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Internet of Things (IoT) applications-advantages for sugarcane farming

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ABSTRACT

Internet of Things (IoT) is a new and evolving technology for internetworking of physical devices. It allows objects to be sensed and/or controlled remotely, creating opportunities for more direct integration of the physical world into computer-based systems, and resulting in improved efficiency, accuracy and economic benefit. Paper discusses real world applications of IoT and also opportunities for its application in sugarcane farming. Further, important concerns for implementation of these technologies in sugarcane sector has also been mentioned. Potential of IoT and future requirements of sugarcane sector demands IoT applications for an effective utilization of resources, higher crop production and protection.

Key words: Internet of Things, Precision farming

Concept of IoT

Idea of communication among devices dates back to 1832 with invention of first electromagnetic telegraph. It enabled communication between two devices by sending electrical signals. Later invention of Internet in 1960 transformed the world into a global village providing a way of communication among computing devices *viz.,* computers, mobiles, tablets, *etc.* Internet of Things (IoT) has recently become ingrained everywhere: in connected cars, home automation, smart office, environment monitoring *etc.* IoT is a new Information and Communication Technology for internetworking of physical devices like home appliances, furniture, clothes, vehicles, roads and smart materials, etc. It allows objects to be sensed and/or controlled remotely, creating opportunities for more direct integration of the physical world into computer-based systems, and resulting in improved efficiency, accuracy and economic benefit. For example, a smart watch will continuously monitor your pulse rate and inform you, your family doctor for any abnormal changes in it automatically. Doctor's in turn may visit you or send prescription to you for treatment. Additionally, he may send a message to nearest medical store and /or ambulance for supply of medicines or emergency treatment services.

The IoT term was coined by Kevin Ashton during presentation made at Proctor & Gamble in 1999 and since then evolving to become biggest worldwide network of intercommunicating devices. It has evolved with convergence of multiple technologies, including ubiquitous wireless communication, real-time analytics, machine learning, commodity sensors, and embedded systems (Vermesan and Friess 2014). In IOT vision everyday objects are "things", such as all home appliances, furniture, clothes, vehicles, roads and smart materials, etc.and these are readable, recognizable, locatable, addressable and/or controllable. As Internet has changed communication among people and their working using World Wide Web, IoT aims to take this connectivity to another level by connecting multiple types of devices at a time to the internet thereby facilitating man to machine and machine to machine interactions.

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Application domain of IoT

IoT has potential for numerous and diverse areas for individuals, enterprises, and society as a whole. A few application areas of IoT are home, city, transportation, lifestyle, retail, supply chain, healthcare, environment, energy, agriculture, industry, security, etc. Some of important application domain of IoT along with key applications are as follows (Vermesan and Friess 2014):

Home automation:

- Remote control appliances to save energy, improve efficiency and reduce pollution
- Weather monitoring
- Safety monitoring and alarm system
- Resources use optimization

Smart cities:

- Monitoring of structures for material conditions, vibrations, safety, etc.
- Intelligent and weather adaptive street lights
- Fire/smoke monitoring and control
- Intelligent roads for traffic and amenities management based on climate conditions, accidents, weather conditions, etc
- Real-time monitoring of parking spaces
- Detection of rubbish levels and waste management

Environment monitoring:

- Monitoring of pollutants and waste
- Forest fire detection and alert
- Monitoring of weather parameters and alert

- Water conservation and management
- Wildlife tracking

Smart industry:
- Monitoring of hazardous substances
- Monitoring of raw material and resources
- Monitoring of machinery and equipments
- Inventory management and market requirements

Health monitoring:
- Patient surveillance
- Monitoring and control of medical fridges
- Telemedicine
- Physical activity monitoring

Energy management:
- Energy consumption monitoring and management
- Monitoring and analyzing the flow of energy from wind turbines & power house
- Controller for AC-DC power supplies that determines required energy, and improve energy efficiency with less energy waste
- Monitoring and optimization of performance in solar energy plants.

Security:
- Surveillance of border activities
- Monitoring of criminal activities
- Identity management

Precision agriculture:
- Green house farming under controlled micro-climatic condition to maximize production
- Monitoring of live stocks
- Precise nutrient management
- Precise irrigation
- Monitoring of biotic and abiotic stresses
- Monitoring and controlling of stores against stresses
- Managing harvesting schedule

Present status and challenges of sugarcane sector in India

India is the second largest producer of sugarcane in the world and provides raw material for sugar production, ethanol production and electricity co-generation. It also supports significantly to 25 other major industries for production of *jaggery, khandsari*, chemicals, papers, and other by-products. 80% of sugarcane is used by Indian sugar industry making it the second largest producer in world and also second largest agro-based industry in India. About 8 million sugarcane farmers and their dependents are involved in sugarcane cultivation, harvesting and ancillary activities.

In recent years, sugarcane improvement and crop management programmes have contributed to substantial increase in sugarcane yield within the country. Sugarcane holds 3% of gross cropped area of the country with production and productivity 411mt and 81.5t/ha respectively (Shukla *et al.* 2018). However, to contribute considerably in doubling farmers' income (as per Govt. of India target of 2020); it is imperative that the quality and productivity of cane, sugar, energy and value added products per se should be enhanced in the field and factory.

Recent statistics reveals that the global population is about to reach 9.6 billion by 2050. United Nations has also set the target of 50% additional production of food by 2050 from less available arable lands under changing climate, food and demography. Estimates say that the demand of sugarcane production by the end of 2050 will be 630mt without increase in area requiring 105t/ha productivity. Further, sugarcane farmers are required to be ready to face challenges of global warming and aberrant weather conditions. To achieve these targets, development and implementation of cost effective technologies is a must (Sah *et al.* 2019). Amongst the challenges like extreme weather conditions, climatic changes, environmental impact, smart farming technologies, IoT is useful in eradicating these challenges and helping us to meet the demand for more food.Keeping in view the potential of digital technologies *viz.,* sensors, robotics/mechatronics, Internet of Things, embedded system, artificial intelligence, *etc.*, and potential of sugarcane, its productivity can be increased by adoption of smart and intelligent farming techniques.

How IoT will be beneficial in sugarcanefarming

Sugarcane farming faces many challenges *viz.* production efficiency, cost, sustainability, market, quality, resources availability and un-controlled environment and climatic impact, *etc*. With increase in population and reduction in cultivable agricultural land, pressure is increasing for improving production efficiency of sugarcane per unit area, time and resources. Farmers need more produce in deteriorating soil, declining land availability and increasing weather fluctuation. IoT-enabled sugarcane production allows real-time monitoring of crop, stresses, livestock, environment and resources for an effective utilization of resources, higher crop protection and crop production. Implications of IoT in this sector are many fold and can be seen in the form of:

1. Optimized resources:

Sugarcane is a long duration crop requires 10 to 18 months for maturity and its productivity highly depend on climatic and soil conditions during germination, elongation, maturity and harvesting phases of the crop. It takes a huge amount of water and nutrient resources and requires optimized utilization to save regularly depleting resources. IoT based monitoring and controlling of resources is one of the primary applications of IoT in the field of agriculture. It will enable optimized and sustainable utilization of resources based on data collected through crop and environment monitoring using IoT devices at various stages of sugarcane crop.

2. Dynamic productivity & quality:

Machine learning techniques can depict better insight into relations between quality and productivity of sugarcane and growing conditions. Data-driven sugarcane production will improve productivity and quality of crop. These tools help in learning from the data for decision support for insight into the system and gain quality and productivity dynamically as per requirement.

3. Environment Friendly:

IoT based precision farming not only reduces excessive utilization of resources particularly pesticide and fertilizer, but also reduces environment pollution and waste.

4. Alertness:

Real-time monitoring of field conditions, resources and environment using sensor based IoT system helps farmers in quick response to changes in these parameters to obtain optimum and sustainable production and save the crop from damaging conditions.

5. Expanding:

Smart green houses not only provides expandable resources for production of disease free quality seed material but also high yielding commercial cane with controlled and optimized resource utilization.

6. Reduced Production Cost:

Optimum and sustainable utilization of resources for optimized and need based production, productivity & quality will reduce cost of production.

Important concerns for IoT implementation in sugarcane sector

As the IoT turn out to be a key element of the future Internet, its application in precision agriculture particularly sugarcane is a must as demand of this sector is increasing alarmingly. However, there are key challenges and implications today that need to be addressed while implementation of IoT in agriculture particularly sugarcane farming (Vermesan and Friess 2013; Vermesan and Friess 2014;https://www.imda.gov.sg/~/media/Files/Infocomm%20Landscape/Technology/TechnologyRoadmap/InternetOfThings.pdf)

1. Cost

IoT uses technology to connect physical objects to the Internet. Technology needed to support capabilities such as sensing, tracking and control mechanisms need to be relatively inexpensive for agricultural sector.

2. Power requirements

Power requirements are also crucial for application of IoT due to energy constraints in rural India. Low energy based technology development is important for implementation of such systems.

3. Interoperability

Essential requirement of Internet connectivity to work is based on ability to "talk the same language" of protocols and encodings. Different industries today use different standards to support their IoT applications and hardware. With numerous sources of data and heterogeneous devices, the use of standard interfaces between these diverse entities becomes important. Therefore, the IoT systems need to handle high degree of interoperability.

4. Data Management

Data management is a crucial aspect in the Internet of Things. Crop and environment monitoring require continuous monitoring of many parameters. An efficient management of volume of generated data and the processes involved in the handling of these data are critical for successful IoT implementation.

5. Security

Information and communication infrastructure shared in IoT application need to be secured for any misuse. Adequate security mechanism should be adopted to maintain privacy in such internet based system.

CONCLUSION

The Internet of Things is a technological revolution that represents the future of computing and communications,and its development depends on dynamic technical innovation in a number of important fields-from wireless sensors to nanotechnology. Many IT firms are now engaged in providing IoT solutions and also coming out with technological enhancement and IoT applications in public domain. Estimates say that by 2025 there will be more than 75 billion connected devices in the world. Government of India has also devised IoT policy with budget allocation of Rs 7,060 crores with objectives of: to create an IoT industry in India of USD 15 billion by 2020; to undertake capacity development (Human & Technology) for IoT specific skill-sets for domestic and international markets; to undertake research & development for all the assisting technologies and; to develop IoT products specific to Indian needs in the domains of agriculture, health, water quality, natural disasters, transportation, security, automobile, supply chain management, smart cities, Automated metering and monitoring of utilities, waste management, oil & gas, *etc*.

Keeping in view the potential of IoT and need of sugarcane sector, its application for precision sugarcane farming is the need of the hour. It is not only essential for meeting the demand of sugar, energy and other value added products, but also will reduce cost of production for possible export potential.

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Morphological characterization of sugarcane varieties (*Saccharum* spp. hybrid) for identification and selection for improvement in Southern Ethiopia

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ABSTRACT

The study was undertaken with objective of morphological characterization of introduced sugarcane varieties for their identification and selection for maintenance of genetic purity. Materials for the study consisted of fourteen sugarcane varieties, ten introduced,'B 49/224', 'B 49/338', 'B 53/165', 'B 57/371', 'Co 842', 'Co 945', 'Co 978', 'Co 1001', 'CP 72/2085', 'PR 1007', and four grown by farmers, *'Habesha', 'Nech Habesha', 'Shelle Habesha'* and *'Wonji'*. Field experiment with varieties was planted in randomized complete block design with two replications at Arba Minch University Research Farm, Southern Ethiopia on April 4, 2018. Data on measurable and observable morphological cane stalk and leaf characteristics were recorded at 9 month crop age and cane weight at 12 month age. Varieties differed significantly for cane characteristics ($p = < 0.05$, or $p =< 0.01$). Long canes were formed in the varieties, *'Wonji'*, 'B 49/338', 'B 53/165' and 'B 49/224', and short canes were in 'CP 72/2083' and *'Shelle Habesha'*. Canes were medium thick in the variety, *'Shelle Habesha'* and medium in the varieties, '*Nech Habesha', 'Habesha'*, 'B 49/224', *'Wonji'* and 'Co 842'. Number of internodes in canes was more in varieties, *'Habesha', 'Nech Habesha', 'Wonji'*, 'B 49/338', 'Co 1001', 'Co 842', 'B 49/224'. Canes were heavy in the varieties, 'B 49/224', *'Shelle Habesha'*, 'B 49/338' and 'Co 842'. Low cane weight was observed in 'Co 978', 'B 53/165', 'PR 1007' and *'Habesha'*. Leaf blade length was long in the varieties, 'Co 978', 'B 53/165' and 'Co 842', and short in 'B 57/371', *'Wonji'*, 'B 49/224' and *'Shelle Habesha'*. Leaf blade width was broad in the variety, *'Shelle Habesha'* and medium in the varieties, *'Nech Habesha', 'Habesha'* and 'CP 72/2083'. Forty seven observable discrete morphological characters under nine sub-heads *viz.,* stool/stem, internode, node and leaf characters, flowering, lodging, cane characteristics, diseases and insect infestation were recorded for identification and selection of sugarcane varieties for maintenance of genetic purity. These characters were distinctive, uniform and stable over environments and can be used as descriptors for identification, selection and maintenance of sugarcane varieties.

Key words: Morphological characterization, Sugarcane varieties, Identification, DUS

INTRODUCTION

Sugarcane (*Saccharum* spp. hybrid) is important sugar crop of tropical and sub-tropical countries which sustains a large sugar industry accounting for about 80 per cent sugar production in the world. Sugarcane belongs to family the *Poaceae (Gramineae),* genus *Saccharum* with three cultivated species, *S. officinarum*, the noble cane, *S. barberi,* the Indian cane and *S. sinense,* the Chinese cane and two wild species, *S. spontaneum* and *S. robustum.* Cultivated sugarcane varieties are the derivatives of complex inter-species hybridization involving clones of *S. officinarum* and *S. spontaneum* initially around 1920s (Nair 2009) and backcrossing or nobilization of inter-species hybrid for improving yield and quality, and further hybridization of inter-species hybrid with *S. barberi* and or *S. sinense* to develop tri-species hybrids incorporating resistance to biotic and abiotic stresses by late 1930s (Nair 2009; Bischoff and Gravois 2004). The tri-species hybrid clones or varieties were used as breeding materials for hybridization between them and hybrids with complementary characters to develop improved varieties with high cane and sugar yields, resistance to diseases and insect pests, different maturity duration and adaptability to different agro-climatic conditions of the countries world over (Nair 2009; Moore *et al.* 2014).

Varieties derived from hybridization between inter-species hybrids were aneuploids with varying chromosome numbers from 90 to 130 (Srivastava 2009; Srivastava and Gupta 2004). The chromosome numbers in noble cane species, *S. officinarum* is $2n = 80$. In elite sugarcane clones of India, GISH revealed that approximately 14-18% chromosome component was from *S. spontaneum* (Srivastava 2009; Srivastava and Gupta 2004). In commercial variety, 'R 570' ($2n = 107$- 115), GISH revealed about 80% of genome was from *S. officinarum*, 10% from *S. spontaneum,* and 10% recombinant chromosomes between *S. officinarum* and *S. spontaneum* (D'Hont *et al*. 1996, Horaru *et al.* 2001). Hence modern sugarcane varieties are scientifically written as *Saccharum* spp. hybrid (Srivastava 2009).

Sugarcane is propagated by sprouting of buds formed on every node of the stem which gives rise toplant or cane stalk with tillers arising from the basal buds of the sprout or plant. There is a great variation in sugarcane morphological

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characters, some of which are discrete diagnostic features without influence of environment. Other characters are quantitative and measurable and influenced by environment to some extent but are sufficient to distinguish one variety or germplasm from another clearly on the basis of cane characteristics, leaf blade length and width. Each variety has characteristic appearance and identifiable on the basis of diagnostic characters. Plant breeders use morphological diagnostic characters for identification of varieties and for ensuring proprietary plant breeders' right (Rae *et al.* 2014). Sugarcane varieties in Ethiopia have been introduced from other countries to sustain sugarcane production (Negi and Damtie 2009). Morphological characterization of varieties is needed to maintain genetic purity and follow up of healthy seed production system for commercial exploitation of the genetic potential of variety (Nagarajan 2009). In view of the above, the present study was carried out on morphological characterization of introduced sugarcane varieties at Arba Minch University, Southern Ethiopia.

MATERALS AND METHODS

Description of the study area

Study was carried out at Arba Minch University Research Farm located at 6.04 ^{0}N latitude, 37.36 ^{0}E and altitude of 1218 meter above sea level. Average proportions of sand, silt and clay particles in the soil of the experimental field were 12.0, 37.30 and 50.70 per cent, respectively. The pH of soil was 7.8. The soil was rated as clay and slightly alkaline (Murphy1968). The average monthly maximum (31^{o}C) and minimum (18^{o}C) temperatures, relative humidity (62%) and rainfall (220 mm) during April, 2018 were suitable for sprouting of buds in cane setts planted. There were moderate temperatures, relative humidity and sunshine hours at cane stalks and millable canes formation during subsequent months up to September, 2018. Mean maximum and minimum temperatures were over 33^{o}C to 39.3^{o}C and 16.9^{o}C to 18.5^{o}C with declining relative humidity and non-sunny days during November, 2018 to February, 2019. Temperatures were also high during March-April, 2019 which could have affected the growth and development and ripening or maturity of sugarcane.

MATERIALS

The materials for the investigation consisted of 14 varieties, ten introduced from other countries *viz.*,'B 49/224', 'B 49/338', 'B 53/165', 'B 57/371', 'Co 842', 'Co 945', 'Co 978', 'Co 1001', 'CP 72/2085', 'PR 1007', and four grown by farmers, *viz.*, *'Habesha', 'Nech Habesha', 'Shelle Habesha'* and *'Wonji'*. Initial alphabets of the name of variety indicate the country of its origin *viz.*, 'B'-Barbados,'Co'-Coimbatore India, 'CP'-Canal Point, Florida, USA; 'PR'-Puerto Rico and four local cultivars, *'Habesha', 'Nech Habesha'* and *'Shelle Habesha'* resembling noble canes and *'Wonji'* from Ethiopian research centre, Wonji, Ethiopia. The seed of introduced varieties was collected from Metahara Research Centre of Ethiopian Sugar Corporation and of 4 locally grown varieties from village, Shara near to Arba Minch University.

Experimental design and procedures

The experiment consisting of 14 sugarcane varieties was started in randomized complete block design with two replications on April 4, 2018. Plot size was 3 rows of 3.0 m length spaced 1.45 m apart. Nine 3-budded setts were planted in 3.0 m long row of each plot. Experiment was fertilized @ 150 kg Urea and 250 kg Diammonium phosphate (DAP) per hectare which was equivalent to 114 kg N and 115 kg P per hectare. Full dose of DAP was applied at the time of planting. Urea was applied in three split doses, one third at planting time, one-third at 30 days after planting and the remaining one third at 90 days after planting. The setts were treated with Tilt 250 EC (Propiconazole) @ 1 ml per litre for a minute before placing in the furrows. Ethiozinone 60 EC insecticide water emulsion was sprayed on the setts @ 43 ml in 10 litre of water emulsion in 100 m furrow length after placement in furrows and covered with 5 cm layer of soil to control insect damage. Light irrigation was given in furrows after planting the same day. After two days of irrigation, the exposed setts from soil were covered with soil in the field. The required cultural practices for raising sugarcane crop like irrigation, weeding, hoeing, earthing up and tying up of sugarcane stalks were done.

Recording of data

Data on measurable morphological characters of cane and leaf characteristics were recorded at 9 month crop age when cane stalks had well developed visible internodes and nodes in stem with stalk length more than 1.0 meter. Cane height, cane diameter and number of internodes in canes were recorded on random sample of 6 cane stalks of each variety from the plot. Cane height was measured in centimetres from bottom to top visible dewlap in leaf. Cane diameter was measured in centimetre from the middle portion of stalk by Vernier callipers. Cane diameter was classified as: 2.0-2.5 cm medium thin, 2.5-3.0 cm medium, 3.0 3.5 medium thick (Akhtar *et al.* 2001). Data on cane weight was recorded on harvested, detopped and leaves stripped off random sample of six canes at 12 month age. Leaf blade length of the longest furled green leaf and leaf width at the broadest point were measured in centimetre on the random sample of 6 cane stalks at 9 month crop age. Leaf width between 4.0-<6.0 was classified as medium, >6.0 cm to 7.0 cm broad and >7.0 cm as broadest leaf (Akhtar *et al.* 2001; Akhtar *et al.* 2006; Khan *et al.* 2007; Khan *et al.* 2016; Khan *et al.* 2017).

Data on observable discrete morphological characters of sugarcane varieties were recorded on representative cane stalks at 9 month crop age. Morphological descriptors included the above ground cane stalk characters, namely, stool/stem characters, internode characters, node characters, leaf characters, flowering, lodging and disease and insect infestation (Akhtar *et al.* 2001; Khan *et al.* 2017; Moore 1987; Shahi 2000; Singh *et al.* 2012; Bonnet 2014). The discrete morphological characters for identification of varieties were as follows:

Morphological characters		Alternative traits
Stool/stem characters		
1	Stool habit	(Spreading/Non-spreading)
2	Stem colour unexposed	(Green to Purple)
3	Stem colour exposed	(Whitish to Purple)
Internode characters		
4	Internode shape	(Cylindrical/Bobbin/Conoidal/Obconoidal/Barrel)
5	Internode circumference	(Round/Ovate)
6	Internode alignment	(Straight/Zig-zag)
7	Internode ivory marks	(Present/Absent)
8	Internode corky patches	(Present/Absent)
9	Internode splits/cracks	(Present/Absent)
10	Internode wax bloom	(Light/Medium/Heavy)
Node characters		
11	Node swelling	(Swollen/Not-swollen
12	Leaf scar	(Flush/Prominent)
13	Root zone swelling	(Swollen/Not-swollen)
14	Root zone colour	(Green/Light green/Yellow/Greenish yellow/Light yellow/Yellowish green)
15	No. of root eyes rows	(Two/Many)
16	Root eye arrangement	(Regular/Irregular)
17	Bud size	(Big/Medium Small)
18	Bud shape	(Triangular-Pointed/Ovate/Round)
19	Germ pore position	(Apical/Sub-apical/Middle)
20	Bud cushion	(Present/Absent)
21	Bud groove	(Present/Absent)
22	Growth ring	(Flush/Swollen/Sunken)
23	Growth ring colour	(Green/Light green/Yellow/Greenish yellow/Light yellow/Yellowish green)
Leaf characters		
24	Leaf sheath colour	(Green/Light green/Greenish yellow/Green with purple blotchesor tinge)
25	Leaf sheath hairiness	(Present/Absent)
26	Leaf sheath spines	(Dense/Sparse)
27	leaf sheath waxiness	(Medium/Light)
28	Leaf sheath clasping	(Loose/Tight/ Self-trashing)
29	Leaf blade colour	(Green/Light green/Dark green/Light yellow)
30	Ligule shape	(Crescent/Deltoid/Strap/Triangular)
31	Auricle shape	(Sloppy/Dentoid/Lanceolate-long, or- short)
32	Dewlap colour	(Green/Light green/Dull green/Greenish yellow/Green with purple tinge)
33	Leaf blade length	(Fully expanded green leaf)
34	Leaf blade width	(Fully expanded green leaf)
35	Leaf carriage	(Erect/Semi-drooping/Drooping)
36	No. of leaves in spindle	(Six to eight)
Flowering		
37	Flowering	(Present/Absent)
38	Flowering extent	(Low: <10%/Medium: 10 to 40%/Heavy: >40 to 100%)
Lodging		
39	Lodging	(Present/Absent)
40	Lodging extent	(Tolerant/Moderately tolerant/Susceptible)
Cane characters		
41	Cane height at month	(cm/m)
42	Cane diameter at month	(cm)
43	No. of internodes in cane	
44	Cane weight at month	(kg)
45	Pith in cane	(Present/Absent)
Diseases in field conditions		
46	Smut/Wilt/ Foliar	(Present/Absent)
Insects infestation		
47	Borers/Bugs	(Present/Absent)

Statistical analysis

The data were subjected to general linear model procedure of statistical analysis for randomized complete block design using SAS software version 9.00[20] (SAS 2004). Variety means for the characters were compared for significant differences with least significance difference (LSD) at 5% probability level.

RESULTS AND DISCUSSION

Measurable morphological cane characters

Varieties differed significantly for measurable cane characteristics, cane height (P= <0.05) and cane diameter and number of internodes (P= <0.01) at 9 month crop age and cane weight at 12 month crop age (Table 1). Maximum and significantly higher cane height than 9 other varieties were observed in the variety, *'Wonji'* but it was at par with 'B 49/338', 'B 53/165' and 'B 49/224'. Next group of varieties, 'Co 978', 'Co 842', 'B 57/371', 'Co 1001', 'Co 945', 'PR 1007', *'Habesha'* and *'Nech Habesha'* were statistically at par for cane height. The lowest cane height was recorded in varieties, 'CP 72/2083' and *'Shelle Habesha'*. The results indicated that there were genetic differences among varieties for cane height. As in the present study, the genotypic differences among varieties for cane height were reported by other workers also (Singh *et al*. 2012; Shahzad *et al.* 2016; Tahir *et al.* 2013; Tena *et al.* 2016; Khan *et al.* 2016). Though cane length is a quantitative character but the varieties could relatively be grouped as forming tall canes, medium canes and short canes. Cane height was a distinguishable character for varieties. Cane diameter was maximum in variety, *'Shelle Habesha'* and formed medium thick canes (>3.0 cm) (Akhtar *et al*. 2001). Cane thickness was medium (>2.5 to 3.0 cm) in varieties, *'Habesha', 'Nech Habesha'*, 'B 49/224', 'Co 842', 'Co 1001', *'Wonji',* 'B 49/338' and 'CP 72/2083'. Medium thin canes (> 2.0 to 2.5 cm) were formed in 5 varieties, 'B 53/165', 'B 57/371', 'Co 945', 'Co 978' and 'PR 1007'. Similar to the present study, the genetic differences for cane thickness among sugarcane varieties were reported by other workers also (Singh *et al*. 2012; Shahzad *et al.* 2016; Tahir *et al.*2013; Tena *et al.* 2016; Khan *et al.* 2016). Cane thickness is a diagnostic genotypic character for varieties as the relative cane thickness among varieties does not change over environments (Khan *et al.* 2007, Singh and Khan 1997, Shanmuganathan *et al.* 2014).

Significantly higher numbers of internodes in canes were formed in the varieties, *'Habesha'* and *'Nech Habesha'* as compared to the 12 other varieties. The next high internode number was in variety, *'Wonji'*, which was at par with that in the varieties, 'B 49/338', 'Co 1001', 'Co 842', 'B 49/224'. Number of internodes in canes of remaining 7 varieties, 'B53/165', 'B 57/371', 'Co 945', 'Co 978', 'CP 72/2083' and *'Shelle Habesha'* was significantly less. As in the present study the differences among varieties for number of internodes in canes were reported by others too (Shahzad *et al.* 2016; Tahir *et al.* 2013; Tena *et al.* 2016; Khan *et al.* 2016). Average internode length could be determined bydividing the cane length with internode number. The short internodes were formed in *'Habesha', 'Nech Habesha'* and *'Shelle Habesha'*, whereas, relatively longer internodes were formed in varieties, 'Co 978', 'B 53/165' and *'Wonji'*. The number of internodes in canes or in turn relative length of internodes in canes was a distinguishing trait of varieties.

Cane weight was significantly higher in variety, 'B 49/224' than 10 other varieties but it was at par with that of varieties, *'Shelle Habesha'*, 'B 49/338' and 'Co 842'. The four varieties with high cane weight had higher cane diameter indicating that the cane weight was related to cane diameter. The next group of varieties with medium cane weight were: 'B 53/165', 'Co 978', 'Co 1001', 'CP 72/2083', *'Nech Habesha'* and *'Wonji'*. Significantly low cane weight was found in varieties, 'Co 945', 'B 57/371', 'PR 1007' and *'Habesha'*. Similar genotypic differences among the varieties for cane weight were reported by other workers also (Shahzad *et al.* 2016; Tahir *et al.* 2013; Tena *et al.* 2016; Khan *et al.* 2016). The cane weight was a distinguishable character between varieties.

Measurable leaf blade length and width characters

Leaf blade length and leaf blade width differed significantly among varieties (P <0.01) at 9 month crop age (Table 1). Leaf blade length was significantly more in variety, 'Co 978' than 11 other varieties but it was on par with varieties, 'B 53/165' and 'Co 842'. The next significant more leaf length was in the varieties, 'Co 945' and 'Co 1001', which was on par with varieties, 'CP 72/2083', 'PR 1007', *'Nech Habesha', 'Habesha'* and 'B 49/338'. Significantly less leaf blade length was noted in varieties, 'B 57/371', *'Wonji'*, 'B 49/224' and *'Shelle Habesha'*. Similar genotypic differences for leaf blade length in sugarcane varieties were reported by other workers indicating that leaf length was a good diagnostic character (Singh *et al.* 2012; Shahzad *et al.* 2016; Khan *et al.* 2016). Leaf blade length, though, is a quantitative character but it was a distinguishable character as the variation in varieties could be grouped into three classes, *i.e.,* varieties with long leaf blade, with medium leaf blade and varieties with short leaf blade. Leaf blade width was significantly more in variety, *'Shelle Habesha'* than 13 other varieties indicating that this variety formed the broadest leaf. Next medium broad leaves were formed in varieties, *'Nech Habesha'*, *'Habesha'* and 'CP 72/2083' followed by varieties, *'Wonji'*, 'B 49/224','B 53/165', 'B 57/371' and 'Co 842'. Narrow leaf blades were recorded in 5 varieties, 'Co 978', 'Co 1001', 'PR 1007', 'B 49/338' and 'Co 945'. As in present study, the genetic differences among varieties for leaf blade width were reported by other workers also (Singh *et al.* 2012; Bonnet 2014; Shahzad *et al.* 2016; Khan *et al.* 2016). As for the leaf blade length, the variation in leaf width among varieties could be categorized into three distinguishable classes, varieties with broad leaves, with medium broad leaves and varieties with narrow leaves.

Table 1 Mean cane height, cane diameter, number of internodes and leaf blade length and width at 9 month crop age and cane weight at 12 month crop age in sugarcane varieties during 2018/19 at Arba Minch, Southern Ethiopia

Varieties	Cane height (cm)	Cane diameter (cm)	No. of internodes in cane	Cane weight (kg)	Leaf blade length (cm)	Leaf blade width (cm)
'B 49/224'	211abc	2.7bcd	16.5bcd	1.79a	145.5de	6.15cd
'B 49/338'	217.5ab	2.6cdef	17.5bc	1.63ab	153cd	5.1fg
'B 53/165'	214ab	2.35fg	15.5de	1.55b	172ab	6.1cd
'B 57/371'	191.5bcd	2.3g	15.5de	1.26c	148de	6.1cd
'Co 842'	200.5bcd	2.7bcd	16.5bcd	1.6ab	167ab	6.05cde
'Co 945'	184.5bcd	2.45defg	15.5de	1.27c	163bc	4.65g
'Co 978'	203.5bcd	2.4efg	14.5e	1.53b	178a	5.8de
'Co 1001'	187bcd	2.65cde	17bcd	1.53b	161.5bc	5.8de
'C P72/2083'	174.5cd	2.65cde	15.5de	1.53b	155.5cd	6.45bc
'PR 1007'	189bcd	2.25g	15.5de	1.25c	155.5cd	5.55ef
'Habesha'	185.5bcd	2.75bc	20a	1.25c	154cd	6.4bc
'Nech Habesha'	184.5bcd	2.95ab	20a	1.51b	155cd	6.9b
'Shelle Habesha'	167.5d	3.15a	16cde	1.65ab	141.5e	8.1a
'Wonji'	242.5a	2.7bcd	18b	1.51b	147de	6.25cd
General Mean	196.64	2.61	16.67	1.49	156.96	6.1
SE (±)	12.16	0.08	0.56	0.07	3.72	0.16
LSD	37.16*	0.26**	1.71**	0.22**	11.39**	0.5**
CV%	8.74	4.72	4.75	6.89	3.35	3.8

*= Significant at 5% level ($P<0.05$);** = Significant at 1% level ($P<0.01$); Means with the same alphabet in column are not significantly different

Observable morphological characters

Observable morphological characters had several discrete alternative traits which were not/little influenced by environment as per ontogeny of their development (Bonnet 2014). These characters were recorded at 9 month crop age when the expression of stool and stem, internode, node, leaf and cane characteristics including occurrence of flowering, lodging, diseases and insect infestation were distinctive, stable and uniform to differentiate sugarcane varieties. The morphological characters were grouped into nine sub-heads as stool/stem, internode, node, leaf, and cane characteristics, flowering, lodging, diseases and insect infestation in field conditions. These sub-heads included 47 different characters with alternative traits to differentiate varieties. These morphological characters were described as morphological descriptors for sugarcane for identification of varieties. The morphological descriptors for fourteen sugarcane varieties are summarized in Tables 2 and Table 3 and are presented as follows:

Stool/stem characters

Stool habit: It was non-spreading in 8 varieties, 'B 49/224', 'B 53/165', 'B 57/371', 'Co 945', 'Co 978', 'Co 1001', 'CP 72/ 2083' and *'Wonji'*, and spreading type in 7 varieties, 'B 49/ 388', 'Co 842', 'PR 1007', *'Habesha', 'Nech Habesha'* and '*Shelle Habesha'*.

