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REVIEW ARTICLE

Integration of sugarcane production technologies for enhanced cane and sugar productivity targeting to increase farmers' income: strategies and prospects

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Abstract

The idea of doubling the farmers' income in next 5 years has been slated by the Government of India. The specific target of increasing sugarcane farmers' income could be achieved by developing cost-effective technologies, transferring them from laboratory to land, educating the farmers and creating a linkage between all stakeholders. Consistent efforts shall be required to harness all possible sources for increasing farmer's income in and outside the agriculture sector with respect to improvement in sugarcane and sugar productivity, enhancement in resource use efficiency and adopting various other ways and means including intercropping, management of pests and diseases, use of biotechnological tools and minimizing post-harvest deterioration. The advances in sugarcane biotechnology could become remarkable in the coming years, both in terms of improving productivity as well as increasing the value and utility of this crop substantially. In future, genetically modified sugarcane varieties with increased resistance to different biotic and abiotic stresses would serve more towards sugarcane crop improvement. Any possibility of enhancement in the income of sugarcane farmers shall also be dependent upon the profitability and sustainability of the sugar industry. Integration of sugarcane production technologies for improvement in farm productivity, diversified sugarcane production system, reduced cost of cultivation along with increased processing plant efficiency and diversification to produce value added products shall ensure smooth and higher payment to the farmers. Development of low-cost technologies to convert "waste to resource" on a smaller scale shall also help the farmers to increase their income further. This paper focuses on possible measures to be taken up in each aspects of sugarcane cultivation including biotechnological approaches to achieve the goal of enhancing the income of sugarcane farmers substantially, particularly in the sub-tropical region of India.

Keywords Sugarcane productivity · Ratoon · Tillering · Bio-refinery · Biotechnological approach · Sustainability · Biofuel

Introduction

The idea to double the income of farmers in next 5 years has been put forth by the Indian government (http://www.krishijagran.com/news/government-seven-point-strategy-for-doubling-farmers-income/&hl=en-IN) with measures to step up irrigation, provide better-quality seeds and prevent post-harvest losses along with focusing on important aspect of value addition of agricultural produce. Thus, the focus should be to increase the production and proper utilization of agriculture produce for the benefit of farmers.

As far as sugarcane cultivation in India is concerned, it is the most important source of sugar production. At present about 359 million tonnes of sugarcane is produced and ¾ of this is processed by 526 operational Indian sugar units into sugar. Sugarcane being a C_4 plant is an excellent source of converting solar energy into biomass. It is imperative that agricultural development should fully exploit the potential of the crop by practicing modern and scientific method of farming. The sustainability of sugarcane cultivation inherits in safeguarding the profitability, which could be met out

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by increasing productivity per unit area and decreasing the cost of cultivation. This is viable by the adoption of new scientific methods of agriculture, mechanization and involvement of newly developed biotechnological tools in sugarcane cultivation and increasing the income by utilizing available land and resources in a more profitable manner. Beside the need to improve yield and productivity of sugarcane along with disease resistance, the current scenario demands for 'Climate-resilient' varieties to mitigate the climate change-induced adverse effects on growth and development of sugarcane. Breeding activities for improved performance under environmental stresses focus on accumulation of favourable alleles that contribute to a particular stress tolerance. This paper deals with the possible measures to be taken up in each aspect of sugarcane cultivation including biotechnological approaches for achieving the goal, particularly in the sub-tropical region of the country.

Balanced adoption of high-yielding new sugarcane varieties

The efficiency of the sugar industry mainly depends on availability of high-yielding and high-sugar cane varieties in adequate quantity. Hence, the quality of sugarcane is of paramount importance in carrying out recommended cultivation of sugarcane varieties, following scientific harvesting schedules so as to achieve a uniform high sugar recovery throughout the crushing season. Selection of appropriate early and mid–late varieties can increase the sugar recovery, as we know that the crushing of sugarcane in India starts during October/November and continues until March/April. The composition of varieties in the cane supply has a major impact on sugar recovery and total sugar production of any region.

There is a need to assess the varietal balance of area grown under improved early and mid–late maturing varieties possessing high sugar contents. Studies by Singh et al. (2017c) also emphasized that a proper balance of early and mid–late maturing sugarcane varieties is very important for longer crushing periods with higher sugar recovery. The cost of production of sugar and profitability of the sugar industry besides many other factors depends primarily on the availability of sufficient quantity of good-quality sugarcane during the crushing season. For increasing productivity of sugarcane and production of sugar, beside use of scientific package of practices, varietal scheduling is important. It helps the cane growers and cane managers in determining the allocation of land to different varieties, their plant and ratoon crops and in planning the harvesting (Table 1). Proper varietal spectrum also helps in planning of the crushing schedule during the peak ripening curve of varieties covering the possible crushing period to provide economic return to both, growers and millers.

Recently, several improved early and mid–late maturing varieties have been developed through biotechnological interventions in varietal improvement programme by different research institutes of the country. The pol% in cane of these newly developed elite early and mid–late maturing varieties has been found to increase across the crushing season (Table 2). Although the area under such early maturing varieties has increased in 2016–17, which resulted in the enhanced sugar recovery in the state of Uttar Pradesh; however, there is still a good scope for increasing the area of these elite varieties and completely discarding the area under rejected varieties. Judicious combination of early and mid–late maturing varieties and ratoons, staggered planting and planned harvesting will ensure adequate supply of mature and fresh-quality cane for crushing. Increasing the area of sugar-rich early and mid–late maturing varieties of sugarcane in a ratio of about 50:50 may help to a great extent in sustaining the enhanced sugarcane and sugar production.

