Survey on Techniques Available for Sugarcane Maturity Testing

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***Abstract*— In this paper, the most recent techniques for sugarcane maturity testing are reviewed. The best time to harvest sugarcane is determined by sugarcane maturity testing, which has a major impact on both sugarcane quality and yield. Traditionally, labor-intensive and time-consuming methods like refractometry and polarimetry have been used to determine the sucrose content in sugarcane. In contrast, new developments in non-destructive techniques like near-infrared spectroscopy (NIRS) and spectroscopy imaging have shown encouraging results in the provision of quick and precise sugarcane maturity testing. The principles and instrumentation of these cutting-edge methodologies, the data analysis methods employed, the difficulties and potential future paths for sugarcane maturity testing are all covered in this review article. It is possible to significantly increase the efficiency and accuracy of sugarcane maturity testing through the integration of cutting-edge technologies, giving farmers crucial knowledge to maximize the yield and quality of their sugarcane crops.**

Keywords*— *sugarcane maturity, advanced technology, Test sensor, AI, ML

I. INTRODUCTION

A vital cash crop grown for the production of sugar and bioenergy sugarcane is grown all over the globe. A crucial element that profoundly influences sugarcane production and quality is the best time to harvest. Thus, determining the ideal harvesting period requires gauging the sugarcane's maturity level. Refractometry and polarimetry are time- and labor-intensive traditional techniques for determining the amount of sucrose in sugarcane. However, new developments in cutting-edge technologies, including near-infrared spectroscopy (NIRS) and spectroscopy imaging, have demonstrated encouraging results in the provision of quick and precise sugarcane maturity testing. The goal of this review paper is to give a summary of the most recent technological developments in sugarcane maturity testing [1].

The world's second-largest producer of sugar after Brazil, India contributes significantly to the global sugar market by producing roughly 15% and 25% of the world's sugar and sugarcane, respectively [2]. It contributes to an important boost to the growth of the nation's social and economic structures, respectively. There are currently 597 functioning sugar factories, 309 distillations, 213 power generation plants, and multiple pulp, paper, and chemical-based establishing units that are all a part of the sugar processing sector. The sugar sector is assisted by four that lead the sugarcane plant research organisations, 22 state sugarcane research points, and world-class sugar machines producers, vendors, and technical specialists. [3]. In order to satisfy domestic sweetener demand, the industry produces about 300-350 MT of cane, 23-25 MT of white sugar, 6-8 MT of jaggery, and khandsari on an average of 5 million ha, or about 3% of the gross cultivable area in the nation. In addition, about 2.9 billion liters of alcohol, 2,330 MW of electricity, and numerous chemicals are produced [4].

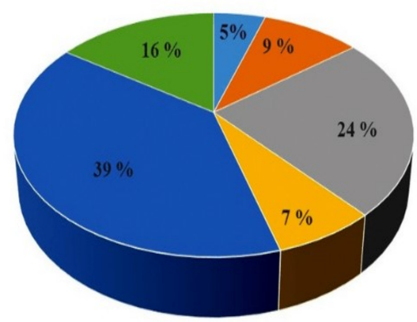

Fig 1 Largest sugarcane-producing states in India

The most common commercial methods for evaluating the Brix content of sugarcane are the refractometer,, Brix hydrometer, spectroscope, and chemical analysis commonly performed in the electronic saccharimeter of Brix. Amongst them, a spectroscope is a one-of-a-kind non-invasive instrument that enables continuous tracking in addition to rapid tests that can be carried out with a high degree of accuracy. On the other hand, monitoring in real time is not practicable because of the tremendous cost of doing so [5]. A wide array of non-destructive technical devices, such as electromagnetic sensors, image processing, ultrasound, magnetic resonance, and laser excitation, can be used to observe the physicochemical features of food. These instruments are generally utilised for the detection of physicochemical parameters such as Brix and TSS. (Total solids that are soluble). Instruments that rely on food scent, capacitive sensors, and spectroscopy (NIR, which stands for near-infrared spectroscopy, and MIR, which stands for medium-infrared spectroscopy) can be used to calculate the amount of sugar that is present in sugarcane. [6]. Sugarcanes are deemed mature and prepared for harvesting when they reach a certain minimum Brix value. Mukhtar's maturity study included additional criteria for when sugar cane is considered ripe, such as when all but the bud of the cane are visibly dried up leaves. Or we could say that the most leaves fall off of the sugarcane when it reaches maturity [7].

