Journal of Computational Systems and Applications

https://jcsa.cultechpub.com/jcsa

Cultech Publishing

Review

Applications of Artificial Intelligence in the Sugar Industry: The Past, Present, and Future

Kingsley O. Iwuozor[1,2,3,*], Ejidike Lynda Chinyere[3], John C. Iwuozor[4], Ebuka Chizitere Emenike[2,3], Abel U. Egbemhenghe[5], Marycynthia Ebere Amadi[3], Adewale George Adeniyi[6]

[1]Factory Operations Department, Nigeria Sugar Institute, Ilorin, Nigeria

[2]Faculty of Physical Sciences, Department of Industrial Chemistry, University of Ilorin, Ilorin, Nigeria

[3]Department of Pure and Industrial Chemistry, Nnamdi Azikiwe University, Awka, Nigeria

[4]Department of Industrial Mathematics, Nnamdi Azikiwe University, Awka, Nigeria

[5]Department of Chemistry and Biochemistry, College of Art and Science, Texas Tech University, Lubbock, USA

[6]Department of Chemical Engineering, University of Ilorin, Ilorin, Nigeria

[*]Corresponding author: Kingsley O. Iwuozor, kingsleyiwuozor5@gmail.com

Abstract

The sugar industry faces unprecedented challenges including climate variability, sustainability demands, and operational efficiency requirements, necessitating innovative technological solutions. While artificial intelligence (AI) applications are transforming various agricultural sectors, there is a lack of comprehensive analysis examining AI implementation across the entire sugar industry value chain from cultivation to supply chain management. This review aims to provide a comprehensive analysis of AI applications in the sugar industry, examining current implementations, economic and environmental impacts, regional variations in adoption, and identifying future research directions and implementation challenges. The study showed that AI is revolutionizing sugarcane and sugar beet cultivation through precision agriculture, optimizing resource management, and enabling early disease detection with high accuracy. In manufacturing, AI optimizes mill processes, enhances quality control, and facilitates predictive maintenance, leading to increased efficiency and reduced waste. Furthermore, AI improves supply chain management by enhancing demand forecasting and logistics. The adoption of AI yields substantial economic benefits, including increased production and reduced costs, while also promoting environmental sustainability through efficient resource utilization. Key challenges include data availability, infrastructure limitations, and the skills gap, but future trends point towards the integration of generative AI, advancements in robotics, and the development of smart farms and mills. In summary, AI offers significant potential to transform the sugar industry, driving efficiency, sustainability, and economic growth, but its successful implementation requires addressing key challenges and embracing future technological advancements.

Keywords

Agriculture, Algorithm, ChatGPT, Sugarcane, Sustainability

Article History

Received: 02 October 2025

Revised: 10 November 2025

Accepted: 09 December 2025

Available Online: 12 December 2025

1. Introduction

The sugar industry holds a position of paramount importance in the global agricultural sector [1], serving as a primary source for a widely consumed commodity and significantly contributing to the economies of numerous nations [2,3]. This sector, encompassing both sugarcane and sugar beet production, faces a complex array of challenges in the modern era [4,5], ranging from the imperative for enhanced sustainability to the constant pursuit of improved operational efficiency [2]. India, for instance, has moved to the forefront as the world's leading producer and consumer of sugar, further solidifying the industry's global impact [6,7]. The sheer scale of the global sugar market, estimated at USD 66.39 billion in 2023 with a projected compound annual growth rate of 6.5% until 2030, shows the critical need for innovative solutions to meet numerous global demands [8]. This substantial market size and anticipated growth depict the potential of integrating advanced technologies like artificial intelligence (AI) to bolster the industry's sustainability and overall efficiency. The contemporary sugar industry operates within an increasingly dynamic environment, grappling with issues such as the growing variability in climate patterns, which directly affects the consistency and quality of raw materials, ultimately impacting production yields [9]. Furthermore, there is mounting societal and regulatory pressure on sugar producers to adopt more sustainable practices, necessitating significant reductions in energy consumption and the minimization of their carbon footprint [9]. Successfully navigating these multifaceted challenges requires a proactive and adaptive approach, one that leverages technological advancements to not only respond effectively to climate uncertainties but also to drive substantial improvements in energy efficiency across the entire production lifecycle [2].

AI, characterized as the ability to imbue computers with the capacity for intelligent thought and action akin to humans [10], has emerged as a powerful catalyst for transformation across diverse industries. By emulating the cognitive processes of the human brain through sophisticated algorithms, AI presents unprecedented opportunities to significantly enhance productivity levels, streamline intricate operational processes, and foster a culture of innovation within established sectors. The fundamental principle of AI, which involves enabling machines to learn and solve problems in a manner analogous to human intelligence, suggests its profound potential to address the intricate and inherent challenges in the sugar industry. The integration of AI into the sugar industry is not merely a theoretical possibility; it represents a tangible pathway to address some of the sector's most pressing concerns while simultaneously unlocking new avenues for sustainable growth and development. The potential of AI extends across the entire range of sugar production, from the initial stages of cultivation and harvesting to the processes of refining and the intricacies of distribution. By embracing AI-driven solutions, sugar producers are positioned to achieve heightened levels of efficiency, considerably reduce their environmental impact, and ultimately deliver higher-quality products that meet the evolving demands of a rapidly changing global market [2].