Un-exposed stem colour: It was whitish green in 7 varieties, 'B 49/224', 'B 49/ 388', 'B 53/165', 'B 57/371', 'Co 978', *'NechHabesha'* and *'Wonji'*,and green stem colour in 5 varieties, 'Co 842', 'Co 945', 'CP 72/2083', 'PR 1007' and *'Shelle Habesha'*. White purplish green stem colour in variety, 'Co 1001' and yellow green purple in variety, *'Habesha'*.

Exposed stem colour: It had variable shades of mixed colours such as whitish green stem in 5 varieties, 'B 49/224', 'B 57/371', 'Co 1001', 'CP 72/2083' and *'NechHabesha'*, green stem in varieties, 'Co 945' and 'PR 1007', green yellow stem in varieties, 'B 49/224' and *'ShelleHabesha'*, yellowish purple stem in 'Co 842' and *'Habesha'*, purplish green stem colour in variety, 'Co 978', purplish yellow stem in variety, 'B 53/165' and greenish purplish green stem colour in variety, *'Wonji'*.

Internode characters

Internode shape: It was cylindrical in 10 varieties, 'B 49/ 388', 'B 53/165', 'B 57/371', 'Co 842', 'Co 945','Co 978', 'Co 1001', *'Habesha', 'Nech Habesha'* and *'Wonji'*, Cylindrical barrel internode shape in variety, 'CP 72/2083', slight barrel in 'PR 1007' and barrel shape internode in varieties, 'B49/224' and '*Shelle Habesha'*.

Internode circumference: It was round in 10 varieties, 'B 49/224', 'B 53/165', 'B 57/371', 'Co 945', 'Co 978', 'CP 72/2083', 'PR 1007', *'Nech Habesha', 'Shelle 'Habesha'* and *'Wonji'*, whereas ovate internode shape was in 4 varieties, 'B 49/388', 'Co 842', 'Co 1001' and *'Habesha'*.

Internode alignment: It was straight in 9 varieties, 'B 53/ 165', 'Co 842', 'Co 945', 'Co 978', 'Co1001', 'CP 72/2083', *'Habesha'* and *'Wonji'*, whereas internode alignment was

Table 2 Morphological descriptors for sugarcane varieties, ‘B 49/224’, ‘B 49/388’, ‘B 53/165’, ‘B 57/371’, ‘Co 842’, ‘Co 945’ and ‘Co 978’ during 2018/19 at Arba Minch, Southern Ethiopia

S.N.	Characters/Varieties	‘B 49/224’	‘B 49/388’	‘B 53/165’	‘B 57/371’	‘Co 842’	‘Co 945’	‘Co 978’
	Stool/ Stem characters							
1	Stool habit	Non-spreading	Spreading	Non-spreading	Non-spreading	Spreading	Non-spreading	Non-spreading
2	Stem colour unexposed	Whitish green	Whitish green	Whitish green	Whitish green	Green	Green	Whitish green
3	Stem colour exposed	Greenish yellow	Purple	Purplish yellow	Whitish green	Yellowish purple	Greenish	Purplish yellow green
	Internode characters							
4	Internode shape	Barrel	Cylindrical	Cylindrical	Cylindrical	Cylindrical	Cylindrical	Cylindrical
5	Internode circumference	Round	Ovate	Round	Round	Ovate	Round	Round
6	Internode alignment	Zigzag	Zigzag	Straight	Zigzag	Straight	Straight	Straight
7	Internode ivory marks	Absent	Absent	Absent	Absent	Absent	Absent	Absent
8	Internode corky patches	Absent	Absent	Absent	Absent	Present	Absent	Absent
9	Internode splits/ cracks	Absent	Present	Present	Absent	Present	Absent	Present
10	Internode wax bloom	Medium	Heavy	Light	Heavy	Medium	Light	Medium
	Node characters							
11	Node swelling	Not swollen	Swollen	Swollen	Swollen	Not swollen	Not swollen	Not swollen
12	Leaf scar	Prominent	Prominent	Prominent	Prominent	Prominent	Prominent	Prominent
13	Root zone swelling	Not swollen	Not swollen	Not swollen	Not swollen	Not swollen	Swollen	Not swollen
14	Root zone colour	Light green	Light green	Light yellow	Light green	Light yellow	Green	Light yellow
15	No. of root eyes rows	Many	Two	Two	Many	Two	Two	Two
16	Root eye arrangement	Irregular	Irregular	Irregular	Irregular	Irregular	Irregular	Regular
17	Bud size	Small	Small	Small	Medium	Small	Small	Small
18	Bud shape	Round	Round	Round	Triangular	Round	Round	Round
19	Germ pore position	Middle	Middle	Middle	Apical	Middle	Middle	sub-apical
20	Bud cushion	Absent	Present	Present	Present	Present	Absent	Present
21	Bud groove	Absent	Absent	Absent	Absent	Absent	Absent	Absent
22	Growth ring	Flush	Flush	Flush	Flush	Swollen	Swollen	Flush
23	Growth ring colour	Light green	Light green	Yellowish green	Yellowish green	Light green	Light green	Yellowish green
	Leaf characters							
24	Leaf sheath colour	Green	Green purple tinge	Green	Green	Green	Green	Green
25	Leaf sheath hairiness	Absent	Present	Absent	Absent	Present	Present	Present
26	Leaf sheath spines		Dense			Sparse	Dense	Dense
27	leaf sheath waxiness	Light	Light	Light	Light	Light	Medium	Light
28	Leaf sheath clasping	Loose	Loose	Tight	Tight	Loose	Loose	Loose
29	Leaf blade colour	Green	Green	Green	Dark green	Dark green	Green	Green
30	Ligule shape	Crescent	Deltoid	Crescent	Crescent	Crescent	Crescent	Crescent

contd.

S.N.	Characters/Varieties	'B 49/224'	'B 49/388'	'B 53/165'	'B 57/371'	'Co 842'	'Co 945'	'Co 978'
31	Auricle shape	Dentoid	Dentoid	Sloppy	Lanceolate short	Dentoid	Dentoid	Dentoid
32	Dewlap colour	Dull green	Light green	Dull green	Light green	Light green	Light green	Dull green
33	Leaf blade length	145.5 cm	153 cm	172 cm	148 cm	167 cm	163 cm	178 cm
34	Leaf blade width	6.15 cm	5.1 cm	6.1 cm	6.1 cm	6.05 cm	4.65 cm	5.8 cm
35	Leaf carriage	Erect	Erect	Erect	Erect	Erect	Erect	Erect
36	No. of leaves in spindle	Eight	Eight	Six	Six	Eight	Six	Eight
	Flowering							
37	Flowering	Absent	Absent	Absent	Present	Absent	Absent	Absent
38	Flowering extent				Low			
	Lodging							
39	Lodging	Absent	Absent	Absent		Absent	Absent	Absent
40	Lodging extent		Tolerant			Tolerant	Tolerant	Tolerant
	Cane characters							
41	Cane height	211 cm	217.5 cm	214 cm	191 cm	200.5 cm	184 cm	203.5 cm
42	Cane diameter	2.7 cm	2.6 cm	2.35 cm	2.3 cm	2.7 cm	2.45 cm	2.43 cm
43	No. of internodes	16.5	17.5	15.5	15.5	16.5	15.5	14.5
44	Cane weight	1.79 kg	1.63 kg	1. 55 kg	1.26 kg	1.6 kg	1.27 kg	1.53 kg
45	Pith in stem	Absent	Absent	Absent	Absent	Absent	Absent	Absent
	Diseases in field conditions							
46	Smut/wilt/ foliar	Absent	Absent	Absent	Absent	Absent	Absent	Absent
	Insect infestation							
47	Borers/ bugs	Mealy bug	Mealy bug	Mealy bug	Mealy bug	Mealy bug	Mealy bug	Mealy bug

zigzag in 5 varieties, 'B 49/224', 'B 49/388', 'B 57/371', 'PR 1007' and *'Shelle Habesha'*.

Internode ivory marks: These were absent in all 14 varieties.

Internode corky patches: These were absent in all varieties except one *i.e.*'Co 842' which had internode corky patches.

Internode splits/cracks: These were absent in 9 varieties, 'B 49/224', 'B 57/371', 'Co 945', 'Co 1001', 'PR 1007', *'Habesha', 'Nech Habesha', 'Shelle Habesha'* and *'Wonji'*, whereas internode splits were present in 5 varieties, 'B 49/388', 'B 53/165', 'Co 842', 'Co 978' and 'CP 72/2083'.

Internode wax bloom: It was light in 5 varieties, 'B 53/165', 'Co 945', *'Habesha', 'Nech Habesha'* and *'Shelle Habesha'*, medium in 6 varieties, 'B 49/224', 'Co 842', 'Co 978', 'Co 1001', 'PR 1007' and *'Wonji'*, and heavy wax bloom was in 3 varieties, 'B 49/388', 'B 57/371' and 'CP 72/2083'.

Node characters

Node swelling: It was present in 3 varieties, 'B 49/288', 'B 53/165' and 'B 57/371', whereas absent in 11 varieties, 'B 49/224', 'Co 842', 'Co 945', 'Co 978', 'Co 1001', 'CP 72/2083', 'PR 1007', *'Habesha', 'Nech Habesha', 'Shelle Habesha'* and *'Wonji'*.

Leaf scar: It was prominent in 13 varieties, whereas flush in only one variety, 'CP 72/2083'.

*Root zone swelling:*It was absent in 13 varieties whereas present in only one variety, 'Co 945'

Root zone colour: It was light green in 12 varieties, whereas green in only 2 varieties, 'Co 945' and *'Shelle Habesha'*.

Number of root eyes rows: This was two in 11 varieties, 'B 49/388', 'B 53/165', 'Co 842', 'Co 945', 'Co 978', 'Co 1001', 'CP 72/2083', 'PR 1007', *'Habesha', 'Shelle Habesha'* and *'Wonji'*, whereas many in 3 varieties, 'B 49/224', 'B 57/371' and *'Nech Habesha'*.

Root eyes arrangement: It was irregular in 11 varieties, 'B 49/224', 'B 49/288', 'B 53/165', 'B 57/371', 'Co 842', 'Co 945', 'Co 1001', *'Habesha, 'Nech Habesha', 'Shelle Habesha'* and *'Wonji'*, whereas regular in 3 varieties, 'Co 978', 'CP 72/2083' and 'PR 1007'.

Bud size: It was small in all the varieties except varieties, 'B 57/371' and *'Nech Habesha'* with medium bud size.

*Bud shape:*It was round in 10 varieties, 'B 49/224', 'B 49/388', 'B 53/165', 'Co 842', 'Co 945', 'Co 978', 'CP 72/2083', 'PR 1007', *'Shelle Habesha'* and *'Wonji'*, ovate shape in 3 varieties, 'Co 1001', *'Habesha'* and *'Nech Habesha'* and triangular shape in one variety, 'B 57/371'.

Germ pore position: It was in the middle position of bud in 9 varieties, 'B 49/224', 'B 49/388', 'B 53/165', 'Co 842', 'CP 72/2083', 'PR 1007', *'Nech Habesha'* and *'Shelle Habesha'*, apical position in 3 varieties, 'B 57/371', 'Co 1001' and *'Wonji'*, and sub-apical germ pore position was in 2 varieties, 'Co 978' and *'Habesha'*.

Bud cushion: It was present in 11 varieties, 'B 49/388', 'B 53/165', 'B57/371', 'Co 842', 'Co 978', 'Co1001', 'CP 72/2083', *'Habesha', 'Nech Habesha'* and *'Wonji'*, whereas absent in 3 varieties, 'B 49/224', 'Co 945' and 'PR 1007'.

Bud groove: It was absent in 11 varieties, 'B 49/224', 'B 49/

Table 3 Morphological descriptors for sugarcane varieties, 'Co 1001', 'CP 72/2083', 'PR 1007', *'Habesha'*, *'Nech Habesha'*, *'Shelle Habesha'* and *'Wonji'* during 2018/19 at Arba Minch, Southern Ethiopia

	Characters/ Varieties	'Co 1001'	'CP 72/2083'	'PR 1007'	*'Habesha'*	*'Nech Habesha'*	*'Shelle Habesha'*	*'Wonji'*
Stool/Stem characters								
1	Stool habit	Non-spreading	Non-spreading	Spreading	Spreading	Spreading	Spreading	Non-spreading
2	Stem colour unexposed	White purplish green	Green	Dull green	Yellow green purple	Whitish green	Green	Whitish green
3	Stem colour exposed	White yellow green	Whitish green	Dull green	Yellow purple stripe	Whitish yellow	Greenish yellow	Greenish purple
Internode characters								
4	Internode shape	Cylindrical	Cylindrical barrel	Slight barrel	Cylindrical	Cylindrical	Barrel	Cylindrical
5	Internode circumference	Ovate	Round	Round	Ovate	Round	Round	Round
6	Internode alignment	Straight	Straight	Zigzag	Straight	Straight	Zigzag	Straight
7	Internode ivory marks	Absent	Absent	Absent	Absent	Absent	Absent	Absent
8	Internode corky patches	Absent	Absent	Absent	Absent	Absent	Absent	Absent
9	Internode splits/ cracks	Absent	Present	Absent	Absent	Absent	Absent	Absent
10	Internode wax bloom	Medium	Heavy	Medium	Light	Light	Light	Medium
Node characters								
11	Node swelling	Not-swollen	Not swollen	Not swollen	Not-swollen	Not-swollen	Not swollen	Not swollen
12	Leaf scar	Prominent	Flush	Prominent	Prominent	Prominent	Prominent	Prominent
13	Root zone swelling	Not-swollen	Not-swollen	Not - swollen	Not-swollen	Not swollen	Not swollen	Not swollen
14	Root zone colour	Light green	Dull green	Light green	Light green	Light green	Green	Light green
15	No. of root eyes rows	Two	Two	Two	Two	Many	Two	Two
16	Root eye arrangement	Irregular	Regular	Regular	Irregular	Irregular	Irregular	Irregular
17	Bud size	Small	Small	Small	Small	Medium	Small	Small
18	Bud shape	Ovate	Round	Round	Ovate	Ovate	Round	Round
19	Germ pore position	Apical	Middle	Middle	Sub-apical	Middle	Middle	Apical
20	Bud cushion	Present	Present	Absent	Present	Present	Present	Present
21	Bud groove	Absent	Absent	Absent	Present	Present-long	Absent	Present
22	Growth ring	Flush	Flush	Swollen	Swollen	Flush	Flush	Slight sunken
23	Growth ring colour	Light green	Light green	Light green	Light green	Light yellow	light yellow	Light green
Leaf characters								
24	Leaf sheath colour	Light green	Green	Green	Light green	Green	Green	Green
25	Leaf sheath hairiness	Present	Present	Present	Absent	Absent	Present	Present
26	Leaf sheath spines	Dense	Dense	Dense			Dense	Dense
27	leaf sheath waxiness	Light	light	Light	Light	Light	Light	Light
28	Leaf sheath clasping	Loose	Loose	Loose	Loose	Loose	Loose	Loose

Characters/ Varieties		'Co 1001'	'CP 72/2083'	'PR 1007'	*'Habesha'*	*'Nech Habesha'*	*'Shelle Habesha'*	*'Wonji'*
29	Leaf blade colour	Light green	Green	Green	Green	Green	green	dark green
30	Ligule shape	Crescent	Crescent	Crescent	Crescent	Crescent	Crescent	Crescent
31	Auricle shape	Dentoid	Dentoid	Dentoid	Dentoid	Sloppy	Dentoid	Dentoid
32	Dewlap colour	Light green	Light green	Dull green	Light green	Dull green	Dull green	Dull green
33	Leaf blade length	161 cm	155.5 cm	155.5 cm	154 cm	155 cm	141.5 cm	147 cm
34	Leaf blade width	5.8 cm	6.45 cm	5.55 cm	6.4 cm	6.9 cm	8.1 cm	6.25 cm
35	Leaf carriage	Erect	Erect	Erect	Erect	Erect	Erect	Erect
36	No. of leaves in spindle	Eight	Eight	Six	Eight	Eight	seven	Six
Flowering								
37	Flowering	Absent	Absent	Absent	Absent	Absent	Absent	Absent
38	Flowering extent							
Lodging								
39	Lodging	Absent	Absent	Present	Present	Present	Present	Absent
40	Lodging extent	Tolerant	Tolerant	Moderate tolerant	Susceptible	Susceptible	Susceptible	Tolerant
Cane characters								
41	Stalk height	187 cm	174.5 cm	189 cm	185.5 cm	184.5 cm	167.5 cm	242.5 cm
42	Stalk diameter	2.65 cm	2.65 cm	2.25 cm	2.75 cm	2.95 cm	3.15 cm	2.7 cm
43	No. of internodes	17	15.5	15.5	20	20	16	18
44	Cane weight	1.53 kg	1.53 kg	1.25 kg	1.25 kg	1.51 kg	1.65 kg	1.51 kg
45	Pith in stem	Absent	Absent	Absent	Absent	Absent	absent	Absent
Diseases in field conditions								
46	Smut/wilt/ foliar	Absent	Absent	Absent	Absent	Absent	Absent	Absent
Insect infestation								
47		Mealy bug	Mealy bug	Mealy bug	Mealy bug	Mealy bug	Mealy bug	Mealy bug

388', 'B 53/165', 'B 57/371', 'Co 842', 'Co 945', 'Co 978', 'Co1001', 'CP 72/2083', 'PR 1007', and *'Shelle Habesha'*, and present in 3 varieties, *'Habesha', 'Nech Habesha'* and *'Wonji'*.

Growth ring: It was flush in 9 varieties, 'B 49/224', 'B 49/388', 'B 53/165', 'B 57/371', 'Co 978', 'Co 1001', 'CP 72/2083' and *'Nech Habesha'*. Growth ring was swollen in 4 varieties, 'Co 842', 'Co 945', 'PR 1007' and *'Habesha'* and slightly sunken growth ring was present in the variety, *'Wonji'*.

Growth ring colour: It was light green in 9 varieties, 'B 49/224', 'B 49/388', 'Co 842', 'Co 945', 'Co 1001', 'CP 72/2083', 'PR 1007', *'Habesha'* and *'Wonji'*, yellowish green in 3 varieties, 'B 53/165', 'B 57/371' and 'Co 978' and light yellow growth ring was in 2 varieties, *'Nech Habesha'* and *'Shelle Habesha'*.

Leaf characters

Leaf sheath colour: It was green in 11 varieties, 'B 49/224', 'B 53/165', 'B 57/371', 'Co 842', 'Co 945', 'Co 978', 'CP 72/2083', 'PR 1007', *'Nech Habesha', 'Shelle Habesha'* and *'Wonji'*, light green in 2 varieties, 'Co1001' and *'Habesha'*, and green with purple tinge in one variety, 'B 49/388'.

Leaf sheath hairiness: It was present in 9 varieties, 'B 49/388', 'Co 842', 'Co 945', 'Co 978', 'Co 1001', 'CP 72/2083', 'PR 1007', *'Shelle Habesha'* and *'Wonji'*, and absent in 5 varieties, 'B 49/224', 'B 53/165', 'B 57/371', *'Habesha'* and *'Nech Habesha'*.

Leaf sheath spines: These were dense in 8 varieties, 'B 49/388', 'Co 945', 'Co 978', 'Co 1001', 'CP 72/208'3, 'PR 1007', *'Shelle Habesha'* and *'Wonji'*, whereas sparse in variety, 'Co 842'.

Leaf sheath waxiness: It was light in all varieties except one variety, 'Co 945' with medium waxiness.

Leaf sheath clasping: It was loose in all the varieties except two varieties, 'B 53/165' and 'B 57/371' with tight leaf sheath clasping.

Leaf blade colour: It was green in 10 varieties, 'B 49/224', 'B 49/388', 'B 53/165', 'Co 945', 'Co 978', 'CP 72/2083', 'PR 1007', *'Habesha', 'Nech Habesha'* and *'Shelle Habesha'*, dark green in 3 varieties, 'B 57/371', 'Co 842' and *'Wonji'*, and light green in variety, 'Co 1001'.

Ligule shape: Ligule shape at the joint of leaf sheath and leaf blade was crescent in all varieties except one variety, B49/388 with deltoid shape.

Auricle shape: It was dentoid in 11 varieties, 'B 49/224', 'B 49/388', 'Co 842', 'Co 945', 'Co 978', 'Co 1001', 'CP 72/2083', 'R 1007', *'Habesha', 'Shelle Habesha'* and *'Wonji'* sloppy auricle in 2 varieties, 'B 53/165' and *'Nech Habesha'* and lanceolate in one variety, 'B 57/371'.

Dewlap colour: Dewlap colour of leaf lamina above leaf sheath- blade joint was light green in 7 varieties, 'B 49/388', 'B 57/371', 'Co 842', 'Co 945', 'Co1001', 'CP 72/2083' and

'Habesha' and dull green in 7 varieties, 'B 49/224', 'B '53/165', 'Co 978', 'PR 1007', *'Nech Habesha', 'Shelle Habesha'* and *'Wonji'.*

Leaf blade length: It varied with the varieties and the varieties could be grouped into 4 classes: short leaf blade in varieties, 'B 49/224', 'B 57/371', *'Shelle Habesha'* and *'Wonji'*, medium in varieties, 'B 49/388', 'CP 72/2083', 'PR 1007', *'Habesha'* and *'Nech Habesha'*, above medium in varieties, 'Co 842', 'Co 945' and 'Co 1001', and long leaf blade in varieties, 'B 53/165' and 'Co 978'.

Leaf blade width: It could be grouped into 4 classes: narrow leaf width in varieties, 'B 49/224' and 'B 57/371', medium in varieties, 'B 49/388', 'Co 978', 'Co 1001' and 'PR 1007', broad leaf in varieties, 'B 49/224', 'B 53/165', 'B 57/371', 'Co 842', 'CP 72/2083', *'Habesha', 'Nech Habesha'* and *'Wonji'* and broadest leaf in variety *'Shelle Habesha'.*

Leaf carriage: It was erect in all the varieties.

Number of leaves: Number of leaves in the spindle was eight in 8 varieties, 'B 49/224', 'B 49/388', 'Co 842', 'Co 978', 'Co 1001', 'CP 72/2083', *'Habesha'* and *'Nech Habesha'*, six were in 5 varieties, 'B 53/165', 'B57/371', 'Co 945', 'PR 1007' and *'Wonji'* and seven leaves in spindle were in variety, '*Shelle Habesha'*.

Flowering

Flowering occurred in only one variety, 'B 57/371'. Flowering was absent in 13 remaining varieties. Extent of flowering in variety, 'B 57/371' was low.

Lodging

Presence/absence of lodging: Lodging was absent in 10 varieties, 'B 49/224', 'B 49/388', 'B 53/154', 'B 57/371', 'Co 842', 'Co 945', 'Co 978', 'Co 1001','CP 72/208'3 and *'Wonji'*, Lodging was observed in 4 varieties, 'PR 1007', '*Habesha', 'Nech Habesha'* and *'Shelle Habehsa'.*

Lodging extent: Lodging behaviour of 10 varieties was tolerant, moderately tolerant in variety, 'PR 1007', and susceptible behavior to lodging was in 3 varieties, '*Habesha', 'Nech Habesha'* and *'Shelle Habesha'.*

Cane Characters

Cane height: It varied with varieties and could be grouped into 3 classes, short height in varieties, 'CP 72/2083' and *'Shelle Habesha'*, medium in varieties, 'B 57/371', 'Co 945', 'Co 1001', 'PR 1007', *'Habesha'* and *'Nech Habesha'* and tall cane in varieties, 'B 49/224', 'B 49/388', 'B 53/165', 'Co 842', 'Co 978' and *'Wonji'.*

Cane diameter or cane thickness: It was medium thin in 5 varieties, 'B53/165', 'B 57/371', 'Co 945', 'Co 978' and 'PR 1007', medium in 8 varieties, 'B 49/224', 'B 49/388', 'Co 842', 'Co 1001', 'CP 72/2083', *'Habesha, 'Nech Habesha'* and *'Wonji'* and medium thick canes in variety, *'Shelle Habesha'* (Akhtar *et al*. 2001).

Number of internodes in canes: It was less in variety, 'Co 978', medium in 10 varieties, 'B 49/224', 'B 49/388', 'B 53/165', 'B 57/371', 'Co 842', 'Co 945', 'Co 1001', 'CP 72/2083', 'PR 1007' and *'Shelle Habesha'* and more internodes in 3 varieties, *'Habesha', 'Nech Habesha'* and *'Wonji'*. The maximum internodes with shorter length were formed in varieties, *'Habesha'* and *'Nech Habesha'.*

Cane weight: It was low in 4 varieties, 'B 57/371', 'Co 945', 'PR 1007' and *'Habesha'*, medium cane weightin 7 varieties, 'B 53/165', 'Co 842', 'Co 978', 'Co 1001', 'CP 72/2083', *'Nech Habesha'* and *'Wonji'* and heavy canes were in 3 varieties, 'B 49/224', 'B 49/338' and *'Shelle Habesha'.*

Pith in stem: It was absent in all the varieties.

Disease in field condition:

Smut, wilt and foliar diseases were absent in all the varieties.

Insect infestation

Borers and bugs were not observed in field condition except infestation of mealy bug at the nodes associated with presence of ants on cane stalks in all the varieties. Mealy bug (*Saccharicoccus sacchari*) is pink colour bug which sucks sap on the internode and develops under warm and moist environment. It is a kind of scale insect and can be transmitted through seed-canes or from infected host plant in the vicinity (Leslie 2004) such as cassava (*Manihot esculenta* Crantz) which was grown in the same field before planting sugarcane varieties experiment. Mealy bug infestation in sugarcane varieties possibly occurred from its presence on cassava crop in the nearby field.

From the study it was evident that sugarcane varieties could be distinguished from each other on the basis of morphological characteristics comprising of measurable cane and leaf characteristics, and various observable morphological characters on stool and stem, internode, node, leaf, flowering, lodging, cane characteristics and diseases and insect infestation in field conditions. These characters can be used for identification of sugarcane varieties as these characters are discrete, distinctive, uniform and stable over environments. These are called as descriptors for identification and release of sugarcane varieties (Shahi 2000; Singh *et al.* 2012).

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Agronomic evaluation of promising sugarcane genotypes raised under different planting techniques in Odisha

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ABSTRACT

A field experiment was conducted at Sugarcane Research Station, Nayagarh (Odisha) consecutively in two planting seasons of 2014-15 and 2015-16 in order to find out the suitable genotypes raised under different planting techniques for enhancing cane and sugar yields in Odisha. The yield and yield attributing characters were influenced by genotypes and different planting techniques. The genotype 'CoOr 04152' produced significantly higher NMC (number of millable canes) (79.82 '000/ha) and cane yield (106.63 t ha^{-1}) than that of others. This above genotype also exhibited better yield contributing characters *viz.,* length of cane (2.73 M), girth of cane (2.99 cm) and per cane weight (1.33 kg) which were significantly higher than that of rest two genotypes. Cane settlings raised from SSI (sustainable sugarcane initiative) technique had the highest survival percentage (87.51%) which differed significantly with that of conventional method of planting (57.31%) and settlings raised from single bud setts (68.28%). Similarly, significant differences were also observed among three techniques of planting with respect to number of tillers at 180 DAP (days after planting) and NMC at harvest. Among these the settlings raised from SSI technique produced the highest number of tillers (87.03'000/ha) and NMC of (83.21'000/ha). The highest cane yield of 113.28 t/hawas obtained when transplanting of sugarcane was done with the settlings raised through SSI technique followed by conventional method of planting (97.36 t/ha) and transplanting of settlings raised from single bud setts (90.37 t/ha).

Key words: Sugarcane planting techniques, Genotypes

INTRODUCTION

Sugarcane is one of the most productive plant species known in terms of dry matter production as it potentially produces from 41 to 65 t of dry matter ha^{-1} year^{-1} (Cheeroo-Nayamuth *et al.* 2000). In India, the crop is cultivated in an area of 5.042 million ha with a total production of 411 m tonnes and 32.48 m tonnes of sugar at an average productivity of 81.5 t/ha (Anonymous 2019), whereas in Odisha it is cultivated in an area of 36,000 ha with cane production and productivity of 25.26 lakh tonnes and 70.43t/ha, respectively (Anonymous 2013). Enhancing sugarcane productivity in Odisha is undoubtedly important both for the farmers and sugar industry as well. The critical steps to be followed in this context are planting with good quality seed cane material for establishment of healthy and good initial plant stand in the field and good agronomic crop management practices for obtaining higher yields of both cane and sugar. There is no scope left for horizontal expansion of sugarcane area in the state due to rapid industrialization of cultivable lands. Therefore, the vertical growth in this context is only possible with the adoption of effective crop management practices and high yielding sugarcane varieties (Manimaran *et al.* 2009). In conventional method of sugarcane planting, a lot of seed cane is wasted besides scanty plant population, reduced vigour and growth of sugarcane plants resulting in less cane yield and productivity. The situation, therefore, calls for innovative methodologies which could be adopted by the farmers for enhanced productivity of cane and sugar leading to higher income of the farmers. Physiologically, sugarcane being a C_4 plant, is one of the most efficient converters of solar energy into sugar and during its peak growth period it has the potentiality to produce around half a tonne of dry matter ha^{-1} day^{-1} (Yadav 1991). However, such performance of the crop depends upon the raising of crop with suitable planting technique and adoption of high yielding sugarcane genotype for efficient harvesting solar radiation and a good crop stand at the initial level.Testing of interaction of planting techniques and sugarcane genotypes in a particular environment is an important consideration for realising the potentiality of a genotype since the ultimate number of millable stalks and weight thereof are only taken into consideration in this regard. Keeping this in view, the present study was carried out.

MATERIALS AND METHODS

A field experiment was carried out at the Sugarcane Research Station Instructional Farm, Nayagarh, (Odisha) (19°54'-20°32' N latitude and 84°29'-85°27' E longitude) during spring seasons of 2014-15 and 2015-16. The experimental site falls under the East and South Eastern Coastal Plain Agro-climatic Zone of Odisha having sub humid climate with unimodel rainfall pattern. The objective of this study was to find out the suitable genotype raised under different planting techniques for

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enhancing sugarcane yield and quality in Odisha. The soil of experimental site was sandy loam in texture, low in organic carbon (0.48 %), medium in available phosphorus (11.2 kg/ha) and exchangeable potassium (137 kg/ha).The experiment was laid out in a split-plot design with three replications. The main plots comprised of three genotypes *viz.,*'CoOr 03151' ('*Sabita*'), 'CoOr 04152' (*'Raghunath'*) and 'CoOr 05346' (*'Neelachakra'*) and sub-plot consisted of three planting techniques*viz.*settling raised from single bud setts, settling raised from SSI method and Conventional method of planting (3 bud setts). The settlings raised from single bud setts and bud chips (SSI) of different genotypes were transplanted in the main field as per recommended package of practices of the region. The three bud setts of different genotypes were planted conventionally in rows of 80 cm apart during spring season,and recommended doses of 250-100-60 kg/ha N, respectively of P_2O_5 & K_2O were applied besides 10t/ha well decomposed FYM. The crop was managed as per standard package of practices of the zone. The observations on germination % at 40 days after planting (DAP), number of tillers ('000/ha) at 180 DAP while cane yield and yield contributing characters and quality (sucrose) of cane at harvest were recorded at the respective stages.

