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RESEARCH ARTICLE

Genetic improvement in sucrose content in elite sugarcane clones of India

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Abstract

The sucrose content in sugarcane is the most important indicator in achieving a high recovery throughout the crushing season. Increasing the sugar content of cane is not as easy as increasing the yield of the cane. Genetic improvement in economic yield is a key to success in a breeding programme of sugarcane crop. For effective monitoring of the programme at the national or zonal level, it needs to be measured in quantitative terms at regular intervals. The overall genetic improvement in sucrose content was found positive from 1991 to 2019 in three groups, i.e. 1.53% from 1991 to 2000, 0.80% from 2001 to 2010, and 1.08% from 2011 - 2019 over the base period 1989 to 1990. However, the progressive trend was observed only in the Peninsular Zone. In Peninsular and North Central Zones, genetic improvement in sucrose content was increasing and found positive during 1991 to 2019. In recent years 2011-2019, a negative trend in sucrose content was observed in North West and East Coast Zones. Improvement in sucrose content was possible because the emphasis was more on the development of early maturing varieties in comparison to mid-late maturing varieties. From 1982 to 2018, nearly 72.45 percent of early maturing varieties were identified in India. These findings will help to identify the causes of trends in genetic improvement in framing the policies for varietal development programmes in a different zones. Such type of studies may be replicated for other crops to estimate the genetic improvement in different zones in yield based on the genotypes tested over a period of time under All India Coordinated Research Project network in the country.

Keywords: Genetic improvement; Elite sugarcane clones; Sucrose content; Agro climatic zones; Sugarcane; India.

Introduction

India was the largest sugar producer in the world during 2018-19 (33.07 million tonnes) which accounted for nearly 17.57% of the total production (Anonymous 2019). In-spite of poor rainfall in some of the tropical sugarcane growing states of India, the country had managed to produce surplus sugar from 2015 to 2020 except 2016-17 and also exported sugar to more than 80 countries during 2011 to 2019. The country emerged as the third-largest exporter (9.1 %) in the world during 2019 by exporting worth Rs. 13.119 thousand crores (1.8 billion US dollars (Anonymous 2020). The total value of sugar and molasses export was Rs. 10.11 thousand crores during 2018-19. It ranked 8th among India's Export of Principal Agricultural and allied Commodities (Source: DAC&FW). India by contributing 18.01 % in area and 19.76 % in production ranked second among sugarcane growing countries of the world for both area and production of sugarcane during 2018 (Anonymous, 2020b). Sugar manufacturing is the second largest agro-based processing industry in our country. The turn over of sugar and other related economic activities (which includes sugarcane, gur, and others) were approximately Rs.123, 372 thousand crores per annum during 2018-19 at the current price, out of which, nearly Rs. 86,277 thousand crores were paid to the sugarcane farmers by the sugar mill as prices for its supply during 2018-19. It is estimated that about 5.568 million sugarcane cultivators/ farmers and 6.769 sugarcane laborers

(total of about 12.337 million sugarcane workers) are engaged in the cultivation of sugarcane in India, which accounts for 1.427 % of the total rural population of India (Kumar et al. 2016). Out of 6.26 million sugarcane landholdings of the country, 82.82 % are marginal (less than 1.0 ha) and small (1.0 to 2.0 ha) which occupy nearly 54.44 % sugarcane area. Five lakh skilled and unskilled workers including highly qualified and trained technologists are engaged in the manufacturing of sugar. It contributed nearly 0.616 % in GDP of the country in the year 2018-19 at current prices with an area of nearly 5.502 million hectares and the same trend is expected to follow in the coming years also.