Various articles have been written in the past that are similar to the subject matter under study. For instance, Hernandez-Palma et al. [11] discussed global research trends and future directions in the application of AI technologies within the sugar industry. However, the study exclusively relied on bibliometric analysis from a single database (Scopus), which omitted other relevant research published in other indexing platforms. Iwuozor et al. [12] evaluated the potential applications of ChatGPT in sugar industry research. However, the study exclusively focused on ChatGPT, thereby not encompassing the broader spectrum of AI tools and applications relevant to the sugar industry. Modi [10] explored the future potential of AI applications in sugarcane cultivation and the broader sugar industry. A principal limitation of this study is its focus on theoretical prospects without empirical validation, as it primarily discusses potential applications rather than presenting data-driven evidence or field-based assessments of AI implementation. Ray [13] provided insights into the potential applications and benefits of generative AI in the sugarcane industry. Bhatt et al. [14] provided an overview of the applications of AI in sugarcane agriculture. From this review, it was observed that no existing review has comprehensively examined AI implementations spanning both sugarcane and sugar beet production systems while simultaneously addressing cultivation, manufacturing, and supply chain applications. This gap is particularly significant given the industry's global economic importance and the accelerating pace of AI technology adoption.

While AI has demonstrated transformative potential across various agricultural sectors, the sugar industry's adoption of AI technologies has received limited comprehensive academic attention. Existing studies have predominantly focused on isolated aspects such as specific AI subsets (generative AI, ChatGPT), singular crop types (primarily sugarcane), or individual production stages (cultivation or processing), thereby lacking an integrative analysis across the complete sugar production value chain. This fragmented research scope necessitates a comprehensive review that synthesizes AI applications across all major sugar crops and production phases. This narrative review aims to: (1) provide a comprehensive analysis of AI applications across the entire sugar industry value chain, from cultivation through processing to supply chain management; (2) examine the economic and environmental impacts of AI adoption with quantitative evidence; (3) analyze regional variations in AI implementation and success factors; (4) identify current challenges and barriers to widespread AI adoption; and (5) highlight future research directions and emerging technological trends. This review makes several distinct contributions to the literature. First, it provides a deeper analysis to date of AI applications spanning both sugarcane and sugar beet production systems. Second, it synthesizes quantitative evidence of AI's economic and environmental impacts across different implementation contexts. Third, it offers a systematic analysis of regional factors influencing AI adoption success. Fourth, it identifies specific technological approaches and their performance metrics across different applications. Finally, it establishes a foundation for future research by highlighting knowledge gaps and emerging opportunities in agricultural AI applications.

2. AI Applications in Sugarcane/Sugar Beet Cultivation

The cultivation of sugarcane and sugar beet, a vital agricultural practice in numerous tropical and subtropical regions, stands to benefit significantly from the integration of AI (Table 1), particularly in the field of precision agriculture. AI-driven methodologies enable a more effective and efficient approach to managing critical resources such as irrigation and fertilization [15]. By providing specific, data-backed recommendations for individual fields, AI moves beyond traditional uniform application strategies. For instance, AI algorithms can analyze soil samples and intricate crop requirements to precisely determine the optimal quantity and type of fertilizers needed for distinct areas within a field [16]. This targeted application not only fosters healthier crop growth but also plays a key role in minimizing the environmental impact associated with excessive fertilizer use [16]. Similarly, smart irrigation systems, powered by AI, leverage real-time data from soil sensors and integrate it with weather forecasts to optimize water distribution, a particularly critical aspect given the high water demands of sugarcane cultivation [17]. This intelligent management of water resources leads to a reduction in water waste and promotes more sustainable farming practices. In regions like Florida, tools such as JEEVN AI utilize satellite-based remote sensing technology combined with machine learning algorithms to provide precision agriculture solutions. These AI-powered systems employ multispectral satellite data analysis and advanced agronomic modelling to deliver detailed insights into soil nutrient levels and provide tailored fertilizer recommendations for sugarcane fields [18]. The convergence of AI with sophisticated sensor technologies and advanced data analytics allows for an unprecedented level of granular control over sugarcane cultivation, representing a significant shift towards site-specific interventions that maximize resource efficiency and minimize ecological harm.

Table 1. AI applications in sugarcane/sugar beet cultivation.

AI Technology	Application	Key Findings	Ref.
CNN-Deep Learning	Disease detection	Sugarcane disease identification	[19]
EfficientNet	Leaf Disease classification	Disease pattern recognition	[20]
Satellite AI + ML	Yield prediction	Weekly yield forecasting	[21]
Random Forest, Support Vector Machine (SVM), Autoregressive Integrated Moving Average (ARIMA)	Yield prediction	Comparative algorithm analysis	[22]
Artificial Neural Network	Multi-stage yield forecasting	Reliable across growth stages	[23]
XGBoost	Phenotype prediction	Key phenotypic trait determination	[24]
Computer Vision + AI	Harvesting robotics	Precise cutting position identification	[25]
Satellite + ML	Precision agriculture	Soil nutrient analysis & recommendations	[18]

Beyond resource management, AI is proving to be instrumental in the early and accurate detection of diseases and pests that can severely impact sugarcane and sugar beet yields [16]. AI-powered systems can analyze images of sugarcane crops, identifying subtle patterns and symptoms indicative of disease outbreaks often before they become visible to the naked eye [16]. This early detection capability enables timely interventions, crucial for managing common sugarcane diseases such as red rot and smut, thereby preventing widespread damage [16]. The application of deep learning techniques, particularly Convolutional Neural Networks (CNNs), has marked a significant advancement in this area, with studies reporting remarkable accuracy rates, reaching as high as 98% in identifying various sugarcane diseases through the analysis of large image datasets [19]. Furthermore, models like EfficientNet have also demonstrated impressive performance, achieving accuracy rates of up to 93.39% in classifying different sugarcane leaf diseases [20]. Hybrid deep learning approaches, combining CNNs and Recurrent Neural Networks (RNNs), have also shown considerable promise in accurately identifying diseases using extensive image datasets [26]. These advancements in automated disease detection offer a more precise, accessible, and scalable solution compared to traditional methods that rely heavily on manual inspection.