RESULTS AND DISCUSSION

Among three genotypes, germination percentage was found higher with 'CoOr 04152' (71.89%), which was at par with 'CoOr 03151' (71.51%). The genotypes 'CoOr 04152' and 'CoOr 05346' produced statistically similar number of tillers at 180 DAP with values of 82.71 '000/ha and 81.38'000/ha, respectively. The genotype 'CoOr 03151' produced the lowest number of tillers at 180 DAP (79.36 '000/ha). Number of millable canes production of different genotypes differed significantly. Chattha *et al.* (2007) reported that tillering is an important yield attributing character and is controlled by genetic and environmental factors. The genotype 'CoOr 04152' produced significantly highest NMC (79.82 '000/ha) over others in the test. Sugarcane genotype 'CoOr 04152' produced significantly higher values of yield contributing characters *viz.*, length of cane (2.73m), girth of cane (2.99 cm) and per cane weight (1.33 kg) than of rest two genotypes in this study. There is no significant difference observed among genotypes in respect of quality parameters like °Brix, sucrose % and CCS (commercial cane sugar) %. However, the genotype 'CoOr 04152' produced higher °Brix (20.18) and sucrose% (18.46) than that of other genotypes in the test. Genotype 'CoOr 04152' produced significantly higher cane yield (106.63 t ha^{-1}), while the lowest cane yield (96.72 t ha^{-1}) was obtained with genotype 'CoOr03151' (Table 1). Similar yield differences in cane due to varieties have also been reported by Kumar *et al.* (2012).Two factor interactions between genotype and planting techniques was also significant and the highest cane yield of 120.47 t ha^{-1} was recorded with genotype 'CoOr04152' when planted under settling raised through SSI technique. Variation in yield due to genotypes and different planting techniques are in accordance with the findings of Bhullar (2002) and Islam *et al.* (2011). Settlings raised through SSI technique had the highest survival percentage (87.51%), and differed significantly from conventional method of planting (57.31%) and settling raised through single bud setts (68.28%). Significant differences observed within three different planting techniques with respect to number of tillers at 180 DAP and NMC at the harvest. Among these settlings raised through SSI technique produced the highest number of tillers (87.03'000/ha) and NMC

Table 1 Effect of promising sugarcane genotypes and planting techniques on yield and quality of sugarcane

Treatments	Germi-nation % at 40 DAP	No of tillers (000/ha) at 180 DAP	Length of cane (M)	Girth of cane (cm)	Weight of cane (kg)	NMC (000/ha)	Cane yield (t/ha)	°Brix	Sucrose %	CCS %	CCS yield (t/ha)
Sugarcane genotypes											
(i) 'CoOr 03151'	71.51	79.36	2.67	2.64	1.28	75.17	96.72	19.96	18.39	12.99	12.61
(ii) 'CoOr 04152'	71.89	82.71	2.73	2.99	1.33	79.82	106.63	20.18	18.46	12.96	13.86
(iii)'CoOr 05346'	69.70	81.38	2.56	2.58	1.26	77.73	97.65	19.24	18.29	13.06	12.78
CD (5%)	1.7	2.0	0.12	0.15	0.03	1.1	2.85	NS	NS	NS	0.52
Planting techniques											
(i) Settling raised from single bud sett	68.28	76.33	2.58	2.69	1.24	73.12	90.37	19.31	17.74	12.48	11.28
(ii) Settling raised from SSItechnique	87.51	87.03	2.86	2.86	1.36	83.21	113.28	20.31	19.07	13.55	15.34
(iii) Conventional method of planting	57.31	80.08	2.53	2.66	1.27	76.39	97.36	19.76	18.32	13.0	12.64
CD (5%)	0.82	0.73	0.1	0.07	0.02	0.7	2.12	NS	NS	NS	0.32

(83.21'000/ha). On the contrary, the lowest number of millable canes were obtained with the settlings raised through single bud setts. The tallest plants of 2.86 m length were produced from settlings raised from SSI technique establishing its superiority over settlings raised from single bud setts (2.58m) and conventional method of planting (2.53m). Similar trend was observed with respect to other yield attributing characters like (girth of cane, weight of cane) and quality parameters like (°Brix, sucrose% and CCS %) in plants raised from SSI technique. However, there was no significant difference among three different planting techniquesin respect of quality parameters. Method of raising settlings under different techniques affected the cane yield significantly. The highest cane yield (113.28 t/ha) was obtained when settlings were raised and then transplanted in the main field through SSI technique, followed by conventional method of planting (97.36 t/ha)and transplanting of settlings raised through single bud setts (90.37 t/ha). The improvement in yield components such as number of millable canes, and length, girth and weight of single cane were mainly responsible for the improvement in cane yield when sugarcane was raised through SSI technique. Bhullar (2008) concluded that the precision in planting technique is an important factor for improving sugarcane productivity as it plays a crucial role in sustaining higher number of millable canes per unit area. Thus, the better spacing under SSI technique of sugarcane planting with resultant reduction in competition in nutrient use and increased utilization of space and light led to greater number of millable canes, and hence the higher cane yield.

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Design and development and optimization of the manufacturing process for free flow Jaggery powder

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ABSTRACT

Jaggery is a traditional sweetener and more nutritious than sugar. Therefore, jaggery is demanded a lot in the global market. Shelf life and user-friendly appearance are the two biggest challenges for commercial use of jaggery. If jaggery is available in powdered form, due to value addition, more earnings are possible to sugarcane producers-farmers. For the production of jaggery in granular form, it is required to dehydrate it up to 2% is studied experimentally. The main objective of this work was to attain higher material rate (yield), lower drying time, and good quality of Jaggery powder. Drying temperature, vacuum pressure, and quality of dehydrated jaggery are the three process parameters that have been considered for optimization of the drying process. Since the process has multiple performance characteristics, the grey relational analysis is used. For pulverizing jaggery efficiently, pin mill is developed by optimizing the influencing parameters, design configuration (pin diameter, number of pins, pitch circle diameter (PCD), and pin configuration), speed of the machine, and feeding rate. The complete process of manufacturing free flow jaggery powder has been developed along with process parameters selection, optimization and equipment design.

Keywords: Jaggery, Vacuum drying, Multi-objective optimization, Grey relational analysis, pin mill

INTRODUCTION

Jaggery is a natural traditional sweetener and healthy sugar made by concentrating the extracted sugarcane juice. India is the largest producer and consumer of jaggery. Out of total world production, more than 70% produced by India(Jagannadha Rao *et al.* 2007). This sector can employ about 2.5 million people. Therefore, it is important to expand the sector, as it provides higher food value to jaggery at a lower cost and boosts-up the rural economic system (Madan *et al.* 2004). In Ayurveda, it is used as a medicine, blood purifier, and base material for syrups. It has a moderate amount of iron, magnesium, calcium, phosphorous, and zinc which helps to optimize the health of a person along with all its benefits such as purification of the blood, prevention of rheumatic afflictions and bile disorders, and thus helps to cure jaundice (Singh 2008; Sahu and Paul 1998; Sahu and Saxena 1994). As people become more health conscious, demand for jaggery will increase not as a sweetener, but as a health supplement and it has great export potential in the world. The use of jaggery in daily diet would help to improve the majority population suffering due to undernutrition and/or malnutrition, and deficient common diet. It may replace sugar in the making of healthy foods, and hence, appears to have a bright future among masses and could be promoted (Singh *et al.* 2013).

The jaggery manufacturers are mostly small and marginal farmers relying on quick returns from jaggery. Therefore, it is essential to safeguard the sugarcane growers to earn more profit from their jaggery manufacturing unit by improving its quality through value addition, packaging and jaggery based products with modern technologies (NAAS 2006). Though a major contributor in the jaggary production, most of the jaggery business in India suffers from losses. The development of different value-added products from jaggery and their commercial availability becomes a need of the hour to sustain future profitability in the jaggery trade (Nath *et al.* 2015). The biggest problem for jaggery manufacturers is shelf life of jaggery because of moisture content and the hygroscopic nature of jaggery. The loss in original texture, colour and flavour is associated with chemical and microbiological changes, which leads to deterioration of jaggery quality and colossal loss to industry and farmers. This loss can be minimized by removing or reducing the moisture content (Verma *et al.* 1990). Jaggery may be value-added if produced in powdered/granular form with different natural flavour (ginger, black pepper, cardamom, lemon, *etc.*), nutrition (protein, vitamins, and phytochemicals), texture (additives) and taste (additives like nuts, spices, cereal, and pulses) (Said and Pradhan 2013)

It is noticed from the literature survey that the established and affordable technologies for producing jaggery powder/ granules are not developed for commercial mass production. Many experiments were performed on different types of grinders such as Ball and tube mills, Ring and ball mill, Hammer and impact pulverizer, HPGR, granulator, shredder pulverizer, Universal mills, Attrition mills, Knife Mills, Turbo Mills, Beater Mills, Disc Mills, and Pin mill to produce lumped jaggery into

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granular/powdered form. It was observed that due to moisture content in jaggery and heat developed during grinding, the machine got blocked and required powder could not produce. Due to moisture content, hygroscopic nature, and heat developed during pulverizing, most of the food materials cannot be pulverized (Jung 2018). With a lot of research and experimentation, it was concluded that due use of chemicals during the manufacturing of jaggery and the presence of moisture, jaggery cannot be pulverized. Hence, chemical-free jaggery was dehydrated up to 3 to 4% moisture content, and experimentation was conducted again on different types of pulverizers and pin mill described better results as compare to other pulverizers.

In present research work, for manufacturing jaggery in granular/powdered form, a pulverizing machine is designed and optimized under various operating parameters. The objective of this research work is to develop an affordable drying process for further pulverizing of jaggery which is the novelty of the proposed method. The present paper is divided into two sections-sections I deal with Optimization of Vacuum drying parameters and section II deals with design, development and optimization of Pin mill pulverizer.

MATERIALS AND METHODS

A. *Optimization of vacuum drying parameters*

Research work

Jaggery is manufactured by the concentration of Sugar cane juice and further surface evaporation or semisolid mass. This jaggery contains moisture within range 8-14% depends on sugarcane variety, different chemicals used during the process, and skill of person processing. Initially drying experiments were conducted in a tray dryer on various eleven samples available in the nearby region. But, it was observed during all these experiments that at higher temperature jaggery get softened and it cannot bring to its original state. In certain trials, caramelization was also observed. Also, the time required for drying was more than six hours. Hence it was decided to conduct trials on vacuum dryer to minimize the time required for drying by preserving quality parameters. All food technologists have recommended the vacuum drying process for agro and food products (Jungam *et al.* 2010; Richeter 2014). Further experimentation was conducted in a vacuum dryer available at NES India Engineers, Pune. During the screening test, somewhat satisfactory results were observed only for a sample of dark chocolate coloured jaggery. With a detailed study, it was investigated that the sample was manufactured from sugarcane variety 'Co 86032'and was processed without any chemicals. From additional experiments, it was revealed that only chemical-free jaggery can be dried. Hence, supplementary experiments were performed on the same sample and consistent results were observed.

The objective was that jaggery should be dried in minimum time without a change in taste, crystalline structure, colour and flavour with moisture content up to 2%. Therefore three process parameters -temperature, vacuum in a dryer, and quality of dried jaggery were considered. Quality of dried product plays an important role in any drying process. Taste is an important criterion, but along with that, its texture, colour, and flavour are also considered for deciding the quality of dried jaggery. With the increased temperature and excessive time, the taste of jaggery is changed. Due to caramelization at high temperature, colour and flavour also change to such an extent that the product cannot be accepted in the market. Therefore, for the overall quality of dried jaggery, the parameter 'Quality Analysis Grading' was decided as QAG on 1 to 10 scales.

Experimental work

Experimental work was carried out in a vacuum dryer with a vacuum pump, condensing unit, drying chamber and all other necessary accessories. Fresh Jaggery samples manufactured from sugarcane variety 'Co 86032' processed without chemicals were collected from jaggery manufacturer-Sudarshan Agrotech, Lavanmachi. Based on previous screening tests, the temperature range of 60-80^{0}C and vacuum range 300-500mm [Hg] were selected for experimentation. Jaggery slab was cut into pieces of cubes of approximate size 25mm. Drying experimentation was conducted at a temperature of 60^{0}C, 70^{0}C, and 80^{0}Cwith vacuum 300mm, 400mm and 500mm [Hg] respectively. The design of experiments was performed using the Taguchi method (Jangam *et al.* 2010).

A 100g of jaggery was placed intray. The drying process was carried out for 2% (w.b) final moisture content of the jaggery sample. During the drying process, the vacuum was broken, and the samples were taken out and weighed at initial intervals of 1hour and then at 30min using a digital electronic balance. The accuracy of the weighing system was 0.001g. Weight measurements took one minute and, after putting the sample in the drying chamber, the vacuum was restored. The moisture content of the samples was calculated as kg water per kg of dry solid. Drying was continued until three consecutive measurements indicated constant weights. Three replicates for each experiment werecarried out. At the end of each experiment, the moisture ratio at any time was calculated to express the drying data as moisture ratio versus drying time, and drying rates at various drying times were calculated to plot drying rate curves. Regression analysis was carried out for selecting optimum temperature and vacuum for the drying process. It has been shown that the grey-based Taguchi method can optimize the multi-response processes (David 1994) through the settings of the process parameter for the drying process for maximum QAG and minimum time.

Design of Experiments

From the experiments conducted in screening tests, it was observed that both temperature in dryer and vacuum in dryer influencing the drying process to a certain level. Hence, experiments were planned with the Taguchi method. L9 mixed orthogonal array was developed using Minitab software.

Design of experiments (DOE) was developed for two variables temperature and vacuum with three levels as-

Process parameters	Level 1	Level 2	Level 3
Temperature^{0}C	60	70	80
Vacuum, mm[Hg]	300	400	500

For the above experiments, the time required for drying and quality analysis grade (QAG) is observed as shown in Table 1.

Table 1 Experimental design

Sl.No.	Vacuum (mm[Hg])	Temperature (^{0}C)	Time (min)	QAG
1	300	60	360	8
2	300	70	300	8
3	300	80	240	1
4	400	60	210	9
5	400	70	150	9
6	400	80	120	1
7	500	60	180	5
8	500	70	150	1
9	500	80	120	1

Analysis of responses

Experiments were planned using the Taguchi method and analysis was done using Minitab software with help of analysis of variance, regression equation, and main effect plots. Analysis of time and analysis of QAG was done. From the analysis of time, it was observed that vacuum and temperature both are significant parameters and optimal conditions are vacuum 300mm [Hg] and temperature 60^{0}C. From the analysis of QAG, it was observed that only temperature was significant parameter with optimal conditions-vacuum 400mm [Hg] and temperature 60^{0}C.

Final experimentation with improved parameters with their levels

There are two responses *i.e.* time and quality analysis grading. It is difficult to find out the optimum level of parameters. Therefore, there is a need to introduce multi-objective optimization to find out the optimum level of time and quality analysis grading (QAG). Also, it is observed from the experimentation that the quality of jaggery deteriorates after 70^{0}C. Therefore temperature 80^{0}C was eliminated for further experimentation. The design of experiments was developed by Taguchi Method. L18 mixed orthogonal array was developed using Minitab software. DOE was developed with two variables vacuum and temperature.Therefore, next experimentation was carried out with one process parameter with three levels and other with two levels as shown below:

Process parameters	Level 1	Level 2	Level 3
Vacuum, mm[Hg]	300	400	500
Temperature ^{0}C	60	70	--

Design of experiment for improved parameters and their levels

For experiments, the time required for drying and quality analysis grade (QAG) observed is shown in Table 2.

Table 2 Improved experimental design.

Temperature (^{0}C)	Vacuum (mm[Hg])	Time (min)	QAG
60	300	360	7
60	300	340	7
60	300	350	7
60	400	210	8
60	400	220	8
60	400	210	8
60	500	180	5
60	500	160	5
60	500	180	5
70	300	300	8
70	300	280	8
70	300	290	8
70	400	180	9
70	400	140	9
70	400	140	9
70	500	120	0
70	500	120	0
70	500	120	0

B. Design and development of pin mill for pulverizing jaggery

Research Work

From the experimentation conducted on different types of pulverizers, pin mill described better results as compared to other pulverizers. Hence further experimentation was conducted on Pin Mill.

Pin Mill

Pin Mill is a high-speed impact grinding machine designed for the grinding of dry materials. The machine's grinding action can be controlled by altering the feed rate to the machine and the speed of the rotor. Pin Mill grinding is gradually done from the centre to the periphery of the rotor, allowing heavy pieces of material to be reduced by stages to the fineness required (Rajkovich 2017).The right number and arrangement of pins can minimize material buildup in the mill during grinding, reducing wash down requirements and the associated downtime. Careful pin specification can also reduce the amount of heat generated during grinding, helping to avoid heat-related material buildup problems and softening or melting of heat-sensitive particles or other particle damage (Coulombe 2015).

Further experimentation with different jaggery samples on pin mill, it was decided to develop pin mill pulverizer for mass production of jaggery powder. The main objective of this study is to obtain a higher material rate (yield), lower dust content, and good quality of jaggery powder. In manufacturing jaggery powder, it is important to select design parameters & operating parameters for achieving the optimal performance of the pin mill. Design configuration (i.e. pin diameter, no. of pins, PCD for pin rows, pin configuration), speed of machine, and feeding rate are the three process parameters with various levels. Usually, the desired grinding parameters are determined based on experience. By specifying the right components and operating features for pin mill, along with optimization, equipment downtime for parts replacement and repairs can also be reduced. However, this does not ensure that the selected design & operating parameters result in optimal or near-optimal grinding performance for jaggery (Rajkovich 2017). It has been shown that the grey-based Taguchi method can optimize the multi-response processes through the settings of the process parameters.

In pin mill design, design configuration plays an important role in its performance for pulverizing a particular product. To decide this particular configuration for pulverizing jaggery, by various permutations and combinations, several screening tests were conducted with different combinations of pin diameter, number of pins, number of rows of pins and pitch circle diameter (Fig. 1 a & b). All these parameters depend upon the nature of substance to be pulverized, feeding size, and average particle size required after pulverizing and expected output of the product. With available research literature, such data is not available for jaggery. Also available analytical data of different pharmaceuticals and food products was not sufficient to design pin mill pulverizer for jaggery. Hence, it was decided to select a particular basic design configuration by performing screening tests.

1. Input-Lumped jaggery from sugarcane variety 'Co 86032' processed without chemicals with 2-3% moisture content, dehydrated in a Vacuum dryer. It was broken into pieces of an approximate size of 50mm × 50mm.
2. Output expected-Granular jaggery sieved through 3mm sieve with a pulverizing rate of 200 kg per day.

Experimental work

For experimentation, basic pin mill pulverizer was designed and further developed as per the following specifications:

1) Fixed Plate-Single row at PCD 170 mm. with 15 number of pins
2) Rotating plate-Two rows at 132mm and 208mm PCD with 15 and 20 number of pins respectively
3) Pin Diameter-12mm.
4) Drive-1 HP with speed 1000rpm, 1400rpm, 1680rpm
5) MOC-Mild steel (MS)

Following experiments were conducted:

Experiment No.1

Trials was conducted with feed rate 500g/min and 750g/min. 40% average yield obtained in two passes. But machine failure observed due to bending of 12 mm diameter pin.

Experiment No.2

With the same configuration, the number of rows on pin mill, the diameter of pin enlarged to 14mm. The number of pins on fixed plate-15. The numbers of pins on the rotating plate are 20 and 15 on outer and inner PCD respectively. Trials were conducted at speed 1000, 1400, 1680 rpm with a feed rate 500, 750, and 1000g/min. It was observed that yield increased with

Fig. 1 (a & b). Different design configurations for pin mill

speed and feed rate, but machine failure observed due to bending of 14mm diameter pins. Further for all configurations from A1 to A5, Trials were conducted at speed 1000, 1440, 1680 rpm with feed rate 500, 750 and 1000g/min.

Experiment No.3. Design configuration A1.

The diameter of pins enlarged to 16mm.

Fixed plate-Number of rows two, with the number of pins 9 and 6 on outer and inner PCD 265 and185 mm.

Rotating Plate-Number of rows three, with the number of pins 12, 9, and 6 respectively on PCD 315, 235, and150mm.

It was observed that yield increased with speed and feed rate. The output obtained- 62% average yield and 6% dust.

Experiment No.4. Design configuration A2.

The diameter of pins-16mm

Fixed plate-Number of rows two with number of pins 12 and 6 on outer and inner PCD265 and185 mm.

Rotating Plate- Number of rows three with number of pins 12, 12 and 6 respectively on PCD 315, 235, and 150mm.

It was observed that yield increased with speed and feed rate. Output obtained-65% average yield and 6% dust.

Experiment No.5. Design Configuration A3

The diameter of pins-16mm

Fixed plate- Number of rows two with number of pins 12 and 6 on outer and inner PCD265 and185 mm

Rotating Plate- Number of rows three with number of pins 18, 12 and 6 respectively on PCD 315, 235, and150mm

It was observed that yield increased with speed and feed rate. Output obtained-70% average yield and 7% dust.

Experiment No.6. Design configuration A4

The diameter of pins-16mm

Fixed plate- No. of rows two with no. of pins 12 and 6 on outer and inner PCD265 and185 mm

Rotating Plate-No. of rows three with no. of pins 24, 12 and 6 respectively on PCD 315, 235, and150mm

It was observed that yield increased with speed and feed rate. Output obtained-75% average yield and 8% dust.

Experiment No.7. Design configuration A5

Square pins-16mm 16mm

Fixed plate-Number of rows two with number of pins 9 and 6 on outer and inner PCD 265 and185 mm

Rotating Plate-Number of rows three with number of pins 12, 9 and 6 respectively on PCD315, 235, and150mm

It was observed that yield increased with speed and feed rate. Output obtained-73% average yield and 20% dust.

But machine failure observed after 30, 24 and 20 minutes for increasing speeds due to blockage on account of fine dust formation. During pulverizing of jaggery, undesirable very fine jaggery particles are produced. This fine dust build up on pins discs and inner casing results in failure of the machine due to the formation of a hard layer of fine dust and blockage of the machine. From the above experimentation, for design configurations, A1, A2, A3 and A4, acceptable results were observed for yield, dust and machine performance.

Design of experiments

As per screening tests, it was observed that along with design configuration, other parameters such as speed and feeding rate are also influencing with certain level to machine performance. The design of experiments (DOE) was developed by Taguchi Method. L16 mixed orthogonal array was developed using Minitab software. DOE was developed with 3 variables- Design configuration, speed and feed rate with 4 levels of each as shown below:

Level of Variables

Process parameters	Levels			
	1	2	3	4
Design configuration	A1	A2	A3	A4
Speed of Pin Mill-(RPM)	800	1000	1400	1680
Feeding rate-(g/min)	250	500	750	1000

For the above experiments, the percentage of yield and dust observed is shown in Table 3.

Table 3 Experimental design for L16 array.

Configuration	Speed (RPM)	Feed rate (g/min)	Yield (%)	Dust%
A1	800	250	58	3
A1	1000	500	60	5
A1	1400	750	64	8
A1	1680	1000	65	5
A2	800	500	65	4
A2	1000	250	65	6
A2	1400	1000	66	8
A2	1680	750	68	12
A3	800	750	62	3
A3	1000	1000	66	6
A3	1400	250	70	8
A3	1680	500	72	12
A4	800	1000	65	3
A4	1000	750	70	5
A4	1400	500	74	8
A4	1680	250	76	15

RESULT AND DISCUSSION

A. *Optimization of vacuum drying parameters*

Analysis of Responses

Experiments were planned using the Taguchi method and analysis was done using Minitab software with help of analysis of variance, regression equation, and main effect plots. From the analysis of the time, it was observed that vacuum and temperature both are significant factors for the minimum drying time. With an increase in the vacuum in the dryer, the corresponding time required for drying decreased.With the increase in temperature, the total time required for drying decreased. All researchers working on drying of various materials observed a similar trend during vacuum drying of dates (Ashraf *et al.* 2012), potato (Dagde *et al.* 2014), and the coconut press cake (Jena and Das 2006) and other food products (Gamli 2014).

From the analysis of QAG (quality analysis grading), it was observed that temperature is the only significant parameter for quality analysis grading. The QAG increases initially for vacuum from 300mm to 400mm and again it decreases. When jaggery is heated at a higher temperature, changes in colour, structure, and taste are observed. Above 70^0C, jaggery gets softened whereas at 76^{0}C, it starts to melt and caramelization is observed. Also, during vacuum drying, the same phenomenon occurs. Henceforth, with increasing temperature, QAG decreases with increases in temperature. Deterioration of quality parameters is observed during drying of many food materials such as date paste, olive cake (Akgunand Doymaz 2005), mango pulp (Jaya *et al.* 2005), apricots (Mirzaeee*et al.* 2010), pumpkin (Arévalo-Pinedo *et al.* 2006). From the main effect of the plot for time, vacuum 300mm [Hg] and temperature 60^0 C are optimum conditions whereas, from the main effect plot for QAG, vacuum 400mm [Hg] and temperature 60^0 C are optimum conditions.

Multi-Objective Optimization for Vacuum Drying Process

It was observed that vacuum and temperature were significant factors for the minimum time required for drying while the temperature was the only significant factor for maximum QAG. Therefore, it is very difficult to identify the optimum level for both cases. Hence, a simple optimization technique will not be useful to solve this problem. To overcome this problem, the multi-objective optimization method is used to solve the present problem (Table 4). In this study, the grey relational analysis method is used to identify the optimum level for minimum time and best QAG. The experimental results were optimized using a grey relational analysis-based Taguchi method for maximum quality analysis grading and minimum time required for the vacuum drying of jaggery.

The grey relational generation is calculated as per the equation (1) and equation (2) (Chang *et al.* 2003), (Kao *et al.* 2003). For QAG, larger is the better,

$$X_{ij} = \frac{Y_{ij} - min_i Y_{ij}}{max_i Y_{ij} - min_i Y_{ij}} \quad (1)$$

For time, smaller the better,

$$X_{ij} = \frac{max_i Y_{ij} - Y_{ij}}{max_i Y_{ij} - min_i Y_{ij}} \quad (2)$$

Where,

is the i^{th} performance characteristic in the j^{th} experiment ($i=1,2,3.....27;\ k=1,2,3$) and is the maximum and minimum values of i^{th} performance characteristics for alternate j respectively. The grey relational coefficient (GRC) is calculated as per the Equation (3), (Kao *et al.* 2003).

$$\gamma(x_0(k)) = \frac{\Delta\, min + \zeta \Delta max}{\Delta_{0i}(k) + \zeta \Delta max} \quad (3)$$

Where,

i= 1, 2……27; k=1, 2, 3

The 'Grey Relational Grade' (GRG) is obtained as per the equation (4)

$$\gamma(x_0, x_i) = \frac{1}{m}\sum_{k=1}^{m} \gamma(x_o(k), x_i(K)) \quad ...(4)$$

From the above experimentation and analysis, it is concluded that for drying of jaggery in a vacuum dryer, an optimum temperature of 70^{0}C and Vacuum of 400mm [Hg] provides the best performance of the dryer. As per the level of process parameters received from the multi-objective optimization technique, validation experiments were conducted for best and worst conditions and it was proved that optimization results are in agreement with validation results.

Table 4. Optimization for mixed Taguchi L18 orthogonal array

Temp ^{0}C	Vacuum mm [Hg]	Time (min)	QAG	Time GRR	QAG GRR	Time GRC	QAG GRC	GRC	GRG
60	300	360	7	0	0.8571	0.5	0.875	0.688	18
60	300	340	7	0.0833	0.8571	0.521739	0.875	0.698	16
60	300	350	7	0.0416	0.8571	0.510638	0.875	0.693	17
60	400	210	8	0.625	1	0.727273	1	0.864	4
60	400	220	8	0.5833	1	0.705882	1	0.853	6
60	400	210	8	0.625	1	0.727273	1	0.864	5
60	500	180	5	0.75	0.571429	0.8	0.7	0.750	11
60	500	160	5	0.8333	0.571429	0.857143	0.7	0.779	10
60	500	180	5	0.75	0.571429	0.8	0.7	0.750	12
70	300	300	8	0.25	1	0.571429	1	0.786	9
70	300	280	8	0.3333	1	0.6	1	0.800	7
70	300	290	8	0.2916	1	0.585366	1	0.793	8
70	400	180	9	0.75	1.142857	0.8	1.166667	0.983	3
70	400	140	9	0.9166	1.142857	0.923077	1.166667	1.045	1
70	400	140	9	0.9166	1.142857	0.923077	1.166667	1.045	2
70	500	120	1	1	0	1	0.5	0.750	13
70	500	120	1	1	0	1	0.5	0.750	14
70	500	120	1	1	0	1	0.5	0.750	15

B. *Design and development of pin mill for pulverizing jaggery*

Analysis of response

Experiments were planned using the Taguchi method and analysis was done using Minitab software with help of analysis of variance, regression equation, and main effect plots. Analysis for maximum yield and minimum dust was performed. From analysis for maximum yield of jaggery powder in two passes, it was observed that configuration and speed both are significant factors. From configuration A1 to A4, in each configuration number of pins in each row are going on increasing for the same number of rows and same pitch circle diameter. With an increased number of pins, chances of hitting & impact of jaggery particles on rotating pins also increases which increases yield due to more grinding in one pass. With the increased speed of the rotating plate, the number of impacts of jaggery particles per unit time with pins increases. Centrifugal force on jaggery particles increases with the rotational speed of disc which results in increased yield. A similar trend was observed by other researchers during the grinding of turmeric rhizomes (Shelake *et al.* 2017) and other minerals (Jankovic 2003) and spices (Tangirala *et al.* 2014)

From the analysis of minimum dust percentage, it was observed that speed is the most significant factor while configuration and feed rate did not play a significant role in dust percentage. As the speed of machine increases, with increased speed and centrifugal force on jaggery particles, dust formation also increases.

Multi-objective Optimization for pin mill

Experimental results were optimized using a grey multi-objective relational analysis-based Taguchi method for maximum yield and minimum dust content during pulverizing of Jaggery. It was observed that configuration and speed were significant factors for maximum yield percentage while speed was the only significant factor for the minimum percentage of dust. Therefore, it is very difficult to identify the optimum level for both cases. Hence, a simple optimization technique will not be useful to solve this problem. To overcome this problem, the multi-objective optimization method will be used to solve the present problem. In this study, the grey relational analysis method is used to identify the optimum level for best yield and minimum dust (Table 5).

As per multi-objective optimization, experiment13, 14 and 15 shows the best readings for the optimum value of yield and the optimum value of dust. The following experimental conditions show the best results:

Ex.	Configuration	Speed (RPM)	Feed rate (g/min)	Yield (%)	Dust (%)	Rank
13	A4	800	1000	65	3	1
14	A4	1000	750	70	5	2
15	A4	1400	500	74	8	3

Experiment-13 shows optimum yield and dust during experimentation for configuration A4, speed 800RPM, and feed rate 1000g/min. The common parameter for these experimentations 13,14 and 15 was designed configuration A4.

Experimental work using improved process parameters

From multi-object optimization, it was observed that design configuration A4 shows excellent results. Also, the concluding results were confusing. Therefore, configurations A1, A2 and A3 eliminated from final experimentations. As per optimum level Speed 800, 1000 and 1400 RPM and Feed Rate 500,750, and 1000g/min were considered for designing final experimentation as given below.