Many sugarcane varieties do not attain their optimum sweetness until mid season. It is, therefore, obvious that any such variety milled before this period contains less than its optimum percentage of sugar and causes a loss to sugar recovery. If early-maturing high sugared varieties are available with optimum sugar content during the 1st and 2nd months of crushing season, each ton of cane crushed would be worth for better recovery (Table 2). In India, a number of early and mid–late varieties like CoS 8436, CoS 08272, CoSe 98231, Co 0238, Co 0118, CoS 767, CoS 97261, CoS 08279, CoSe 01434, BO 91, Co 98014, CoPk 05191 (sub-tropical region of India), Co 86032, Co 8011, Co 85004, Co 8014, Co 92005, Co 99004 (tropical region of India) are showing promising results regarding higher sugar recovery and productivity throughout the crushing season. By increasing the area of these varieties there will be a significant

Table 1 Harvesting schedule: maturity-based harvesting schedule leads to 10–25% more yield and 0.5–1.5% increased sugar recovery

Oct	Nov	Dec	Jan	Feb	Mar	Apr
EMV—ratoon (autumn, spring)	EMV—ratoon (autumn, spring)	Autumn EMV—plant MLMV—ratoon	MLMV—ratoon Spring EMV—plant	Spring MLMV—ratoon and plant	Spring MLMV—plant	Late maturing plant

EMV Early maturing varieties, *MLMV* Mid–late maturing varieties

Table 2 Pol percent cane and yield (t/ha) of some promising early and mid–late maturing varieties of sub-tropical regions of India. Source: (Singh et al. 2017c)

Variety	Month							Yield (t/ha)
	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	
Early maturing								
CoS 8436	10.1	11.3	11.9	13.4	13.6	13.9	14.0	64–78
CoS 08272	10.5	11.7	12.2	12.7	13.3	13.8	14.1	105–110
CoSe 98231	11.0	11.8	12.3	12.8	13.0	13.7	13.9	76–90
Co 0238	11.4	11.8	12.4	12.9	13.2	13.7	13.9	81–85
Co 0118	12.1	12.6	13.0	13.6	13.8	14.2	14.4	78–80
Mid–late maturing								
CoS 767	10.6	11.0	11.7	12.4	12.7	13.2	13.3	101–105
CoS 97261	10.3	11.2	11.5	12.3	12.5	12.7	12.9	98–109
CoS 08279	10.4	11.4	11.6	12.1	12.7	13.2	13.3	101–106
CoS 07250	10.1	11.5	11.8	12.4	12.8	13.1	13.3	100–105
CoSe 01434	10.3	11.4	11.7	12.5	12.7	13.1	13.3	101–103

Least significant difference ($P < 0.05$) = 0.258

improvement in recovery. The proper varietal planning of early and mid–late maturing varieties and by adopting scientific harvesting schedule together for the target area may help to a great extent in sustaining the higher sugar production and also help the farmers to attain higher sugarcane yield and income as well (Singh et al. 2017c).

Good-quality planting material

Germination in sugarcane is one of the most important factors contributing towards the quality and yield of the crop. To improve germination, healthy canes from irrigated field should be selected for planting. It is also suggested that field area having mother plants should be located in the low risk of major diseases and pests.

The 2–3 bud setts preferably from the top portion of canes should be planted soon after the cutting, when soil moisture and temperature are above 15% and 16–32 °C, respectively. Normally the seed-cane quality is judged by the size, thickness, food reserve and health of setts, besides the age and the standard of crop that is proposed to be used as planting material is also considered.

It is believed that the setts sown from crop grown on high nitrogen and high water level did not only provide over 20% more germination, but also improve the yield and sugar content of the cane. Since, the sprouting buds grow purely on the food reserves of the setts until the shoots' roots are formed, its quantity in seed body has to play an important role in germination. Presence of adequate moisture in the setts is necessary for good germination. Its effect is particularly marked under later planting. In summers, when setts are soaked in water, the ability to germinate is increased appreciably.

The size and thickness of setts also relate to food reserves of the planting material. Thick canes are known to provide 5% more germination than the thin canes. The 2–3 bud setts give more germination compared to one bud sett and provide a good stand of the crop. The setts should be treated with carbendazim (0.1%) before planting. Under the conditions of inadequate moisture, high temperature, late planting and if staled canes are used, the treatment and soaking of setts in water becomes even more important and the field must be irrigated soon after planting. These practices are immensely important and may augment increase in germination by about 30–40 percent (Singh et al. 2017a, b, c).

Agro-technologies for higher sugarcane productivity

Planting methods play crucial role in sustaining maximum number of millable canes and sugarcane yield in plant as well as ratoon crop (Table 3). The manipulations in planting techniques for different conditions are aimed to increase germination and shoot density, and reduced tiller mortality. Flat-planting technique is popular in north India where fast depletion of soil and sett moisture takes place after planting and germination of buds is usually poor. Studies have found that trench method of planting assured higher cane yield than the flat-planting method. Under shallow plantings, high soil moisture gives significantly more germination, tillers, millable canes and yield than normal soil moisture. But under deep plantings, the results are just reversed (Yadav 2004).

Tillers which are considered as the base for final commercial yield and tillering in sugarcane are affected by spacing. There is a positive interaction between row spacing and soil fertility with the result that under low level of soil fertility,

Table 3 Comparative profitability of various sugarcane planting methods. Source: modified from Yadav (2004)

Particulars	Conventional planting	Double row planting	STP	Furrow planting	Trench planting
Cane yield (t/ha)	75	92	81	76	126
Cost of cultivation (INR/ha)	1,23,948	1,52,011	1,40,320	1,23,948	1,59,000
Gross return (INR/ha)	2,36,250	2,89,800	2,55,150	2,39,400	3,96,900
Net return (INR/ha)	1,12,302	1,37,789	1,14,830	1,15,452	2,37,900
Benefit: cost ratio	1.90	2.06	1.81	1.93	2.49

1 US dollar = ~ 73 INR

closer spacing is better whereas under high fertility wider spacing is remunerative.

Nutrients also play a vital role in regulating crop growth and juice quality and their management which is one of the most important factors for higher sugar production. Nutrient requirement for sugarcane is generally considered in terms of nitrogen, phosphorus and potassium. Continuous use of primary nutrients usually depletes the soil organic matter resulting in inherent loss of organic carbon, soil nitrogen, available phosphorous, potassium and sulphur. Due to escalated price of fertilizers, consumption of phosphorous and potassium fertilizers has drastically reduced resulting in an imbalanced crop nutrition and low productivity and fertility of soil. The soils under sugarcane cultivation are exhausted rapidly due to its long duration nature and high nutrient uptake for luxurious growth and higher biomass. Although the important nutrient elements are nitrogen, phosphorus and potassium, micronutrients also play a crucial role in the growth and metabolism of cane plant. However, the balanced application of NPK with various micronutrients as per soil test values considerably increases the yield of sugarcane. Application of nitrogen at 125 kg/ha through neem coated urea gave cane yield at par with recommended dose of nitrogen at 180 kg/ha in sugarcane (Singh and Rai 1996). Development of site-specific fertilizer recommendation schedules to match the changing soil fertility scenario, integrated nutrient supply system-based recommendation for sugarcane crop, soil fertility rating for low-, medium- and high-nutrient status are also absolute serious doubts which have been raised about the actual validity of soil test results. Fertilizer recommendations based on the targeted yield need to be developed for sugarcane crop in different climatic zones. Soil health cards should also be prepared and made available to each and every farmer for balanced application of fertilizers for increased sugarcane and sugar productivity (Singh et al. 2008a, b, 2018a, b, c) (Tables 4, 5).