The equal percentage of %brix of sugar cane in the bottom and upper parts of the plant is a chemical sign that the plant is mature. We must conduct a measurement in order to learn the sugar concentration of the sugarcane in the field. Cutting some samples of sugar cane plants and squeezing them into the milling, then transferring the liquid solution to the laboratory for identification, is the most current technique for determining sugar content. This approach is regarded as a challenging, costly, and time-consuming approach. There is a chance of using an alternative technique to determine the sugar content. As a light source, they used a photometric detector emitter (LED), and the sensors they used were LDR and photodiode array. Yeh and Tseng (2006) also made an effort to create a low-cost spectrometer using LED and LDR. However, all of the instruments mentioned above should be used with sugar cane watery solution. It denotes the destruction of the tested substance. Additionally, using LEDs as a light source has a range drawback. Naderi-Boldaji provided a description of a non-destructive technique. They used a parallel plate capacitor to explain the technique for calculating sugar content based on the characteristics of the dielectric constant. They suggest the non-destructive Brix meter, which is founded on the optical characteristics of sugar content, as a result of the concept of non-destructive measurement. This method of measuring using a photometer and spectroscopy methods employs the Brix scale. Our device uses a photodiode array as a detector and LEDs as its light source [8].

This research used the portable, inexpensive, and non-destructive Vis/SWNIR method to forecast sugarcane Brix based on stalk scanning. The PLS systems provided a good level of constraint for both the baseline ranges and the estimated amounts of the reflectance and absorbance spectra, with R2 values of 0.91 and 0.89, respectively. With an overall accuracy of 83.1%, the ANN that was used to divide Brix into various quality classes had produced acceptable classification performance ranging from 50 to 100% accuracy. Overall, this research has shown that the combination of ANN and Vis/SWNIR spectroscopy possesses the ability to be utilised for real-time quality monitoring in order to fulfil PA criteria. This review article provides a detailed overview of the techniques used to determine sugarcane maturity.

II. REVIEW AND TESTING METHODS

A. Advanced methods of sugarcane maturity testing

Two primary techniques are available in advanced methods: a destructive method and a non-destructive method.

B. Destructive method

destructive methods of sugarcane maturity testing provide accurate and detailed information about the composition of sugarcane samples, but they require specialized equipment and expertise, and they destroy the sample in the process.

C. Lipid polymer membrane method (sweetness sensor)

Sugarcane maturity testing frequently makes use of sweetness test instruments. These sensors are made to measure a sample's sweetness or sugar content, which is a crucial indicator of how mature it is [9]. There are many different types of technology, but sugarcane skin scanning is the most prevalent. That strategy also functions well in the field of agriculture. markers of fruit and vegetable maturity. The two groups into which maturity has been divided are physiological maturity and horticultural maturity [10]. The maturity index serves as a sign that a commodity is available for harvest. The timing of harvest is determined using this as a guide. A. Physiological development: When a fruit or vegetable reaches this stage of development, it has experienced its greatest growth and maturation The various formulation types offered on the pharmaceutical market come in a variety of forms, but tablets and capsules are the most widely used [11].