Process parameters	Levels		
	1	2	3
Design Configuration	A4	A4	A4
Speed of Pin mill (RPM)	800	1000	1400
Feeding Rate (g/min)	500	750	1000

Table 5. L16 Grey relational optimization

Sl. No. (Experiment No.)	Yield (%)	Dust (%)	Yield (GRR)	Dust (GRR)	Yield (GRC)	Dust (GRC)	GRG	Rank
1	58.0000	3.0000	0.0000	1.0000	0.5000	1.0000	0.5000	6
2	60.0000	5.0000	0.1111	0.8333	0.5294	0.8571	0.4622	13
3	64.0000	8.0000	0.3333	0.5833	0.6000	0.7059	0.4353	14
4	65.0000	10.0000	0.3889	0.4167	0.6207	0.6316	0.4174	16
5	65.0000	5.0000	0.3889	0.8333	0.6207	0.8571	0.4926	7
6	65.0000	6.0000	0.3889	0.7500	0.6207	0.8000	0.4736	10
7	66.0000	8.0000	0.4444	0.5833	0.6429	0.7059	0.4496	12
8	68.0000	12.0000	0.5556	0.2500	0.6923	0.5714	0.4212	15
9	62.0000	3.0000	0.2222	1.0000	0.5625	1.0000	0.5208	4
10	66.0000	6.0000	0.4444	0.7500	0.6429	0.8000	0.4810	9
11	70.0000	8.0000	0.6667	0.5833	0.7500	0.7059	0.4853	8
12	72.0000	12.0000	0.7778	0.2500	0.8182	0.5714	0.4632	11
13	65.0000	3.0000	0.3889	1.0000	0.6207	1.0000	0.5402	1
14	70.0000	5.0000	0.6667	0.8333	0.7500	0.8571	0.5357	2
15	74.0000	8.0000	0.8889	0.5833	0.9000	0.7059	0.5353	3
16	76.0000	15.0000	1.0000	0.0000	1.0000	0.5000	0.5000	5

The design of experiments was developed by Taguchi method. L9 mixed orthogonal array was developed using Minitab software. DOE was developed with two variables. Speed and feed rate were with 3 levels of each with A4 design configuration. For the above experiments, the percentage of yield and dust observed is shown in Table 6.

Table 6. Experimental design for improved parameters

Exp. Run	Speed (RPM)	Feed Rate (g/min)	Yield (%)	Dust (%)
1	800	500	62	6
2	800	750	64	8
3	800	1000	64	8
4	1000	500	74	7
5	1000	750	75	6
6	1000	1000	73	8
7	1400	500	72	9
8	1400	750	74	8
9	1400	1000	73	10

Analysis of responses

Experiments were planned using the Taguchi method and analysis was done using Minitab software with help of analysis of variance, regression equation, and main effect plots. Analysis of variance for maximum yield and minimum dust was performed. From the analysis of yield, speed is a significant factor with optimal conditions speed 1000 rpm and feed rate 750g/min. From the analysis of dust, speed is a significant factor with optimal conditions speed 800 rpm and feed rate 500 g/min.

Multi-objective optimization

It was observed that speed was significant factors for maximum yield percentage and also speed was the only significant factor for the minimum percentage of dust. Therefore, it is very difficult to identify the optimum level for both cases. To overcome this problem, the multi-objective optimization method will be used to solve the present problem. In this study, the grey relational analysis method is used to identify the optimum level for best yield and minimum dust. As per equation (1) and (2) mentioned, the grey relational analysis was carried out as shown in Table 7.

From optimization, it is observed that experiment 5 shows optimum results for optimum yield and dust. For this, optimal conditions are tabulated below:

Design Configuration	Speed (RPM)	Feeding Rate(g/min)	Yield %	Dust%
A4	1000	750	75	6

Experimentation was performed for validation of optimum parameter values obtained by analysis with Pin Mill A4 design configuration, 1000 RPM speed, and 750 g/min feed rate. Results obtained for optimum yield and dustare in good agreement with experiments.

CONCLUSION

In the present research work, technology for manufacturing free flow, jaggery powder is investigated for commercial production. The following conclusions are drawn:

- It is necessary to dehydrate jaggery up to moisture content 2% and only the jaggery processed without chemicals can be dried.
- The time required to dry jaggery from the initial moisture content of 9% (Wb) was in the range of 120 to 330 min at different drying conditions at different temperatures 60, 70, and 80 ^{0}C and vacuum 300, 400, and 500 mm [Hg] is observed experimentally.
- The optimum condition for pressure 400 mm of Hg and temperature 70 ^{0}C was obtained by grey regression and multi-objective optimization and are the more suitable parameters against minimum time and quality of jaggery required are studied.
- For drying jaggery processed without chemicals from any variety of sugarcane, pressure 300 to 400 mm of Hg and temperature 60 to 70 ^{0}C are recommended.
- Vacuum Dryer for 200kg batch size is designed and installed at the agro-processing unit Sudarshan Agrotech. During jaggery powder manufacturing and operation with the same recommended parameters, resulting in the required drying time range of 2.25 to 3 hours depending on the variation in initial moisture content, variety of sugarcane, and the average size of input broken jaggery. Hence, optimized experimental

Table 7. L9 Grey relational optimization

S. No. (Experiment no.)	Yield (%)	Dust (%)	Yield % (GRR)	Dust % (GRR)	Yield (GRC)	Dust (GRC)	GRG	Rank
1	62	6	0.0000	1.0000	0.5000	1.0000	0.5000	5
2	64	8	0.1667	0.5000	0.5455	0.6667	0.4040	8
3	64	8	0.1667	0.5000	0.5455	0.6667	0.4040	9
4	74	7	1.0000	0.7500	1.0000	0.8000	0.6000	2
5	75	6	1.0833	1.0000	1.0909	1.0000	0.6970	1
6	73	8	0.9167	0.5000	0.9231	0.6667	0.5299	4
7	72	9	0.8333	0.2500	0.8571	0.5714	0.4762	6
8	74	8	1.0000	0.5000	1.0000	0.6667	0.5556	3
9	73	10	0.9167	0.0000	0.9231	0.5000	0.4744	7

results and actual results for commercial mass scale vacuum dryer for 200 kg capacity are in good agreement.

- For manufacturing jaggery in a granular form of average particle size 3 mm (sieved through 3mm sieve), Pin Mill pulverizer provides better performance as compared to other grinding/pulverizing machines. But before pulverizing, it is necessary to dehydrate it up to 2%moisture content. The optimization of the Pin Mill pulverizer for pulverizing of jaggery is performed by the grey relational analysis method.
- The analysis of the multiple performance characteristics has been performed by a grey relational grade. As a result, the response variables are yield of jaggery pulverized in two passes with the minimum amount of dust which is improved through this method. The effectiveness of this approach is verified by experiments and analysis of variance. As per grey relational grade, best condition for pulverizing jaggery in pin mill from an experimental run with A4 design configuration, 1000 RPM Speed and 750g/min Feed rate. Hence, it is recommended to use A4 design configuration for the design of pin mill at an optimum speed of 1000 RPM and feed rate of 750 g/min having 3 HP electrical motor drive for desired output of 350 kg jaggery powder per day.

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Evaluation of intra-specific hybrids of *Saccharum robustum* for yield, quality and yellow leaf disease incidence

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ABSTRACT

Improvement of *Saccharum robustum,* a wild species of *Saccharum* through repeated cycles of intra-specific hybridization and selection was undertaken at ICAR-Sugarcane Breeding Institute, Coimbatore during 1987-1996. Thirty four clones selected from six polycrosses involving 13 clones of *S. robustum* constituted Cycle 1 (C-1) hybrids. Inter-mating among the six C-1 hybrids followed by selection resulted in the identification of 22 Cycle (C-2) hybrids. Eleven hybrids selected in C-2 and C-1 cycles were inter-mated or selfed to generate Cycle 3 (C-3) hybrids. As the original parental clones of *S. robustum* were poor in juice quality, emphasis was given on selecting progenies with high brix % and sucrose % at all stages. The C-1, C-2 and C-3 hybrids totalling 89 (designated as Population Improved *S. robustum* or PIR clones) were evaluated at ICAR-SBI Research Centre, Agali, Kerala during 2015-16 for number of millable canes (NMC), single cane weight, cane yield, brix %, sucrose % in juice and incidence of yellow leaf disease (YLD). Generation-wise improvement for the targeted traits over three stages of selection was determined. Significant improvement in brix % (20.53%) and sucrose % (26.24%) was achieved after three cycles of selection. Eight YLD-free improved PIR hybrids with acceptable juice quality and cane yield were identified. They were: 'PIR 89-80', 'PIR 96-270', 'PIR 96-508', 'PIR 96-326', 'PIR 98-1174', 'PIR 00-39', 'PIR 00-1049' and 'PIR 00-1188'. Utilization of these improved species hybrids in the inter-specific crosses is suggested to obtain hybrids with better sucrose content and a diverse genetic base.

Key words: Sugarcane, Intra-specific improvement, Selection cycles, *Saccharum robustum*

INTRODUCTION

Inter-specific hybridization between *Saccharum officinarum* L. and *S. spontaneum* L. has been the mainstay of sugarcane improvement programmes throughout the world. The wild species *S. robustum* Brandes and Jeswiet ex Grassl has been sparingly used in the sugarcane varietal development programmes barring a few early attempts in Hawaii (Tew 1987) and India (Rao 1972). Nonetheless, this species is a potential source for improving traits like cane yield, fibre and water logging resistance. A total of 145 accessions of *S. robustum* are maintained in the World Collection of Sugarcane Germplasm in India (Chandran *et al.* 2010). However, its contribution in the development of commercial varieties has been negligible due to lack of flowering, non-synchronization of flowering, low seed set and poor juice quality attributes associated with the species. The narrow genetic base of the present-day commercial sugarcane varieties tracing back to not more than twenty *S. officinarum* and two *S. spontaneum* demands utilization of more species level clones for broadening the genetic base of the varieties. In this context, improvement of the *S. robustum* species *per se* prior to inter-specific hybridization was suggested to optimize their utilization (Brown *et al.* 1969; Dunckelman and Breaux 1971; Walker 1987).

In Hawaii, the *S. robustum* clone 'Port Moresby' was used in the breeding programmes. *Saccharum officinarum* x *S. robustum* hybrids such as 'H 37-1933', 'H 38-4443', 'H 54-807', 'H 54-4523', 'H 50-2036' and 'H 57-5174' were developed. Significant improvement in cane yield was reported in the hybrid 'H 37-1933' (Heinz 1965). In Mauritius, inter-specific hybrids of *S. officinarum* x *S. robustum* with improved stalk number and fibre % was reported but the hybrids were inferior for stalk diameter and pol% of cane (Ramdoyal and Badaloo 2002). In India, the first inter-specific 'Co' cane obtained from *S. robustum* was 'Co 633' in 1964 (Amalraj and Balasundaram 2006). 'Co 97016', a back cross derivative of *S. robustum* was registered as Genetic Stock ('INGR 09052') by Bakshi Ram and co-workers in 2009. 'Co' canes such as 'Co 07010', 'Co 07011', 'Co 07017', 'Co 07032', 'Co 12012' etc. were developed at ICAR-SBI utilizing the 'population improved *S. robustum*' clones (PIR). Recently, Chandran *et al.* (2020) reported development of red fleshed inter-specific hybrids utilizing red fleshed *S. robustum f. Sanguineum* clones 'NG 77-76' and 'NG 77-84'. Although commercial varieties derived from *S. robustum* crosses have not yet come, there is increased efforts in utilizing *S. robustum* clones in sugarcane improvement programmes in India.

A programme to develop improved hybrids of *S. robustum* through repeated cycles of intra-specific hybridization and

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selection was initiated at ICAR-Sugarcane Breeding Institute (SBI) during late 1980s (Nair *et al.* 1998). The primary objective was to improve the sucrose content of the hybrids in view of the poor juice quality inherent to the species, without compromising on stalk yield and associated traits. Improvements made in the targeted traits in three cycles of hybridization and selection are presented in this paper.

MATERIALS AND METHODS

Development of improved S. robustum (PIR) hybrids

Six poly crosses were made during 1988 to 1990 at ICAR-SBI Research Centre, Kannur (Kerala) using 13 typical and atypical clones of *S. robustum,* designated as C-0 clones (Table 1). The typical *S. robustum* clones have somatic chromosome number 2n = 80 whereas in atypical clones it ranged from 2n = 100 to 165. Two hundred and twenty six seedlings obtained from the above crosses were evaluated at ICAR-SBI, Coimbatore (Tamil Nadu). Based on yield and quality attributes, 34 hybrids showing superiority over the parental clones were selected to constitute Cycle 1 (C-1) hybrids (Table 1).

In 1992, crosses were made among the C-1 hybrids that came to flowering. Seedlings could be obtained only from three crosses involving six C-1 hybrids (Table 2). Eighty five seedlings obtained from these crosses were evaluated for yield contributing traits and sucrose % during 1994-95 at Coimbatore and 22 superior hybrids were selected to constitute the Cycle 2 (C-2) hybrids.

During 1995-96, a total of 5 crosses were made among C-2 hybrids as well as between C-1 and C-2 hybrids (Table 3). Two C-2 hybrids were selfed. A total of 254 progenies from these crosses were evaluated and finally 33 hybrids were selected to make up the Cycle 3 (C-3) hybrids. At each of the selection stage, emphasis was given on selecting clones with better sucrose % and stalk weight.

Evaluation of PIR hybrids

Eighty nine hybrids selected from three cycles of hybridization and selection (designated as Population Improved *S. robustum* or PIR hybrids) were pooled and evaluated at ICAR-SBI Research Centre, Agali, Kerala during February 2015. Each clone was planted in 2 rows of 5 m length x 0.9 m row spacing, replicated twice. Data on number of millable canes (NMC), single cane weight (kg), cane yield (t/ha), Brix % and sucrose % in juice were recorded at harvest (12^{th} month). Agali is a hot spot for sugarcane yellow leaf disease (YLD). The natural incidence of YLD was recorded on all hybrids. The pooled data of each cycle were analysed for measures of variation following standard statistical procedures (Sharma 2006). Elite clones selected during 2015-16 were re-planted during 2016-17 season at Agali Centre (2 row per entry x 6 m L x 0.90 m row spacing) for confirming the natural incidence of YLD.

Table 1 Parentage of Cycle 1 hybrids (PIR*) of *S. robustum*

Sl. No.	Crosses	No. of progenies selected	Progenies selected to constitute C-1 hybrids
1	'IJ 76-417' x ('IJ 76-293', '-336', '-414'; 'NG 77-21', '-215')	7	'PIR 89-28', '-33', '-42', '-51', '-67', '-78', '-80'
2	'NG 77-57' x ('51 NG 6', '57 NG 253', 'NG 77-167')	6	'PIR 89-271', '-286', '-301', '-302', '-309', '-329'
3	'NG 77-58' x ('51 NG 6', '57 NG 253', 'NG 77-167')	8	'PIR 89-350', '-369', '-370', '-381', '-389', '-392', '-397', '-398'
4	'NG 77-57' x ('IJ 76-293', '-336, -414'; 'NG 77-21', '215')	4	'PIR 89-88', '-90', '-91', '-96'
5	'NG 77-59' x ('NG 77-21', '-215'; 'IJ 76-293', '-336', '-414')	3	'PIR 89-01', '-15', '-18'
6	'NG 77-58' x ('51 NG 91A', '57 NG 11', '-54')	6	'PIR 88-3355', '-3337', '-3347', '-4007', '-4021', '-4025'
	Total	34	

*PIR = Population Improved *S. robustum* hybrids

Table 2 Parentage of Cycle 2 hybrids of *S. robustum* derived from C-1 x C-1 crosses

Sl. No.	Crosses	No. of progenies selected	Progenies selected to constitute C-2 hybrids
1	'PIR 88-3347' x 'PIR 89-91'	6	'PIR 94-408', '-435', '-438', '-454', '-458', '-482'
2	'PIR 89-354' x 'PIR 89-329'	12	'PIR 96-255', '-257', '-267', '-270', '-285', '-293', '-295', '-305', '-320', '-475', '-508', '-530'
3	'PIR 89-96' x 'PIR 88-3355'	4	'PIR 93-307', '-313', '-309', '-354'
	Total	22	

Table 3 Parentage of Cycle 3 hybrids of *S. robustum*

Crosses involving	Crosses	No of progenies selected	Progenies selected to constitute C-3 hybrids
C-2 x C-1	'PIR 93-307' x 'PIR 88-3347'	3	'PIR 96-326', '-328, '-337'
C-2 x C-1	'PIR 93-313' x 'PIR 88-4021'	4	'PIR 96-400', '-402A', 'PIR 98-1068', '-1120'
C-2 x C-1	'PIR 94-458' x 'PIR 89-397'	5	'PIR 98-635', '-671', '-704', '-871', '-1319'
C-2 x C-1	'PIR 93-309' x 'PIR 88-4025'	4	'PIR 96-72', 'PIR 98-937', '-1250', '-1174'
C-2 x C-2	'PIR 93-307' x 'PIR 96-475'	3	'PIR 98-328', 'PIO 00-893', '-1122'
C-2 Self	'PIR 96-255' self	3	'PIR 00-1049', '-1057', '-1058', '-1062', '-1162', '-1163', '-1174', '-1188', '-1193'
C-2 Self	'PIR 96-270' self	5	'PIR 00-29', '-34', '-39', '-1100', '-1157'
	Total	33	

RESULTS AND DISCUSSION

The range, mean and coefficient of variation (CV%) in selected hybrids at each cycle of selection and % improvement over the selection cycles for NMC, single cane weight, brix %, sucrose % and cane yield t/ha are presented in Table 4.

C-1 hybrids

The mean brix % was 14.61 and sucrose % was 10.67 (Table 4) in C-1 hybrids. NMC ranged from 46,296 to 2,08,333/ha with a mean of 112121/ha while single cane weight varied from 0.20 to 0.65 kg (mean: 0.44 kg). The mean cane yield was 48.08 t/ha with a range of 21.08 to 100.00 t/ha. The progenies of the cross 'IJ 76-417' x ('IJ 76-293', '-336', '-414'; 'NG 77-21', '-215') recorded a mean sucrose % of 9.48. The incidence of YLD was recorded in all the progenies except 'PIR 89-78' and 'PIR 89-80'. The progenies of the cross 'NG 77-57' x ('51 NG 6', '57 NG 253', 'NG 77-167') and 'NG 77-59' x ('NG 77-21', '215'; 'IJ 76-293', '-336', '-414') exhibited thin stalk with low sucrose (8.87%). YLD and SGSD (sugarcane grassy shoot disease) were recorded in the progenies. On the contrary, crosses 'NG 77-58' x ('51 NG 6', '57 NG 253', 'NG 77-167') and 'NG 77-58' x ('51 NG 91A', '57 NG 11', '-54') recorded relatively higher sucrose (12.00%, 11.84%, respectively) but YLD incidence was noticed in most of the progenies. The mean sucrose % in the cross 'NG 77-57' x ('IJ 76-293', '-336', '-414', 'NG 77-21', '-225') was 11.56. YLD was observed in all the progenies in this cross except the hybrid 'PIR 89-95'.

C-2 hybrids

The mean NMC in C-2 was 1,21,204/ha (Table 4) which was 8.10% improvement over C-1 hybrids. The mean single cane weight (0.45 kg) showed marginal improvement (2.27%) over C-1 mean. Cane yield ranged from 24.63 to 85.56 t/ha with a mean of 54.47 t/ha which was 13.29% higher than the C-1 mean. Mean brix % and sucrose % in juice were 15.99 and 12.24, respectively. The improvement in C-2 over C-1 hybrids was 9.45% for Brix% and 14.71% for sucrose. Of the three C-2 cycle crosses, higher sucrose % was recorded in the cross 'PIR 88-3347' x 'PIR 89-91' (16.38%) and 'PIR 89-96' x 'PIR 88-3355'

Table 4 Range, mean and CV% in 'PIR' hybrids at three cycles of selection and % improvement over selection cycles

Selection cycle	Variability statistics	Brix % at 12 m	Sucrose % at 12m	NMC /ha	Single cane weight (kg)	Cane yield (t/ha)
C-1 cycle (34 clones)	Range	10.42-17.12	5.84-13.79	46,296-2,08,333	0.20-0.65	21.08-100.00
	Mean	14.61	10.67	1,12,121	0.44	48.08
	CV%	12.07	18.73	41.35	28.89	47.83
C-2 cycle (22 clones)	Range	13.90-17.50	8.99-15.30	74,074-1,57,407	0.28-0.60	24.63-85.56
	Mean	15.99	12.24	1,21,204	0.45	54.47
	CV%	7.52	14.04	19.87	21.03	31.37
C-3 cycle (33 clones)	Range	14.10-18.70	8.98-16.85	54,630-1,94,444	0.20-1.13	21.48-140.63
	Mean	17.61	13.47	1,14,366	0.48	53.07
	CV%	6.20	10.86	35.87	46.73	55.24
% improvement in different cycles of selection						
C-1 to C-2		9.45	14.71	8.10	2.27	13.29
C-2 to C-3		10.13	10.05	-5.64	6.67	-2.57
C-1 to C-3		20.53	26.24	2.00	9.09	10.38

(16.14%). The cross 'PIR 89-354' x 'PIR 89-329' recorded maximum number of selectable progenies. The progenies were free from YLD but there was wide variation for stalk thickness in the cross.

C-3 hybrids

The C-3 hybrids consisted of three types, (i) three hybrids derived from inter-crossing among C-2 hybrids, (ii) sixteen hybrids derived from C-2 x C-1 crosses, and (iii) 14 selfed progenies of C-2 hybrids. The mean brix % of C-3 hybrids was 17.61(Table 4) which was 10.13% improvement over C-2 and 20.53% improvement over C-1 hybrids. The mean sucrose % was 13.47 (range: 8.98 to 16.85%) which was 10.05% and 26.24% improvement over the mean of C-2 and C-1hybrids, respectively. The NMC ranged from 54,630 to 1,94,444/ha with a mean of 1,14,366/ha. There was no improvement in this trait from cycle 2 to cycle 3, rather marginal reduction of 5.64% was discernible. The improvement in NMC from cycle 1 to cycle 3 also was marginal (2.0%). Single cane weight ranged from 0.20 to 1.13 kg (mean: 0.48 kg). Cycle 3 hybrids registered 6.67%and 9.09% improvement for single cane weight over C-2 and C-1hybrids, respectively. Cane yield in C-3 hybrids ranged from 21.48 to140.63 t/ha with a mean of 53.07 t/ha. Cycle 3 hybrids recorded 10.38% improvement over C-1 hybrids but from cycle 2 to cycle 3, there was no improvement for this trait as the maximum improvement was attained by the second cycle of selection. This is expected as the selection was for juice brix % and sucrose and not for cane yield *per se*.

Observations on the natural incidence of YLD in 'PIR' hybrids showed that Cycle-1 hybrids 'PIR 89-78', 'PIR 89-80', 'PIR 89-381', Cycle-2 hybrids 'PIR 94-482', 'PIR 96-270', 'PIR 96-28'5, 'PIR 96-508' and Cycle-3 hybrids 'PIR 00-39', 'PIR 00-1049', 'PIR 00-1062', and 'PIR 00-1188' were free from YLD. Field observations during second year (2016-17) confirmed that these hybrids remained free from natural incidence of YLD. The wild species *S. robustum* is susceptible to sugarcane mosaic and YLD (Nithya *et al.* 2018). Nonetheless, PIR hybrids reported above were free from the natural incidence of YLD which offer scope for identifying true resistance through further intensive screening as suggested by Viswanathan *et al.* (2016).

The intra-specific hybrids showed progressive improvement for targeted traits namely brix % and sucrose % in successive selection cycles (10.67% to 12.24% to 13.47%). The mean sucrose % of C-3 hybrids was 13.47, which was 1.23 units higher than the C-2 and 2.80 units higher than the C-1 hybrids. About 14.71% improvement was achieved in the first cycle of selection and 10.05% in the second selection cycle (Table 5) which is a significant improvement in a wild species like *S. robustum*. Individual hybrids with sucrose % as high as 13.79, 15.30 and 16.85 were identified from C-1, C-2 and C-3 selection cycles, respectively. The sucrose % reported in *S. robustum* germplasm maintained in the World Sugarcane

Table 5 List of YLD-free 'PIR'** clones identified for further utilization in the inter-specific hybridization

Sl. No.	Selected PIR clones	Selection Cycle	Parentage	Brix % at 12m	Sucrose % at 12m	NMC/ ha	Single cane weight (kg)	Cane yield (t/ha)
1	'PIR 89-80'	C-1 (C-0 x C-0)	'IJ 76-417' x ('IJ 76-293', '336', 414', 'NG 77-21', '-215')	15.54	11.40	2,08,333	0.48	100.00
2	'PIR 96-270'	C-2 (C-1 x C-1)	'PIR 93-354' x 'PIR 89-329'	17.50	15.30	1,24,074	0.51	63.28
3	'PIR 96-508'	C-2 (C-1 x C-1)	'PIR 93-354' x 'PIR 89-329'	13.90	8.99	1,48,148	0.40	59.26
4	'PIR 96-326'	C-3 (C-2 x C-1)	'PIR 93-307' x 'PIR 88-3347'	18.20	16.85	89,815	0.78	69.61
5	'PIR 98-1174'	C-3 (C-2 x C-1)	'PIR 93-309' x 'PIR 88-4025'	18.05	16.02	1,25,000	1.13	140.63
6	'PIR 00-39'	C-3 (C-2 self)	'PIR 96-270 'self	15.95	12.20	1,75,926	0.37	64.21
7	'PIR 00-1049'	C-3 (C-2 self)	'PIR 96-255' self	18.19	14.23	84,259	0.67	56.03
8	'PIR 00-1188'	C-3 (C-2 self)	'PIR 96-255' self	18.44	12.73	69,444	0.50	34.72
Mean				16.97	13.46	1,28,125	0.60	73.47
Mean of 12 parental (C0) clones*				12.68	9.84	95,416	0.32	31.38

*Source: Rao *et al.* (1985)

**Population Improved *S. robustum* hybrids

Germplasm Collection at Kannur was 5.62% with a range of 1.02 to 10.09 (Rao *et al.* 1985). Thus, the improvement in Brix% and sucrose % in juice achieved through three cycles of hybridization and selection are significant in comparison to the sucrose levels reported for the species in the World Collection.

Eight 'PIR' hybrids with better juice quality, higher cane yield and free from YLD were identified for further utilization in breeding (Table 5). The twelve original parents (C-0) used to generate the C-1 hybrids could not be grown along with the PIR hybrids at the Agali Centre due to quarantine and other issues. Hence, the published data on these clones form the Kannur Centre (Rao *et al.* 1985) was utilized for comparison. The mean brix % and sucrose % of these improved hybrids were 16.97% and 13.46%, respectively which was 4.29 units and 3.62 units higher than the mean of the twelve parental clones used in the study. Hybrids 'PIR 96-326' and 'PIR 98-1174' recorded >16% juice sucrose and cane yield of 69.61 to 140.63 t/ha, respectively besides being free from natural incidence of YLD. Thus, substantial improvement in sucrose % could be achieved in the wild species *S. robustum*, through three cycles of hybridization and selection. The use of these improved 'PIR' hybrids as parents in inter-specific hybridisation or in crosses with commercial varieties would yield hybrids with better sucrose content. The improved 'PIR' hybrids are clonally maintained at ICAR-SBI Research Centre, Agali (Kerala) and are being utilized in the breeding programmes.

CONCLUSION

Intra-specific improvement of the basic *Saccharum* species prior to inter-specific hybridization has been suggested by various authors to achieve faster gains. However, development of intra-specific hybrid populations in a wild species like *S. robustum* is difficult to achieve because some parental clones do not flower in certain years and in case of flowering clones, sparse and/or non-synchronization of flowering and poor seed set was encountered. Therefore, such studies had been few in the past and the first such attempt in the country was undertaken during late 1980s by Nair *et al.* (1998). Three cycles of hybridization and selection were completed under this programme, with particular focus on improving the juice sucrose in the species. The results showed that significant improvement in sucrose % juice could be achieved in *S. robustum* through repeated cycles of hybridisation and selection. The eight YLD-free PIR hybrids identified from the study with better juice quality can serve as superior species-germplasm for developing inter-specific hybrids of sugarcane with better productivity and with diverse genetic base.

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Evaluation of ratooning ability of introduced sugarcane varieties (*Saccharum* spp. hybrid) for cane yield and quality characteristics in Southern Ethiopia

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ABSTRACT

Sugarcane varieties with good ratooning ability for high cane yield and quality need to be identified for Southern Ethiopia. With this major objective, introduced sugarcane varieties were evaluated for their performance in third year ratoon crop at Arba Minch University Research Farm during 2018/19 cropping season. The plant crop experiment consisting of 16 varieties was conducted in RCBD with two replications during 2015-16. In third ratoon crop, the varieties differed significantly (P=<0.05,or = <0.01) for cane yield and quality characters. High cane stalks per clump or stubble and per unit area, and high millable canes per hectare were recorded in varieties, 'Co 622', 'E 188/56', 'N 52/219', 'N 14', 'Mex 54/245', 'N 53/216' and 'NCo334'. Cane height was more in varieties, 'Mex 54/245', 'Co 622', 'B 59/212', 'C 86/165', 'B 52/298', 'NCo 334' and 'B 41/227'. Cane thickness was medium in varieties, B41/227 and B 4906, and medium thin in varieties, 'B 52/298', 'B 60/267', 'B 59/212', 'CP 69/105' and'N 14'. Cane weight was more in varieties, 'B 59/212', 'B 52/298', 'DB 228/57', 'N 14', 'B 60/267', 'C 86/65' and'Mex 54/245'. Estimated cane yield was high in varieties, 'N14', 'Co 622', 'N 53/216','Mex 54/245', 'DB 228/57', 'N 52/219', 'NCo 334' and 'B 59/212'. Pol or sucrose % juice was high in varieties, 'N 53/216', 'N 52/219', 'NCo 334', 'CP 69/105' and 'Mex 54/245', 'B 59/212' and 'Co 622'. Juice purity was high in varieties, 'C 86/165', 'Co 622', 'CP 69/105', 'N 52/219','N 53/216', 'NCo 334' and 'B 59/212'. Estimated sugar recovery % cane was high in varieties, 'N 53/216', 'N 52/219', 'NCo 334', 'CP 69/105', 'Mex 54/245' and 'Co 622' and 'B 59/212'. Estimated sugar yield was high in varieties, 'N 53/216', 'Co 622', 'N 52/219', 'Mex 54/245', 'NCo 334','N14', and 'B 59/212'. It was concluded that the seven varieties with high sugar yield in third ratoon crop were promising and recommended for testing for adaptability in Southern Ethiopia.

Key words: Sugarcane varieties, Ratoon, Yield and quality characteristics

Sugarcane is an important sugar crop of subtropical and tropical countries belonging to the genus *Saccharum* of family, *Poaceae (Gramineae*). It stores sugar in its stems or culms which on maturity called, millable canesare used to extract juice in mill tandem and processing for crystallization of sugar along with other valuable by-products like bagasse, molasses, ethanol, co-generation of electricity and filter press mudin sugar mills. It is an asexually propagated crop of one year or more duration depending on the maturity of the variety and growing environment. Ratoon crop is raised from the sprouting of buds below soil on the stubble or clump or stool. Ratooning ability is an important genetic characteristic feature of sugarcane varieties making them suitable for raising several ratoon crops successively (Getaneh *et al.* 2015). Ratoon crop has great importance in sugarcane production as it requires about 30 per cent less expenditure than plant crop because of savings on preparation of land, seed cost, planting and on early establishment on the one hand (Sundara *et al.* 1992) and on crop management for shorter period on the other hand because of its early maturity by about one month (Verma 2009) allowing early harvesting and crushing. Four to six ratoon crops are raised at the same field after harvesting of plant as well as subsequent ratoon crops in Ethiopia. Varieties play important role in sugarcane and sugar production due to their inherent potential for high cane yield and quality, maturity, ratooning ability, resistance to diseases and insect pests and adaptability to different agro- climatic conditions (Rafiq *et al*. 2006).