Application of organic manures along with inorganic fertilizers plays a major role in boosting up the macro- and micronutrient content in the soil. It also enhances the physico-chemical and biological properties of the soils. The studies carried out on the soils with long-term application of inorganic fertilizers in sugarcane cultivation strongly advocates necessity of the application of farm yard manure and compost for maintaining the soil fertility. Addition of green leaves as organic manure from outside has also found to be beneficial in the same way as that of above-ground portion of a green manure crop included into the soil. A sugar industry produces about 3–7% of filter cake or pressmud cake as a by-product of the cane crushed in the factory. Studies carried out by Singh et al. (2007) revealed that, sulphitation press mud cake (SPMC), a by-product of sugar factory, could increase the organic carbon content and the availability of N, P, K, S, Zn and Mn in the soils. The integrated use of SPMC and nitrogen fertilizer increased the nitrogen use efficiency by 4–8%. It is widely concerned that for a 10–12 months crop, the time of application of fertilizers may be restricted to the first 45–90 days, i.e., period of tillering. It has also been suggested to apply 1/3rd of nitrogen as base during planting and remaining 2/3rd as top dressing in two equal splits before the onset of monsoon. Nitrogen application schedule is an important issue to regulate sugar content and yield of the cane.

Table 4 Fertilizer recommendation to achieve targeted yield. Source: Singh and Rai (1996), Singh and Tiwari (2018b)

N (kg/ha) = 0.236 (T) − 0.27 × Soil N (available)
P (kg/ha) = 0.113 (T) − 1.59 × Soil P (available)
K (kg/ha) = 0.101 (T) − 0.25 × Soiil K (available)

T target yield

It has also been reported that addition of *Azotobacter, Azospirillium, Acetobacter* and *Bacillus* has reduced the use of nitrogen fertilizer by more than 25% of its quantity which is applied to sugarcane. Therefore, bio-fertilizers play a crucial role in economizing the use of nitrogen in sugarcane farming (Yadav 2004). The results of long-term manurial experiments on sugarcane have shown that to sustain the soil fertility and crop productivity the integrated nutrient management by tapping all the possible sources of organic, inorganic and bio-fertilizers in a judicious and synchronous way has proved superior to maintain soil fertility and productivity.

Table 5 Scenario of fertility status in Uttar Pradesh soils. Source: Singh and Rai (1996); Singh and Tiwari (2018a, b)

Characteristics	Fertility status before green revolution (average)	Present status (average)	(%) Decrease
Organic carbon (%)	0.61	0.39	63
Available N (kg/ha)	437	208	47
Available P (kg/ha)	30.0	10.5	35
Available K (kg/ha)	290.0	180.0	62

Table 6 Comparative losses due to unhindered growth of weeds in sugarcane fields. Singh et al. (2018a, b)

Stages of weed treatment	No. of millable canes ('000/ha)	Cane height (cm)	Cane yield (t/ha)
0 DAP	112.33	224	97.07
30 DAP	110.49	222	96.45
60 DAP	98.29	220	91.11
90 DAP	77.97	214	72.89
120 DAP	66.20	206	59.63
Harvest	62.65	200	58.25

DAP Days after planting

The late tillers in sugarcane result in low percentage of surviving tillers and they also cause competition for nutrients due to overcrowding on the other. However, after giving scope for early produced tillers, tillering needs to be suppressed for which earthing up of cane rows is essential. The practice of trash mulching not only decreases the tiller production but it turns out in increasing the production of canes (Shukla et al. 2014) with greater weight, height and number of millable canes. Trash mulching also conserves soil moisture, which is reflected in an increase in stalk number, stalk density, cane, and sugar yields.

Losses up to 40% in sugarcane yield have been recorded due to unhindered growth of weeds in sugarcane fields. During germination and until the development of crop canopy, i.e., the initial 60–120 days after planting weeds have to be suppressed to avoid competition during the growth stage. Atrazine as pre-emergence spray at the rate of 2.0 kg a.i./ha suppresses most of the weeds, this followed by 2,4 D at the rate of 1.0 kg a.i./ha at 60 days after planting and hoeing 90 days after planting keeps the weed problem below economic threshold level (Table 6).

It is also important to improve the water use efficiency during the entire cycle of sugarcane production following "more crop per drop". Adoption of micro-irrigation systems shall not only reduce the water requirement by 30–35%, but shall also result in reduction in requirement of fertilizers and improve the productivity of cane and sugar. As micro-irrigation technique is costly, using trench method of planting, which is now widely accepted and popular among farmers of India, is also useful in saving water up to 30% as compared to traditional method of planting.

Intercropping/crop diversification

The compatibility of sugarcane with both kharif and rabi crops by virtue of its varying planting seasons and economic importance for every socio-economic group of farmers, makes it an indispensable component of all the major cropping systems prevalent in India and in the state of Uttar Pradesh (India) in particular. In addition to the compatibility of sugarcane crop to fit in various crop sequences, it provides enough room for growing intercrops. The wide space (120 cm) available between two rows of sugarcane, long duration for sprouting (30–45 days), initially slow rate of growth and its ability to compensate for any loss of tillers due to intercropping has helped successful intercropping of grain legumes, oilseeds, vegetables, spices and maize, in plant crop and forage legumes in winter-initiated ratoon. Seeing the higher returns and better resource use efficiency, intercropping of winter pulses may encourage autumn planting of sugarcane.

Intercropping with autumn-planted sugarcane

Autumn planting of sugarcane invariably yields 15–20% higher as also more sugar recovery than spring-planted cane (Singh and Rai 1996). Research on intercropping cereals, oilseeds, pulses and spices with autumn planted cane has been intensified recently to understand the biological validity of the system by way of possible increase in yield, efficient use of solar energy and better land use resulting in higher net returns. The traditional agriculture aimed at increasing the production through two dimensions viz; expanding the cultivated area and increasing the potential yield per unit area of the crop. The modern agriculture stresses on efficient use of resources—land, light, water and nutrients. It is the need of the hour to utilize the resources within a given time by raising two or more crops simultaneously by exploiting the space more effectively and planting crops of varying architecture.