Quality of sugarcane is the most important in achieving a high recovery throughout the crushing season. Increasing the sugar content of cane is not as easy as increasing the cane yield of the cane. As every cane grower knows, the cultural practices line irrigation, inter-cultivation, etc. have noticeable effect on the tonnage of cane, but none of these are commonly credited with being able to increase the sugar content of cane (Panje 1965). Only at peak maturity, the juice quality will be at its best and contains the highest amount of sucrose and purity and a minimum amount of reducing and other-sugars. Sugarcane is considered to have attained maturity when it contains a minimum of 16 % sucrose and 85 % purity in juice (Chiranjivi Rao 1982). Sugar recovery mainly depends on sugarcane variety, condition of the crop at the time of harvest, weather conditions prevailed during the crop season and duration of the crushing season (Rao et al. 1979). Sugarcane is an important source of sucrose, which has been for years an essential source of energy, even for consumption as food or to produce liquid fuels. Sugar was initially made in India during the fourth and sixth centuries by cutting sugarcane into pieces, crushing the pieces by weight to extract the juice, and then boiling it to crystalize. These crystals were called 'Sarkara' meaning gravel in Sanskrit. The word sugar is a derivative of 'Sarkara'. Arabs introduced it in Europe. Sucrose is the most important component in the processing of sugarcane, resulting in a crystal form, being susceptible to reactions as the decomposition in acidic and basic, through the effect of temperature and enzymes (Chen and Chou 1993).

Genetic improvement in economic yield is a key to success in a breeding programme of any crop. For effective monitoring of the program at the national or zonal level, it needs to measure in quantitative terms at regular intervals. Sugar recovery zones were developed for efficient planning and development of the sugar industry (Kumar and Mishra 2002). Genetic Contribution to yield gains in the Florida Sugarcane Industry across 33 Years was studied by Edme et al. (2005). They inferred that the genetic potential of the working germplasm has not been exhausted (no evidence of a yield plateau for sugarcane) in this sugarcane breeding program. These gains and future advances are possible because of the use of a diverse gene pool and a breeding strategy that integrates growers' participation in the program. Hogarth (1976) inferred that 75 % of the gains in cane yield in Australia were attributed to the varietal improvement and Edme et al. (2005) estimated that genetic improvement alone contributed 69 % of the sugarcane yield. Evans (1993) indicated that half of the increase could be traced to improvement introduced through plant breeding and a half through agronomy, both independent of each other. Hemaprabha et al. (2015) also reported the genetic improvement achievement at specific time intervals to assess the extent of genetic improvement in 48 sugarcane varieties commercially cultivated by the farmers in tropical India before 1960 till those of 2000 AD. In India, Nair (2008) reported that the yield and quality (sucrose %) potential of the varieties developed in the country has shown consistent

improvement over the years and there had been a progressive improvement in both yield and quality of the entries during the period, particularly for the Peninsular Zone. India is one of the pioneering countries for almost all the growing conditions in the world and varietal improvement through breeding has been a major focus and new varieties are continuously being evolved by Sugarcane Breeding Institute, agricultural universities and sugarcane research and development centers world over (Hemaprabha et al. 2015).

The All India Coordinated Research Project on Sugarcane (AICRP(S)) has been playing a pivotal role in the development of improved, location-specific sugarcane varieties for four agro-climatic zones viz., Peninsular, East Coast, North West and North Central and North-East zones of India The first workshop on sugarcane research, held at the Indian Institute of Sugarcane Research, Lucknow during January 15-18, 1970, suggested that under a coordinated variety trial, the promising types from the trial would be selected and shall be tested at all sub-centers and in farmer's holding (Anonymous 1970). Since then a large number of improved varieties have been identified through the AICRP trials, which are currently under cultivation in most parts of the country and have contributed in to improving sugarcane productivity. One of the major coordinated efforts right from the inception of the AICRP on Sugarcane has been the Zonal Varietal Trials which are conducted under the Crop Improvement discipline at about 40 research stations located in five sugarcane agro-climatic zones across the country (Figure 1). (North West Zone, North East Zone and North Central Zone, East Coast Zone and Peninsular Zone)