Accurate yield prediction and continuous crop health monitoring are also key areas where AI is making substantial contributions to sugarcane cultivation [16]. By analyzing vast quantities of data encompassing weather patterns, soil quality, and historical disease incidence, AI can develop sophisticated predictive models that optimize both crop health and overall yield [16]. Machine learning algorithms play a crucial role in analyzing historical and real-time data to generate accurate forecasts of sugarcane yields, which in turn helps optimize planting schedules and determine the most opportune times for harvesting [27]. Companies like GAMAYA have developed patented AI-powered solutions that utilize multispectral satellite data, coupled with advanced agronomic and weather models, to provide precise weekly predictions regarding yield, sugar content, and the optimal timing for harvest [26]. Similarly, Farmonaut's JEEVN AI employs satellite-based farm intelligence to forecast critical parameters such as sugarcane crop height, expected yield per acre, and the anticipated harvest period [18]. Vishwajeet, Med [22] explored the effectiveness of various machine learning algorithms, including Random Forest, Support Vector Machines, and Gradient Boosting Machines, for predicting sugarcane yields. Time series models like Autoregressive Integrated Moving Average (ARIMA) have demonstrated competitive performance in yield prediction, with comparative studies showing ARIMA achieving a root mean square error of 36,700.68 and minimum Akaike Information Criterion (AIC) value of 456.7, outperforming traditional machine learning approaches in specific contexts [27]. Artificial Neural Network models have shown reliable forecasting capabilities with R^2 values reaching 0.994 and adjusted R^2 of 0.993 (For context, a Root Mean Square Error (RMSE) value of 36,700.68 in ARIMA models indicates the average deviation in predicted yield relative to measured output (typically tons per hectare), while an R^2 value of 0.994 in Artificial Neural Network (ANN) shows exceptionally high predictive reliability), demonstrating reliability in forecasting yields across different stages of crop development with RMSE values maintained within acceptable limits of 10% [23], and the Extreme Gradient Boosting (XGBoost) algorithm has exhibited superior predictive performance for key phenotypic traits, with studies showing R^2 values of 0.815 for high-precision sugarcane yield prediction and accuracy rates of 71.83% in yield grade classification, significantly outperforming baseline prediction methods that achieved only 51.52% accuracy [24].

The integration of AI with robotics and automation technologies is also beginning to transform sugarcane and sugar beet farming practices. AI-driven automation has the potential to revolutionize the entire crop lifecycle, from the initial planting stages right through to harvesting, promising not only increased yields but also significant reductions in operational costs [27]. Autonomous tractors, drones, and intelligent irrigation systems, all powered by AI, enable farmers to make data-informed decisions concerning soil health monitoring, disease detection, and the optimization of planting schedules [27]. Research is underway to explore the use of robotics in sugarcane planting, with a focus on developing systems that can identify and remove damaged sugarcane segments (billets) while ensuring the consistent distribution of healthy ones [28]. Furthermore, Zhu et al. [25] applied AI in the development of specialized sugarcane harvesting robots capable of identifying the precise stem nodes and cutting positions, which can lead to a reduction in impurities and minimize damage to the sugarcane roots. Alencastre-Miranda et al. [29] utilized computer vision, a key component of AI, to analyze the quality of sugarcane billets post-harvest, specifically to identify any damage that could potentially lead to disease and reduced germination rates. In Brazil, companies like Solinftec are deploying AI-powered robots on sugarcane farms for comprehensive crop protection, leveraging AI to continuously monitor and manage each section of the fields, resulting in a substantial decrease in the application of herbicides [30].

Although multiple AI models have been applied in sugarcane yield prediction and disease detection, their performance differs depending on data quality, input variables, and climatic variability. CNN models demonstrate superior image-based disease detection accuracy (>95%), but they require extensive training datasets. ARIMA models, while effective for time-series yield forecasting with an RMSE of 36,700.68, often underperform when nonlinear relationships dominate. In contrast, ANN and XGBoost models exhibit higher adaptability and accuracy (R^2 up to 0.99 for ANN and 0.815 for XGBoost), though they demand higher computational resources. Comparative evaluation across these models reveals that hybrid and ensemble approaches generally offer improved reliability and robustness for agricultural prediction tasks.

3. AI Applications in Sugar Manufacturing and Processing

AI is not confined to the agricultural aspects of the sugar industry; it is also playing an increasingly pivotal role in revolutionizing the manufacturing and processing stages. One of the most significant applications lies in the optimization of mill processes. AI algorithms are being implemented to continuously monitor and dynamically adjust critical parameters, such as milling speed and applied pressure, with the primary goal of maximizing sugar extraction rates while simultaneously minimizing energy consumption [16]. This dual focus on yield enhancement and resource efficiency directly translates to higher overall production and a reduction in operational costs [16]. Advanced AI-driven platforms, such as C3 AI Process Optimization, utilize sophisticated data unification techniques and cutting-edge optimization algorithms to facilitate continuous process improvement within sugar mills, leading to tangible benefits such as increased throughput, improved yields, and a significant decrease in energy expenditures [31]. These platforms function by creating a comprehensive digital representation, or "digital twin," of the entire sugar mill operation through the integration of data from disparate systems [32]. The AI then generates actionable set-point recommendations, delivered through intuitive user interfaces, empowering mill operators to make informed decisions and implement changes that lead to continuous optimization [32]. The impact of such AI-powered systems is evident in real-world applications. For example, a sugar manufacturer leveraging C3 AI Process Optimization projected an impressive 1.9% increase in their annual sugar yield, which translates to a potential annual economic value exceeding $8 million [31]. Another manufacturer using the same technology estimated a 1.85% improvement in their annual yield and a potential economic benefit of $2.9 million at their largest production facility [33].