Currently, the sugar production in Ethiopia is able to meet 60 percent of the demand for domestic consumption. However, the per capita consumption of sugar is lower in Ethiopia which is 5 to 6 kg, whereas it is 16.5 kg in Africa and 24 kg in the World (Shimelis *et al.* 2011, ISO, 2012, Firehun *et al.* 2013). In order to meet the sugar demand, the Ethiopian Govt. has launched an ambitious project for increasing sugarcane and sugar production by establishment of 10 new sugar factories and expanding the capacity of existing four sugar mills. Sugarcane plantations are being developed at three new sugar projects, OmoKuraz, Tana Beles, and Wolkayit. It has been planned to plant sugarcane in 150,000 ha at OmoKuraz sugar project where 6 sugar factories are being established with a production capacity of 556,000 tons (ESDA, 2013; ESIP, 2017).

Suitable varieties for new OmoKuraz sugar project in Southern Ethiopia need to be identified. Improved sugarcane

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varieties are derived from inter-species hybridization (*Saccharum* spp. hybrid) involving cultivated and wild species, backcrossing to cultivated species and subsequent hybridization between inter-species hybrids combining high yield and quality in plant and ratoon crops, and resistance to biotic and abiotic stresses at the country of breeding (Bischoff and Gravois 2004; Nair 2009). Sugarcane varieties have been introduced from different countries in Ethiopia as sugarcane breeding work is not done in the country (Negi and Damtie 2009). Evaluation of these varieties is important for selecting suitable ones for high cane and sugar yields in plant and ratoon crops for different plantation areas of Ethiopia (Tedesse *et al.* 2014). Since, Arba Minch is near to the OmoKuraz sugar project, the present investigations were undertaken to evaluate the ratooning ability of introduced sugarcane varieties in third ratoon crop for identifying promising ones with high cane yield and quality for Southern Ethiopia.

MATERALS AND METHODS

Description of the study area

The study was carried out at Arba Minch University Research Farm located at 6.04 ^{0}N latitude, 37.36 ^{0}E and altitude of 1218 meter above sea level. Average proportions of sand, silt and clay particles in the soil of the experimental field were 12.0, 37.30 and 50.70 per cent, respectively. The pH of soil was 7.8. The soil was rated as clay and slightly alkaline as per Murphy (1968). The average monthly maximum (28.3°C) and minimum (16.9°C) temperatures, relative humidity (54.7%) and rainfall (136 mm) during May, 2018 were suitable for sprouting of underground buds in stubbles or stools for thirdratoon crop. There were moderate temperatures, relative humidity and sunshine hours at tillering, cane stalk formation, grand growth stage up to September, 2018. Average maximum and minimum temperatures were 33.5 to 34.2°C and 16.9°C to 19.9°C with declining relative humidity during December, 2018 to April, 2019 which could have affected the growth and ripening of sugarcane.

Materials

The material for the investigation consisted of 16 introduced varieties, 'B 41/227', 'B 4906', 'B 52/298', 'B 59/212', 'B 60/267', 'C 86/65', 'C 86/165', 'Co 622', 'CP 69/105', 'D B 228/57', 'E 188/56', 'N 14', 'N 52/219', 'N 53/216', 'NCo 334' and 'Mex 54/245'. Initial alphabet of variety indicates the country of breeding, *viz.,* 'B'-Barbados, 'C'-Cuba, 'Co'-Coimbatore, India, 'CP'-Canal Point, Florida, USA, 'DB'-Demerera, Barbados, 'E'-Ebene, Mauritius, 'N'-Natal, South Africa, 'NCo'-Natal and Coimbatore and 'Mex'-Mexico.

Experimental design and procedures

The plant crop of the experiment was raised during 2015-16. The design of experiment was randomized complete block design with two replications. The plot size was 3 rows of 3.0 m length. The distance between rows was 1.0 m. The distance between two budded setts was 60 cm. After harvesting of previous crop, stubble shaving was done in the first week of May, 2018 to raise the third ratoon crop during May, 2018 to April, 2019. The fungicide, *Tilt* 250 EC (Propiconazole)@ 1 ml per litre was sprayed on stubbles for controlling fungal infection. Water emulsion of *Ethiozinone* 60 EC insecticide was sprayed on the setts @ 43 ml in 10 litre of water in 100 m furrow length and side dressed to control insects, termite and ants.*Malathion* insecticide emulsion was also side dressed to control termite and ants.The experiment was fertilized with Diammonium phosphate @ 80 kg/ha as basal side dressing of rows followed covering with soil and Urea was applied @ 150 kg/ha in three split doses, first basal side dressing after stubbles shaving, and at 30 and 90 days after stubble shaving.

Recording of data

Yield characteristics

The data were recorded on number of cane stalks in all clumps in plot and number of cane stalks in middle clumps excluding border clumps at 8 months crop age. Number of cane stalks with visible nodes and internodes in the stem, length greater than 1.0 m were recorded at 10 months after initiation of ratoon crop. Cane stalk length and diameter, number of internodes and cane weight were recorded on random sample of 6 cane stalks per plot at 10 months crop age. Cane thickness was classified as :<2.0 cm thin, 2-2.5 cm medium thin, 2.5-3.0 cm medium, 3.0-3.5 medium thick and >3.5 thick as per Akhtar *et al.* (2001). Cane yield was estimated by multiplying number of the number millable canes per plot with average cane weight of a random sample of 6 laves stripped off detopped millable canes per plot at 11 monthscrop age.

Quality characteristics:

Juice quality characteristics, °Brix, pol (sucrose) and purity per cent were determined in the composite juice of 5 random cane samples of each plot following standard procedures at Sugar Quality Laboratory, Ethiopian Sugar Corporation, Wonji on April, 12, 2019. °Brix in juice was recorded using Rudolf Automatic Refractometer made by Rodolf Research Analytical, USA which gives direct reading of refractometric dry substance, °Brix or soluble solids from the refraction angle. Pol per cent juice was determined by using Autopol 880 Automatic Sacharimeter made by Rodolf Research Analytical, USA by polarizing the clear juice filtered after precipitation of non-sugars by addition of basic lead (1.0 g/100ml) and Celite filtering aid and filtering through Whatman 91 filter paper. Pol or apparent sucrose per cent juice was noted from the table corresponding to pol reading and °Brix reading. Purity per cent was derived from ratio of pol and °Brix readings multiplied by 100. Recoverable sugar per centcane was estimated as per the method followed at Ethiopian Sugar Corporation using Winter Carp indirect method of cane juice analysis (James and Chung 1993) as follows :

$$ERS (\%) = [Pol\% - (°Brix - Pol\%) \times NSF] - CF$$

where, ERS =estimated recoverable sucrose per cent, NSF= non sugar factor (0.70) and CF= cane factor (0.57) as per Hundito *et al.* (2009).

Estimated sugar yield was estimated as follows:

$$ESY (t/ha) = CYH (t/ha) \times ERS (\%)$$

Where; ESY = estimated sugar yield, CYH = cane yield per hectare, ERS = estimated recoverable sucrose per cent (Hundito 2009).

Statistical analysis

The data was subjected to General linear Model procedure of statistical analysis for randomized complete block design using SAS software (SAS 9.00, 2004). Variety means for the characterswere compared for significant differences with least significance difference (LSD) at 5% probability level.

RESULTS AND DISCUSSION

Number of cane stalks and millable canes

The average number of cane stalks per clump or stool or stubble over all the clumps in plot and over middle clumps in plot excluding border ones differed significantly ($P < 0.01$) among sixteen varieties at 8 months crop age in the third year ratoon during 2018-19 (Table 1). Varieties, 'E 188/56' and 'Co 622' had the maximum and significantly higher number of cane stalks per clump or stool or stubble over all the clumps than the remaining 14 varieties. The next significantly higher number of cane stalks per clump was recorded in varieties, 'N 52/219', 'N53/216', 'NCo 334', 'Mex 54/245', 'N 14' and 'C 86/165'. The third significantly higher number of cane stalks was observed in varieties, 'B 41/227', 'C 86/65' and 'DB 228/57'. Significantly low number of stalks per clump was formed in varieties, 'B 4906', 'B 52/298', 'B 59/212', 'B 60/267' and 'CP 69/105'. The results indicated that the cane stalk formation per clump was a varietal characteristic and varied with the varieties. The results of the present study in third ratoon crop on cane stalk formation per clump generally matched with cane stalk formation per two budded setts in plant crop at 7 months crop age during 2015-16 with the exception of variety, 'Co 622' which had formed more stalks per clump in ratoon than the cane stalks per two budded setts in plant crop (Khan *et al.* 2016) indicating that the variety 'Co 622' has better potential for cane stalk formation in ratoon.

The average number of cane stalks per middle clump excluding the border ones was maximum and significantly higher in variety 'Co 622'as compared to the other 15 varieties. The second significantly higher number of cane stalks per middle clump was recorded in varieties, 'E 188/56', 'N 52/219' and 'N 14', which were statistically at par with 'Mex 54/245' and 'N 53/216' and the latter ones were at par with 'NCo334'. Next significantly low cane stalks were formed in varieties, 'B 41/227', 'C 86/65', 'C 86/165', 'B 4906', 'B 59/212' and 'DB 228/57'. The lowest number of cane stalks was recorded in varieties, 'B 52/298', 'B 60/267' and 'CP 69/105'. The cane stalks per

Table 1 Mean number of cane stalks over all the clumps and middle clumps, and number of cane stalks, and millable canes in sugarcane varieties in ratoon crop during 2018/19 at Arba Minch, Southern Ethiopia

Varieties	No. of cane stalks over all the clumps at 8 months crop age	No. of cane stalks over middle clumps at 8 months crop age	No. cane stalks ('000/ha) at 8 months crop age	No. of millable canes ('000/ha) at 10 months crop age
'B 41/227'	10.95^{cd}	10.1^{d}	191.1^{c}	181.1^{d}
'B 4906'	9.65^{de}	8.95^{de}	161.1^{de}	144.9^{e}
'B 52/298'	8.95^{ef}	8.25^{ef}	151.1^{e}	136.1^{e}
'B 59/212'	9.15^{ef}	8.75^{de}	152.7^{e}	144.9^{e}
'B 60/267'	7.65^{f}	6.85^{f}	122.7^{f}	116.6^{f}
'C 86/65'	11.4^{c}	10.2^{d}	189.9^{c}	171.1^{d}
'C 86/165'	13.85^{b}	10.25^{d}	230.5^{b}	212.2^{c}
'Co 622'	17.6^{a}	16.65^{a}	293.3^{a}	275.5^{a}
'CP 69/105'	8.35^{ef}	7^{f}	139.9^{ef}	132.7^{ef}
'DB 228/57'	10.95^{cd}	9.55^{de}	182.7^{cd}	174.4^{d}
'E 188/56'	18.4^{a}	14.25^{b}	307.7^{a}	283.8^{a}
'N 14'	14.25^{b}	14.2^{b}	237.7^{b}	230.5^{bc}
'N 52/219'	15.05^{b}	14.15^{b}	251.1^{b}	238.8^{b}
'N 53/216'	15.05^{b}	13.25^{bc}	256.1^{b}	243.3^{b}
'NCo 334'	15.05^{b}	12.35^{c}	251.6^{b}	238.8^{b}
'Mex 54/245'	15^{b}	13.5^{bc}	250.5^{b}	231.1^{bc}
General Mean	12.59	11.14	210.6	197.2
SE (±)	0.55	0.49	8.8	6.3
LSD	1.66^{**}	1.5^{**}	26.6^{**}	19.2^{**}
CV%	6.21	6.33	5.93	4.57

** = Significant at 1% level ($P < 0.01$); Means with the same alphabet in column are not significantly different middle clump were generally less in number than that overall the clumps including the border ones in all the varieties. This showed that border clumps in plots formed more number of cane stalks than the middle clumps because of availability of more space for light and nutrition in comparison to the middle stools in the plot. As in the present study, the competition for light among tillers within a row for developing into cane stalks was reported by Singles and Smit (2009). Similarly, competition to radiation or shading effect on late formed tillers within the row at 4 months crop age leading to higher mortality was observed by Vasantha *et al.* (2012).

Varieties differed significantly (P <0.01) for number of cane stalks per hectare at 8 month age. Number of cane stalks was maximum and significantly higher in the varieties 'Co 622' and E188/56 than the remaining 14 varieties. The second significantly higher number of cane stalks was recorded in varieties, 'C 86/165', 'N14', 'N 52/219', 'N 53/216', 'NCo334' and 'Mex 54/245' than other varieties. The third significantly higher number of cane stalks was observed in the varieties, 'B 41/227', 'C 86/65' and 'DB 228/57'. Significantly low number of cane stalks was found in the varieties, 'B 4906', 'B 52/298' and 'B 59/212' while the lowest number of cane stalks were recorded in the varieties, 'CP 69/105' and 'B 60/267'. The results of number of cane stalks per hectare or per plot corroborated with those of cane stalk formation per clump in sugarcane varieties. It was evident that cane stalk formation was a varietal characteristic and it varied with the varieties. It was worth mentioning that cane stalk formation in ratoon crop of the varieties was generally more than that in plant crop during 2015-16 (Khan *et al.* 2016) indicating that more cane stalks were formed in ratoon than plant crop.

Number of millable canes in varieties differed significantly (P<0.01) at 10 months crop age. Maximum and significantly higher number of millable canes was recorded in varieties, 'Co 622' and 'E 188/56' than the other 14 varieties. The next significantly higher number of millable canes was formed in the varieties, 'N 52/219', 'N 53/216', 'NCo 334', which was at par with 'N14' and 'Mex 54/245'. The third significantly higher number of millable canes was observed in varieties, 'C 86/165', 'B 41/227', 'C 86/65' and 'DB 228/57'. The fourth significant group of varieties for number of millable canes was 'B 4906', 'B 52/298' and 'B 59/212'. Significantly lowest number of millable canes was recorded in varieties, 'CP 69/105' and 'B 60/267'. From the comparison of general means, it could be noted that the millable canes in varieties at 10 months crop age were generally less than those of cane forming stalk at 8 months crop age. The decrease in millable canes with increasing age from the cane forming stalks is commonly observed in sugarcane due to mortality of cane stalks which is caused by the shading of slow growing and late formed cane stalks by the early formed ones. The competition for radiation and nutrition, lodging and smothering among cane stalks were the causes of reduction in millable canes (Bell and Gerside 2005; Singles and Smit 2009 and Khan *et al*. 2016). However, the millable canes formed in ratoon crop were more than that formed in plant crop (Verma 2009; Khan *et al*. 2016)

Cane characteristicsand estimated cane yield

The varieties differed significantly (P<0.01) for cane height and cane diameter at 10 months crop age (Table 2). Cane height was significantly higher in the varieties, 'Mex 54/245' than 13 other varieties but was statistically at par with 'Co 622' and 'B 59/212'. The latter varieties were at par in cane height with 'C 86/165', 'B 52/298' and 'NCo 334' followed by 'B 41/227', 'DB 228/57', 'N 14' and 'N 52/219' (221.0 cm) in descending order. Significantly lower cane height was observed in the varieties, 'B 60/267', 'CP 69/105', 'E 188/56' and 'N 53/216'. The order of cane height in the varieties, 'B 52 298', 'NCo 334' and 'B 41/227' generally matched with that at Ethiopian Tendaho sugar estate (Tedesse *et al*. 2009). Cane height of the varieties was generally less in ratoon crop but the order of height matched with that in plant crop during 2015-16 indicating that cane height was a varietal characteristics (Khan *et al*. 2016). The reduction of cane height in ratoon could result from the greater competition among more cane population than that in plant crop for light and shading effect, water and nutrition because of shallow root system leading to lesser uptake of water and nutrients, and slowing of growth and early ripening in ratoon crop. Reduced availability of moisture and nutrition due to shallow root system was attributed to reduced cane height in ratoon by Verma (2009).

Cane diameter was significantly more and cane thickness medium in the varieties, 'B 41/227' and 'B 4906', and medium thin in varieties, 'B 52/298', 'B 60/267', 'B 59212', 'CP 69/105' and 'N 14' according to classification by Akhtar *et al*. (2006). The latter varieties were on par in cane thickness with'DB 228/57' and 'N 52/219'. The remaining varieties having thin canes in descending order were 'Mex 54/245', 'C86/65', 'C 86/165', 'E 188/56', 'N 53/216' and 'NCo 334', 'Co 622'. It could be noted that the varieties with higher cane height were generally less thick and *vice versa* indicating inverse relation between cane height and cane diameter. It could plausibly be due to genetic differences as well as external environmental factors such as competition for light among stalks promoting elongation of cane stalks with less cane thickness.

Cane diameter of varieties was generally less in ratoon crop than that in plant crop during 2015-16. It could be due to the competition for light and nutrition among the plants for formation of more number millable canes per clump in ratoon than that in two budded setts in plant crop (Khan *et al.* 2016).

Number of internodes in canes differed significantly (P <0.05) among varieties at 10 months crop age. Significantly higher number of internodes was recorded in the variety, 'C 86/165' than the other 13 varieties but was at par with 'C 86/65' and 'NCo 334'. This, in turn, indicated that the length of internodes in these varieties was relatively short. The next group of sugarcane varieties with above average number of

Table 2 Mean cane height, cane diameter and number of internodes at 10 months crop age and cane weight at 11 months crop age of sugarcane varieties in ratoon crop during 2018/19 at Arba Minch, Southern Ethiopia

Varieties	Cane height (cm)	Cane diameter (cm)	No. of internodes	Cane weight (kg)	Estimated cane yield (t/ha)
'B 41/227'	229.5^{cde}	2.56^{a}	17.5^{bcd}	1.19^{d}	215.7^{ef}
'B 4906'	199^{g}	2.55^{a}	15.5^{d}	1.13^{d}	163.6^{gh}
'B 52/298'	237.5^{bc}	2.4^{a}	17^{bcd}	1.43^{bc}	195.2^{fg}
'B 59/212	250.5^{ab}	2.3^{ab}	16.5^{cd}	1.73^{a}	251.°C^{de}
'B 60/267'	218.5^{defg}	2.4^{a}	17.5^{bcd}	1.38^{bc}	160.8^{gh}
'C 86/65'	250^{ab}	1.85^{de}	19.5^{ab}	1.4^{bc}	238.9^{de}
'C 86/165'	239^{bc}	1.65^{de}	21.5^{a}	1.1^{d}	233.4^{de}
'Co 622'	250.5^{ab}	1.55^{e}	16.5^{cd}	1.12^{d}	309.9^{ab}
'CP 69/105'	206.5^{fg}	2.25^{abc}	15.5^{d}	1.17^{d}	149.8^{h}
'DB 228/57'	227.5^{cde}	2b^{cd}	16.5^{cd}	1.53^{b}	265.6^{cd}
'E 188/56'	217.5^{defg}	1.65^{de}	15.5^{d}	0.86^{e}	240.7^{de}
'N 14'	228^{cde}	2.25^{abc}	16.5^{cd}	1.44^{b}	331.9^{a}
'N 52/219	221^{cdef}	2.0^{bcd}	18^{bcd}	1.12^{d}	268.7^{cd}
'N 53/216'	213.5^{efg}	1.8^{de}	18.5^{bc}	1.18^{d}	287.1^{bc}
'NCo 334'	236^{bcd}	1.75^{de}	19^{abc}	1.09^{d}	261.2^{cd}
'Mex 54/245'	260.5^{a}	1.9^{cde}	18^{bcd}	1.24^{cd}	288.0^{bc}
General Mean	230.31	2.05	17.43	1.258	241.4
SE (±)	6.79	0.11	0.89	0.05	12.5
LSD	20.48**	0.35**	2.68*	0.167**	37.7**
CV%	4.17	8.02	7.23	6.23	7.34

*= Significant at 5% level (P <0.05); ** = Significant at 1% level (P< 0.01); Means with the same alphabet in column are not significantly different

internodes was: 'N 53/216', 'B 41/227', 'B 52/298', 'B 60/267' and 'Mex 54/245'. Significantly lower number of internodes was formed in the varieties, 'DB 228/57', 'N 14', 'B 4906', 'CP 69/105' and 'E 188/56'. These varieties had also less cane height. Dividing the cane height by the number of internodes indicated that relatively longer internodes in canes were formed in the varieties, 'B 59/212', 'Co 622', 'Mex 54/245', 'E 188/56' and 'B 52/298'. This showed that the internode number and cane height were genetic characteristics which varied with the varieties. Further, it may be mentioned that the number of internodes formed in canes of ratoon was on an average, 5 internodes less than that in plant crop during 2015-16 (Khan *et al.* 2016). This observation also explained the reason for less cane height in the ratoon crop.

Cane weight among the varieties differed significantly (P <0.01) at 11 months crop age. Maximum and significantly higher cane weight was recorded in the variety 'B 59/212' than other 15 varieties. The next significantly high cane weight was found in the varieties, 'B 52/298', 'DB 228/57' and 'N 14', which was at par with 'B 60/267' and 'C 86/65'. Cane weight in the latter varieties was at par with 'Mex 54/245'. Low cane weight was recorded in remaining 8 varieties, namely, 'B 41/227', 'B 4906', 'C 86/165', 'Co 622', 'CP 69/105', 'N 52/219', 'N 53/216' and 'NCo 334'. The lowest cane weight was found in the variety, 'E 188/56'. As in the present study, the low cane weight in these varieties was also found at Wonji-Shoa sugar estate, Ethiopia (Getaneh *et al.* 2013). Cane weight among varieties in ratoon crop matched with that in the plant crop during 2015-16 (Khan *et al.* 2016). From the data of mean cane height, cane diameter and cane weight in sugarcane varieties, it could be inferred that the cane weight had correspondence with the cane diameter and the cane height. Cane weight is a varietal characteristics and depends on cane diameter, cane height and the interior cane stalk contents and filling (Bell and Garside 2005; Khan *et al.* 2016).

Estimated cane yield differed significantly among varieties at 11 months crop age (Table 2). Cane yield was maximum and significantly higher in the variety, 'N14' than the other 14 varieties but was at par with the variety, 'Co 622'. However, the cane yield in 'Co 622' was at par with 'N 53/216' and 'Mex 54/245'. The latter varieties were at par in yield with varieties, 'DB 228/57', 'N 52/219', 'NCo 334' and 'B 59/212'. The remaining 8 varieties recorded lower yield than the general mean of varieties with lowest in the variety, 'CP 69/105'. The level and order of the estimated cane yield generally matched with that of plant crop during 2015-16 (Khan *et al.* 2016) and some of the varieties matched with that recorded at Tendaho, Metahara, Finchaa and Wonji-Shoa sugar estates of Ethiopia (Tedesse *et al.* 2009; Ayele *et al.* 2012; Getaneh *et al.* 2013a; Getaneh *et al.* 2013b; Ayele *et al.* 2014).

Cane quality characteristics and estimated sugar yield

°Brix in juice or total soluble solids% juice did not show significant difference although mean °Brix among varieties varied from 16.29 to 21.63 per cent. It could be due to much variation in °Brix of the replicated samples of varieties. However, the varieties differed significantly (P<0.01) for pol in juice and purity per cent, estimated recoverable sugar per cent and estimated sugar yield (Table 3). Pol or sucrose per cent juice was maximum and significantly higher in the variety, 'N 53/216' (18.98%) than the 11 other varieties but was statistically at par with 'N 52/219', 'NCo 334', 'CP 69/105' and 'Mex 54/245' (>16.5%). The next higher pol in juice (general mean 15.64%) was recorded in the varieties, 'B 59/212', 'Co 622' and 'B 4906'. The remaining varieties had lower sucrose with the lowest in 'B 52/298', 'B 60/267' and 'C 86/65'. Pol per cent juice and its order among varieties in ratoon crop matched with that recorded in plant crop during 2015-16 (Khan *et al.* 2017) except varieties, 'N 53/216' and 'B 52/298'. Former variety had relatively higher pol and the latter one had lower pol in juice in ratoon crop. It could be due to the quick sprouting in ratoon in 'N 53/216' and late sprouting in 'B 52/298'. The stubbles or stools of variety, 'B 52/298' were infested by ants and rodents which affected the root zone of stools resulting in slow growth and delayed formation of millable canes affecting sugar accumulation.

The juice purity per cent was significantly higher in the varieties, 'C 86/165', 'Co 622', 'CP 69/105', 'N 52/219','N 53/216' and 'NCo 334' than 6 other varieties but it was at par with 'B 59/212', 'E 188/56', 'Mex 54/245' and 'B 4906'. This showed that these 10 varieties matured earlier than the remaining 6 varieties which had juice purity less than 85 per cent with the lowest in 'B 52/298'. Purity per cent juice among varieties in the ratoon crop generally matched with that in the plant crop (Khan *et al.* 2017) except for the variety 'B 52/298' whose stubble sprouting, growth rate and maturity was affected by poor root zone because of infestation by ants and rodents.

Estimated recoverable sugar or sugar recovery per cent cane was the maximum and significantly higher in the variety, 'N 53/216' than the 10 other varieties but it was statistically at par with that of 'N 52/219', 'NCo 334', 'CP 69/105', 'Mex 54/245' and 'Co 622' (10.88%). Sugar recovery per cent in the varieties, 'B 59/212' and 'E 188/56' was numerically above general mean for sugar recovery. The lowest sugar recovery per cent cane was found in the varieties, 'C 86/65' and 'B 52/298'. Recoverable sugar per cent cane among the varieties in ratoon crop generally matched with that in plant crop (Khan *et al.* 2017). Sugar recovery per cent of most of the varieties matched with that recorded at Ethiopian sugar estates at Wonji-Shoa (Getaneh *et al.* 2013) and Finchaa (Tedesse *et al.* 2009). This indicated that the sugar content in cane was a varietal characteristics.

Table 3 Mean °Brix, pol and purity% juice, estimated recoverable sugar% cane and estimated sugar yield (t/ha) at 11 months crop age in sugarcane varieties during 2018/19 at Arba Minch, Southern Ethiopia

Varieties	°Brix	Pol (%)	Purity (%)	Estimated recoverable sugar (%)	Estimated sugar yield (t/ha)
'B 41/227'	19.58^{abc}	15.24^{cdefg}	78.03^{cd}	9.15^{defg}	19.7^{fghi}
'B 4906'	18.99^{abc}	15.62^{bcde}	82.4^{abc}	9.95^{cdef}	16.2^{hi}
'B 52/298'	19.365^{abc}	13.51^{fg}	69.69^{e}	7.06^{g}	13.7^{i}
'B 59/212'	18.88^{bcd}	16.11^{bcdef}	85.4^{ab}	10.63^{bcde}	26.6^{bcdef}
'B 60/267'	18.53^{bcd}	13.91^{fg}	75.1^{de}	8.02^{fg}	12.8^{i}
'C 86/65'	16.29^{d}	12.92^{g}	79.45^{bcd}	7.92^{fg}	18.9^{fghi}
'C 86/165'	17.23^{cd}	14.27^{efg}	86.53^{a}	9.52^{cdef}	22.2^{efgh}
'Co 622'	18.74^{bcd}	15.96^{bcdef}	88.45^{a}	10.88^{abcd}	33.7^{ab}
'CP 69/105'	19.55^{abc}	17.11^{abcd}	87.69^{a}	11.55^{abc}	17.2^{ghi}
'DB 228/57'	18.85^{bcd}	14.62^{cdefg}	76.96^{cd}	8.67^{efg}	24.3^{defg}
'E 188/56'	18.14^{bcd}	14.62^{bcdefg}	85.03^{ab}	10.19^{cde}	25.4^{cdef}
'N 14'	18.55^{bcd}	14.62^{defg}	79.72^{bcd}	8.94^{defg}	29.8^{abcde}
'N 52/219'	20.49^{ab}	18.12^{ab}	88.49^{a}	12.35^{ab}	33.1^{abc}
'N 53/216'	21.63^{a}	18.98^{a}	87.67^{a}	12.84^{a}	36.8^{a}
'NCo 334'	19.67^{abc}	17.2^{abc}	87.4^{a}	11.6^{abc}	30.3^{abcd}
'Mex 54/245'	19.67^{abc}	16.79^{abcde}	84.98^{ab}	11.03^{abcd}	31.6^{ab}
General Mean	19.01	15.64	82.68	10.02	24.5
SE (±)	0.89	0.89	2.15	0.69	2.6
LSD	2.68^{NS}	2.69^{**}	6.5^{**}	2.1^{**}	7.8^{**}
CV%	6.62	8.08	3.69	9.87	15.03

^{NS} = Non-significant; ** = Significant at 1% level (P < 0.01);Means with the same alphabet in column are not significantly different

Estimated sugar yield was the maximum and significantly higher in variety 'N 53/216'than the 10 other varieties but was statistically on par with that of the varieties, 'Co 622', 'N '52/219', 'Mex 54/245', 'NCo 334' and 'N14' (29.8t/ha). Sugar yields above the general mean were found in the varieties, 'B 59/212' and 'E 188/56'. The lower sugar yield in descending order was recorded in the varieties, 'C 86/165', 'C 86/65', 'CP 69/105' and 'B 4906' with the significantly lowest sugar yields in varieties, 'B 52/298' and 'B 60/267'. The order of estimated sugar yields in ratoon crop of varieties generally matched with that in plant crop during 2015-16 except 'B 52/298', 'B 60/267' and 'C 86/165' (Khan *et al.* 2017) indicating that these varieties were poor ratooner. Further, estimated sugar yields in some varieties matched with that recorded at four Ethiopian sugar estates at Wonji-Shoa, Finchaa, Tendaho and Metahara (Getaneh *et al.* 2013; Getaneh *et al.* 2013; Getaneh *et al.*, 2015; Tedesse *et al.* 2009; Ayele *et al.* 2012 and Ayele *et al.* 2014). This showed that the sugar content in juice, sugar recovery per cent cane and sugar yields were varietal characteristics and generally matched over locations depending on the cane stalks and stubble sprouting population in plant and ratoon crops.

From the foregoing results, it could be concluded that six varieties, namely, 'N 53/216', 'Co 622', 'N 51/219', 'Mex 54/245','NCo 334' and 'N 14' recorded high cane and sugar yields in the third ratoon crop after four years of their growing in field conditions of Arba Minch University Research Farm. These varieties were promising for verification of their performance for adaptability at Omo-Kuraz sugar project and selecting the best ones for plantation in Southern Ethiopia.

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Assessing potentiality of integrated application of organic and inorganic fertilizers with bio-inoculants in improving the productivity of sugarcane plant-ratoons system

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ABSTRACT

Results of a field experiment with nine treatments *viz.,* T_1- No organic manure + 50% RDF (recommended dose of fertilizers), T_2- No organic manure + 100% RDF, T_3- No organic manure + STBR (soil test based recommendation), T_4- Application of FYM @ 20 tonnes/ha + 50% RDF (inorganic source), T_5- Application of FYM @ 20 tonnes/ha + 100% RDF (inorganic source), T_6- Application of FYM @ 20 tonnes/ha + STBR, T_7- Application of FYM @ 10 tonnes/ha + biofertilizer (*Acetobacte*r + PSB @ 5 kg/ha each) + 50% RDF, T_8- Application of FYM @ 10 tonnes/ha + biofertilizer (*Acetobacter* + PSB@ 5 kg/ha each) + 100% RDF, and T9- Application of FYM @ 10 tonnes/ha + biofertilizer (*Acetobacter* + PSB@ 5 kg/ha each) + STBR conducted consecutively during 2014-15, 2015-16 and 2016-17, on sugarcane crop with one plant and two subsequent ratoons indicated that the application of farm yard manure-FYM @ 10 t/ha + bio-fertilizers (*Acetobacter* + phosphorus solubilising bacteria-PSB) + soil test based fertilizers (NPK) application (T_9) produced significantly higher number of shoots (180 days after planting-DAP) and millable canes and cane yield than that of other treatments including 100% recommended doses of fertilizers application (T_2) as a conventional practice of sugarcane growing in the area of operation. The above treatment-T_9, however, was at par with T_8 (FYM @ 10 t/ha + bio-fertilizers: *Acetobacter* + phosphate solubilising bacteria + 100 % recommended doses of fertilizers application) for number of shoots and millable canes including cane yield. The yield of plant cane recorded under T_9 was higher to the tune of 18.12, 12.67, 11.10, 16.74, 11.90, 9.81, 12.99 and 5.54% than that recorded under T_1, T_2, T_3, T_4, T_5, T_6, T_7 and T_8 treatments, respectively. The sugar yield (t/ha) as commercial cane sugar (CCS) exhibited almost the similar trend with the cane yield obtained under different treatments in the study. The treatment - T_9 also produced significantly higher cane yield under its subsequent ratoon-I and ratoon-II as compared to rest of the treatments except T_8 which was at par in this regard. Accordingly, the treatment-T_9 produced the higher cane yield to the tune of 11.43 and 13.57 % under ratoon-I and ratoon-II, respectively than that of conventionally raised ratoons with 100% RDF application. The sugar yield (t/ha) obtained under ratoon-I and ratoon-II in different treatments was almost similar to that of cane yield recorded in different treatments under study. The study thus suggests that the integrated application of plant nutrients through inorganic and organic sources in conjunction with bio-fertilizers is a potential tool not only for sustaining the productivity of sugarcane and its subsequent ratoons, but also to enhance the profit per unit area and time besides improving the health of soils in sugarcane based cropping systems.