Genetic improvement in cane yield (t/ha) and sucrose (%) is a key to success in any breeding program of sugarcane. Effective monitoring of the program at the national or zonal level needs to measure in quantitative terms at regular intervals. Under new zonal varietal trial in sugarcane, elite clones are being evaluated since 1998-99 in all the five sugarcane agro-climatic zones. It is necessary to assess the impact of breeding programs on genetic improvement in sucrose (%) of sugarcane over the years. In this paper, an attempt has been made to assess the genetic improvement in sucrose content in elite sugarcane clones evaluated in zonal varietal trials conducted from 1989 to 2019 in all the four zones of varietal testing in India under AICRP(S) to develop a mechanism for evaluating the efficiency of proposed programs based on the estimated values of sucrose content. This will help in the modification of the varietal development program for sucrose content in the country.

Materials and Methods

Long term database of sucrose % in sugarcane juice recorded in zonal varietal trials, conducted in four zones of the country, was analyzed for genetic improvement over the years commencing from 1989 to 2019. The trials were conducted under the same set of agro-ecological conditions in a zone with separate trials of early (10 months crop) and mid-late (12 months crop) maturing varieties. In a particular zone, the trials were conducted for each year at all the locations with the same set of varieties, a package of practices, same time of planting/harvesting, seed rate, plot size, number of replications, and time of harvesting and with the same system of data recording. This is being done to maintain the uniformity of the trials in a zone which helps in the true assessment of the genetic expression of sugarcane clones. Data of average sucrose % of all the trials conducted were collected from reports of the Principal Investigator (Varietal Improvement Programme), AICRP(S) during the period 1989 to 2019. In calculating the average sucrose %, only test entries were considered. The entire period (twenty-seven years) was divided into four groups as 1989-1990, 1991-2000, 2001-2010, and 2011-2019. Percent

increase or decrease in sucrose % was calculated for each period over 1989-1990 (base year). This was done for each zone independently as well as overall (for the country as a whole) for early and mid-late trials. Genetic improvement in sucrose (%) is calculated as follows:

Genetic improvement in sucrose (%) =

$$\frac{\text{(Average value of sucrose (\%) for current year - Average value of sucrose (\%)for base year*)}}{\text{(Average value of sucrose (\%)for base year*)}} \times 100$$

*1989-1990.

The exponential equation which directly gives constant rate of increase/decrease per unit of time is a compound growth rate. In order to estimate compound growth rates of sucrose (%), exponential equations were fitted using time as independent and sucrose (%) as dependent variable. The equation is as follows:

$$Z=A(1+i)^x$$

By giving B=1+i in the above equation we get as

$$Z=AB^x$$

Z is sucrose % and x is time

The above equation can be rewritten in the logarithmic form as follows :

$$\log Z = \log A + x \log B$$

% compound growth rate is

Antilog (Log(b) -1) x 100.

Results and Discussion

Database on the evaluation of sugarcane clones on a zonal basis

From 1989 to 2019, a total of 633 trials were conducted in five zones representing different agro-ecological conditions under the Crop Improvement Programme of AICRP(S). Depending on the number of locations in a zone, the highest number (184) of trials (29.07 %) were conducted in Peninsular Zone followed by North West Zone (26.07 %), North Central & North Eastern Zones (24.01 %) and in East Coast Zone (20.85 %). In all the zones, 310 (48.97 %) trials were conducted in the early maturity group and 323 (51.03 %) in the mid-date maturity group (Table 1).

A total of 2872 elite clones were evaluated from 1989 to 2019. The highest number (39.69 %) of clones was tested in Peninsular Zone followed by 26.08 % in North West Zone, 22.70 % in North Central Zone and North Eastern Zone and minimum (11.56 %) in East Coast Zone. Out of 2872 clones, 548 (19.08 %) early maturing clones were evaluated in Advanced Varietal Trial (AVT) and 663 (23.08 %) in Initial Varietal Trial (IVT). Under the mid-late maturity group, a total of 686 (23.89 %) clones were evaluated in Advanced Varietal Trial (AVT) and 975 (33.95 %) in Initial Varietal Trial (IVT). From Table 2, it can be concluded that rejection of entries from IVT to AVT is more in mid-late than early group.