Ensuring the consistent quality of the final sugar product is key in the industry, and AI is providing powerful tools for quality control and anomaly detection [16]. Machine learning algorithms are being deployed to meticulously analyze production data, enabling the real-time detection of any deviations from established quality standards [16]. By identifying these anomalies early in the process, AI systems help to minimize waste and reduce the need for costly rework, ultimately ensuring that the final product meets the required specifications [16]. The application of automated visual inspection, powered by computer vision, allows for the thorough examination of sugar products for any physical defects [16]. In the field of sugar beet processing, the Austrian Institute of Technology has developed an innovative AI-based method for the automated optical quality control of sugar beets, demonstrating high accuracy in detecting damage and contamination [34]. Furthermore, companies like Scangrading are providing specialized AI and machine vision systems designed for the precise measurement and analysis of sugar crystal size distributions, automating these critical processes and enhancing the reliability of testing procedures within sugar factories [35]. These advancements explain how AI-driven quality control systems offer a more objective, consistent, and potentially faster approach to ensuring sugar quality compared to traditional manual inspection methods. AI-driven quality control systems detect deviations related not only to physical properties such as crystal size, colour uniformity, and shape but also to chemical purity parameters, including sucrose concentration and moisture content. These systems integrate hyperspectral imaging and machine vision to ensure chemical and physical quality alignment, minimizing waste and reprocessing. Another important application of AI in sugar manufacturing lies in the domain of predictive maintenance [16]. By continuously analyzing data related to the performance of various pieces of equipment within a sugar mill, AI algorithms can identify subtle patterns and indicators that may signal an impending failure [4,16,36]. This predictive capability allows for the scheduling of maintenance activities proactively, before a complete breakdown occurs, thereby minimizing unplanned downtime and significantly reducing the overall costs associated with equipment maintenance [16]. AI Insight, for example, is recognized as a valuable tool for implementing predictive maintenance strategies within sugar mills [37].

4. AI in the Sugar Industry Supply Chain Management

The complexities of the sugar industry supply chain, from the initial harvesting of sugarcane or sugar beets to the final delivery of refined sugar to consumers, present numerous opportunities for optimization through the application of AI. One key area is demand forecasting and inventory optimization [2]. AI algorithms can analyze vast datasets, including historical sales figures, seasonal trends, weather patterns, and even external market factors, to generate more accurate predictions of future demand for sugar [38]. This enhanced forecasting capability enables sugar producers and distributors to optimize their inventory levels, ensuring that they have sufficient stock to meet anticipated demand without incurring excessive storage costs associated with overstocking [39]. AI-powered supply chain management systems can integrate data from various stakeholders, including suppliers, distributors, and end customers, to create a more holistic view of the supply chain, further improving the accuracy of demand forecasts and the efficiency of inventory management. The ability of AI to provide more precise demand predictions leads to better production planning, reduced instances of stockouts, and a more streamlined and cost-effective supply chain operation [39].

Logistics and transportation efficiency represent another significant area where AI is making a substantial impact on the sugar industry supply chain [16]. AI algorithms can analyze various factors, such as delivery locations, road conditions, traffic patterns, and vehicle availability, to optimize transportation routes for both the raw materials (sugarcane or sugar beets) and the finished sugar products. Real-time AI supply chain monitoring systems, often leveraging video analytics and machine learning, can provide accurate tracking of vehicles involved in the transportation process, leading to improved visibility and more efficient management of logistics [40]. For instance, a leading sugar mill implemented such a system and achieved a remarkable 99% accuracy in vehicle tracking, resulting in significant improvements in inventory management efficiency and annual cost savings of $1.5 million [40]. In Brazil, Bevap, a major sugar producer, utilized AI and the Internet of Things (IoT) to optimize the transportation of sugarcane from the fields to the mill. By intelligently dispatching trucks based on real-time data and predictive analytics, Bevap achieved an 8% increase in overall efficiency, representing a substantial economic benefit of €150 million [41].

5. Economic and Environmental Impact of AI Adoption

The integration of AI into the sugar industry is yielding significant economic benefits across various stages of the value chain (Table 2). In sugarcane cultivation, for example, the implementation of AI-powered farming techniques in India has demonstrated the potential for substantial increases in production, ranging from 30% to 40%, coupled with significant reductions in production costs, estimated between 20% and 40% [42]. Moreover, these AI-driven approaches have also led to considerable water savings, with reports indicating reductions of up to 30% in water usage [42]. A specific AI project undertaken by Agricultural Development Trust of Baramati in India resulted in sugarcane test plots exhibiting a 30% to 40% increase in weight at harvest and a 20% rise in sucrose content, all while requiring less water and fertilizer and benefiting from a shorter overall crop cycle [43]. The broader impact of AI technology on sugarcane farming is evidenced by research suggesting a 40% upturn in yields and improved sugar recovery rates, along with high efficiencies in water and fertilizer utilization [44]. In the field of sugar manufacturing, a sugar producer utilizing C3 AI technology projected a potential annual economic benefit of $2.9 million directly attributable to yield improvements [33]. Furthermore, Bevap's adoption of AI and IoT in their Brazilian operations resulted in an 8% increase in efficiency, translating to an impressive €150 million in economic gains [41].