Keywords : Sugarcane, Bio-inovulants, Farm yard manure, INM

INTRODUCTION

Sugarcane (*Saccharum* spp.) hybrid is an important crop of India which is cultivated in an area of 5.04 million ha with a total production of 411 m tonnes and 32.48 m tonnes of sugar at an average productivity of 81.5 t/ha (Anonymous 2019). The crop is of long duration and nutrient exhaustive which removes about 2.05, 0.24, 2.28 kg NPK/t of cane production (Singh *et al*. 2007). Fertilizer use in India is inadequate, imbalanced, skewed and mainly is in favour of N, P and K only. The frequent and excessive use of chemical fertilizers has created problems like deterioration of soil health and ecology. It has been observed in recent years that yield of sugarcane has reached a plateau due to decline in factor productivity. The loss of organic matter in soil is the root cause for decline in factor productivity. Soil organic matter is the key factor in maintaining the soil fertility as it is reservoir of nutrients and provides metabolic energy for biological processes. Restoration of organic matter is thus, needed for maintaining soil health and improving sugarcane productivity. In the present era of climate change where environment and sustainable agriculture are the major concerns, combined application of organic and inorganic fertilizers is expected to solve the puzzle to a higher extent. This, not only provides a balanced diet to the crop but also improves the soil health with minimum environmental hazard. Sugarcane produces large quantity of biomass and thus naturally removes the nutrients in proportionate quantities. The nutrients need replenishment through addition of manures and fertilisers in the soil. Chemical fertilisers supply only one or two plant nutrients whereas organic manures supply number of macro and micro-nutrients essential for healthy growth and development of sugarcane.

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Organic manures not only replenish lost nutrients but also improve the physical, chemical and biological properties of soil which will enhance the performance of soil applied inputs. For sustainability in sugarcane and sugar production neither chemical fertilisers nor organic manures alone but their integrated use has been observed to be highly beneficial. The impact of applying integrated sources of organic and inorganic fertilizers has also been found beneficial in improving yields of cane and sugar in subsequent ratoons too, since keeping 1-2 ratoons after harvesting of plant cane is a profitable practice provided factors affecting yield declines in ratoons are suitably addressed.

The success of the sugarcane farming operations depends on the productivity of plant and its subsequent ratoons. Ratoon cropping is an established practice in sugarcane agriculture contributing significantly to the over-all profitability. Ratoons are cheaper to grow by around 25-30% (Sundara 1998) since no cost is involved on fresh seed cane material and land preparation, besides saving in irrigation and crop maintenance through reduced crop duration. A recent assessment made in Maharashtra (India) indicated that ratoon crop was cheaper by 45% with a net return twice to that of a plant crop (Pawar *et al*. 2000). In spite of that the sugarcane ratoons raised in our country is limited to almost one owing to subsequent cane yield declines. Enhancing the productivity of ratoon through various agronomic manipulations is one of the most important factor as it occupies more than 50% of cane acreage and yield only 30% of the sugarcane production (Sundara 1987). Thus, there is an ample scope for improving sugarcane productivity in plant-ratoon system by following proper ratoon management practices besides application of integrated sources of organic and inorganic fertilizers. In Mauritius where multiratooning is common, the organic matter content in the soil reported to be high. The present study was, therefore, carried out to study the impact of applying organic and inorganic sources of fertilizers aiming to improve the productivity of sugarcane and its subsequent ratoons.

MATERIALS AND METHODS

The experiment was conducted at Sugarcane Research Station (OUAT), Nayagarh in 2014-15 and succeeding ratoons were initiated during 2015-16 and 2016-17 cropping seasons. The soil of the experimental site was slightly acidic (pH-6.3), sandy loam with less available N (155 kg/ha), medium available P (11.2 kg/ha), K (137 kg/ha) and less organic carbon (0.48 %). The variety of the crop was 'CoOr 10346'. The experiment consisted of *Bacillus* spp. was used as phosphate solubilising bacteria. These 9 treatment combinations were replicated thrice in complete randomized block design. The recommended dose of fertilisers *i.e.* 250:100:60 N, P_2O_5, K_2O kg/ha were applied. For soil test based recommendation fertiliser treatments, 25% more nitrogen fertiliser was applied since the initial status of available N content was low. Organic manures and full doses of P and K fertilisers were applied as basal and N fertiliser was applied in three equal splits at 45, 90 and 135 DAP. The parameters taken for the observation were tiller population at 180 days after planting/ratoon initiation and millable canes population & cane and sugar yield at the time of harvesting of plant and ratoon crops of sugarcane in the respective cropping seasons. Juice quality parameters (°Brix and pol & purity percent) were recorded at the harvesting stages. Cane juice was extracted with power crusher and juice quality was estimated as per the method prescribed by Spencer and Meade (1955). Sugar yield was calculated as sugar yield (tones/ha) = [S-0.4 (B-S) x 0.73] x cane yield (t/ha)/100; where S and B are sucrose and °Brix values in cane juice, respectively.

RESULTS AND DISCUSSION

Results of a field experiment conducted during 2014-15, 2015-16 and 2016-17 cropping seasons, on sugarcane crop with one plant and two subsequent ratoons are presented in Table 1. It clearly indicated that the application of farm yard manure-FYM @ 10 t/ha + bio-fertilizers (*Acetobacter* + phosphate solubilising bacteria-PSB) + soil test based fertilizers (NPK) application (T_9) produced significantly higher number of shoots (180 days after planting-DAP) & millable canes and cane yield than that of other treatments in the test including 100 % recommended doses of fertilizers application (T_2) as a conventional practice of sugarcane growing in the area of operation. The above treatment-T_9, however, was at par with T_8 (FYM @ 10 t/ha + bio-fertilizers: *Acetobacter* + phosphate solubilising bacteria + 100 % recommended doses of fertilizers application) in producing the above growth parameters including cane yield. The yield of plant cane recorded under T_9 was higher to the tune of 18.12, 12.67, 11.10, 16.74, 11.90, 9.81, 12.99 and 5.54 % than that obtained under T_1, T_2, T_3, T_4, T_5, T_6, T_7 and T_8 treatments, respectively. Tyagi *et al*. (2011) also reported that integrated application of inorganic fertilizers along with FYM and bio-fertilizers in plant where as in subsequent ratoon, inorganic along with trash incorporation and bio-fertilizers improved NMC. Virdia and Patel (2010) and Singh and Srivastava (2011) also reported almost similar findings. Scientists working in sugarcane crop have reported that the integrated use of chemical and organic fertilizers is found to be more beneficial for sustainable sugarcane production. The combined use of organic and inorganic fertilizers gave significantly higher sugarcane yield and economic benefit (Paul *et al*. 2007). Pressmud or FYM is one such source of organic matter which can be profitably utilized for sugarcane production. These are known as the good source of organic matter, NPK and important micronutrients, and have established its importance in improving fertility, productivity and other physical properties of agricultural soils.The sugar yield (t/ha) as commercial cane sugar (CCS) exhibited almost similar trend with that of cane yield obtained under different treatments in the study since it is the function of CCS% in

Table 1 Impact of integrated application of organic and inorganic fertilizers on yield of sugarcane and its subsequent ratoons

	Treatment	Plant crop				Ratoon I				Ratoon II			
		No of shoots (000' /ha) at 180 DAP	NMC (000'/ha)	Cane yield (t/ha)	CCS yield (t/ha)	No of shoots (000'/ha) at 180 DARI	NMC (000'/ha)	Cane yield (t/ha)	CCS yield (t/ha)	No of shoots (000'/ha) at 180 DARI	NMC (000'/ha)	Cane yield (t/ha)	CCS yield (t/ha)
T_1	50% RDF (recommended dose of fertilizers)	76.45	75.21	80.53	8.75	62.34	61.63	64.48	7.07	55.23	53.75	58.22	6.38
T_2	100% RDF	82.56	82.08	85.88	9.19	67.45	65.61	74.34	7.97	60.95	59.76	65.63	7.05
T_3	Soil test based fertilizer application (NPK)	83.67	82.35	87.43	10.14	71.36	69.08	73.47	8.51	64.35	62.22	67.21	7.82
T_4	Application of FYM (farm yard manure) @ 20 t/ha+ 50% RDF	80.24	78.20	81.92	9.04	72.67	70.37	71.54	7.96	62.16	60.84	65.44	7.30
T_5	Application of FYM @ 20 t/ha+ 100% RDF	82.88	82.51	86.65	10.04	72.86	71.63	73.93	8.59	63.78	62.87	68.72	7.97
T_6	Application of FYM @ 20 t/ha+ Soil test based fertilizers application (NPK)	83.78	83.41	88.70	10.07	75.15	73.78	75.47	8.59	64.95	63.46	70.46	8.05
T_7	Application of FYM @ 10 t/ha+(*Acetobacter*+PSB)+50% RDF	82.45	81.01	85.57	9.61	77.22	75.88	81.87	9.11	67.34	65.88	71.75	7.95
T_8	Application of FYM @ 10 t/ha+(*Acetobacter*+PSB)+100% RDF	87.14	86.66	93.04	10.76	77.54	76.71	82.73	9.55	70.24	68.42	75.03	8.58
T_9	Application of FYM @ 10 t/ha + *Acetobacter* + PSB + Soil test based fertilizers application (NPK)	91.82	91.49	98.35	11.24	78.68	77.52	83.93	9.68	72.25	69.85	75.93	8.79
	SEm (±)	2.58	2.65	2.63	0.86	2.14	2.42	2.15	0.72	2.43	2.44	2.25	0.81
	CD at 5 %	7.86	8.17	8.12	2.75	5.75	6.24	6.65	2.47	7.26	5.64	6.32	2.36

DAP: days after planting; DARI: days after ratoon initiation cane and yield of sugarcane.

The T_9 treatment also produced significantly higher cane yield under its subsequent ratoon-I and ratoon-II as compared to rest of the treatments except T_8 being at par in this regard. Accordingly, the treatment-T_9 produced the higher cane yield to the tune of 11.43 and 13.57% under ratoon-I and ratoon-II, respectively than that of conventionally raised ratoons with 100% RDF application. The sugar yield (t/ha) obtained under ratoon-I and ratoon-II in different treatments was almost similar with that of cane yield recorded in different treatments in the test. The reason behind increased values in all the sugarcane ratoon traits was due to decomposition of organic manures in conjunction with different bio-fertilizers. It is reported that organic fertilizer has residual effect after the year of its application to land, as the decomposition of organic material usually takes more than a season (Lund and Doss1980). Consequently, mineralization generally extends over a much longer period than just one year. Manures, therefore, have a residual effect on crop as well as soil fertility (Magdoff and Amadon1980). The increase in sugarcane traits with the integrated use of organic and inorganic nutrient sources might have been due to the efficiency of these nutrient sources to cause for increased microbial activity, soil porosity, water holding capacity and nutrient uptake of the crops which ultimately enhanced quantitative as well as qualitative traits of sugarcane and its subsequent ratoons. The study thus suggests that the integrated application of plant nutrients through inorganic and organic sources in conjunction with bio-fertilizers is a potential tool not only for sustaining the productivity of sugarcane and its subsequent ratoons, but also to enhance the profit per unit area and time besides improving the health of soils in sugarcane based cropping systems.

CONCLUSION

It may be concluded that the supply of nutrients in sugarcane plant ratoon system through integrated use of organic manures along with bio fertilizers and inorganic fertilizers based on soil test values were found beneficial for enhanced yields of sugarcane and its subsequent ratoons and it would not only help us to minimize the expenditure on costly inorganic fertilizers but also to sustain the soil health besides enhancing the productivity and profitability of the system.

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'CoLk 12207' (*Ikshu-6*) - an early maturing sugarcane variety for North Central and North East zone

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ABSTRACT

'CoLk 12207' ('*Ikshu-6*') has an improved IISR clone 'CoLk 8002' as its female parent and was selected from the progeny of open pollinated general collection (GC). The selected progeny were subsequently evaluated in clonal generations. 'CoLk 12207' was proposed and accepted as early maturing sugarcane clone for multi-location testing in the North Central and North East zone of All India Coordinated Research Project on Sugarcane during 2012. 'CoLk 12207' was tested in zonal varietal trials along with popular standard varieties *viz.,* 'BO 130' and 'CoSe 95422' for its performance regarding cane yield and its components, quality traits and resistance to major diseases and insect pests for three consecutive years, i.e., 2015-16 to 2017-18. It has given excellent performance in the zonal varietal trials with commercial cane sugar yield and cane yield of 8.74 and 75.42 t/ha, respectively. The variety has shown an improvement of 16.39%, and 10.49 % for cane yield over the standard varieties 'CoSe 95422 and 'BO 130', respectively. It has also shown an improvement of 15.61% and 9.11% for CCS yield over the standard varieties 'CoSe 95422 and 'BO 130', respectively. For sucrose % in juice at harvest (300 days), 'CoLk 12207' recorded an average value of 16.9 % for two plant and one ratoon crops across six locations in the North Central and North East zone which is numerically better to the best adopted standard 'CoSe 95422' (16.32%). Ratoon performance of 'CoLk 12207' was assessed along with the popular standard varieties and it was found that this variety had very good ratooning potential. No major disease was noticed under natural field condition in 'CoLk 12207' while it had shown resistant to moderately resistant reactions to *Cf* 07 and *Cf* 08 red rot pathotypes under artificial inoculation conditions. It had also shown least susceptible reaction to the borer complex. 'CoLk 12207' is lodging tolerant and suitable for multiple ratooning with lush green top at maturity. Based on the superiority of the 'CoLk 12207' over standards in 2 plant and 1 ratoon crop for cane yield and quality traits over six locations, it has been identified as a new early maturing variety of sugarcane by the Varietal Identification Committee for its release. Later on, it has been notified through the Gazette of India No. S.O. 1498 (E) dated 01 April, 2019 and was released for commercial cultivation in North Central and North East zone comprising of eastern parts of Uttar Pradesh, Bihar, Jharkhand, West Bengal and Assam.

Keywords: 'CoLk 12207', early variety, sugarcane, cane and CCS yield and Red Rot resistance.

Sugarcane is one of the most important agro-industrial crop grown in India. It is cultivated over 5.0 million hectare area with a total production of 405.4 million tonnes (2018-19). Sugarcane is grown in both tropical and subtropical India. In subtropical India, it is cultivated as a commercial crop mainly in North West zone as well as North Central and North East zone. North Central and North East zone is mainly comprising of eastern parts of Uttar Pradesh, Bihar, Jharkhand, West Bengal and Assam. In this zone, specially, areas in eastern part of Uttar Pradesh and Bihar have peculiar problems like water logging and the deadly disease of red rot. Many popular sugarcane varieties of this zone have been wiped out in the past due to this disease. In recent years, sugarcane productivity and sugar recovery at national level have been improved with the adoption of new high sugar and high yielding varieties. But, sugarcane productivity and sugar recovery particularly in this zone are comparatively low due to these peculiar problems. Concerted efforts for the development of improved sugarcane varieties for water logging tolerance and resistance to red rot was initiated and carried out at ICAR-Indian Institute of Sugarcane Research, Lucknow and its Regional Centre at Motipur (Bihar). The results of carefully planned hybridization programme including selection of suitable parents and their utilization, followed by rigorous selection for high cane and sugar yield and screening for tolerance to water logging and resistance to red rot is reflected in the form of improved sugarcane clones identified for commercial cultivation in this area.

Keeping these facts in view, a high yielding and high sugar early maturing variety of sugarcane, 'CoLk 12207' ('*Ikshu-6*')

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has been released and notified for commercial cultivation in North Central and North East zone. This paper is aimed to discuss newly released early maturing sugarcane variety 'CoLk 12207' ('*Ikshu-6*') for North Central and North East zone as one of the end products of such concerted efforts, along with its salient features.

MATERIALS AND METHODS

'CoLk 12207' ('*Ikshu-6*') has an improved IISR clone 'CoLk 8002' as its female parent (Fig.4) and has been selected from the progeny of its open-pollinated general collection (GC) and was subsequently evaluated in clonal generations. This particular general collection was made at National Hybridization Garden, Coimbatore during the crossing season 2002. Fluff was sown in the glass house to raise the seedlings and thereafter it was transplanted in the field for evaluation and selection. The genotype was selected from the seedling population and designated as 'LG 04006'. Later on, it was tested under different clonal stages for quality and yield attributes. In 2008-09, 'LG 04006' was sent to IISR, RC, Motipur for its evaluation under target environment. Further, it was evaluated under station trial at Motipur during 2010-11 to 2011-12. The clone was proposed for multi-location testing under zonal varietal trials of North Central and North East zone of All India Coordinated Research Project on Sugarcane during 2012 and was designated as 'CoLk 12207'. The promising clone 'CoLk 12207' was accepted as early maturing clone for multi-location testing in the North Central & North East zone of the All India Coordinated Research Project on Sugarcane. The clone was evaluated against popular standard varieties for its performance on yield and its attributes, quality parameters and resistance reaction to major diseases at six locations for three consecutive years (2014-2017). Ramburan (2018) reported that strong variety x season interaction shall be exploited more aggressively in irrigated sugarcane selection programme.

The final trials i.e., Advanced Varietal Trials comprising of three promising sugarcane clones, 'CoLk 12207', 'CoP 12436'

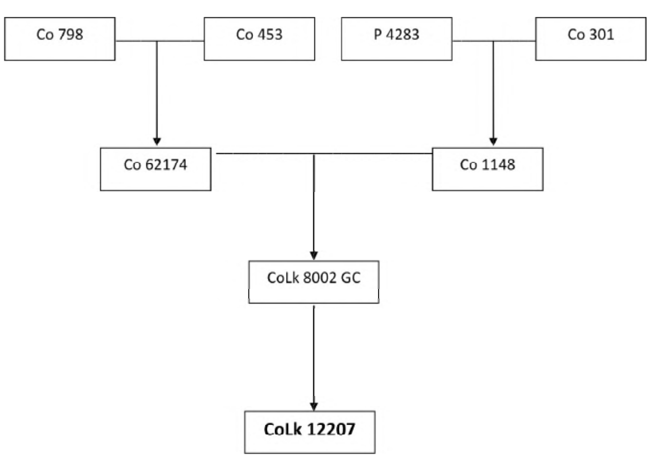

Fig. 1. Pedigree chart of 'CoLk 12207'

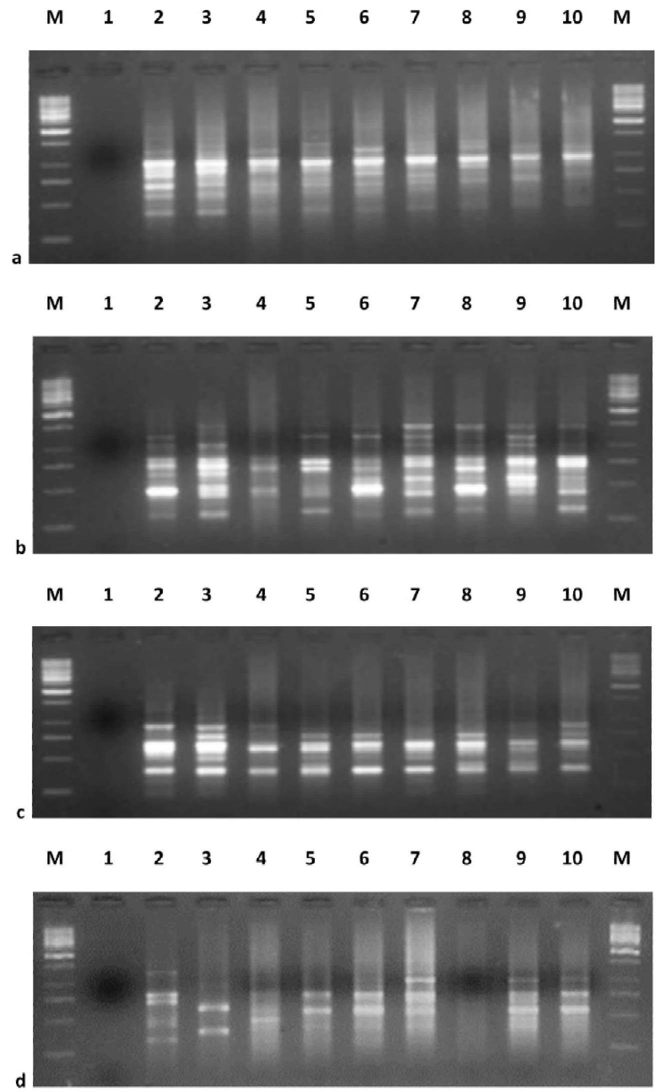

Fig 2. Genetic fingerprint profiles of the nine sugarcane varieties as generated by ISSR (inter simple sequence repeat) primers UBC 826 (a), UBC 834 (b), UBC 840 (c), and UBC 847 (d). Lanes: M: DNA size marker, 1: negative control, 2: 'Co 0238', 3: 'CoLk 94184', 4: 'CoLk 11203', 5: 'CoLk 11206', 6: 'CoLk 14201', 7: 'CoLk 14203', 8: 'CoLk 14204', 9: **'CoLk 12207'**, 10: 'CoLk 12209'.

and 'CoSe 12451' along with two popular standard varieties 'BO 130' and 'CoSe 95422' were conducted for two plant and one ratoon crops at six locations of the North Central and North East zone. These experiments were laid out in randomized complete block design with four replications having plot size of eight rows of six meters and inter row spacing of 90 cm. Recommended agronomic package of practices were followed to raise a good and healthy crop stand during the crop seasons as per the technical programme. The observations on cane yield and its attributes like number of millable canes, single cane weight, stalk length and diameter etc and quality

Fig 3. Field view of 'CoLk 12207' (*Ikshu*-4)

Fig 4. Size and shape of bud of 'CoLk 12207' (*Ikshu*-4)

parameters like brix reading, sucrose content in juice, purity %, CCS %, Pol % cane, fibre content and extraction% were recorded as per schedule. Juice quality analysis was carried out at harvest stage in plant as well as ratoon crops as per standard procedures (Meade and Chen, 1971). The commercial cane sugar (CCS) yield was estimated by multiplying the cane yield and CCS% and used as major criteria for ranking of the best performing clones. The test clones were also screened for resistance to major diseases and insect pests and rated accordingly. Statistically analyzed data from all the locations were presented during biennial workshop of AICRP(S) and published in the Principal Investigator's Report (Varietal Improvement Programme) (Anon., 2017; 2018).

RESULTS AND DISCUSSION

Based on the mean performance over two plant and one ratoon crops at six locations, 'CoLk 12207' was identified for its release and notification by the Varietal Identification Committee during 2018 and later on released and notified in 2019 vide Gazette Notification No. S.O. 1498 (E) dated April 01, 2019. Salient features of 'CoLk 12207' are presented below.

Cane and sugar yields

'CoLk 12207', an early maturing sugarcane variety recorded cane yield of 75.42 t/ha averaged over the plant and ratoon crops and locations studied. It showed an improvement of 16.39%, and 10.49 % over the popular standard varieties 'CoSe 95422' and 'BO 130', respectively. As far as commercial cane sugar (CCS) yield is concerned, the mean value was 8.74 t/ha which was an improvement of 15.61% and 9.11 % over best standards 'CoSe 95422' and 'BO 130', respectively (Table 1). Kumar *et al*., (2007) suggested that varieties found most stable with high CCS yield under a given set of conditions have dynamic stability.

Yield components

Manifestation of cane yield mainly depends on its component traits like number of millable canes, single cane weight, cane length , its thickness etc. 'CoLk 12207 ' had produced 103.9 thousand millable canes per hectare averaged over crops and locations which was numerically *at par* with the best standard 'BO 130'. This variety recorded higher single cane weight (0.87 kg) than the best standard 'BO 130' (0.72 kg). Low single cane weight in the popular cultivated varieties of sugarcane is one of the limiting factor for the higher cane productivity particularly in subtropical India. Higher single cane weight along with higher NMC in 'CoLk 12207' is an indication of its potential for high cane yield. Kumar *et al.* (2003) studied the direct and indirect effects of different traits on cane yield and revealed that the higher positive direct effect of cane weight was intensified further with marginal indirect effects via number of millable canes and single cane weight. Other important yield parameters like stalk length and diameter were also higher in 'CoLk 12207' as compared to the best popular standard 'BO 130'.

Quality parameters

Various quality parameters, such as sucrose content in juice, CCS %, pol % cane and fibre % were recorded at harvest stage (300days) and are presented in Table 2. For sucrose% in juice at harvest, 'CoLk 12207' recorded an average value of 16.90% for two plant and one ratoon crop across six locations in the North Central & North East Zone which is 3.55% more than

Table 1 Performance of 'CoLk 12207' for cane and CCS yields in Zonal Varietal Trials*

Variety	Cane yield (t/ha)					CCS yield (t/ha)				
	Plant-I	Plant-II	Ratoon	Mean	% improvement over check	Plant-I	Plant-II	Ratoon	Mean	% improvement over check
'CoLk 12207'	80.11	78.58	66.64	75.42		9.32	9.30	7.48	8.74	
Standards										
'BO 130'	75.77	68.27	59.24	68.26	10.49	8.93	7.96	6.97	8.01	9.11
'CoSe 95422'	72.76	64.07	55.98	64.80	16.39	8.52	7.40	6.58	7.56	15.61

*Mean value averaged over 2 plant + 1 ratoon crops at six locations of North Central and North East zone under AICRP(S)

Table 2 Mean performance of 'CoLk 12207' for quality parameters at harvest stage in zonal varietal trials*

Variety	Sucrose %	CCS %	Pol % cane	Fibre %
'CoLk 12207'	16.90	11.57	13.17	12.88
Standards				
'BO 130'	17.03	11.79	13.52	12.89
'CoSe 95422'	16.32	11.30	12.95	12.37

*Mean value averaged over 2 plant + 1 ratoon at six locations of North Central and North East zone under AICRP (S)

the adopted standard CoSe 95422 (16.32 %). Similarly, 'CoLk 12207' recorded 11.57 % CCS at 10 months stage which was also numerically higher than the standard varieties 'CoSe 95422' (11.30 %). Pol in cane (13.17 %) of variety 'CoLk 12207' at harvest stage was higher compared to the popular standard 'CoSe 95422', however, fibre content was comparable with the standard varieties.

Ratoonability

Ratoon performance of 'CoLk 12207' was assessed along with the popular standard varieties and it was found that this variety has a very good ratooning potential. Perusal of data presented in Table 1 indicated that 'CoLk 12207' had recorded higher ratoon cane yield (66.64 t/ha) compared with the best standard 'BO 130' (59.24 t/ha). Similarly, CCS yield was also higher in 'CoLk 12207' (7.48 t/ha) than the standard varieties 'BO 130' (6.97 t/ha) and 'CoSe 95422 (6.58 t/ha) in ratoon crop. Similar results were also reported by Kumar *et al.* (2018) and Kumar *et al.* (2019). Milligan *et al.* (1996) studied the inheritance of ratooning ability and its traits among crops in sugarcane.

Reaction to major diseases and insect pests

No major disease was noticed under natural field conditions in 'CoLk 12207'. It was observed that 'CoLk 12207' had shown resistant (R) to moderately resistant (MR) reactions against red rot pathotypes *Cf* 07 and *Cf* 08 under artificial inoculation by plug method during three consecutive years at major locations of North Central and North East zone. Similarly, 'CoLk 12207' exhibited moderately resistant (MR) to (R) resistant reaction against these two pathotypes of red rot under nodal or cotton swab methods at different test locations (Mohanraj *et al.,* 1997; Duttamajumder, 2008). In view of the non availability of effective systemic fungicides for controlling red rot under field conditions, breeding for red rot resistance remains the most practical, economical and effective option (Meeta *et al.,* 2007; Kaur *et al.,* 2014). 'CoLk 12207' had shown moderately resistant reaction to wilt and smut diseases under natural field conditions. 'CoLk 12207' was also screened for its tolerance to the major insect pests such as top borer, stalk borer and early shoot borer at different test locations. It was observed that 'CoLk 12207' exhibited least susceptible (LS) reaction to top borer, stalk borer and early shoot borer.

Distinguishing characteristics

'CoLk 12207' is an early maturing, tall growing sugarcane variety and could be easily identified through its green cane top having erect leaves with curved tip. 'CoLk 12207' had been characterized based on 27 morphological characters used in the DUS testing (Singh *et al.,* 2017). These distinguishing morphological characters of 'CoLk 12207' are presented in the Table 3. In addition, 'CoLk 12207' had also been characterized through molecular profiling with 07 SSR markers along with other varieties including standards (Fig-1).

Table 3 Morphological characteristics (DUS) of sugarcane variety 'CoLk 12207'

S. No.	Character	State
1.	Plant growth habit	Erect
2.	Leaf Sheath: hairiness	Absent
3.	Leaf Sheath: Shape of ligule	Crescent
4.	Leaf Sheath: Shape of inner auricle	Dentoid
5.	Leaf Sheath: Colour of dewlap	Yellowish green
6.	Leaf Blade: Curvature	Erect
7.	Leaf Blade: Width	Medium
8.	Plant: Adherence of leaf sheath	Weak
9.	Internode: Colour (Not exposed to sun)	Yellow green (RHS) 145 C
10.	Internode Colour: (Exposed to sun)	Yellow green (RHS) 153 D
11.	Internode: Diameter	Medium
12.	Internode: Shape	Conoidal
13.	Internode: Zig zag alignment	Present

S. No.	Character	State
14.	Internode: Growth crack (Split)	Absent
15.	Internode : Rind surface appearance	Corky patches only
16.	Internode: Waxiness	Light
17.	Node: Shape of bud	Round
18.	Node: Size of bud (Measured from base of bud to the tip)	Small
19.	Node: Bud groove	Absent
20.	Node: Bud cushion (Space between bud base and leaf scar)	Absent
21.	Node: Bud tip in relation to growth ring	Below growth ring
22.	Node: Prominence of growth ring	Strong (Swollen)
23.	Node: Width of root band (opposite to bud)	Narrow
24.	Internode Cross section	Round
25.	Internode: Pithiness	Absent
26.	Plant: Number of millable canes (NMC) per stool	Medium
27.	Plant: Cane height	Medium

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Response of sugarcane to N&K application through drip fertigation in southern zone of Andhra Pradesh

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ABSTRACT

A field investigation was carried out at Agricultural Research Station, Perumallapalle, Andhra Pradesh during 2016-17 and 2017-18 to suggest optimum dose of N & K for drip fertigation in sugarcane. The experimental results revealed that application of 125% RDN and K in 12 equal splits through drip fertigation in the form of urea and muriate of potash commencing from 30-150 days after planting recorded the highest cane yield (114.5 t/ha) but was on par with 100% RDN + and K (111.7 t/ha).Cane yield was increased by 8.9% when urea and muriate of potash were applied through drip fertigation as compared to soil application at 100% recommended dose.