Table 1. Number of trials conducted under All India Coordinated Research Project on Sugarcane during 1989 -2019 in different zones

Zone	Early	Mid-late	Total
Peninsular Zone	81	103	184 (29.07)
East Coast Zone	77	55	132 (20.85)
North West Zone	80	85	165 (26.07)
North Central and North Eastern Zone	72	80	152 (24.01)
Total	310 (48.97)	323 (51.03)	633 (100)

Table 2. Number of entries tested in Initial Varietal Trials (IVT) and Advance Varietal Trials (AVT) under All India Coordinated Research Project on Sugarcane during 1989-2019

Zone	Early		Mid-late		Overall
	AVT	IVT	AVT	IVT	
Peninsular Zone	161	258	275	446	1140 (39.69)
East Coast Zone	125	84	64	58	331 (11.56)
North West Zone	106	186	179	278	749 (26.08)
North Central and North Eastern Zone	156	135	168	193	652 (22.7)
Total	548 (19.08)	663 (23.08)	686(23.89)	975 (33.95)	2872 (100)

Rejection level was 29.64 % in mid-late and 17.35 % in early group of entries in the country (Table 2).

Growth in sugar content in elite clones of sugarcane

Trend in sugar content of genotypes was found positive in Peninsular Zone, East Coast Zone, North Central and North Eastern Zone and overall India (Map 1). It was also observed that growth of sugar content is more in 2010-2019 than 2000-2009 for Peninsular Zone, East Coast Zone, North Central and North East Zone and overall India (Table 3). However, the largest cane producing zone (North West Zone) had growth of around 0.15% which is less than the previous decade 2000-2009 (Table 3). In previous decade, it recorded the highest growth of around 0.308% per annum in sugarcane clones of North West Zone. It is a very serious issue and it should be looked into. During 2010-2019, highest growth (0.893 % per annum) in sugar content was observed in East Coast Zone. Same trend was also observed in Peninsular Zone and overall India for improvement in sugar content. It can be concluded that if growth in sugar content in test genotype is more than 0.30% per annum in a zone then varieties released from that period will help in increasing the sugar production in next decade in the zone.

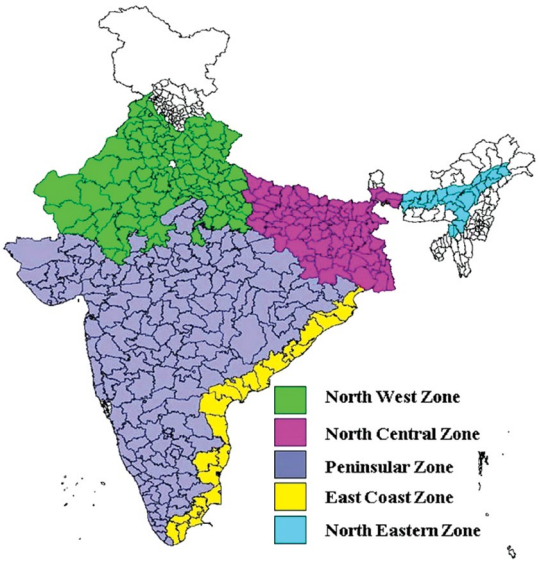

Figure 1. All India Coordinated Research Project on Sugarcane

Table 3. Annual compound growth rate (%) of sugar content in different zones of India during 2000-2019

Period	Peninsular Zone	East Coast Zone	North West Zone	North Central and North Eastern Zone	All India
2000-2009	0.247	0.104	0.308	-0.623	0.009
2010-2019	0.378	0.893	0.151	0.045	0.364