Beyond the direct economic benefits, AI is playing an increasingly important role in enhancing the sustainability of sugar production. AI-driven approaches are enabling more efficient and targeted utilization of critical resources, leading to a reduced environmental footprint [16]. In sugarcane cultivation, precision agriculture techniques guided by AI allow for the application of water, fertilizers, and pesticides only where and when they are needed, minimizing waste and reducing the potential for environmental contamination [16]. Smart irrigation systems, powered by AI, provide precise recommendations on irrigation schedules and water volumes, leading to significant conservation of this vital resource [45]. AI's ability to predict soil nitrogen concentrations enables farmers to make more informed decisions regarding fertilizer application rates, thereby reducing nutrient runoff and waste [14]. The deployment of AI-powered robots for crop protection, as demonstrated by Solinftec in sugarcane fields, has resulted in a substantial reduction in the amount of herbicides required [30].

Table 2. Summary of reported quantitative outcomes of AI applications in the sugar industry.

AI Technique	Application Area	Quantitative Outcome	Ref.
CNN	Disease detection	98% accuracy in disease identification	[19]
ARIMA	Yield prediction	RMSE: 36,700.68; AIC: 456.7	[22]
ANN	Yield forecasting	$R^2 = 0.994$; RMSE < 10%	[23]
XGBoost	Yield grade classification	Accuracy = 71.83%; $R^2 = 0.815$	[24]
C3 AI Process Optimization	Sugar milling	1.9% yield increase; $8 million annual gain	[31]
IoT + AI (Bevap, Brazil)	Logistics optimization	8% efficiency increase; €150 million gain	[41]
AI irrigation	Smart farming	30% reduction in water usage	[42]
AI robotics (Solinftec)	Herbicide management	Significant herbicide reduction	[30]

6. Regional Perspectives on AI in the Sugar Industry

The adoption and impact of AI in the sugar industry vary across key sugar-producing regions, depicting differences in agricultural practices, prevailing challenges, and the maturity of technological infrastructure. In India, a major global player in sugarcane production, farmers are increasingly leveraging AI for critical tasks such as weather prediction, proactive management of pests and diseases, and optimization of harvesting schedules [43]. These AI-driven interventions have shown promising results in terms of enhanced yields and more efficient utilization of resources. The adoption of AI in the Indian sugar industry is being significantly propelled by collaborative efforts between agricultural research institutions and technology companies, fostering the development and deployment of tailored solutions [43]. Brazil, another dominant force in the global sugar market, is actively exploring and implementing AI technologies across the sugarcane production lifecycle. AI is being utilized for sophisticated sugarcane yield prediction and the optimization of harvest timing, often relying on the analysis of multispectral satellite data combined with advanced agronomic modelling [26]. Companies like Solinftec are providing comprehensive AI-powered platforms that integrate monitoring, productivity enhancement, traceability, and logistical management for sugarcane producers [41]. In addition, AI is also being deployed in Brazil for innovative applications such as the early detection and mitigation of wildfire risks in sugarcane farming regions [46].

In Thailand, a significant sugar exporter in Asia, the Mitr Phol Group, in collaboration with public sector organizations, has been a pioneer in adopting AI to modernize sugarcane farming practices [47]. The collaboration with Thailand's National Science and Technology Development Agency (NSTDA) and International Business Machines Corporation (IBM) has introduced IBM Watson Decision Platform for Agriculture combined with IBM Physical Analytics Integrated Repository and Services (PAIRS) Geoscope technology for integrating intelligent geospatial-temporal data including multispectral crop images captured by satellites, soil data, and digital elevation models. The system utilizes AI algorithms, IoT sensors, satellite remote sensing, and hyper-local weather forecasting data through the development of an Agronomic Insights Assistant that provides actionable insights on crop health, soil moisture, pest and disease infestation risk, expected yield, and commercial cane sugar index. This precision farming approach integrates four key technological components: AI engines customized for agriculture, satellite data analysis, weather data from The Weather Company, and IoT device sensors deployed across pilot areas of 2,000 rai (320 hectares) of sugarcane farms. Additionally, Khon Kaen University in Thailand has developed a highly accurate AI-powered drone specifically designed for measuring the sweetness levels in sugarcane plantations, showcasing local innovation in this area [48]. The European Union, while primarily focused on sugar beet production, is also witnessing the application of AI across various aspects of the sugar industry. Research efforts are concentrated on developing AI-driven solutions for automated quality control of sugar beets during processing. Companies like Scangrading are offering specialized AI and machine vision systems for the detailed analysis of sugar crystal size distributions in sugar factories, aiming to automate processes and improve the reliability of quality testing [35]. Furthermore, the potential of Generative AI is being explored within the European Union (EU) to enhance the performance of field robots used in sugar beet cultivation, particularly in tasks such as plant detection and navigation [13]. These regional perspectives collectively depict a global recognition of the transformative potential of AI within the sugar industry. The specific applications and the pace of adoption are influenced by regional agricultural practices, the unique challenges faced by producers in each area, and the existing technological infrastructure. While India and Brazil demonstrate significant activity in applying AI to enhance sugarcane cultivation and processing, the EU is also making strides in leveraging AI for sugar beet production and quality control.

Regional implementation success varies significantly based on infrastructure readiness, government support, and farm scale, with Brazil and India benefiting from established digital infrastructure and policy frameworks, while smaller-scale operations require cooperative models to justify AI investment costs. For demand forecasting and logistics, the industry primarily employs machine learning algorithms that analyze historical sales data and seasonal trends, combined with real-time vehicle tracking systems that have achieved up to 99% accuracy in supply chain monitoring [38].