The consumption of winter vegetables is in increasing demand at faster rate in modern time as these are protective foods in human nutrition. Their cultivation is of utmost importance to the growers of north-central India because it offers tremendous potential of brining higher income per unit area and time. It is a general practice of the farmers to take spring cane after winter vegetables which sometimes negatively affects the quality and yield of the cane. The information for wider adoptability of intercropping of short duration winter vegetables with autumn-planted cane with respect to yield potential and economic return is very much lacking particularly in north-central India where farmers grow vegetables and sugarcane in plenty under winter vegetables—spring sugarcane cropping sequence.

Results of an on-farm field trial conducted consecutively during autumn seasons of 2010–12, 2011–13 and 2012–14 at farmers' fields of Lucknow district in Uttar Pradesh clearly indicated that the intercropping of potato with autumn-planted sugarcane increased the cane yield significantly as compared to rest of the intercropping treatments including cane alone (Singh et al. 2017a). Potato as intercrop with autumn cane improved the cane yield by 8.25% while, cane + cauliflower, cane + cabbage, cane + knol-khol and cane + turnip treatments being statistically at par with the cane yield obtained under sole cane, exhibited minor reduction in cane yield to the tune of 4.03%, 3.49%, 4.42% and 4.75%, respectively, than that of cane alone (Singh et al. 2017a). Cane-equivalent yield under different treatments produced the same trend as that of cane yield. Economics of different treatments indicated that the cane + potato intercropping system was found to be the most remunerative and thus, gave highest B:C ratio of 1.97 followed by 1.58, 1.65, 1.62 and 1.41 under cane + cauliflower, cane + cabbage, cane + knol-khol, cane + turnip, cane + carrot and cane + radish treatments, respectively as against 1.10 obtained under cane alone. The vegetable viz., carrot and radish as intercrop with autumn cane decreased the cane yield by 6.87% as compared to other vegetables (cauliflower, cabbage, knol-khol and turnip) in the intercropping system, but the values of net returns and B:C ratio were higher as compared to cane alone (Table 7) (Singh et al. 2017a, b).

Intercropping with spring-planted sugarcane

The intercropping of mungbean and urdbean in spring-planted sugarcane especially in UP, Bihar, Punjab and Haryana states of India has been estimated to add about one million hectare area under pulses. In addition to this, after picking green pods for vegetables and mature pods for grains, the residues of legume plants with larger leaf area are incorporated in the soil between the inter-row spaces of sugarcane for enriching valuable soil organic matter. This has positive impact on nitrogen economy in sugarcane cultivation to the extent of 35–40 kg/ha besides producing bonus yields of pulses (Table 8).

Table 7 Effect of vegetable intercropping on sugarcane growth, yield potentials, quality and economic returns (pooled over data of 2010–12, 2011–13 and 2012–14). Source: Singh et al. (2017a)

Treatments	Germination (%)	No. of tillers (000/ha)	No. of millable canes (000/ha)	Yield of intercrops (q/ha)	Yield of cane (t/ha)	CCS% cane	Cane equivalent yield (t/ha)	% Decrease in cane yield over cane alone	% Increase in cane equivalent over cane alone	Cost of cultivation (Rs/ha)	Net returns (Rs/ha)	B:C ratio
T_1_autumn cane alone	38.73	315	134	–	94.50	10.20	94.50	–	–	1,21,715	1,33,395	1.10
T_2_cane + cauliflower	40.15	253	129	201.20	90.69	10.14	137.10	4.03	45.08	1,43,623	2,26,547	1.58
T_3_cane + cabbage	39.13	254	126	225.40	91.20	10.12	141.15	3.49	49.37	1,43,715	2,37,525	1.65
T_4_cane + knol-khol	37.68	257	122	245.20	90.50	10.31	139.54	4.42	47.66	1,43,709	2,32,941	1.62
T_5_cane + turnip	41.03	248	121	280.00	90.01	10.41	129.78	4.75	37.33	1,45,634	2,04,826	1.41
T_6_cane + carrot	37.80	215	111	182.50	85.15	10.60	123.81	9.89	3.50	1,45,579	1,88,681	1.30
T_7_cane + radish	39.42	229	113	305.00	83.60	10.44	113.06	11.53	19.64	1,43,810	1,61,560	1.12
T_8_cane + potato	40.85	341	139	245.05	102.30	10.29	179.44	(+)8.25	89.88	1,63,098	3,21,282	1.97
CD (P = 0.05)	NS	30.71	6.85	–	4.05	NS	–	–	–	–	–	–

Table 8 Increase in production and net profit by intercropping of urdbean and mungbean with spring-planted sugarcane. Source: Singh et al. (2017a)

Treatment	Cane yield (t/ha)	Increase in cane yield due to intercropping	Intercrops' yield (q/ha)	Cane-equivalent yield (t/ha)	Comparative Increase in cane equivalent yield	Cost (INR/ha)	Gross profit (INR/ha)	Net profit (INR/ha)	Increase in net profit due to intercropping
Sole cane	72.33	–	–	–	–	1,35,446	2,09,757	74,311	–
Cane + urdbean	75.46	4.33%	5.17	90.51	20.09%	1,49,846	2,62,479	1,12,633	37.34%
Cane + mungbean	76.69	6.03%	7.41	99.16	27.06%	1,50,446	2,87,564	1,37,118	45.81%

*Prevailing market rate (at present): Sugarcane: INR 315/q, Urdbean: INR 50/kg, INR 52/kg (1 US$ = ~73 INR)