Genetic improvement in sucrose content of sugarcane elite clones

The genetic improvement in sucrose content was found positive from 1991 to 2019, i.e. 1.57% from 1991 to 2000, 0.85 % from 2001 to 2010, and 1.11 % from 2011 to 2019 over the base period 1989 to 1990 for over all the zones (Table 4). In case of Peninsular zone, it was found progressive and recorded as 4.96 % for 1991 to 2000, 4.65 % for 2001 to 2010, and 6.04 % for 2011 to 2019 over the base period 1989 to 1990. Breaux (1984) also reported that a recurrent selection program to improve sucrose content has raised the average sugar recoveries in Louisiana to tropical levels (over 100 kg of sugar per net tonne of cane) in a 9-month growing season. Sugar content in cane mainly depends on sugarcane variety, condition of the crop at the time of harvest, weather conditions prevailing during the crop growth and duration of the crushing season (Rao 1979). Besides this, sugar content is also influenced by biotic and abiotic stresses. Post-harvest management of sugarcane also plays an important role in realizing better sugar recovery by the sugar factories.

In Peninsular Zone, the highest genetic improvement (5.73 %) was observed during the period 2011 to 2019 followed by (4.75 %) during 1991 to 2000 and 4.44 % during the period 2001 to 2010 over the base period (1989 to 1990). The sucrose % increased from 17.38 in the period 1989 to 1990 to 17.57 in the period 2011to 2019 in the country. Lowest genetic improvement (negative) was observed in East Coast Zone during the period 2001 to 2010 (-2.86%) followed by the period 2011 to 2019 (-0.94%) and (-0.64 %) during 1991 to 2000 in North Central Zone and North Eastern Zone. In recent years, the genetic improvement in sucrose percent is positive in Peninsular Zone and North Central and North Eastern Zone whereas in the case of North West Zone and East Coast Zone it was observed as zero and negative trend respectively.

Some of the observations made by different workers were also given in the following paragraph. The percent improvement in sucrose % is relatively small. In general, the sucrose % in juice appeared to be satisfactory in Maharashtra, Gujarat, and Karnataka. Under such a situation sugar yield per unit area can be improved by increasing the yield potential while maintaining the sucrose % at the threshold level (Ram 2010). In tropical India, from 1931-40 to 1941-50, there was an improvement from 18.00 percent to 19.26

Table 4: Genetic improvement in sucrose (%) of sugarcane clones testes under All India Coordinated Research Project on Sugarcane

Year	Peninsular Zone	East Coast Zone	North West Zone	North Central and North Eastern Zone	Overall
1989-1990	17.43	17.26	17.38	17.23	17.38
1991-2000	18.30 (4.75) (4.99)	17.59 (1.91)	17.58 (1.14) (1.15)	17.12 (-0.64)	17.65 (1.53) (1.55)
2001-2010	18.24 (4.44) (4.65)	16.78 (-2.86) (-2.78)	17.51 (0.74)	17.57 (1.94) (1.97)	17.52 (0.80)
2011-2019	18.49 (5.73) (6.08)	17.10 (-0.94) (-0.93)	17.38 (0.00)	17.31 (0.46)	17.57 (1.08)

Figure in parentheses indicate percent increase over average sucrose (%) of 1989 to 1990