Key words: DAP, Drip fertigation, Millable canes, 3 budded setts

Sugarcane is one of the major commercial crops cultivated in the state of Andhra Pradesh and grown over an area of 1.0 lakh ha. The sugarcane productivity is dwindling between 75-80 t/ha for the last two decades and there is dire need to increase the productivity of cane and sugar recovery by maximizing yield and quality of sugarcane through balanced fertilization and judicious use of irrigation water. Sugarcane, a long duration crop, requires irrigation water to an extent of 1400-2000 mm. Providing optimum soil moisture conditions throughout the crop growing period is of paramount importance to realize higher yields (Sundara 1998). Sugarcane is a heavy feeder of nutrients. Its root system is shallow and fibrous therefore fertigation is recommended for higher nutrient use efficiency. High cost of liquid or water soluble fertilizers like mono ammonium phosphate, multi K and 19:19:19 used for fertigation leads to increased cost of cultivation in sugarcane. Therefore exploring the possibility of using straight fertilizers for fertigation in sugarcane has been taken up to suggest optimum dose of N and K straight fertilizers to be supplied under drip fertigation for sugarcane in southern zone of Andhra Pradesh.

MATERIALS AND METHODS

Field experiment was conducted at Agricultural Research Station, Perumallapalle, Andhra Pradesh for two consecutive years during 2016-17 and 2017-18 on a sandy loam soil. The experimental soil was neutral in pH (7.32) normal in EC (0.09 ds/m), low in organic carbon (0.42) and available nitrogen (208kg/ha), medium in available phosphorus (15.5 kg/ha) and high in available potassium (262 kg/ha).The experiment was designed with six treatments in a randomized block design with four replications. The treatments consisted of Soil application of 100% recommended Nitrogen (224 kg N/ha) in two equal splits at 45 and 90 DAP and entire P_2O_5 and K_2O (112kg P_2O_5 and -112 kg K_2O/ha) at planting(T_1), Soil application of 100% recommended Nitrogen and Potassium (224 kg N/ha and 112 kg K_2O/ha) in four equal splits at 30,45, 60 and 75 DAP and entire P_2O_5 (112kg/ha) at planting (T_2),50 %RDN and K in 12 equal splits from 30-150 DAP through drip fertigation (T_3), 75 %RDN and K in 12 equal splits from 30-150 DAP through drip fertigation (T_4) 100% RDN and K in 12 equal splits from 30-150 DAP through drip fertigation (T_5), 125 % RDN and K in 12 equal splits from 30-150 DAP through drip fertigation (T_6). Land was prepared to a fine tilth and furrows were formed with ridger at 80 cm spacing. The inline drip with 40 cm emitter spacing and discharge rate of 2.8 lph was arranged at 0.8m spacing. Irrigation was scheduled uniformly once in three days to all the treatments. The quantity of irrigation water applied was recorded using a water meter and it was regulated based in the ET calculated from open pan evaporimeter readings. A quantity of irrigation water 94.6 ha-cm and 98.2 ha-cm were applied through drip for both years of study respectively. Drip fertigation treatments were imposed for a period of 120 days and N&K fertilizers were scheduled in 12 splits at 10 days interval as per doses through ventury assembly. Phosphorus @ 112 kg P_2O_5/ha was applied as basal in planting furrows. Three budded setts of an early maturing variety '2005 T16 - Swarnamuki' (used as test variety) were planted in furrows using a seed rate of 10.0 t/ha. Atrazine was sprayed @ 5 kg/ha at 3 days after planting. All the cultural operations like weeding, earthing up, trash twist propping etc., were carried out as per recommendation to southern zone.

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Yield attributing parameters like number of millable canes, cane length, cane diameter and cane yield were recorded at the time of harvest. Cane juice of different treatments was analysed for quality at harvest. Brix was recorded by using hydrometer and pol% was recorded by polarimeter and sucrose was estimated by using standard procedures (Spencer and Meade, 1945).

RESULTS AND DISCUSSION

Results pertaining to the yield attributes, yield and juice quality parameters are presented in Table 1and 2. Application of 125% RDN and K as urea and muriate of potash (white) in 12 equal splits commencing from 30-150 days after planting recorded higher number of millable canes (89,342 /ha) over other doses and it was on par with 100 % RDN and K. Lowest number of millable canes/ha was recorded with 50% RDN and K (72,283/ha). Variation in number of millable canes due to drip fertigation was also reported by Raskar and Bhoi (2001). Length and girth of millable canes at harvest increased with increase in N & K doses from 50% to 25% recommended dose. Significantly longer and thicker millable canes were produced with the application of 100% RDN & K in the form of solid fertilizers through drip fertigation over lower levels of application (Table 1).

Cane yield showed significant differences with different levels of drip fertigation. A significant increase in cane yield was observed with increase in fertilizer dose of nitrogen and potassium from 50% to 125% RDN and K during both the years of study. Increase in yield with increase in fertilizer level under drip fertigation was also reported by Rajana and Patil (2003) and Gouri *et al.* (2012). Supply of N&K at 125% recommended dose in 12 equal splits from 30-150 DAP recorded significantly higher cane yield of 121.3 t/ha during 2016-17 and 114.1 t/ha during 2017-18 compared to lower levels through drip fertigation and 100% recommended dose through soil application but was on par with 100 % RDN & K through drip fertigation. Soil application of 100% RDN and K in 4 equal splits at 30, 45, 60 and 75 DAP did not prove advantageous (103.6 t/ha) over soil application of RDN in 2 equal splits and entire K as basal at planting (102.6 t/ha). Higher shoot population coupled with efficient conversion of tillers into millable canes at harvest on account of effective utilisation of applied nutrients might have contributed for higher cane yield under drip fertigation. Raskar and Bhoi (2001) and Gouri *et al.* (2012) reported that use of N&K straight fertilizers as urea and muriate of potash were the best alternative source for water soluble fertilizers. Application of 100% recommended N&K through drip fertigation recorded higher cane yield (111.7 t/ha) than soil application (102.6 t/ha). Bharathalakshmi *et al.* (2017) reported increase in cane yield with drip fertigation of nitrogen over soil application.

Table 1 Yield attributes of sugarcane as influenced by the drip fertigation treatments

Treatment	Millable cane length (cm)			Millable cane diameter (cm)			Millable cane population /ha		
	2016	2017	Mean	2016	2017	Mean	2016	2017	Mean
T_1: Soil application of 100% recommended Nitrogen (224 kg N/ha) in two equal splits at 45 and 90 DAP and entire P_2O_5 and K_2O (112kg P_2O_5 and -112 kg K_2O/ha) at planting.	250	289	269	2.52	2.72	2.62	86789	86766	86777
T_2: Soil application of 100% recommended Nitrogen and Potassium (224 kg N/ha and 112 kg K_2O/ha) in four equal splits at 30, 45, 60 and 75 DAP and entire P_2O_5 (112kg/ha) at planting.	256	292	274	2.59	2.80	2.69	87452	86522	86987
T_3: 50 % RDN +50% RDK in 12 equal splits from 30-150 DAP through drip fertigation at 10 days interval	262	251	256	2.52	2.58	2.55	76482	68085	72283
T_4: 75 % RDN +75% RDK in 12 equal splits from 30-150 DAP through drip fertigation at 10 days interval	264	275	265	2.74	2.72	2.73	87263	76315	81789
T_5: 100% RDN +100% RDK in 12 equal splits from 30-150 DAP through drip fertigation at 10 days interval	266	276	271	2.69	2.82	2.75	88689	88996	88842
T_6: 125 % RDN +125 % RDK in 12 equal splits from 30-150 DAP through drip fertigation at 10 days interval	262	290	276	2.64	2.93	2.78	89963	89247	89342
SEm$\pm$	33	11		0.05	0.02		5653	2618	
CD (0.05)	99	55		NS	0.06		1721.3	796.4	

Table 2 Yield and quality of sugarcane as influenced by the fertigation treatments

Treatment	Cane yield (t/ha)			Sucrose (%)		
	2016	2017	Mean	2016	2017	Mean
T_1: Soil application of 100% recommended Nitrogen (224 kg N/ha) in two equal splits at 45 and 90 DAP and entire P_2O_5 and K_2O (112kg P_2O_5 and -112 kg K_2O/ha) at planting.	98.7	106.5	102.6	17.60	19.68	18.64
T_2: Soil application of 100% recommended Nitrogen and Potassium (224 kg N/ha and 112 kg K_2O/ha) in four equal splits at 30, 45, 60 and 75 DAP and entire P_2O_5 (112kg/ha) at planting.	99.6	107.7	103.6	16.88	19.69	18.28
T_3: 50 %RDN +50% RDK in 12 equal splits from 30-150 DAP through drip fertigation at 10 days interval	82.8	77.3	80.0	17.21	20.38	18.79
T_4: 75 %RDN +75% RDK in 12 equal splits from 30-150 DAP through drip fertigation at 10 days interval	92.4	96.4	94.4	17.38	20.47	18.92
T_5: 100% RDN +100% RDK in 12 equal splits from 30-150 DAP through drip fertigation at 10 days interval	104.2	119.4	111.7	17.14	20.35	18.74
T_6: 125 % RDN +125 % RDK in 12 equal splits from 30-150 DAP through drip fertigation at 10 days interval	107.8	121.3	114.5	17.43	20.10	18.76
SEm+/-	1.98	1.02		0.38	0.20	
CD (0.05)	4.77	3.11		NS	NS	

Quality parameters

Quality in terms of sucrose was not significantly influenced by fertigation treatments and mean sucrose% ranged from 18.28 to 18.92. Juice quality mainly depends on genetic nature of the variety. Rajannna and Patil (2003) reported that quality parameters such as Brix, Pol (%) and CCS% were not affected by fertilizer levels. Non significant differences in quality with the application of nitrogen through soil and drip fertigation were also reported by Bharathalakshmi *et al*. 2017.

CONCLUSION

It is concluded from the two years study that application of 125% RDN and K in 12 equal splits through drip fertigation commencing from 30-150 days after planting recorded the higher mean cane yield (114.7 t/ha)than lower levels of application but it was on par with 100% RDN and K (111.7 t/ha). Supply of 100% recommended N and K through drip fertigation in the form of urea and muriate of potash in 12 equal splits enhanced the cane yield by 8.9% over soil application.

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Mathematical model for thin-layer vacuum drying kinetics of jaggery

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ABSTRACT

A systematic approach is proposed to investigate the thin layer vacuum drying characteristics of chemical-free jaggery using a mathematical model as well as experimentally. Drying experiments were conducted at drying temperature of 60, 70 and 80^{0}C and at a three vacuum pressure range 300, 400 and 500 mm of Hg with the initial moisture content of 9% and final moisture content of 2%, for slab thickness 5mm and 10mm with continuous drying at selected temperature range. The drying rates increased with an increase in temperature and vacuum in the drying chamber. Based upon the coefficient of correlation, estimated drying curves were analyzed and compared with six different acknowledged mathematical drying models. The Page and Arithmetic Diffusion model illustrated an excellent fit to predict the vacuum drying behavior of the chemical-free jaggery. The percentage relative deviation was found to vary in the range of 3 to 9% for predicted and actual moisture ratios at various drying conditions. Also for this model, the highest coefficient of determination (R^2), minimum values of Residual Sum Square (RSS), and the root mean square error (RMSE) were observed. The effective diffusivity varied from 2.0198E-10 to 1.89611E-09m^2/s over the temperature range. In general, the diffusivity values obtained by using the Arrhenius model can be predicted with high efficiency and good expandability. Activation energy varied from a minimum of 27.9936 to a maximum of 86.031kJ/mol.

Keywords: Drying, Vacuum drying, Jaggery cubes, Mathematical modeling.

Nomenclature

T	Temperature (^{0}C)	Ea	Activation energy (kJ/mol k)
P	Pressure (kpa)	R	Universal gas constant (8.3143 kJ/mol k)
R^2	Coefficients of correlation	Ta	Absolute temperature (k)
RSS	Residual Sum square	Xt	Moisture content at any given time (min)
RMSE	Root mean square error	Xe	Equilibrium moisture content
MR	Moisture ratio	X_0	Initial moisture content
D_{eff}	Moisture dependent diffusivity (m^2/s)	Xt+dt	Moisture content at time t+dt
Z	Diffusion path (m)	Dx	Change in moisture content
L	Length of slab (m)	Dt	Change in drying time
L^2	Thickness of slab (m^2)	a,b,c,d	model constant
D	Diffusivity (m^2/s)	Wb	Wet basis
D_0	Pre-exponential factor (m^2/s)		

INTRODUCTION

Jaggery is the natural sweetener manufactured from sugarcane juice also known as 'gur' in India. It is available in solid form and contains sucrose 70-85%, reducing sugar 10-15%, total minerals 3.54%, crude protein 1.53%, crude fats 0.21%, carbohydrate 86.42% and energy 353.69Kcal/100g (Jagannadha Rao *et al.* 2007). In Ayurveda way of medicine, it is used as a medicine, blood purifier, and base material for syrups. It has a moderate amount of iron, magnesium, calcium, phosphorous, and zinc so it helps to optimize the health of a person along with all its benefits such as it purifies the blood, prevents rheumatic afflictions, bile disorders, and thus helps to cure jaundice. Jaggery has proved itself better as compared to white sugar due to its nutritional value (Singh 2013). Average moisture present in the fresh jaggery is found to vary between 10-12%. Jaggery loss of up to 25% has been reported due to hygroscopic nature and presence of moisture. Due to this, biological activity is initiated and sucrose is transformed into reducing sugar, further making jaggery more hygroscopic to attract more moisture. This phenomenon is an endless chain reaction until total jaggery mass deteriorates by further liquefaction. Hence, before storage, it is necessary to dehydrate jaggery up to moisture content level of 2% to increase shelf life (Kumar and Tiwari 2006).

For value addition to the product, it is necessary to bring it in a user-friendly form like granular powder which will give more returns to sugar cane producers (NAAS 2006; Nath *et al.* 2015). During research and experimentation for manufacturing jaggery in granular/powdered form, this work

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was designed and optimized for various operating parameters of the pulverizing machine. But the most important factor before pulverizing is to dehydrate jaggery up to 2 to 3% moisture content, otherwise due to present moisture content, hygroscopic nature, and heat developed during pulverizing, jaggery cannot be pulverized (Jung 2006). Dehydration of food is one of the oldest and easiest techniques for the preservation & production of a variety of food products (Jangam *et al.* 2010), which decreases the moisture content and further activities. Drying brings about the reduction in weight and volume, minimizing the packaging, storage, and transportation costs and enables the storability of the product under ambient temperature. The mathematical model of the drying process is used for designing and controlling the drying process. Experimental data on the drying process, optimum process parameters, and quality standards for dried jaggery are required to design process equipment for efficient and economic production of any dried product (Gamli 2014).

Apart from available literature concerning jaggery production & value addition, information and experimental research on systematic modeling of the vacuum drying process is still missing. In vacuum drying, oxidative degradations of carbohydrates and caramelization are reduced because drying is carried out in the absence of oxygen. Vacuum drying below 75^0C is carried out to dry food products which are sensitive to oxygen and heat (Jangam *et al.* 2010; Jaya and Das 2012). In the jaggery drying process, drying temperature, vacuum, and the thickness of the jaggery slab affect the drying rate of jaggery. Therefore, detailed analysis and exploration of the effect of these parameters on the vacuum drying process must be experimentally verified. A most important aspect of the analysis of a drying process is to develop a mathematical model of the drying processes and equipment. Drying characteristics of the chosen product and simulating model are required in the design, construction, and operation of the drying system (Gunhan *et al.* 2005). The drying phenomenon of food products can be described by the thin-layer drying models that can be categorised as theoretical, semi-theoretical, and empirical. The theoretical models are derived from Fick's second law of diffusion while semi-theoretical models are generally derived from Fick's second law by its modifications and from Newton's law of cooling. Moisture transfer phenomenon is heavily influenced by sample properties *viz.*; shape, size, thickness, and humidity (Ashraf *et al.* 2012; Gamli 2014). From the available published literature, it is observed that there is no unique drying model to describe the drying kinetics of all products appropriately. Many researchers have worked on vacuum drying of different vegetables, fruits, and grains. But still, no one has addressed the dehydration phenomenon of jaggery along with moisture diffusivity and activation energy.

In this study, the thin layer drying behavior of jaggery in the vacuum dryer has been investigated. Two important mass transfer phenomenon in drying which are diffusion and evaporation of moisture are studied for jaggery through experimental investigation. Suitable drying characteristics model from literature are fitted to experimental data to obtain model parameters for jaggery. These models are mentioned in table 1. The semi-theoretical thin-layer drying model provides better prediction of results as compared to other models. In the end many critical drying parameters such as effective moisture diffusivity, activation energy and parameters of Arrhenius relation for diffusion and evaporation of moisture are found. Effects of drying temperature, slab thickness and vacuum levels on these parameters are reported.

MATERIALS AND METHODS

Experimental set up

Laboratory-scale vacuum dryer was used for experimental work with a vacuum pump, condensing unit, drying chamber & heater. The unit consists of a drying chamber (tempo, serial no. 264 CAT No. 061-721) of stainless steel sheet as a circular tunnel with a diameter of 400mm and length 300 mm. Two dryer trays placed inside the drying chamber. A high vacuum pump (Jebivac. ser no. 200616, Mumbai) with the vacuum control unit, a cold trap was used for maintaining the accurate vacuum in the chamber. The vacuum pressure in the desiccators was maintained at the required range with a vacuum pump. The temperature controller used as desiccator, was placed inside the dryer to maintain the desired drying temperature. The heating system consists of an electric heater with a power of 6000W fitted inside the drying chamber and temperature was controlled by heater power control. K type thermocouples were used for the measurement of temperature with a manually controlled automatic digital thermometer, with the accuracy of $\pm$ 2% °C. To determine the loss in weight of the drying sample, a digital balance (Wenser, Mumbai) with the measurement range of 0-300g with an accuracy of 0.001 g, and to measure vacuum pressure, vacuum gauge (PVR 0606A81, Mumbai) was used. Initial moisture content was measured by digital moisture analyzer (Citizen, Mumbai) and the average value was determined.

Procedures

Fresh jaggery samples were collected from four different jaggery manufacturers from nearby Kolhapur region were heated at various temperatures to select a range of temperatures for drying. With this initial screening experiment, jaggery manufactured from sugarcane variety 'Co 86032', processed without chemicals, temperature range 60-80^0C, and vacuum range 300-500 mm (Hg) was selected for further experimentation (Jangam *et al.* 2010; Richester 2014; Sahdev 2014; Tiwari *et al.* 2004; Kumar and Tiwari 2006). Jaggery slab was cut into pieces of the approximate size of the 1-inch cube. Drying experimentation was conducted at 60^0C, 70^0C, and 80^0C temperature with vacuum 300, 400, and 500 mm (Hg). The design of experiments was done by the Taguchi method. Grey Regression analysis and multi-objective optimization were carried out for selecting optimum temperature and vacuum for the drying process. For the two responses-minimum times required for drying and quality of dried jaggery, optimal conditions 400 mm (Hg) and temperature 70 ^{0}C were observed. 100g of jaggery placed in the tray and drying process was carried out for final moisture content of the jaggery sample *i.e.,* 2-3(w.b), a limiting value as the taste of jaggery alters at lower value. The samples were taken out during the drying process from the vacuum and weighed on digital electronic balance with a gap of one hour. The exactness of this weighing balance was up to 0.001g. The vacuum was brought back in the drying chamber after weight measurements. Few experiments were stopped either after the change in colour or texture due to high temperature. The moisture content of the samples was measured (kg water per kg dry solid). The drying process was carried out until steady-state values for 3 consecutive readings. The moisture ratio was calculated at the end of each experiment and the drying factor was articulated as moisture ratio against drying time.

To study the effect of slab thickness on vacuum drying, further experimentation was carried out for jaggery slab thickness 5mm and 10mm at the selected temperature and the vacuum pressure range and drying process continued for moisture content up to 2%. For high temperature and or high vacuum, jaggery gets softened and caramelization is observed. Hence, experimentation were stopped at this stage only. Mathematical modeling was performed using MATLAB software and best-fitting models were selected based on values of Relative deviation, R^2, RSS, and RMSE values.

Mathematical Modeling and Drying Curve

In thermal modeling, the thermal parameter of drying techniques such as temperature, vacuum pressure, moisture content, moisture ratio, drying rate, effective moisture diffusivity, and the activation energy was calculated. Moisture ratio (MR) is one of the most important criteria to determine the characteristic of food products. MR determined according to the external condition is expressed as

$$MR = \frac{X_t - X_e}{X_0 - X_e} \tag{1}$$

Where, MR is a moisture ratio. X_t is Moisture content at any instant expressed as kg of water per kg of solid. X_e is equilibrium moisture content and X_0 Initial moisture content X_e. The equilibrium moisture content is the moisture content at which the product neither absorbs nor liberates moisture. It is affected by relative humidity and temperature and is written as:

$$MR = \frac{X_t}{X_O} \tag{2}$$

Drying rate calculated can be expressed as

$$\frac{dX}{dt} = \frac{X_{t+dt} - X_t}{dt} \tag{3}$$

Where,

X_t is the moisture content at time and X_{t+dt} is the moisture content at the time X_{t+dt} and 't' is the drying time. The experimental data of drying time versus dimensionless moisture ratio were fitted into 5 different thin-layer drying models widely used by many researchers given in table 1.

To assess the appropriate fitness of the models to the experimental data, the percentage relative deviation R_d between experimental and predicted moisture ratios were calculated. For the goodness of fit, the percentage relative deviation value10 or less was decided (Jena and Das 2007). The relative deviation can be estimated by Eq. (4) as

$$R_d = \frac{100}{N}\left[\sum_{i=1}^{N} \frac{(|M_{R\,pre,i} - M_{R\exp i}|)}{M_{R\exp i}}\right] \tag{4}$$

The goodness of fit is decided using three parameters:

For modeling purposes, the regression coefficient (R^2) was the primary criterion for selecting the most suitable equation from experimental data which can be expressed as

$$R^2 = 1 - \left[\frac{\sum_{N=1}^{N}(MR_{pre,i} - MR_{exp,i})^2}{\sum_{i=1}^{N}(\overline{MR}_{pre} - MR_{exp,i})^2}\right] \tag{5}$$

Residual sum square (RSS) providing information about the correlation by allowing a comparison of the actual deviation between predicted and experimental values term by term can be expressed by Eq. (6). Generally, Ideal values are "zero".

$$RSS= \sqrt{\frac{\left[\sum_{i=1}^{n}(M_{Rexp,i} - M_{Rpre,i})\right]^2}{N - n_1}} \tag{6}$$

Where, N is called the number of constant

The Root Mean Square Error (RMSE) can be expressed as

$$RMSE = \left(\frac{1}{N}\sum_{i=1}^{N}\left[MR_{pre,i} - MR_{exp,i}\right]^2\right)^{\frac{1}{2}} \tag{7}$$

In the above equations $MR_{pre,\,i}$ is the i^{th} predict moisture ratio, $MR_{exp,\,i}$ is the i^{th} experimental moisture ratio, N is the number of observations of constant. The higher values of R^2 is near about 1 or equal to 1 and lower values of RMSE are chosen as the better criteria for the goodness of fit (Gamli 2014).

Effective diffusivity of moisture

The food drying process mostly takes place in the falling rate period. Moisture transfer takes place from inside to outside surface by liquid diffusion. Fick's second law is used to describe the drying process of the jaggery. This unidirectional diffusion equation applies to various shaped bodies. An analytical solution to Fick's second law was developed by Crank (1975) with assumptions that uniform distribution of initial moisture throughout the sample, negligible internal resistance to mass transfer, moisture transfer by diffusion mechanism, negligible product shrinkage and constant diffusion coefficient during drying (Jena and Das 2007) can be expressed as

$$MR = \frac{Xt - X_e}{X_o - X_e} = \frac{\pi}{8}\sum_{n=0}^{\infty}\frac{1}{(2n+1)} exp\left(-\frac{(2n+1)^2\pi^2 D_{eff}}{4L^2}\ t\right) \quad (8)$$

Where, *MR* is the moisture ratio, *Deff* (m^2/s) the effective moisture diffusivity, *t* (s) is the drying time, *l* (m) is the sample thickness of the slab, and n is a positive integer.

For the long drying time, only the first term of the series can be simplified as

$$MR = \frac{Xt - X_e}{X_o - X_e} = \frac{\pi}{8} exp\left(-\frac{\pi^2 D_{eff}}{4L^2}\ t\right) \quad (9)$$

Effective moisture diffusivity was evaluated by plotting the experimental drying data in terms of ln (MR) *vs* drying time. A plot of ln (MR) versus drying time gives a straight line with a negative slope of k is given by:

$$k = \frac{\pi^2 D_{eff}}{4L^2} \quad (10)$$

Estimation of the Activation energy

Activation Energy estimated is expressed as

$$D_{eff} = D_o\ exp\ exp\left(\frac{-E_a}{RT}\right) \quad (11)$$

Where *Ea* implies activation energy (kJ/mol), R implies universal gas constant (8.3143 kJ/mol K), *Ta* is the absolute temperature, (K) and D_0 is the Arrhenius equation's pre-exponential factor (m^2/s).

The energy of activation can be estimated from the slope. In (D) versus 1/ Ta. From equation (11), a plot of ln (D) versus 1/ Ta gives a straight line, the slope of which is given by K_2

$$K_2 = \frac{E_a}{R} \quad (12)$$

Evaluation of thin layer model

In this section the thin layer mathematical drying models have been used to describe the drying characteristics of jaggery which is presented in table 1. Total six models have been considered to investigate the characteristics of jaggery (Gamli 2014) and subsequently results are presented in the following sections.

Table 1 Thin-layer mathematical drying models used to describe the drying characteristics of jaggery

Model	Equations
Newton	MR=$exp(-kt)$
Page	MR=$exp(-kt^n)$
Logarithmic	MR=$aexp(-kt) + c$
Approximate diffusion	MR=$aexp(-kt) + (1 - a)\ exp(-kbt)$
Lewis	MR=$exp(-kq)$
Ficks' Law	MR=$a.\ exp(-kq)$

MR moisture ratio, t drying time, a, k, b, c, and n are the model constant.

Design of Experiments

From the experiments conducted in screening tests, it was observed that temperature in dryer and vacuum in dryer both are influencing the drying process to a certain level. Hence, the experiments were planned with the Taguchi method. L9 mixed orthogonal array was developed using Minitab software. DOE was developed for two variables, temperature and vacuum with three levels of each. Input-jaggery manufactured from sugarcane variety 'Co 86032' processed without chemical was broken into the approximate size of 25 mm x 25mm.

Process Parameters	Levels		
	1	2	3
Temperature ^{0}C	60	70	80
Vacuum, mm (Hg)	300	400	500

For the above experiments, the time required for drying and quality analysis grade (QAG) observed is shown in table 2.

Table 2 Experimental Design

Sl. No.	Vacuum (mm^3)	Temperature (^{o}C)	Time (min)	QAG
1	300	60	360	8
2	300	70	300	8
3	300	80	240	1
4	400	60	210	9
5	400	70	150	9
6	400	80	120	1
7	500	60	180	5
8	500	70	150	1
9	500	80	120	1

QAG-Quality Analysis Grading points were decided by experts working in the field of jaggery marketing, depending upon taste, color, structure, and flavor. From the above experimentation, due to the lowest QAG, experiments 3, 6, 8 and 9 were eliminated due to caramelization observed during drying (High-temperature 80^{0}C). The new sets of experiments conducted for two different slab thicknesses are tabulated in table 3.

RESULTS AND DISCUSSION

The jaggery sample used in experimentation was manufactured from sugarcane variety 'Co 86032' and processed without chemicals with initial moisture content 9%. Drying of the chemical-free jaggery started with the initial moisture content of 9.00 % (Wb) and continued up to 3 to 2.00 % (Wb).

Variation of moisture ratio at various temperature, pressure and slab thickness

Figure 1 show the moisture ratio for dried jaggery at 300 mm (Hg) at 60 ^{0}C for 10 mm and 5 mm slab thickness. Value of moisture contents M of the jaggery at different drying time't' was measured for different drying temperatures and slab thickness. The variation in moisture ratio (M/Mi) with the drying time for various sample thicknesses and temperature at different vacuum levels was plotted in Figs. 1–5. From all these curves, it is concluded that the drying rate of jaggery is not constant and is fluctuating. Drying of most food generally takes place in the sinking rate during which moisture transfers from the core to the exterior surface of the material by diffusion. While the drying process continues the amount of moisture decreases, and the drying mechanism changes (Dash *et al* 2013).

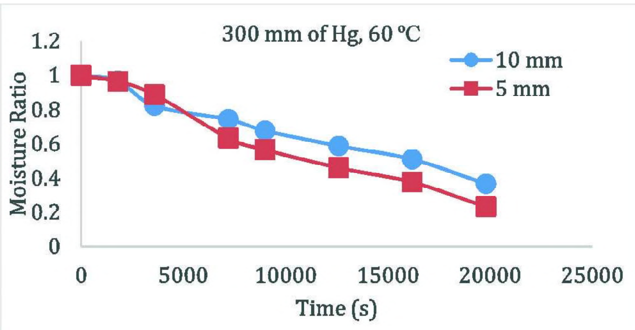

Fig 1. Moisture ratio for dried jaggery at 300 mm (Hg) at 60 ^{0}C for 10mm and 5 mm slab thickness

It is observed that the time required to achieve the same MR for 10mm slab thickness is more than the time required for 5mm slab thickness as reported in Fig. 1.

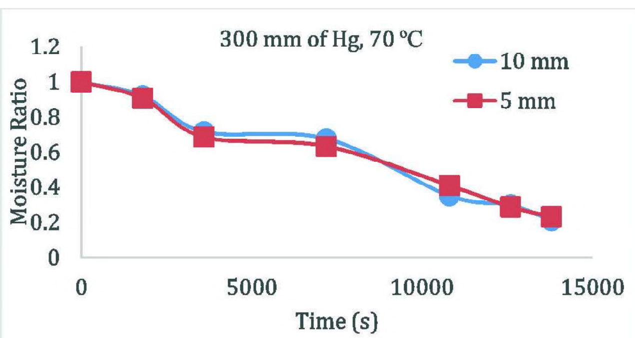

Fig 2. Moisture ratio for dried jaggery at 300 mm (Hg) at 70 ^{0}C for 10mm and 5 mm slab thickness

It is observed that the time required to achieve particular moisture ratio MR for 10mm slab thickness is more than the time required for 5mm slab thickness. But, the effect of slab thickness at 70^{0}C on time variation is very less as compared to 60^{0}C is shown in Fig. 2.

The time required to achieve particular moisture ratio MR for 10mm slab thickness is more than the time required for 5mm slab thickness. The observed trend is similar to drying at 60^{0}C and 300 mm (Hg) is shown in Fig. 3.

It is observed that the time required to achieve particular moisture ratio MR for 10mm slab thickness is more than the time required for 5mm slab thickness. But, the effect of slab thickness at 70 ^{0}C on time variation is very less as compared to 60^{0} C is shown in Fig. 4. This trend is similar to drying at

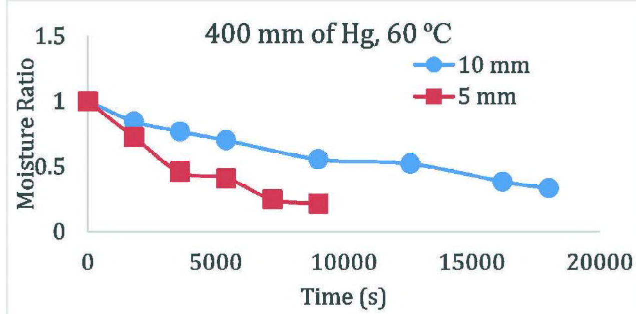

Fig. 3 Moisture ratio for dried jaggery at 400 mm (Hg) at 60 ^{0}C for 10mm and 5 mm slab thickness

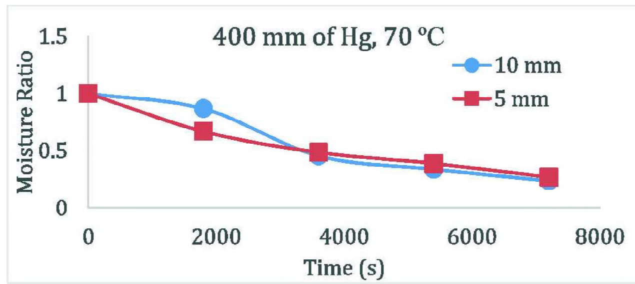

Fig 4. Moisture ratio for dried jaggery at 400 mm (Hg) at 70 ^{0}C for 10mm and 5 mm slab thickness

temperature70^{0}C and vacuum 300 mm (Hg).