7. Challenges and Future Trends in AI for the Sugar Industry

Despite the considerable promise of AI in the sugar industry, several challenges need to be addressed to facilitate its widespread and effective adoption (Figure 1). One significant hurdle is the availability and quality of data [9]. The effectiveness of AI algorithms is intrinsically linked to the quantity and quality of the data they are trained on. While the deployment of sensors and digital modernization efforts are crucial first steps, deriving meaningful and actionable insights requires comprehensive, reliable, and well-integrated datasets from across the entire sugar production chain [9]. Issues such as data silos, where information is stored in isolated systems, and ensuring the accuracy and consistency of data collected from diverse sources pose significant challenges [33]. The reliability of AI-powered yield predictions, for instance, is directly dependent on the quality and quantity of the underlying data used to train the models. Overcoming these data-related challenges is essential to fully realize the potential benefits of AI in the sugar industry. Infrastructure limitations and technological barriers also present obstacles to the widespread adoption of advanced AI technologies [13]. The implementation of sophisticated AI solutions, such as those involving Generative AI, often requires substantial upfront investments in infrastructure development [13]. Furthermore, the sugar industry, particularly in its manufacturing sector, often relies on legacy equipment. Integrating new AI-driven systems with these existing, potentially outdated, technologies can be a complex and costly endeavour. Ensuring seamless interoperability between new AI capabilities and established machinery requires careful planning and may necessitate significant upgrades or the development of intricate integration solutions.

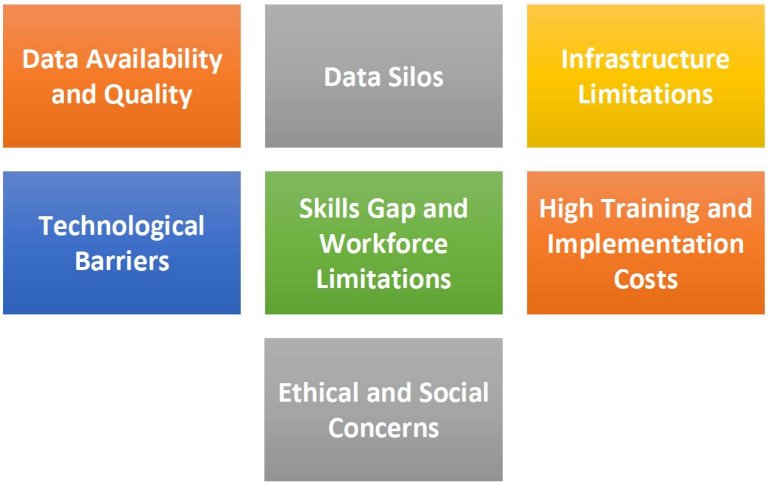

Figure 1. Challenges affecting the use of AI in the sugar industry.

The issue of data silos, where farm-level data from sensors remain disconnected from factory and supply chain databases, directly constrains AI's predictive performance in yield forecasting and process optimization. For example, data collected from mill operations are often incompatible with field sensor formats, impeding model training continuity. Similarly, limited data sharing between regional cooperatives weakens the precision of supply chain forecasting models, particularly for perishable sugarcane. Addressing these integration barriers is critical to realizing AI's full capacity for predictive analytics across the production cycle.

A critical challenge that spans both the agricultural and manufacturing sectors of the sugar industry is the skills gap and the need for adequate training [9]. The successful implementation, management, and maintenance of AI systems require a workforce with specialized knowledge and skills in areas such as data science, machine learning, and AI engineering. The manufacturing sector, in particular, is already facing a labour shortage, and finding skilled personnel to oversee AI applications in factory settings is anticipated to be equally challenging. While upskilling the existing workforce through training programs is a potential solution, it can be a costly and time-consuming undertaking. Addressing this skills gap through targeted education and training initiatives is crucial for enabling the effective adoption and utilization of AI technologies within the sugar industry. Ethical considerations surrounding AI implementation include data privacy and ownership rights for farm-generated information, potential algorithmic bias that may disadvantage smallholder farmers, and employment impacts in rural communities as automation reduces traditional agricultural jobs. Robust data security measures and transparent AI decision-making processes are essential to maintain stakeholder trust and ensure responsible technology adoption.

Looking towards the future, several emerging trends are poised to shape the role of AI in the sugar industry. The integration of Generative AI, which can create synthetic data to augment real-world datasets and simulate various scenarios, holds significant promise for improving the development and testing of AI models, particularly in areas like field robotics. Advancements in robotics are expected to lead to the development of more versatile and autonomous robots capable of performing a wider range of agricultural tasks with greater precision and efficiency. The long-term vision includes the evolution towards fully integrated smart sugar farms and mills, where AI acts as the central nervous system, leveraging real-time data from interconnected devices and systems to optimize decision-making across all aspects of production, from planting and harvesting to processing and supply chain management. These future trends suggest a continued and accelerating transformation of the sugar industry driven by the power of AI.

