoS 91269 and BO 91. In experiments with varietal mixtures, BO 91 was found to be a very aggressive partner in competition, so much so that it would smother other varieties by the ratoon crop [15]. No wonder, this variety is tolerant to water-logging and has an ideal plant type [16].

Coming to harvest index for cane yield (Table 3), it was found that varieties with harvest index towards the upper range, were morphologically closer to *Saccharum officinarum*. These were relatively thick-stalked, easy detrashing with a smaller proportion of green leaves and root mass. Such varieties were LG 95056, CoPant 90223, Co 87263, R 1-40-8 and CoS 687. However, it must be noted that the varieties with maximum area under them in subtropical India in 1980s and 1990s, namely, Co 1148 and BO 91, both mid-season maturing varieties, had rather intermediate harvest index for cane yield around 73%. Varieties found suitable for sugar productivity, the ultimate parameter of sugarcane plant's commercial efficiency, were CoLk 8001, LG 95056, CoS 687 and Co 1148. Genotypes with high HI for sugar were CoLk 8001, CoS 687 and LG 95056. All these happen to be high sugar varieties. It may be mentioned that earlier workers also observed significant differences for harvest index in a set of ten and thirty tropical varieties, respectively [10, 4]. On the other hand, harvest index was used to study the efficacy of gamma BHC and nitrogen application in sugarcane variety, CoJ 46 [3]. Interestingly, genotypes with high HI for fibre yield are among those with high HI for cane, and these were not necessarily the varieties with higher content of fibre. A similar observation was made with respect to sucrose in two Australian varieties that stalk biomass rather than stalk sucrose concentration was the major determinant of stalk sucrose accumulation [17]. Its noteworthy that in none of these studies, root mass was considered as a part of biological yield.

Table 3. Harvest index for various economic end - products

S. N.	Variety	Harvest index for cane yield	Harvest index for sugar yield	Harvest index for bagasse yield
1	Co 1148	73.20	9.92	9.84
2	CoLk 9606	77.23	9.02	11.15
3	CoLk 9617	66.37	7.82	11.62
4	Co 87263	79.08	8.95	12.46
5	Co 1158	71.43	7.31	12.21
6	CoLk 8901	73.06	8.98	10.68
7	CoLk 8001	72.83	10.59	10.71
8	CoS 687	78.42	10.01	10.08
9	CoS 95255	67.27	8.81	8.51
10	LG 95056	81.22	10.06	10.92
11	R 1-40-8	78.89	9.42	9.70
12	BO 91	73.49	8.02	9.25
13	CoJ 64	69.84	8.54	12.19
14	CoPant 90223	81.13	9.23	12.57
15	CoS 94257	68.22	7.24	10.83
16	CoS 91269	70.10	6.75	8.94
17	CoPant 90222	72.92	8.79	10.00
	Mean	73.81	8.79	10.70
	Max	81.22	10.59	12.57
	Min	66.37	6.75	8.51
	CV %	6.45	12.30	11.65

A preliminary comparison of the components of biological yield among hybrid cultivars of sugarcane and the representative accessions of *Saccharum* species presents an interesting scenario (Table 4). It is obvious that the hybrid varieties are far superior in harvest index than the parental species in terms of root weight, cane weight and plant weight to root weight ratio. Sugarcane cultivars have a much greater root efficiency and are more efficient utilizers of applied nutrition, particularly the ones with high harvest index, for example Co 87263 and Co 1148. The weed-like species accessions namely, Saretha (*S. barberi*) and WB-1 (*S. spontaneum*) have nearly a quarter of their biological yield attributable to root mass. The hardiness of these species on account of larger root system has been well reported [18, 19]. Further, the former has nearly 60% contribution of leaves to the biological yield. Viewed in this light, hybrid sugarcane varieties show more efficient plant type.

Results on harvest index are indicative of two types of sugarcane varieties that broadly get accepted by the farmers and the industry. The rugged kind with intermediate HI are better adapted to subtropical agro-climates and become popular with the farmers. The other kind is rather the high-input, management responsive varieties with better cane quality. These require greater care and better nurture to perform to their potential, generally possible with only the progressive well-to-do farmers and are more popular with the industry due to a greater juice extraction (lower fibre content) and higher sugar content. Such varieties, exemplified by LG 95056, Co Pant 90223 and Co 87263, tend to be self-detrashing and erect in bearing and may be more amenable to mechanical harvesting.

The current sugarcane scenario is much more flexible in accepting varied kind of varieties where higher fibre content is no more a taboo, if it is

Table 4. Proportion of biological components and harvest index for cane yield in pot-grown material from single buds

S.No.	Genotype	Total plant weight	Cane weight (kg)	Weight of green leaves (kg)	Weight of dry leaves (kg)	Root weight (kg)	% stalks harvest index (cane)	% RW	% GLW	% DLW	CW/ RW	PW/ RW
1	CoS 95255	4.735	2.000	1.600	0.160	0.700	42.24	14.78	33.79	8.00	2.86	6.76
2	Co 1148	3.800	2.500	0.575	0.250	0.195	65.79	5.13	15.13	10.00	12.82	19.49
3	Co 87263	4.150	3.000	0.600	0.250	0.150	72.29	3.61	14.46	8.33	20.00	27.67
4	BO 91	6.675	3.800	1.375	0.375	0.715	56.93	10.71	20.60	9.87	5.31	9.34
5	Rayada (SO)	5.600	2.900	1.150	0.250	0.860	51.79	15.36	20.54	8.62	3.37	6.51
6	WB-1 (SSp)	4.925	2.000	0.675	0.250	1.300	40.61	26.40	13.71	12.50	1.54	3.79
7	Saretha (SB)	9.100	1.800	2.550	0.550	2.375	19.78	26.10	28.02	30.56	0.76	3.83
8	Khelia (SS)	7.350	3.350	2.600	0.400	0.950	45.58	12.93	35.37	11.94	3.53	7.74
	Average	5.792	2.669	1.391	0.311	0.906	49.38	14.38	22.70	12.48	6.27	10.64
	Max	9.100	3.800	2.600	0.550	2.375	72.29	26.40	35.37	30.56	20.00	27.67
	Min	3.800	1.800	0.575	0.160	0.150	19.78	3.61	13.71	8.00	0.76	3.79
	SD	1.802	0.716	0.820	0.124	0.704	16.37	8.45	8.68	7.48	6.68	8.48
	CV(%)	31.1	26.8	59.0	39.9	77.7	33.2	58.8	38.2	59.9		

RW: Root weight; CW: weight of canes; GLW: weight of green leaves; DLW: weight of dry leaves; PW: Total plant weight
SO : *Saccharum officinarum;* SSp: *Saccharum spontaneum;* SB: *Saccharum barberi;* SS: *Saccharum sinense*

accompanied by good sugar content. It is obvious that HI for sugar or fibre is much influenced by HI for millable canes/ cane yield, being the sink for these components. Till the technology for biomass conversion into bioethanol is economically feasible, the means to sugar and fibre are through a higher HI for cane yield. Therefore, breeders can keep a close eye on genotypes which better translate plant assimilates into economic plant parts. Harvest index can be a key parameter, which if not ignored, is seldom quantified to be a reliable selection parameter. This paper is a modest initiative in bringing forth the utility of this genotypic attribute as an aid to selection.

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