Table 5. Sugarcane varietal development under AICRP on Sugarcane

Period of development	Sugarcane varieties	
	Early group	**Mid late group**
1982- 1992	Co 1295, MS 7110, MS 7455, Co 6907, CoC 671, CoJN 86141, Co 7508, CoC 771, Co 7717, CoJ 64, CoJ 75, Co 6304, CoLk 7701, CoS 767, CoS 771, CoS 802, CoLk 7901, CoLk 8001, BO 90, BO 100, CoS 767, BO 91, BO 109, CoS, 7918, Co 7201 and S 101/72	Co 7219, Co 7318, Co 62175, CoM 7125, Co 7527 and Co 8021
1992- 2002	Co 86249, CoPant 90223, Co 87263, Co 87268, CoBln 9605, BO 120, CoH 92201, CoS 91230, CoS 95255, CoPant 93227, Co 94008, CoP 9103, BO 128, Co 89029, CoSe 95422, CoSe 92423, CoSe 96234 and CoSe 96436	Co 87044, Co 86032, Co 87025, CoM 88121, Co 8371 and Co 91010
2002-2012	CoLk 94184, CoS 96268, Co 98014, Co 0232, Co 0118, Co 0238, Co 0232, Co 0239, Co 0237, CoPK 05191, CoSe 01421, CoSe 05451, CoC 01061, CoOr 03151, CoA 03081, CoA 05322, CoA 05323 and Co 06030	CoS 94270, CoH 119, CoJ 20193, CoS 96275, Co 0124, CoH 128, Co 05011 and BO 146
2012-2018	Co 05009, CoLk 07201, CoPb 08212, CoLk 09204, Co 09022, UP 09453, Co 06022, CoN 05071, Co 0233 and PI 07131	Co 06027, CoPant 05224, Co 06034, CoP 06436, CoP 09437, CoBln 04174 and CoP 09437

Sources: AICRP on Sugarcane, Coordination Unit, ICAR-IISR, Lucknow (Shukla et al. 2018)

percent in juice sucrose percent and afterwards it decreased to 16.35 percent in 1961-70 and then it increased again, and juice sucrose percent of around 18.97 percent was obtained in 1991-94 in early maturing varieties (Shrivastava et al. 2002) which was better than the present period (1991 to 2015). Similarly, in mid-late varieties in tropical India, released in 1918-20, there was an improvement of 7.7 5% in sucrose percent in juice. In the period from 1918-20 to 1991-94, there was an improvement of 17 % in sucrose in juice. For Northwest Zone, the highest increase in sucrose content of 5.41% was observed in 2001 to 2010 over 1989-90.

In recent years 2011-2019, for North West Zone and East Coast Zone, it was observed as zero and negative trend respectively. The matter should be looked into and reasons should be identified for taking further necessary action in different zones where genetic improvement is negative because the impact will be visible in the next decade. The overall genetic improvement in sucrose % in juice in the country is good and positive. Ram (2010) also reported that sufficient variability exists in the sugarcane germplasm for sucrose content. New cycles of nobilization involving *Saccharum* species clones and proven parents to broaden the genetic base to combine genes for sucrose from different species in single genetic background may be attempted to increase the sugar content in cane.

Improvement in sucrose % was possible in the country because the emphasis was more on

the development of early maturing varieties in comparison to mid-late maturing varieties, from 1982 to 2018; nearly 72.45 % early maturing varieties were identified for release. Under AICRP on sugarcane, 116 high yielding and high sugared varieties were identified and in total fifty-five sugarcane varieties (early and mid-late maturity group) have been released and notified by Central Variety Release Committee (CVRC) during 2000 to 2018 (Shukla et al. 2018). This has increased the area under early maturing varieties, especially in the Uttar Pradesh, largest producer of sugarcane, where it has gone more than 85 %.

Conclusion

Out of 15 cases, only in three cases, genetic improvement in sucrose was observed negative. It showed that there is a continuous increase in improvement in sucrose % in sugarcane clones tested in the country. However, the progressive trend was observed only in the Peninsular Zone. Cultivation of high-sugared varieties with high cane yield, high germination and early tillering and practicing early planting, if possible 15 to 18 months cropping, or if this is not possible at least full 12-month cropping, and light frequent and timely irrigations, early manuring, weeding, inter-culture and good management for ratoon crops are the some of the positive measures likely to promote high sugar outturns (Panje, 1965) in other Zones. Out of 116 sugarcane clones identified, 55 varieties have been released and notified by CVRC during 2000 to 2018 which has increased area under high yielding varieties. Such type of studies may be replicated for other crops to estimate the genetic improvement in yield in different zones based on the trials conducted over a period of time.

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