The time required to achieve particular moisture ratio MR for 10mm slab thickness is more than the time required for 5mm slab thickness. The trend is similar to drying at 60^{o}C and vacuum 300mm (Hg) and 400 mm (Hg). It can be concluded that the thin layer vacuum drying process of jaggery is drastically affected by slab thickness at lower temperature 600^{o}C compared to the higher temperature of 70^{o}C as shown in Fig. 5.

From the above Fig. 1 to Fig. 5, it is observed that the drying rate decreases continuously with an increase in drying time. All the drying operations were in a falling drying rate period and the constant rate drying period was not detected. It was observed that the drying rate was directly proportional to temperature. The presence of a sinking drying period is also supported by previous researchers during vacuum drying

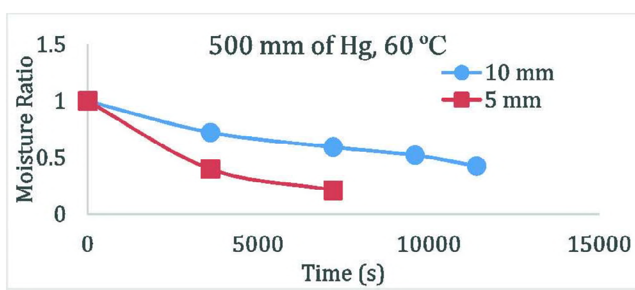

Fig 5. Moisture ratio for dried jaggery dried at 500 mm (Hg) at 60 ^{0}C for 10mm and 5 mm slab thickness

of coconut press cake, olive cake and potato (Akgun and Doymaz 2005; Jena and Das 2007; Singh *et al.* 2014). With an increase in the slab thickness corresponding drying time increases. The rate of moisture removal was very high for first hour. 60% of the moisture was removed in one-third of total drying time and two-third drying times were consumed on eliminating the remaining 40% of the moisture. This observed fact may be due to less effective moisture diffusivity throughout the remaining part of the dehydration process. Similar drying behavior was observed and reported by many researchers in the process of thin-layer drying of olive cake (Akgun and Doymaz 2005), mango pulp (Jaya and Das 2012), apricot (Mirazee *et al.* 2010), carrot (Darvishi *et al.* 2012) and kiwifruit (Orikasa *et al.* 2014). It is revealed that the rate of moisture loss rises with increasing drying temperature, vacuum pressure, and a decrease in slab thickness. From Fig. 2 to 6, it is very clear that the total drying time required to reach the moisture ratio from 1 to 0.6 was less as compared to the time required to reach moisture ratio from 0.6 to 0.2 in all experimental conditions. Approximately this time is in the ratio of 1:2 to 1:3. It means that for various conditions of temperature, vacuum & thickness, more time is required to achieve a moisture ratio from 0.6 to 0.2. This is in agreement with the vacuum drying of the different fruits.

Modeling of Drying Characteristics

The drying data obtained from the experiments were fitted to the selected models mentioned in table 1. The values of relative deviation and different constants have been presented in table 3.

Table 3 Relative deviation, R^2, RSS and RMSE values for all selected models

Model	k	y	a	b	c	R^2	RSS	RMSE	R_d
Thickness 10 mm slice, 300 mm of Hg vacuum pressure, temperature is 60 ^{0}C									
Lewis	0.00004					0.99162	0.00148	0.04645	3.71500
Page	0.00008	0.93001				0.99045	0.00160	0.03527	3.95730
Fick's Law	0.00004		1.00794			0.99163	0.00105	0.04514	3.74850
Logarithmic	0.00011		0.70313		0.38305	0.97306	0.00429	0.67939	6.57000
Approx. Diff.	0.00302		0.10476	0.02464		0.99176	0.00104	0.02611	3.69650
Thickness 5 mm slice, 300 mm of Hg vacuum pressures, temperature is 60 ^{0}C									
Lewis	0.00006					0.99123	0.00247	0.07716	6.03580
Page	0.00000	1.40657				0.99162	0.00166	0.06516	4.34790
Fick's Law	0.00007		1.10411			0.98920	0.00233	0.07377	5.60750
Logarithmic	0.00014		0.01706		0.03424		0.70380	0.07980	8.12050
Approx. Diff.	0.00302		0.10476	0.02464		0.99600	0.00109	0.05762	4.30180
Thickness 10 mm slice, 300 mm of Hg vacuum pressure, temperature is 70 ^{0}C									
Lewis	0.00010					0.97137	0.00695	0.06084	9.03500
Page	0.00000	1.42070				0.98112	0.00466	0.03728	6.74270
Fick's Law	0.00010		1.02414			0.97077	0.00635	0.06608	8.74730
Logarithmic	0.00011		0.94737		0.07699	0.96613	0.01114	0.07489	9.82140
Approx. Diff.	0.00375		0.11724	0.02853		0.97527	0.00743	0.05974	7.72540
Thickness 5 mm slice, 300 mm of Hg vacuum pressure, temperature is 70 ^{0}C									
Lewis	0.00010					0.97896	0.00625	0.03246	8.35091
Page	0.00000	1.78729				0.97680	0.00785	0.02348	5.57120
Fick's Law	0.00010		1.00000			0.97896	0.00510	0.03111	8.35089
Logarithmic	0.00015		0.07878		0.27686	0.96475	0.00813	0.03322	4.06609
Approx. Diff.	0.00046		0.07810	0.22546		0.98084	0.00510	0.02486	7.97600
Thickness 10 mm slice, 400 mm of Hg vacuum pressure, temperature is 60 ^{0}C									
Lewis	0.00006					0.99256	0.00120	0.03684	4.01000
Page	0.00025	0.85100				0.99445	0.00100	0.03223	2.72390
Fick's Law	0.00005		0.93363			0.99215	0.00111	0.03736	3.13441
Logarithmic	0.00004		1.11470		0.18785	0.99076	0.00177	0.05155	3.05530
Approx. Diff.	0.00058		0.07285	0.09733		0.99494	0.00074	0.03109	2.67229

Table 3 contd...

Table 3 contd...

Model	k	y	a	b	c	R^2	RSS	RMSE	R_d
Thickness 5 mm slice, 400 mm of Hg vacuum pressure, temperature is 60 ^{0}C									
Lewis	0.00018					0.99348	0.00144	0.08021	6.66981
Page	0.00037	0.91401				0.99412	0.00125	0.07870	6.17095
Fick's Law	0.00017		0.97985			0.99278	0.00166	0.07739	6.61101
Logarithmic	0.00011		1.18819		0.25704	0.98541	0.00532	0.08537	8.95100
Approx. Diff.	0.02230		0.02015	0.00756		0.99336	0.00263	0.07386	6.27522
Thickness 10 mm slice, 400 mm of Hg vacuum pressure, temperature is 70 ^{0}C									
Lewis	0.00020					0.97095	0.01749	0.02762	5.35909
Page	0.00022	0.98819				0.97293	0.01032	0.01322	5.26317
Fick's Law	0.00020		1.00000			0.97290	0.01749	0.01129	5.35908
Logarithmic	0.00001		17.81473		16.81473	0.97009	0.01822	0.02209	13.48170
Approx. Diff.	0.02025		0.01459	0.00977		0.97290	0.01608	0.01129	5.31380
Thickness 5 mm slice, 400 mm of Hg vacuum pressure, temperature is 70 ^{0}C									
Lewis	0.00018					0.99586	0.00095	0.02422	3.60828
Page	0.00060	0.86620				0.99903	0.00029	0.02401	1.62640
Fick's Law	0.00017		0.90749			0.99487	0.00032	0.02422	3.39890
Logarithmic	0.00001		11.09367		10.28725	0.96852	0.00122	0.03793	6.46940
Approx. Diff.	0.08026		0.09251	0.00211		0.99919	0.00016	0.02124	1.54869
Thickness 10 mm slice, 500 mm of Hg vacuum pressure, temperature is 60 ^{0}C									
Lewis	0.00007					0.99372	0.00096	0.03433	2.75159
Page	0.00097	0.70916				0.99508	0.00073	0.03139	2.69424
Fick's Law	0.00007		1.00000			0.99372	0.00113	0.03433	2.75158
Logarithmic	0.00022		0.58832		0.45005	0.98530	0.00360	0.15800	5.04110
Approx. Diff.	0.00107		0.12589	0.05015		0.99653	0.00073	0.03198	2.23936
Thickness 5 mm slice, 500 mm of Hg vacuum pressure, temperature is 60 ^{0}C									
Lewis	0.00022					0.99668	0.00177	0.03875	4.96222
Page	0.00177	0.76347				1.00000	0.00523	0.03432	0.00000
Fick's Law	0.00022		1.00000			0.99668	0.00177	0.03945	4.96221
Logarithmic	0.02034		0.86439		0.13561	0.97341	0.00863	0.03876	3.38827
Approx. Diff.	0.06211		0.24236	0.00286			0.00159	0.03499	0.00000

From table 3, it is observed that relative deviation for all models is less than 10%. Based on the value of the relative deviation of models, drying kinetics can be described during the vacuum drying of jaggery within a certain level of accuracy. Fick's law model, the Lewis model, and Logarithmic models were revealed in poor fit as compared to Page and Approximate diffusion models regarding values of percentage Relative Deviation (R_d). The Approximate Diffusion model predicted the drying characteristics significantly well at a lower temperature at 60°C while the Page model predicted the drying characteristics satisfactorily well at a higher temperature at 70°C. For vacuum 300mm and 500mm, drying data was predicted well by the Approximate Diffusion model. But, overall drying data for nearly all experiments were better predicted by the Page model.

From table 3, statistical results showed the highest values of R^2 (approaching to 1) and lower values of RSS and RMSE for Page and Approximate Diffusion models compared to the other three models. Based on these values, it may be revealed that Page and Approximate Diffusion models can predict the drying behavior of jaggery compared to the other three models under consideration. Regarding these statistical values, it is inferred that the Approximate Diffusion model projected the drying characteristics significantly at the lesser temperature at 60°C, and Page model projected the drying characteristics satisfactorily at a higher temperature at 70°C. This is in support to the earlier conclusion drawn on basis of percentage relative deviation values.

Therefore, the remaining three models are not that useful to predict the vacuum drying characteristics of jaggery. The optimal condition for vacuum drying 400mm of vacuum and temperature 70°C (obtained with grey regression analysis & multi-objective optimization) is well predicted by Page model with R^2 value 0.9729; RSS value 0.009152, and RMSE value 0.05523.

Best curve fitting Models for 10 mm thickness

For best fitting models, values of relative deviation R_d, R^2, RSS, and RMSE are given below in table 4.

Percentage Relative Deviation observed in the range from 2 to 6%.

Table 4 Relative deviation R_d, R^2, RSS and RMSE

Vacuum (mm of Hg)	T ^{0}C	R_d	R^2	RSS	RMSE	Model
300	60	3.6965	0.99176	0.001035	0.02611	Approximate Diffusion
	70	6.74370	0.98112	0.004655	0.03728	Page
400	60	2.67229	0.99494	0.000735	0.03109	Approximate Diffusion
	70	5.2631	0.97293	0.010323	0.01129	Page
500	60	2.23936	0.99653	0.000733	0.03198	Approximate Diffusion

Best fitting Curve

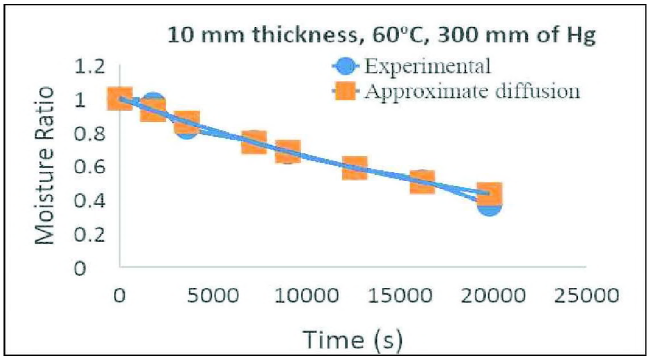

Fig 6. Variation of moisture ratio between experimental and predicted by Approximate Diffusion model for 10mm slab thickness at 60 ºC and 300 mm (Hg)

Approximate Diffusion model predicting drying behaviour at 60ºC and 300 mm (Hg) regarding minimum relative deviation 3.69%, the highest value of R^2 as 0.99176, lowest values of RSS as 0.001035, and RMSE as 0.02611 compared to other models under consideration is shown in Fig. 6.

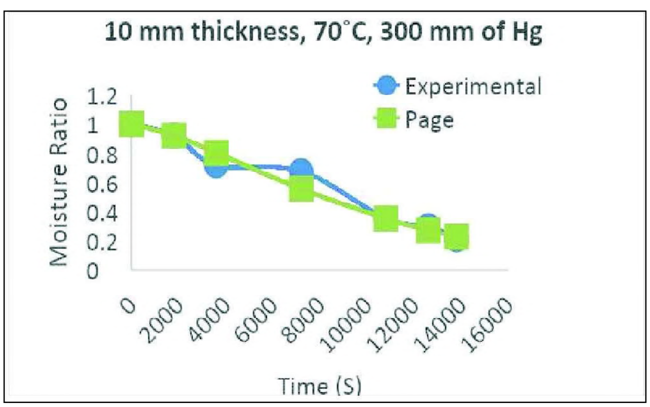

Fig. 7. Variation of moisture ratio between experimental and predicted by Page model for 10mm slab thickness at 70 ºC and 300 mm (Hg)

Page model predicting drying behaviour at 70 ºC and 300 mm (Hg) concerning minimum Relative Deviation 6.74%, the highest value of R^2 as 0.98112, lowest values of RSS as 0.004655, and RMSE as 0.03728 compared to other models under consideration is shown in Fig. 7.

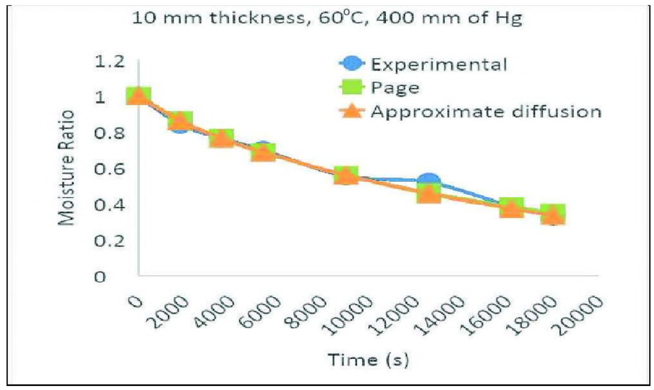

Fig 8. Variation of moisture ratio between experimental and predicted by Page model and approximate diffusion model for 10mm slab thickness at 60 ºC and 400 mm (Hg)

Approximate Diffusion model predicting drying behaviour at 60ºC and 400 mm (Hg) regarding minimum relative deviation 2.67%, the highest value of R^2 as 0.99494, lowest values of RSS as 0.000735, and RMSE as 0.03109 compared to other models under consideration is shown in Fig. 8.

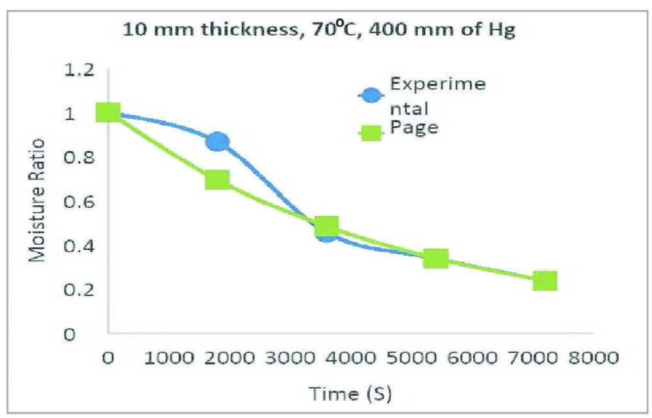

Fig 9. Variation of moisture ratio between experimental and Page model for 10mm slab thickness at 70 ºC and 400 mm (Hg)

Page model predicting drying behaviour at 70ºC and 400 mm (Hg) concerning minimum relative deviation 5.26%, the highest value of R^2 as 0.97293, lowest values of RSS as 0.010323, and RMSE as 0.01129 compared to other models under consideration is shown in Fig. 9 respectively.

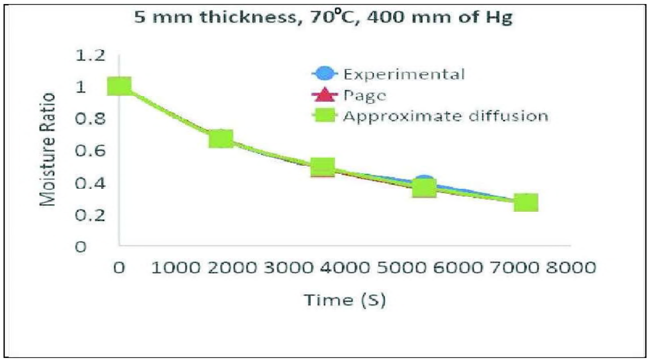

Fig 10. Variation of moisture ratio between experimental and predicted by Approximate Diffusion model, and Page model for 5mm slab thickness at 70ºC and 400 mm (Hg)

Figure 10 show the approximate diffusion model predicting drying behaviour at 70ºC and 400 mm (Hg) concerning minimum Relative Deviation 1.54%, the highest value of R2 as 0.99919, lowest values of RSS as 0.00016, and RMSE as 0.02124 compared to other models under consideration.

Page model also predicts drying behaviour at the above condition very closely to the Approximate Diffusion model concerning relative deviation 1.62%, the value of R^2 as 0.99903, lowest values of RSS as 0.00029, and RMSE as 0.02401 compared to other three models under consideration.

Figure 11 depicts the approximate diffusion model predicting drying behaviour at 70ºC and 500mm (Hg) concerning minimum Relative Deviation 2.23%, the highest value of R^2 as 0.99653, lowest values of RSS as 0.000733, and RMSE as 0.03198 compared to other models under consideration.

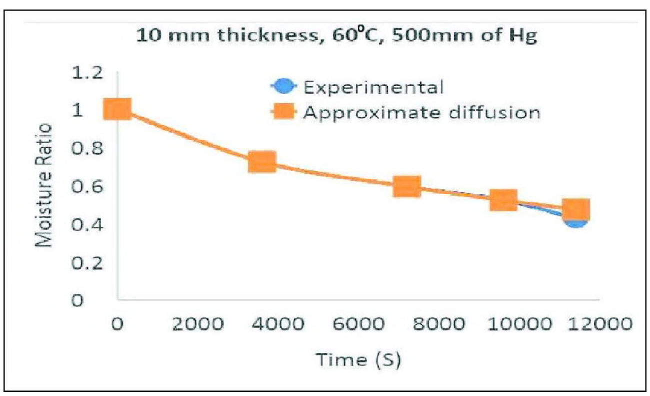

Fig. 11 Variation of moisture ratio between experimental and approx. diffusion for 10mm slab thickness at 60ºC and 500 mm of Hg

Effect of vacuum pressure and thickness on effective moisture diffusivity

Effective moisture diffusivity of jaggery calculated from experimental data and values is presented in table 5.

Moisture diffusivity was seen to be increased with both values of temperature and vacuum. Because when jaggery is dried at extreme temperature and vacuum, with improved heating energy results in higher moisture diffusivity. It is also inferred that effective moisture diffusivity increases with an increase in thickness for the same vacuum and temperature. Effective moisture diffusivity is found to vary between 2.0198×10^{-10} to 1.896110×10^{-9} m^2/s. The values were within the range of 10^{-8} to 10^{-12} m^2/s for drying of food material (Zogzas 1996). The values of D_{eff} are in agreement with the reported values of date paste (Asharf *et al.* 2014), kiwifruit (Orikasa *et al.* 2014), potato (Singh *et al.* 2014), red pepper (Akipinar *et al.* 2003), apricot (Mirazee *et al.* 2010), carrot (Darvishi *et al.* 2012) and pumpkin (Arévalo *et al.* 2006).

Table 5 Effective moisture diffusivities of jaggery at various vacuum, temperature and slab thickness

Pressure (mm of Hg)	Temperature (ºC)	Thickness (mm)	Diffusivity (m^2/s)
300	60	10	4.44502E-10
		5	2.0198E-10
	70	10	1.1049E-09
		5	2.78688E-10
400	60	10	9.35162E-10
		5	5.82394E-10
	70	10	1.89611E-09
		5	7.83222E-10
500	60	10	7.80998E-10
		5	8.46202E-10

Estimation of Activation Energy

The activation energy (E_a) is the energy level that the reactant molecules must overcome before a reaction can occur. Activation energy is calculated from the slope of the curve of graph In /T (Table 6).

$$D_{eff} = D_o exp\left(\frac{-E_a}{RT}\right) \tag{13}$$

Taking Log both sides:

$$ln(D_{eff}) = ln\ (D_o) - \frac{E_a}{R}\frac{1}{T} \tag{14}$$

Table 6 Activation Energy

Vacuum (mm of Hg)	Thickness (mm)	Slope of line $\left(\frac{E_a}{R}\right)$	E_a(kJ/mol)
300	10	10347.727	86.031
	5	3647.727	30.327
400	10	8032.193	66.7796
	5	3367.045	27.9936

Activation energy at a vacuum 500mm can not be calculated because the experiment was conducted at only 60ºC. Caramelization was observed at temperature 70ºC. The activation energy required to detach and move the water out from jaggery during the drying process was found out as 27.99 to 86.031 (kJ/mol). The values of activation energy are comparable with the reported values for different food items (Gamli 2014; Jangam *et al.* 2010).

CONCLUSIONS

For manufacturing jaggery in powdered form, it is necessary to dehydrate it up to moisture content of 2% and only the jaggery processed without chemicals can be dried. The time required to dry jaggery from the initial moisture content of 9% (Wb) was in the range of 120 to 330 min at different drying conditions at different temperatures 60, 70, and 80 and vacuum 300, 400, and 500 mm (Hg). Optimum condition -pressure 400 mm (Hg) & temperature 70^{0}C was obtained by grey regression and multi-objective optimization and are the more suitable parameters against minimum time and quality of jaggery required. For drying jaggery processed without chemicals from any variety of sugarcane, pressure 300 to 400 mm (Hg) and temperature 60 to 70^{0}C are recommended.

The most important aspect of this study was the modeling of vacuum drying characteristics of jaggery. Drying time decreased with an increase in drying temperature &vacuum and increased with an increase in slab thickness. The experimental drying data was evaluated to predict the moisture content of jaggery processed without chemicals against acknowledged mathematical models. The drying characteristics were significantly predicted well by the Approximate Diffusion model at a lower temperature at 60^{o}C and by Page model at a higher temperature at 70^{o}C.

For vacuum 300 mm and 500 mm, drying data was well predicted by the Approximate Diffusion model. But overall drying data for nearly all experiments was well predicted by the Page model. According to results, the Arithmetic Diffusion and Page model both were the most appropriate for predicting drying characteristics of jaggery against time. Effective moisture diffusivity is estimated by using Fick's second law considering only the first term of infinite series. It is found to vary between $2.0198*10^{-10}$to $1.89611*10^{-9}$ m^2/s. The effect of drying temperature on effective moisture diffusivity was described by the Arrhenius model. Effective moisture diffusivity increases with both temperature and vacuum and also, for the same vacuum and temperature, it increases with an increase in slab thickness. The activation energy of moisture diffusion during drying was found to be 27.99 to 86.01 kJ/mol. Activation energy is found to be decreasing with an increase in a vacuum and a decrease in the thickness of the sample. Vacuum dryer for 200 kg batch size is designed and installed at the agro-processing unit Sudarshan Agrotech. During jaggery powder manufacturing and operation with the same recommended parameters, resulting in the required drying time range of 2.25 to 3 hours depending on the variation in initial moisture content, variety of sugarcane, and average size of input broken jaggery. Hence, optimized experimental results and actual results for commercial mass scale vacuum dryer for 200 kg capacity are in agreement.

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Short Communication

Another white fly infesting sugarcane in India

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Sugarcane an important cash crop of India is infested by many insect pests. Around 1300 species of insects have been reported worldwide that infest sugarcane(Box 1953). In India, around 288 insect species and mites have been reported to infest sugarcane (David *et al*. 1986). Among the sucking pests that infest sugarcane,white flies form an important group. In India, infestation of three species of white fly has been recorded from sugarcane.The common and important white fly that infest sugarcane and cause perceptible loss is the *Aleurolobus barodensis* Muskell. The puparia of this fly are usually observed on the ventral side of a sugarcane leaf. Puparia of this species remain covered with white waxy material. A female adult white fly of this species lays cone shaped creamy white eggs (which later turn dark) in a linear row along with the veins on the lamina (underside) (Fig.1). The adults are rarely observed in the field.

Fig 1. Linear row of eggs and nymphs at different instars of common white fly *A. barodensis* infesting on the underside of a sugarcane leaf

The other two white flies belong to the genus *Neomaskelliaviz., N. bergii* Signoret and *N.andropogonis* Corbett. These two white flies lay eggs generally at ventral surface of leaf in crescent egg masses and embed the eggs on the leaf surface with wax or a white mealy coating. The adults are observedcaringthe eggs. The wings of these two species have darker bands or striations on the wings. The bands are more prominent in *N. bergii* and lighter in the *N. andropogonis* (Prasad 1954; David and Banerjee 1981).

In this communication, the occurrence of anew white fly in the sugarcane fields at IISR farm, Lucknow is reported on several sugarcane genotypes (*Saccharum* spp. hybrid). Its symptoms of infestation,and a part of its biology have been worked out.The new white fly appears yellow to pale white winged with yellow body. The white fly remains distinct on the green background of the sugarcane leaf. Presence of the adult of this white fly was first noticed at the micro-plots of sugarcaneat ICAR-IISR, Lucknowin 2009. In February 2016, some insect emergence was observed from the tiny yellow scaly puparium.Sugarcane leaves with tiny scaly pupariawere kept under close observations for the emergence of the insect in the laboratory. After certain period, emergence of a yellowish adult insect from mature puparium was observed (Fig. 2, 3 & 4). As the yellowish pupal structure was near the visual acuity,

Fig 2. A mature nymph

Fig 3. A nymph under microscope

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Fig 4. Emergence of a yellow bodied white fly

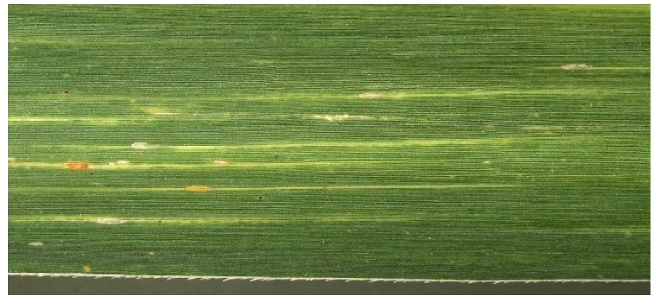

Fig 5. Development of faint narrow elongated yellow streaks on the leaf

it was difficult to perceive at the first instance, however, it was apparent under micro-scope that the insect in question was a new species of white fly that was not reported to infest sugarcane crop in India so far.

Presence of a similar white fly in *Miscanthus sinensis (Gramineae)*, an allied genus of sugarcane was reported by Ko*et al.*(2001) which is the first record of occurrence of a new genus and species of white fly from *Miscanthus*.This new white fly genus *Agrostaleyrodes* was erected by Koand the white fly was named as *Agrostaleyrodes arcanus* Ko (Ko *et al.* 2001). Further, on one occasion in 1999, Ko was able to collect only 4 pupal cases (exuviae) from sugarcane and thus, indicated sugarcane may also be a host of this species. Regarding the biology of *Agrostaleyrodes arcanus* Ko, Ko *et al.* (2001) recorded that this species occurs only on certain members of *Gramineae* and is of no economic importance. They did not record any perceptible symptoms on the leaf of *Miscanthus* due to its infestation.

Symptoms of infestation of new white fly at IISR, Lucknow

During the investigation of this new white fly, symptoms of infestation on sugarcane were recorded in the two sugarcane crop seasons of 2016-2017 and 2017-18. The infestation mostly took place at ventral side of the sugarcane leaf. In sensitive sugarcane varieties, due to its continuous feeding at one site, a faint yellow elongated area was produced on the leaf. The elongated yellowish streak mostly extended downwards from the feeding site (Fig.5).On surveying the IISR farm in February 2016-17 and subsequently inothermonths, it became immediately apparent that this species is infesting several sugarcane genotypes. More than fifty puparia were frequently observed in one infested leaf of a sensitive sugarcane variety. In heavy infestation, as in case of 'Co 0238', one leaf supported around 180 puparia. The puparia were mostly found on the ventral side of the leaf and their concentration was more towards lower half of the leaf. However, presence of puparia on the upper side of the leaf is also not uncommon but it occurs in much lesser number. Usually the puparium remains attached on the leaf orienting its head towards the leaf base. However, in spite of the presence of more than 180 puparia on the sugarcane leaf, the leaf appears green from the dorsal side.

Biology of new white fly

The pale translucent immature stages (eggs and nymphs) of new white fly in sugarcane are not easily visible to the naked eye. They remain mostly cryptic in the nymphal stages and become more visible due to change of colour of final in star nymph or puparium, a few days before the emergence of the adult. As the developing adult is yellow, the puparium appears yellowish. The adult was found active during June-July, September-October and in February. An adult holds the wings in a *tecti* form position when at rest.

Eggs

Eggs are laid singly and are quite similar to a rice grain in shape, cylindrical, elongated, tapered one side and bluntat the other side. The egg remains attached with the leaf surface with the help of a small stalk from arising from the blunt side (Fig. 6).

Fig 6. Male and female white flies

Puparium

A mature puparium usually covers three to four minor veins (depending on the variety in question) of the sugarcane leaf and measures around 2.42mm x 0.48mm (length and width ratio of mature puparium is around 4.8). In the mature puparium, the two coloured areas at the anterior end appear and these indicate the development of compound eyes. Eye area is followed by a demarcating line or furrow which runs all through the body and ends after crossing the *vasi*form orifice (like a horseshoe), which is placed dorsally at the posterior end. In fact, the dorsal portion of the puparium is raised centrally throughout its length giving an appearance of an uppercase omega (Ω) in cross section (Fig. 2). The pupal case is of light yellowish cream colour and with maturity, it gradually turns yellowish due to the development of yellowish adult inside. Before the emergence of the adult, the puparium becomes yellowish with prominent eye area. Wax secretions by the puparia are insignificant and it could be observed only in higher magnification of a microscope.

Adult

Adults are typical yellow bodied at the time of emergence (Fig. 7). The wings remained folded and appeared yellowish.

Fig 7. A white fly after emergenceand small rice grain like single egg

The wings need certain period of time for the full expansion. The wings initially remained clear and translucent but later turned pale whitish. Fore wings are larger than the hind wings. The male and female white flies have very similar appearance except their size. A female fly measures around 1.30 to 1.45 mm whereas, a male fly measures around 0.90 to 1.15 mm. Usually a female fly is 1.3 to 1.4 times of a male fly. Head, thorax and abdomen remain yellowish. Forewing of a female measures around 0.7mm. The compound eyes are red in colour and appear dumbbell shaped due to development of central invagination dividing an eye in nearly two halves (Fig. 6).

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