Enhancing ratoon-cane productivity and multi-ratooning

A better ratoon crop is an answer to increased productivity, improved recovery, low cost of production and sustainability in the system and bringing more income to the farmers. A more focused approach is needed to enhance the yield of ratoon crop. Efforts to enhance ratoon yield (90 t/ha) through suitable agronomic packages and physiological interventions will surely help in increasing the income of farmers. Sugarcane ratoon occupies a substantial proportion of the total area under cane cultivation. It is up to 50% of cane area in sub-tropical states like Uttar Pradesh. However, the contribution of ratoon yield to total cane production is around 30% only. One of the major reasons for adopting sugarcane crop over the other crops among the farmers lies in taking 2–3 ratoon crop so as to augment the high cost of sugarcane cultivation; however, poor management practices of the field and ratoon crop after harvest of plant crop leads to substantially reduced yield of ratoon. For a better ratoon crop, trash mulching/shredding should be done manually or mechanically after harvesting of plant crop and organo-decomposer (*Tricoderma* at 10–15 kg/ha) should be apply for decomposing of trash and improving organic carbon in the field. Application of chemical fertilizer (N-100Kg, P-80Kg, K-60 Kg) along with bio-agents (*Azotobactor*, PSB, *Trichoderma* at 10 kg/ha each) along with organic manure at 10 t/ha followed by hoeing at proper moisture and the remaining dose of nitrogen should be applied at the tillering phase for a better ratoon yield (Singh et al. 2018). Fresh press mud at 10 t/ha should be applied in cane harvested during winter (Dec./Jan.). Gap filling with poly-bag/settling just before second irrigation should be carried out. Earthing and binding of the ratoon crop should be done at proper time to protect the cane from lodging. It has now become imperative to imply proper field management after harvest of plant crop and manage multi-ratooning of sugarcane crop to make the sugar sector more profitable.

Development of sugarcane detrasher-cum harvester

Sugarcane cultivation requires high labour input right from the planting of the seed to harvesting of the crop. However, scarcity of labour is observed during pivotal cultural operations and the condition is severe nowadays. It has been calculated that being a labour-intensive crop, almost 60–70% of cost of production of sugar lies in cost utilized in the production of sugarcane (Nagendran 2014). By the utilization of machinery like, automatic cane planter, cultivator, harrow rotavator, hoeing machine, power sprayer and ratoon management device (RMD), one could save almost 40–50% of total cost of production. The production cost could be significantly down by introduction of mechanism-based sugarcane farming. In spite of introduction of several cost effective farm machinery for planting, intercultural operations, trash mulching, ratoon management devices and harvesting, in India most of the growers perform the farm operations using traditional equipments which increases the cost of production. The reason behind this is mostly lack of information and the small land holdings. Studies also indicate that manual harvesting by different sizes, shapes and weights of knives has been set up as a trend in India which prevents the grower from adopting new technology in this regard. Apart from other cultural operations in sugarcane cultivation the highest costing labour-intensive operation is harvesting. The non-use of machinery causes a lot of pressure on demand of labour in sugarcane growing areas which results in scarcity as well as high wage rates during peak seasons. Presently non availability of labour is being experienced almost all over the country. Thus, the need of the hour is introduction of sugarcane detrasher-cum-harvester especially in the areas where harvesting is carried out by paid labours. Apart from reducing cost of production, mechanized harvesting will also ensure well-timed operations, better quality work, cutting of drudgery, etc. This will also impart timely clearing of the field for next crop and increasing overall productivity (Singh et al. 2018a, b).

Management of sugarcane diseases

In India many disease epidemics related to red rot, smut, wilt, yellow leaf disease (YLD), grassy shoot disease along with leaf scald and pokkah boeng occur at timely intervals and affect the crop badly at its severity. In a year, around 30–40% yield losses are estimated due to the several diseases associated with the sugarcane crop in India especially in sub-tropical zone (Viswanathan and Rao 2011). The severity of any disease of sugarcane depends on variety, which resulted in withdrawal of many popular varieties from the cultivation. In the varietal development programme, major emphasis is put on disease indexing and screening for red rot, smut and wilt resistance because of their capability to cause severe damage to the crop. Off late, diseases like yellow leaf, grassy shoot and pokkah boeng have also emerged and received major attention because of their high incidence in almost all the popular commercial varieties. YLD causes serious damage to cane production and up to 40% qualitative losses are reported (Iqbal et al. 2015). At the same time, severity and high incidence of grassy shoot disease has also become a major problem for sugarcane growers in most parts of India (Rao et al. 2014). SCGS alone may cause up to 40% yield losses (Tiwari et al. 2012, 2016) and in case of heavy incidence, losses may be up to 100%. The disease is spread by infected setts and vectors (Rao et al. 2014; Tiwari et al. 2017a, b). Development of new biotechnological and molecular diagnostic protocols contributed significantly for authentic diagnosis of fungal, bacterial and virus diseases of sugarcane at different stages of growth and development. Breeders always attempt to evolve varieties resistant to the diseases especially red rot, wilt and smut to avoid the losses caused by them. Early detection of incipient pathogen through serological and molecular techniques would help to check the spread of the disease at early stage of infection (Srivastava et al. 2006; Viswanathan and; Rao 2011). Selection of healthy seed materials and seed treatments through fungicide during planting is also helpful in control of fungal diseases. Hot-water treatment at 50 °C for 2 h would help to prevent sett-borne disease like *Sugarcane mosaic virus*, grassy shoot disease and ratoon stunting. Certified breeder seed distribution from research institutes and regional stations also plays significant role in minimizing the disease and pest incidence. Conclusively, use of disease-resistant varieties along with healthy seed nursery programmes would form the basis to successfully manage the diseases in sugarcane and this helps to check the losses caused by the diseases.

Management of insect-pests

The estimated losses in terms of tonnage to farmers and in sugar industry is about 20% of the crop yield and 20% sugar is lost due to different pests especially borers. The insect-pests vary according to the agro-ecological conditions, so the management strategies of insect-pests should be planned accordingly and this will enhance the productivity. Sugarcane is infested by about 288 insects of which nearly two dozen cause heavy losses to the yield and quality. The scenario of insect-pests and diseases varies in sub-tropical and tropical belt of sugarcane. Shoot borer (*Chilo infuscatellus snell*), Top borer (*Scirpophaga excerptalis* Walk), *Pyrilla perpusilla* and stalk borer (*Chilo auricilius* Dudgeon) are found pre-dominantly in sub-tropical and in tropical region. Ever since the establishment of sugar industry, efforts to evolve effective control measures for sugarcane insect-pests were made to benefit farmers. However, seeing the losses, this aspect still needs major concern. Although, some of the effective methods in the sugarcane pest management under cultural control could be earthing up of the crop latest by May, avoiding irrigation during hot months, avoiding heavy manuring during tillering and trash mulching, etc. are recommended. Emphasis should be given on use of natural enemies such as predators, parasites and pathogenic microorganisms or antagonists to control pest populations or diseases, especially borers which cause major hazards at all the growth stages of cane which largely affects the income of growers by reducing the yield by 20–30% as well as sugar recovery (Solomon et al. 1995). Termite (*Odontotermes obesus* Rambur) and white grub (*Holotrichia consanguinea* Blanch) are also responsible for crop losses in many sugarcane growing areas of India. The most popular method of biological control of insect-pests involved inundated release of bio-agents in suitable dose and at appropriate time. Application of bio-pesticide, i.e., *Metarihizium* and *Beauveria* has to be encouraged to limit the population of soil-dwelling insects (Pandey et al. 2011). The cost per hectare of this method is about ten times lower than that of chemical pesticides. Release of *Trichogramma* sp. and *Cotesia flavipes* has to be encouraged for the control of borers. Application of pheromone trap should be encouraged as it reduces the borer population by mating disruption (David et al. 1985; Pandey et al. 1994).