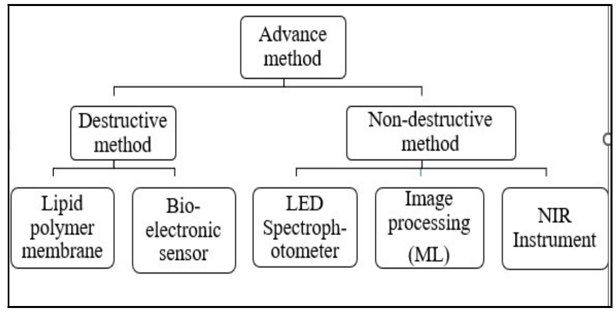

Fig 2 Advance methods of sugarcane maturity testing

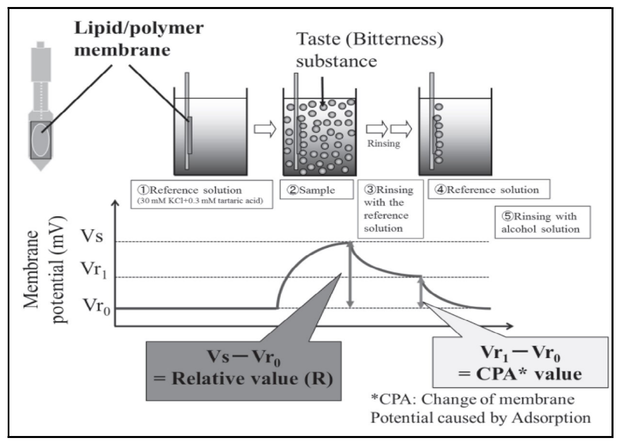

Fig 3 Lipid polymer membrane [11]

These formulations provide numerous advantages, such as dosage accuracy and relatively high stability, as well as the ability to alter the medication release profile in order to delay or keep a therapeutic effect. However, their palatability is crucial for patient adherence and effective medication, especially if they have a bitter flavor [12]. have investigated the variations between the Insent taste-sensing device for pharmaceutical formulations and the ASTREE electronic tongue. Both systems have benefits and drawbacks, according to those writers. Because each taste sensor membrane reacts to a particular flavor, the Insert taste sensing system excels at quantifying taste attributes like bitterness strength. However, this approach cannot identify all substances [13].

D. Bio-electronic sensor method

An appropriate pattern recognition tool and a sensor array with limited individual discrimination were described as the electronic tongue. established the terminology for liquid potentiometric analysis used globally [14]. In this context, the term "electronic tongue" refers to a multisensory system that makes use of a wide range of low-selective instruments and advanced mathematical signal processing methods based on pattern recognition and/or multivariate analysis. This device is employed to classify data. Its operation is founded on measuring a large number of samples and using principal component analysis to monitor their variability. (PCA) [15].

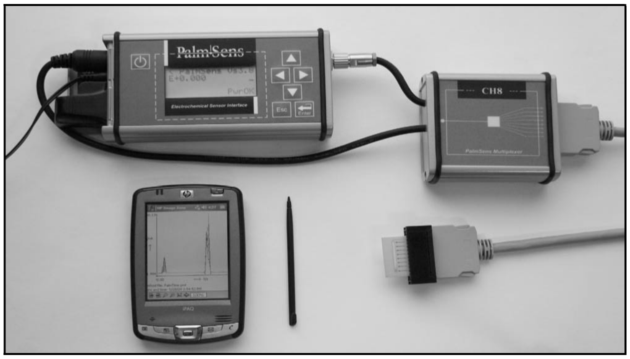

Fig 4 Bio electronic sensor

As a consequence, the data are divided into distinct groups according to various sample characteristics. The created artificial tongues make use of the electrochemical properties of samples. Potentiometry and voltammetry, which employ a variety of modified working electrodes, are used to provide appropriate responses and are adequate detecting systems. Electrochemistry was replaced with systems based on visual and piezoelectric principles (Surface Acoustic Wave, Quartz Crystal Microbalance) [16].

E. Non-Destructive method - LED Spectrophotometer method

Non-destructive methods of sugarcane maturity testing involve analyzing the sugarcane without damaging or destroying the sample. These methods are becoming increasingly popular in the industry because they are faster, more convenient, and do not require the destruction of the sample.