8. Conclusion

This study discusses the potential of AI across the sugar industry, from cultivation to processing and supply chain management. This study noted that AI is enabling precision agriculture in sugarcane and sugar beet cultivation through optimized resource management, early disease detection, and accurate yield prediction. In sugar manufacturing, AI optimizes mill processes, enhances quality control, and facilitates predictive maintenance, leading to increased efficiency and reduced waste. AI also enhances supply chain management through improved demand forecasting and logistics. The adoption of AI offers economic benefits, including increased production and reduced costs, while also promoting environmental sustainability through efficient resource utilization and reduced chemical inputs. Regional perspectives reveal that countries like India and Brazil are already leveraging AI to enhance sugarcane production and optimize processes. However, the widespread adoption of AI faces challenges, including data availability and quality, infrastructure limitations, the skills gap, and ethical considerations. Future trends indicate that continued research and development in AI technologies, coupled with a focused effort to address existing challenges such as data availability, infrastructure limitations, and the skills gap, will be critical for unlocking the full power of AI. Emerging trends, including the integration of generative AI and advancements in robotics, promise to further enhance the capabilities and impact of AI across the sector. As the sugar industry continues to evolve, the strategic and responsible adoption of AI will be instrumental in ensuring its long-term sustainability, efficiency, and profitability in the face of increasing global demand and environmental pressures.

Funding

This work received no external funding.

Conflict of Interest

The authors declare they have no conflicts of interest.

Generative AI Statement

The authors declare that no Gen AI was used in the creation of this manuscript.

References

[1] Okoro HK, Iwuozor KO, Isaac I, Egbemhenghe A, Ehiguina JI, Emenike EC, et al. Utilization of Sugarcane Bagasse-Derived Bioadsorbents in a Packed Bed System for the Treatment of Fish Pond Effluent. Sugar Tech, 2025, 27, 1171-1184. DOI: 10.1007/s12355-025-01575-5
[2] Kumar R. AI for Sugar Industry. Kindle Edition ed: Amazon; 2024. 1-200 p. ISBN-13: 979-8321936849.
[3] Lee JY, Naylor RL, Figueroa AJ, Gorelick SM. Water-food-energy challenges in India: political economy of the sugar industry. Environmental Research Letters, 2020, 15(8), 084020. DOI: 10.1088/1748-9326/ab9925
[4] Mohammed K, Iwuozor KO, Anyanwu VU, Olaniyi BO. Sugar dust explosion in the sugar industry: Case studies and prevention strategies. Sugar Tech, 2024, 26, 12-19. DOI: 10.1007/s12355-023-01307-7
[5] Mohamed MA, Hafez MM, Rabeiy R, El Nagreedy EA. Noise pollution: Assessing and control in the beet sugar industry. Egyptian Sugar Journal, 2020, 15, 39-51.
[6] Gyan I. International Sugar Organization 2024. Available at: https://www.iasgyan.in/daily-current-affairs/international-sugar-organization (accessed on 28 April 2025).
[7] Balakrishnan M, Batra V. Valorization of solid waste in sugar factories with possible applications in India: A review. Journal of Environmental Management, 2011, 92(11), 2886-2891. DOI: 10.1016/j.jenvman.2011.06.039
[8] GrandView. Sugar Market Size, Share & Trends Analysis Report By Product Type (White Sugar, Brown Sugar), By Form (Granulated Sugar, Powdered Sugar), By End-use, By Source, By Region, And Segment Forecasts, 2024-2030, 2024. Available at: https://www.grandviewresearch.com/industry-analysis/sugar-market-report (accessed on 28 April 2025).
[9] Stewart B. Transforming sugar manufacturing with the power of AI. Sugar Industry International, 2025, 150(2), 123-127. DOI: 10.36961/si33025
[10] Modi RU. Future prospects of artificial intelligence in sugarcane culture and in sugar industry. 2022. In: Recent Approaches for Doubling Farmers Income in Sugarcane Based Cropping System(pp.41-47)Chapter: 7Publisher: ICAR-Indian Institute of Sugarcane Research, Lucknow, UP, India.
[11] Hernandez-Palma HG, Alvarado JR, Guiliany JE, Rios AL. Technological tools based on artificial intelligence in the sugar industry: A bibliometric analysis and future perspectives for energy efficiency. Latin American Developments in Energy Engineering, 2023, 4(2), 49-64. DOI: 10.17981/ladee.04.02.2023.4
[12] Iwuozor KO, Olaniyi BO, Anyanwu VU, Suleiman MA, Omoleye WS, Enahoro-Ofagbe FE, et al. The effect of ChatGPT on sugar industry research. Sugar Tech, 2023, 25, 1278-1284. DOI: 10.1007/s12355-023-01300-0
[13] Ray PP. Generative ai and its impact on sugarcane industry: An insight into modern agricultural practices. Sugar Tech, 2024, 26(2), 325-332. DOI: 10.1007/s12355-023-01358-w