Biotechnological approaches

State-of-the-art biotechnological techniques and genetic engineering can be a powerful tool to alter the physiological features and sugar content of the sugarcane. For example, altering, introducing genes responsible for high sugar content, thick stem, shorter leaves and resistance to diseases etc. Recent advances in sugarcane biotechnology are expected to become remarkable in the coming years, both in terms of improving productivity as well as substantially increasing the value and utility of this crop. In the last two and a half decades, several biotechnological tools have been developed to improve various yield- and quality-related traits in sugarcane. Various molecular marker systems have been developed for diversity analysis, varietal identification and trait-mapping studies (Ming et al. 2006; Srivastava and Gupta 2008; Swapna and Srivastava 2012). Since the days of SUC-EST (Sugarcane EST) project, with 238,000 ESTs developed from 26 cDNA libraries (Vettore et al. 2003) and, 26,000 tissue specific and 1069 ESTs from tissue infected with red rot (Gupta et al. 2010), the functional genomics of sugarcane has made considerable progress. Several EST-based molecular markers have been developed for yield, sugar content and other related quantitative as well as qualitative characters (Banerjee et al. 2015; Ming et al. 2006; Singh et al. 2013). A number of QTLs associated with tiller number and suckering (Jordan et al. 2004), sugar content (Ming et al. 2001; Hoarau et al. 2002; Aitken et al. 2006) and yield-related traits (Aitken et al. 2008) have been detected in sugarcane.

Biotechnological tools augment the breeding process in two ways; first, by searching for desirable genes or alleles either from other genotypes or cultivars of sugarcane or from related genera with which sugarcane could not hybridize easily, and second, by placing such genes into sugarcane to confer adaptability to climatic changes and biotic stresses. Moisture stress including waterlogging and drought, along with salinity are the crucial environmental factors that adversely affect sugarcane productivity. Structural and functional characterization of stress-induced genes has contributed to a better understanding of how sugarcane responds and adapts to different abiotic and biotic stresses. Several stress-related genes, stress proteins, signal transduction components, stress promoters and transacting factors binding to stress promoters, that are involved in eliciting stress responses (reviewed by Shrivastava and Srivastava 2012) have been unraveled by stress response studies at molecular level.

Studies have shown that the specific '*Stress Proteins*' accumulate in response to imposition of moisture stress, temperature stress and oxidative stress conditions. A large number of genes/proteins associated with tolerance to drought, waterlogging, high and low temperatures, salinity and nutrient stress etc. have been identified in different crop species which might be utilized in times to come to develop genetically modified plants that are tolerant/resistant to various biotic and abiotic stresses. Expression of candidate genes for dehydration responsive transcription factor (DREB), late embryogenesis abundance-related proteins (LEAs), heat shock proteins (HSPs), proteins responsive to absicisic acid (RAB), early response to dehydration protein 4 (ERD4), sugarcane ethylene-responsive factor (SodERF3) and accumulation of osmotin, dehydrin, trehalose, proline, annexin and choline oxidase and other stress-inducible proteins showing differential expression are some of the examples of genes identified in sugarcane in response to biotic and abiotic stress conditions (Trujillo et al. 2009; Iskandar et al. 2011). Most common molecular response of sugarcane plants challenged with heat stress is the expression of heat shock proteins (HSPs) and dehydrin proteins (DHNs) (Wahid and Close 2007). Thirty-four cold-inducible ESTs have been identified having 20 novel cold responsive genes including cellulose synthase, ABI 3- interacting protein 2, a negative transcription regulator, phosphate transporter by Nogueira et al. (2003).

Differential expression of some genes or proteins has been observed in response to temperature stress in sugarcane e.g., upregulation of 600 genes related to the trans-membrane transporter activity along with ~ 2.5-fold increase in expression of *SspNIP2* (*Saccharum* homolog of a NOD26-like major intrinsic protein gene) in response to chilling stress, dehydrin-like proteins (WCOR410b and DHN2) protecting membranes against chilling damage (Park et al. 2015), induction of sugarcane ESTs encoding pyruvate orthophosphate dikinase (PPDK) and *NADP*-Malate dehydrogenase (MDH) enzymes under chilling damage, reduced activity of sucrose phosphate synthase (SPS), heat stress-induced dehydrins, reduction of H_2O_2 by peroxidase/catalase under heat stress, genes encoding super oxide radical (O^-), hydroxyl radical OH^-, hydrogen peroxide (H_2O_2) tolerance, sorbitol, HSPs and LEA (Du et al. 1999; Nogueira et al. 2003; Wahid and Close 2007; Chagas et al. 2008).

Induction of galactional synthase (GolS), pyrroline-5-carboxylase synthetase (P5CS) and osmolytes like proline and glycine betaine during salinity-induced stress are some of the examples of such differential expression under stress conditions (McQualter and Dookun-Saumtally 2007; Patade et al. 2008). Deterioration of peroxidase and catalase enzyme activity is considered as a limiting step to manage reactive oxygen species (ROS) in sugarcane (Chagas et al. 2008). The accumulation of the osmolytes such as trehalose and proline causes reduction in the damage by ROS and provides enhanced tolerance to drought (Zhang et al. 2006; Molinari et al. 2007). Twenty-five stress-related clusters in sugarcane were found to be homologous to osmotic stress or dehydration stress-associated proteins and showed > two-fold relative expression during water-deficit stress (Gupta et al. 2010). Expression of an unknown 18-kDa protein (p18) along with other stress-inducible proteins was upregulated in sugarcane leaves under drought conditions (Jangpromma et al. 2010). Higher levels of chlorophyll and SOD in drought-tolerant sugarcane genotypes had a high level of p18 expression also. Drought stress also upregulated the expression of genes coding for polyamine oxidase, cytochrome-*c*-oxidase, *S*-adenosylmethionine (SAM) decarboxylase and thioredoxins (Prabu et al. 2011).