Modern tools like LED spectrophotometers are used to check the sugarcane's ripeness. They are based on the spectrophotometric principle, which entails determining how much light is absorbed or transmitted by a sample at various wavelengths [17]. illumination-emitting diodes (LEDs), as opposed to conventional lamps or lasers, are used as the illumination source in LED spectrophotometers. LED spectrophotometers are used to gauge the sugar concentration of the juice during sugarcane maturity testing. The LED spectrophotometer produces light with a particular wavelength and gauges how much of it reaches the sample [18].

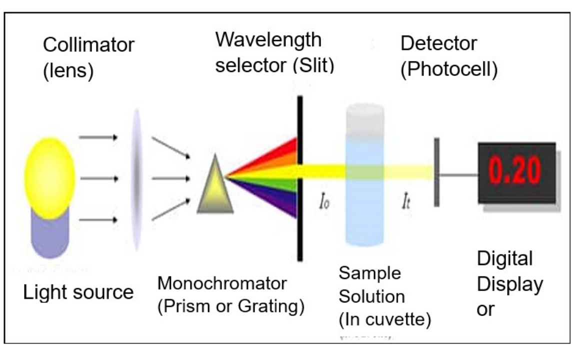

Fig 5 LED Spectrophotometer [18]

The sample's ability to absorb light is proportionate to how much sugar is present. Due to their advantages over conventional spectrophotometers, such as low power consumption, high sensitivity, cheap cost, and a long lifespan of the LED light source, LED spectrophotometers are preferred. They are ideal for field applications due to their portability and compactness [19]. In the sugarcane business, a variety of LED spectrophotometers, including benchtop and handheld models, are employed. Handheld spectrophotometers are appropriate for use in the field, whereas benchtop spectrophotometers are best used in laboratories. The DS2500 UV-Vis Spectrophotometer, the Jenway Genova Nano UV/Vis Spectrophotometer, and the spectrophotometer are a few of the well-known LED spectrophotometer models used in the sugarcane business.

F. Non-Destructive method - Image processing (ML) method:

Methods of image analysis are frequently employed to gauge sugarcane maturity. These techniques involve examining digital pictures of samples of sugarcane and extracting characteristics that indicate maturity. Utilizing color-based techniques, the maturity of sugarcane samples is determined by examining their hue [20]. These techniques extract color characteristics from the images, such as hue, saturation, and intensity, using image processing algorithms. The maturity level of the sample is then determined by comparing the color characteristics to a reference color chart. Utilizing texture-based techniques, the maturity of sugarcane samples is determined by examining their structure. These techniques derive texture characteristics from the images, such as entropy, contrast, and homogeneity. The samples are then categorized into various maturity levels using the texture characteristics. A model is trained using a dataset of images of sugarcane and the associated maturity levels in machine learning-based methods [21]. The model learns to categorize the pictures based on their maturity level by extracting features from them using image processing algorithms. Then, the learned model can be used to forecast the maturity level of fresh samples of sugarcane. Images of sugarcane samples are taken using multispectral imaging at various light frequencies. After that, spectral characteristics that are suggestive of maturity are extracted from the images using image processing algorithms. Compared to color-based and texture-based approaches, these techniques can offer more comprehensive information about the sugarcane samples [22].

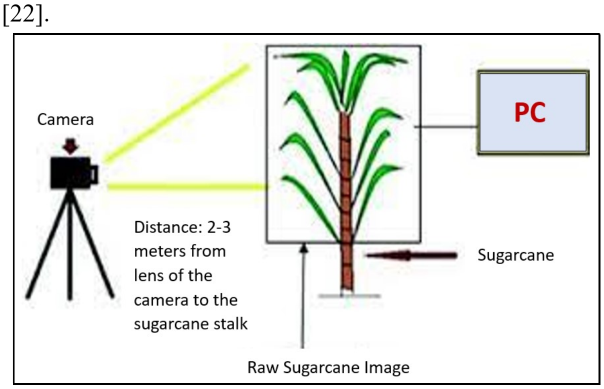

Fig 6 Image processing method for sugarcane maturity testing

Orbital images are frequently used in agriculture to identify large-scale spectral fluctuations brought on by soil and crop features. This aids farmers in making better management decisions by giving diagnostics for agronomical crop factors. For instance, the definition of management zones for annual harvests through the use of orbital. [23].