Upregulation of genes responsible for synthesis/ expression of trehalose 5-phosphate and sucrose-phosphate in response to drought has been observed in sugarcane (Almeida et al. 2013). One differentially fragment (TDF) showing complete identity with a drought-inducible gene (SoDip22) was upregulated in the drought-tolerant cultivar of sugarcane. Some of the sugarcane genes expressed under water-deficit stress might be involved in the pathways that lead to the production of such osmoprotectants.

Similar differential expression of genes in response to biotic stress has been observed in case of sugarcane chitinase gene (*ScChi*) involved in host–pathogen interaction (Que et al. 2014) and 62 genes in smut and eyespot disease inoculated plants of sugarcane, of which 19 TDFs are homologous to known defense/ signaling-related sequences (Borrás-Hidalgo et al. 2005). Some differentially expressed EST clusters involved in signaling of ROS, defense response and plant's innate immunity against red rot infection have also been identified (Sathyabhama et al. 2015).

Agrobacterium tumefaciens-mediated genetic transformation with *Arabidopsis* Vascular Pyro-phosphatase (AVP1) gene conferred tolerance to drought and salinity (Kumar et al. 2014). Two plasmid LBA4404 pB1 121 construct GLY1 (Shaik et al. 2007) and SodERF3 have been used for genetic manipulation of sugarcane plants to improve their stress tolerance (Luis et al. 2009). Sugarcane transgenics overexpressing PDH45 gene from pea, exhibited an upregulation of DREB2-induced downstream stress-related genes and improved tolerance to drought and salinity (Augustine et al. 2015). Trehalose synthase (*Tsase*) gene from *Grifola frondosa* inculcated resistance against drought stress in sugarcane (Zhang et al. 2006). A transgenic developed in Indonesia using the *betA* gene from the *Rhizobium meliloti* producing glycine-betaine, imparted drought tolerance in sugarcane (Waltz 2014). Recently, Brazilian sugar mills have planted the world's first borer-resistant genetically modified (GM) variety of sugarcane having Bt (*Bacillus thuringiensis*) genes in an area of 400 hectares with the expectation to improve cane yield, reduce production costs, and increase profit margins to both, farmers as well as to the industry (Gomes 2018).

MicroRNAs are involved in regulation of plant development and nutrition, responses to biotic and abiotic stresses, signal transduction, and protein degradation (Srivastava and Sunkar 2013). Rojas et al. (2010) elucidated the possible roles and regulation of sugarcane microRNAs in regulation of drought stress. Thiebaut et al. (2012) identified differentially expressed miRNA in sugarcane subject to cold stress (4 °C). Carnavale-Bottino et al. (2013) suggested that miRNA can play important roles in response to salinity in sugarcane. These studies suggested that miRNA potentially play a major role during abiotic stresses and they can be used to regulate the expression of key genes.

The polyploid nature of sugarcane with multiple sets of chromosomes coupled with very few recombinant chromosomes due to diploidized behavior poses major challenge to conventional plant breeders. Use of fast-emerging gene and genome-editing technologies such as the zinc finger nucleases (ZFNs), transcription activator-like effector nucleases (TALENs), single-stranded oligonucleotides and RNA-guided engineered nucleases—the type II clustered regularly interspaced short palindromic repeat (CRISPR)/Cas9 (CRISPR-associated) in many polyploid crops has helped editing of some or all of the genes targeted for modification on homologous chromosomes (Augustine 2017). Such techniques may allow incorporation of disease resistance, and improvement of important plant traits. Being world's largest source of white sugar along with ethanol and biofuel production, sugarcane is expected to be a prime target for gene editing. Recently, Jung and Altpeter (2016) successfully targeted the multiple caffeic acid *O*-methyltransferase (COMT) genes using TALENs-mediated reduction in lignin content in sugarcane to make it more amenable for biofuel production. The latest technology of CRISPR/Cas9 is more versatile than TALENs and ZFNs, and is being successfully employed in several crop plants but its use in sugarcane has been scanty (Chakravarthi 2016). Development of genetically edited sugarcane will help in sustaining sugarcane improvement at a faster pace by combating abiotic and biotic stresses. Besides, such non-GM genetically engineered sugarcane will face reduced regulatory restrictions and much more acceptance in social system as they would lack any foreign DNA (Srivastava and Kumar 2018).

Biotechnological tools have played a major role in improving cane quality, reducing losses due to diseases and pests and decreasing use of chemical control methods which in turn has helped in environmental sustenance (Chondler and Dunwell 2008). Though the application of marker-assisted selection for target traits has not shown much progress in sugarcane due to first, its large-sized genome and second, its polyploid nature with more than 100–130 chromosomes per cell; however, available molecular markers associated with agronomic characters and molecular diagnostics for pathogens in sugarcane and their use would definitely enhance the efficiency of plant breeders to select more precisely for desired traits from available sugarcane germplasm (Ming et al. 2006; Abd El-Tawab et al. 2008; El-Seehy et al. 2008; Shrivastava and Srivastava 2016).

Biotechnology alone is not panacea for all the problems associated with sugarcane production and crop improvement; however, it certainly has the potential to address specific problems such as healthy seed production, increased resistance to abiotic stresses, pests and diseases, increasing sugarcane productivity and sugar recovery through post-harvest management, and diversification of end products to enhance the income generation (Abah et al. 2010). Much scientific work needs to be done with renewed focus on sugarcane breeding to develop high-yielding, climate-resilient, pest- and disease-resistant sugarcane varieties. Currently, sugarcane is important not only for the production of sugar but also as a source of energy (Richard 2009). To date, sugarcane is among the most efficient crops in the world together with other C4 grasses such as switchgrass (*Panicum virgatum*), *Miscanthus* species and *Erianthus* species (*Erianthus arundinaceus* Retz.) in terms of converting solar energy into stored chemical energy and biomass accumulation (Furtado et al. 2014). It is anticipated that usage of biotechnological tools for production of bio-fuels, bio-organic matter, bio-fertigation and biological control of pests and diseases will greatly increase in future and enhance the diversified utilization of sugarcane leading to enhanced income of farmers'.

Managing post-harvest sucrose losses

In India there are 526 sugar factories with the capacity ranging from 2500 to 15,000 TCD. In 2016–17 crushing session almost 306,070 thousand tonnes of sugarcane was produced and almost 63% of the cane was utilized in the production of white sugar with the average recovery of 10.48%. As sugarcane is a highly perishable crop, it must be processed into sugar as soon as it is harvested. However, in India the processing of the harvested crop extends from 4 to 7 days resulting in sugar losses beyond economic limits. The factories in India receive 6–10 days stale cane especially in northern part of the country, which brings down the recovery severely. In addition, there are also processing losses which further bring down the sugar production. The delay in processing causes many folds reduction in cane tonnage as well as sugar recovery (Singh et al. 2008a, b) due to several chemical, biochemical and microbiological processes in the cut canes. This reduction in cane quality due to delay in processing not only affects sugar industry but also the cane growers significantly. The payment of cane to growers especially in sub-tropical India is on weight basis. Sugarcane constitutes maximum portion (≥ 70%) of water, however, the huge amount of moisture loss from cut cane affects the grower due to reduction in cane weight. So, the delay in supply of harvested cane to sugar factory could result into major economic loss to cane farmers, and this loss may reach up to INR15–20 per quintal cane (Solomon and Madan 1995) (Table 9).

The most efficient solution for the issue of post-harvest losses is proper, quick and efficient communication between the growers and the industry personnel which will reduce the cut-to-crush delay. The harvested cane must be processed within 24–48 h of harvest. The factory management must ensure fresh cane supply regularly. The indent should be placed accordingly which will result in favour of growers as well as industry.

Sugarcane-based entrepreneurship

Apart from sugar, sugarcane is a wonderful source of fibre, fodder, fuel, energy and many chemicals. Sugar, *khandsari* and jaggery are main products of sugarcane; however, tops, bagasse, molasses and press mud are by-products which are very important for agriculture-based industries. Besides, the fly ash and spent wash are by products of sugar industry and distillery which also do have an economic value. Sugarcane is considered as a divine crop in which no part goes waste and while green tops and leaves serve as a fodder, the trash and dry leaves can be a source of fuel using them along with bagasse. The future of the Indian sugar industry lies in converting it into "Bio-refinery" producing sugar, sugar derivatives, alcohol and alcohol-based chemicals and so on for creating value addition. Increase in the paying capacity of the sugar factories will result in better price of sugarcane to the sugarcane farmers. Sugarcane factories have many such opportunities to be explored viz.:

1. Apart from being used as fuel, utilization of bagasse for production of cellulosic ethanol, surfactants, cattle feed, fertilizer and making cutlery.
2. In addition to use of press mud for bio-manure, its utilization for producing wax and for generating bio-CNG.
3. Use of molasses for producing ethanol and alcohol-based chemicals.
4. Production of organic and other special sugars including liquid/invert sugar.

In addition to above, since the common perception about jaggery produced under hygienic conditions is growing, the same may be developed as a small-scale/cottage industry producing jaggery duly packed as per demand. This may be done at the farmers' end only as individual or by a group of farmers. Similarly, production of Bio-gas or Bio-CNG through agriculture waste and food waste etc. may be taken

Table 9 Post-harvest losses during different season (per 100 ton cane). Source: modified from Solomon and Madan (1995)

Hours after harvest	Early milling		Late milling	
	Weight loss (%)	Loss to farmers (Rs.)	Weight loss (%)	Loss to farmers (Rs.)
24	2.72	2176	4.44	3552
48	4.54	3632	6.31	5048
72	7.27	5816	10.59	8448
96	12.72	10,176 (US$160)	16.00	12,800 (US$200)

up, which may help further in enhancing the income of the farmers. The Government of India has launched several schemes for promotion of innovation and entrepreneurship in the favour of farmers to help them become self-dependent and for earning better returns for their produce.

Inclusion of dairy animals/livestock in sugarcane production system

Inclusion of dairy animals in the entire chain of sugarcane production system is to be considered as an important source of income to the farmers since livestock production is important in enhancing rural economy. Mixed farming systems (sugarcane crop-livestock) provide flexible asset resume and reduce risk and vulnerability of the resource-poor sugarcane farmers. Beside producing milk and/or draft power, the dairy animals are also good source of farm yard manure and an excellent remedy for organic matter addition leading to improvement in soil fertility. In addition to enhancing income of farmers with the sale of milk besides keeping agrarian population healthy on account of sufficient milk available to them, the other benefits of rearing dairy animals in sugarcane production systems are given as under:

1. Sugarcane green tops (green leaves, leaf sheath and water/late shoots) consisting 15–20% of the aerial biomass are highly palatable and a high-quality fodder source for dairy animals.
2. It contains 6.2% protein, 30.9% fibre and 52.9% NFE which qualifies for a good fodder to sustain dairy farming.
3. Sugarcane green tops as fodder are available to dairy animals during lean period from November to April/May.
4. Sufficient quantity of sugarcane will be available for crushing in sugar mills during later period of crushing.
5. If dairy animals are in the sugarcane-based farming system and looking into the need of fodder availability for the longer period, farmers generally harvest their sugarcane crop at proper maturity stage. On the contrary, they are generally in hurry to harvest their sugarcane crop, particularly in central and eastern Uttar Pradesh during Holi festival and well before wheat harvesting looking into the escalating labour cost.
6. Farmers will visit their sugarcane crop regularly in search of fodder to feed their dairy animals, which will facilitate better monitoring and application of need-based inputs/packages to sugarcane crop.
7. During monsoon period and even after that the farmers will visit their sugarcane crop in search of fodder to feed their dairy livestock, and accordingly detrash dry leaf sheaths from the sugarcane stalks and also cut the emerging water/late shoots from the base of cane stools. This practice will indirectly remove the insect-pests harbouring inside the leaf sheaths. Cutting of water/late shoots will also remove competition for soil moisture and plant nutrients with the main sugarcane crop.

Conclusion

Sustained efforts and holistic approach in integration of various sugarcane production technologies are required to be implemented to enhance the productivity of cane and sugar. This in turn, will increase the income of sugarcane based agrarian populace, and would accordingly lead to achieving the target set by the Government of India of doubling farmers' income by the year 2022–23. The realized achievement of the target also requires proper intervention of policy, productivity and product diversification. Beside, the key to success would always be the value addition by utilizing the existing resources in an innovative and fruitful manner. The implementation of the suggestions given in the paper shall undoubtedly help in boosting up the entire rural sugarcane based economic system of India, especially in the sub-tropical zone.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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