G. Non-Destructive method -NIR Instrument method

Sugarcane ripeness can be assessed quickly and non-destructively using a technique called near-infrared spectroscopy (NIRS). By measuring the sugarcane samples' near-infrared reflectance or transmittance, NIRS generates a spectrum that can be used to identify the molecular makeup of the sample [24]. By measuring the sucrose concentration of the juice obtained from the sugarcane stalks, one can ascertain the sugarcane's maturity. By examining the near-infrared spectrum of the sugarcane samples, NIRS can be utilized to forecast the sucrose concentration. The sugarcane samples' near-infrared spectra reveal details about their molecular make-up, including the amount of sucrose present [25,26].

A spectrometer, a light source, and a sample holder are the usual components of the NIRS device used to assess sugarcane maturity. Depending on the measurement method, the sample holder may be a reflectance or a transmission cell. In the reflectance setting, the sample is mounted on the sample holder and exposed to the near-infrared light [26]. The sample is positioned between two clear windows in transmission mode, allowing the near-infrared radiation to pass through the sample. The near-infrared reflectance and transmittance of the sugarcane samples over a variety of wavelengths are measured by the NIRS instrument. The acquired near-infrared spectrum is then processed using chemometric methods like principal component regression (PCR) or partial least squares regression (PLSR). These methods make it possible to predict the correlation between the near-infrared spectrum and the sucrose content. The maturity of sugarcane can be ascertained by examining the near-infrared spectrum of the sugarcane samples after the connection between the near-infrared spectrum and the sucrose content has been established.

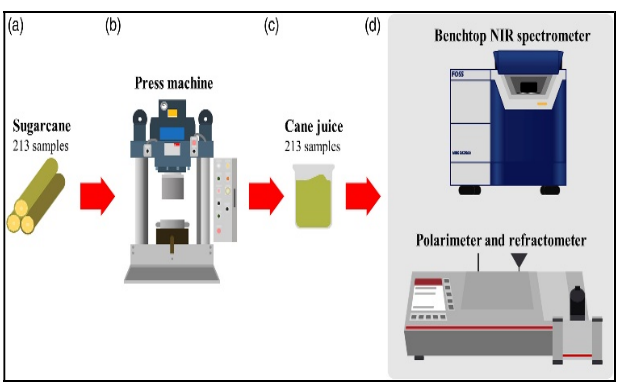

Fig 7 NIR Spectroscopy method [26]

The near-infrared spectrum can then be used to forecast the sucrose content and identify the sugarcane's maturity [27,28]. The data is obtained from the various literature and content is highlighted in the Table-1. The dataset mentors about the year, methods used and corresponding findings obtained by the various researchers has been listed. Next to that, further discussion is carried out and pointed out in the results and discussion section.

III. Result and Discussion

In the current review paper, there is a debate regarding advanced methods of sugarcane maturity assessment. This paper examines 27 works to determine whether or not those papers are relevant to this subject. There are a total of 15 papers that can be accessed, with 8 of them referring to destructive techniques of sugarcane maturity testing and 11 of them pertaining to non-destructive methods of sugarcane maturity testing. The scope of the other studies is extremely vast.

The process of determining the maturity of the sugarcane is an essential step for the sugar industry since it has a substantial impact on the amount of sugar in the final product, as well as the yield and quality of the product overall. Brix and Pol readings, which are often used to determine the maturity of sugarcane, can be labour- and time-intensive to measure, in addition to occasionally producing inaccurate results. However, as a result of developments in technology, a number of sophisticated methods have been developed. These methods provide precise, non-destructive, and speedy evaluations of the sugarcane crop's development stage.

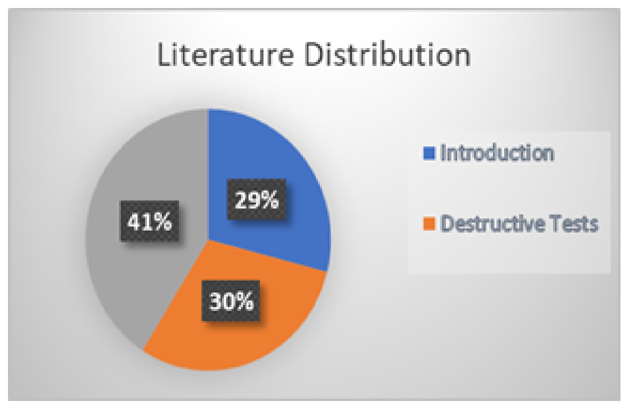

Fig 8 Total papers available for sugarcane maturity testing

The Near-Infrared Spectroscopy (NIRS) technique is one of the more sophisticated ways to gauge sugarcane ripeness. NIRS is a quick, non-destructive technique that measures how well sugarcane samples transmit or reflect near-infrared light. The method produces a spectrum that can be used to identify the chemical makeup of the sample, including its sucrose content. The sugar business has widely adopted the NIRS method because it has been demonstrated to be an accurate and trustworthy method for determining sugarcane maturity. [29-31]

An further cutting-edge strategy for figuring out when sugarcane is ready to be harvested is to use various sensors and imaging techniques. These methods involve the utilization of several pieces of equipment such as thermal imaging, laser-induced fluorescence, and hyperspectral cameras in order to monitor the evolution of the sugarcane's physical and chemical properties over time. It has been demonstrated that these sensors are accurate and dependable ways for evaluating the maturity of sugarcane, and the data that they collect may be utilized to construct models that can predict when sugarcane will attain maturity.

TABLE I. FINDINGS FOR THE EXPECTED SURVEY YEARWISE MENTIONED THE INFORMATION FROM LAST DECADES

REF. NO.	YEAR	METHODS USED	FINDINGS
[1]	2014	-	This paper gives about general introduction about sugarcane production in India.
[2]	2021	Ultra brix device	Utilizing Brix monitoring from planting to harvest, Ultra Brix can also be used as a support tool in the creation of best practices in agricultural management, cultural treatments, and the study of new varieties (genetic improvement).
[3]	2012	Remote sensing technique	In comparison to merely counting canes, the laborious and expensive measurement of early-season yield offers a marginally stronger prediction.
[4]	2019	LED-Refractometer method	The findings demonstrated that, when compared to a digital spectrophotometer used as a reference instrument to measure the sugar content of a solution, the LED-refractometer can measure sugar content of sugarcane plantations in the field with an accuracy of 95%.
[5]	2013	NIR Spectrophotometer	In order to predict sugar content from skin scanning, the potential use of a visible and shortwave near infrared (Vis/SWNIR) spectroscopic method was assessed.
[6]	1972	-	The respected paper reviews about soil condition suitable for sugarcane production and gives positive point to increase maturity of sugarcane.
[7]	2014	Image processing (Sampling Technique)	The main factors to be taken into account when developing a measurement technique and sampling mechanism in the field are also covered.
[8]	2018	HSV (Hue saturation value) technique	The proponents discovered that there is a substantial shift in Hue and Saturation values as sugarcane crops mature through a series of experiments in the HSV color space.
[9]	2016	Sweetness test sensor	The objective of this review is to explore the benefits and drawbacks of taste sensors in assessing the flavor and palatability of various oral dosage forms.
[10]	2007	Lipid polymer electrode	For use as nonspecific amperometric sensors for blind analysis on actual matrices, such as various fruit juices from various fruits or different brands, three distinct electrodes were put to the test.
[11]	2020	Sweetness Detection, Fdc2214, STM32	A gadget that measures the sweetness of sugar water is suggested, and its processor is an STM32 single chip microcomputer. The FDC2214 sensor is used to measure sugar water content.
[12]	2006	Electronic tongue, Sequential injection analysis	An acceptable comparison was also made using the technique to determine anions in synthetic samples and actual water samples.
[13]	2009	Electronic tongue, Bioelectronic tongue	This study contrasts different (bio)electronic tongue types. Applications in food and environmental analysis are addressed along with the design and operating principles of potentiometric and voltammetric electronic tongues.
[14]	2011	Taste sensor, Electronic tongue	The Astree electronic tongue and the Insent taste sensing system are already widely available. Additionally, there are numerous experimental prototype iterations available.
[15]	2010	Taste cell sensor, Electrochemical impedance spectrum	This article proposes a novel sweet taste cell-based sensor for the detection of tastes. On the carbon screen-printed electrode, human colorectal carcinoma NCI-H716 cell lines are grown that express gustducin and the sweet taste receptor T1R1/T1R3.
[16]	2010	Electronic tongue	The outcomes demonstrate the potential of the electronic tongue for analysis of drug masking effects and microencapsulation impact detection.
[17]	2020	Image processing, Data analysis	This study's goal was to ascertain the impact of Funneliformis mosseae KKU-BRP-KK6-2, an arbuscular mycorrhizal fungus (AMF), inoculation on sugarcane physiology during the maturation and ripening phases under field circumstances.
[18]	2012	Object Based Image Analysis (OBIA) Data Mining (DM)	The purpose of this study was to create a technique for automating the mapping of sugarcane over large areas using time-series remote sensing data.
[19]	2020	UAV-LiDAR; random forest regression.	Their research offers recommendations for determining the ideal planting density, minimizing the negative effects of human activity, and choosing the best tillage techniques for real cultivation and production.
[20]	2018	Maturity analysis using image processing	The maturity identification comparison module, which employs the 90.16% accurate RandomForest algorithm, used the Hue and Saturation frequencies of both mature and immature sugarcanes as data.
[21]	2021	remote sensing, orbital images	The study's methodology involved creating forecasting sugarcane production models that combined time-series orbital imaging with machine learning.
[22]	2021	Non-destructive method, Artificial Intelligence	A thorough review is offered, building on earlier reviews that primarily addressed the crop's spectral behavior and takes into account the advancements made with new data analysis methods and better data sources.
[23]	2013	NIR Spectroscopy	They used a portable near infrared (NIR) instrument to explore the non-destructive measurement of the sugar content of cane stalks.
[24]	2012	NIR Spectroscopy	A low cost visible and shortwave near infrared (VIS eSWNIR) spectrometer and an artificial neural network were assessed for their potential in the non-invasive measurement of pineapple's soluble solids content.

[25]	2018	UAV ,Yield estimation, Remote sensing	The very high spatial resolution of UAV images and OBIA's sophisticated image classification show a lot of promise for enabling farmers and associated sectors to forecast yield prior to harvest.
[26]	2008	NIR Spectroscopy	They used a portable near infrared (NIR) instrument to explore the non-destructive measurement of the sugar content of cane stalks.
[27]	2017	Image processing	Using metrics from time series of the normalized difference vegetation index (NDVI) from the Moderate Resolution Imaging Spectroradiometer (MODIS) sensor and an ensemble model of artificial neural networks, the goal of this research is to forecast the sugarcane yield in So Paulo State, Brazil. (ANNs).

CONCLUSION

In summary, the utilisation of cutting-edge methodologies may significantly contribute to an improvement in both the efficiency and accuracy of the sugarcane ripeness testing process. Many cutting-edge methods, such as the NIRS method, sensors and imaging methods, machine learning algorithms, and artificial intelligence, have been developed and deployed within the sugar business. These methods provide rapid, non-destructive, and accurate assessments of the maturity of the sugarcane, which can assist in increasing the amount of sugar that can be produced as well as the overall quality of the end product.

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