[14] Bhatt R, Hossain A, Majumder D, Chandra MS, Ghimire R, Faisal M, et al. Prospects of artificial intelligence for the sustainability of sugarcane production in the modern era of climate change: An overview of related global findings. Journal of Agriculture and Food Research, 2024, 18, 101519. DOI: 10.1016/j.jafr.2024.101519
[15] Indu PV, Nanjundan P, Thomas L. AI for optimization of farming resources and their management. AI in Agriculture for Sustainable and Economic Management: CRC Press; 2024, 42-52.
[16] Medhe PG. Use of artificial intelligence in sugar industry for proper and timely decisions to achieve sustainability, 2024. Available at: https://www.chinimandi.com/use-of-artificial-intelligence-in-sugar-industry-for-proper-and-timely-decisions-to-achieve-sustainability/ (accessed on 29 April 2025).
[17] Belghachi M. Smart irrigation systems using AI to optimize water usage. In Cases on AI-Driven Solutions to Environmental Challenges: IGI Global Scientific Publishing; 2025. p. 241-68. DOI: 10.4018/979-8-3693-7483-2.ch009
[18] Famonaut. Introduction to JEEVN AI: A Game-Changer for Florida's Sugarcane Industry: Farmonaut Technologies Pvt. Ltd.; 2025. Available at: https://farmonaut.com/usa/revolutionizing-sugarcane-farming-in-florida-with-farmonauts-satellite-ai-based-farm-intelligence/ (accessed on 29 April 2025).
[19] Upadhye SA, Dhanvijay MR, Patil SM. Sugarcane disease detection using CNN-deep learning method: An Indian perspective. Universal Journal of Agricultural Research, 2023, 11(1), 80-97. DOI: 10.13189/ujar.2023.110108
[20] Kunduracıoğlu İ, Paçal İ. Deep learning-based disease detection in sugarcane leaves: Evaluating efficientnet models. Journal of Operations Intelligence, 2024, 2(1), 321-235. DOI: 10.31181/jopi21202423
[21] Gamaya. GAMAYA Granted Patent for AI driven Breakthrough Sugarcane Yield Prediction and Harvest Optimization Technology, 2024. Available at: https://www.gamaya.com/post/gamaya-granted-patent-for-ai-driven-breakthrough-sugarcane-yield-prediction-and-harvest-optimization (accessed on 29 April 2025).
[22] Vishwajeet S, Med RV, Subhash KY. Predictive modelling for sugarcane production: A comprehensive comparison of ARIMA and machine learning algorithms. Applied Biological Research, 2024, 26(2), 199-209. DOI: 10.48165/abr.2024.26.01.23
[23] Sridhara S, Soumya BR, Kashyap GR. Multistage sugarcane yield prediction using machine learning algorithms. Journal of Agrometeorology, 2024, 26(1), 37-44. DOI: 10.54386/jam.v26i1.2411
[24] Sun J, Sun C, Li Z, Qian Y, Li T. Prediction method of sugarcane important phenotype data based on multi-model and multi-task. PLOS ONE, 2024, 19(12), e0312444. DOI: 10.1371/journal.pone.0312444
[25] Zhu C, Wu C, Li Y, Hu S, Gong H. Spatial location of sugarcane node for binocular vision-based harvesting robots based on improved YOLOv4. Applied Sciences, 2022, 12(6), 3088. DOI: 10.3390/app12063088
[26] Angamuthu T. Hybrid deep learning technique for Identifying Diseases in Sugar-cane Crops. In Preprint. 2025. DOI: 10.21203/rs.3.rs-6145260/v1
[27] Medhe PG. AI can revolutionise sugarcane farming in India, boost yields, and cut costs: ChiniMandi, 2025. Available at: https://www.chinimandi.com/ai-can-revolutionise-sugarcane-farming-in-india-boost-yields-and-cut-costs/ (accessed on 29 April 2025).
[28] M.I.T. The 77 Lab: Pushing Human-Robot Interactions to Empower Humans, 2025. Available at: https://the77lab.mit.edu/agricultural-robotics/ (accessed on 29 April 2025).
[29] Alencastre-Miranda M, Davidson JR, Johnson RM, Waguespack H, Krebs HI. Robotics for sugarcane cultivation: Analysis of billet quality using computer vision. IEEE Robotics and Automation Letters, 2018, 3(4), 3828-3835. DOI: 10.1109/LRA.2018.2856999
[30] Farming F. Agrishow: crop protection 100% by robots and multifunctional truck for grains, 2024. Available at: https://www.futurefarming.com/tech-in-focus/agrishow-crop-protection-100-by-robots-and-multifunctional-truck-for-grains/ (accessed on 29 April 2025).
[31] Gurobi. Case studies: Optimizing business processes with customized AI solutions, 2025. Available at: https://www.gurobi.com/case_studies/c3-ai-optimizing-business-processes-with-customized-ai-solutions/ (accessed on 30 April 2025).
[32] Brett S. Optimize sugar production with AI: AI-enabled optimization improves operations and maximizes sugar mill profitability, 2024. Available at: https://c3.ai/wp-content/uploads/2024/07/Optimize-Sugar-Production-with-AI-new.pdf?utmMedium=fg8d04 (accessed on 30 April 2025).
[33] C3.ai. Sugar manufacturer increases yield with AI-driven setpoint recommendations, 2025. Available at: https://c3.ai/customers/sugar-manufacturer-increases-yield-with-ai-driven-setpoint-recommendations/ (accessed on 30 April 2025).
[34] AIT. New AI method for determining the quality of sugar beets, 2024. Available at: https://www.ait.ac.at/news-events/single-view?tx_ttnews%5Btt_news%5D=8199&cHash=15262c236376a357e795b6c28f22b2ba (accessed on 30 April 2025).
[35] ScanGrading. Cases: Automating processes for measuring and analyzing sugar crystal size distributions, 2025. Available at: https://www.scangrading.com/cases/ (accessed on 30 April 2025).
[36] Iwuozor KO, Ojeyemi T, Emenike EC, Umeh CT, Egbemhenghe A, Ayoku BD, et al. Management of sugar dust in the sugar industry. Heliyon, 2023, 10, e23158. DOI: 10.1016/j.heliyon.2023.e23158
[37] AI. AI-assisted sugar mill efficiency analysis, 2025. Available at: https://aimlprogramming.com/services/ai-assisted-sugar-mill-efficiency-analysis/ (accessed on 30 April 2025).
[38] Samuels A. Examining the integration of artificial intelligence in supply chain management from Industry 4.0 to 6.0: A systematic literature review. Frontiers in Artificial Intelligence, 2025, 7, 1477044. DOI: 10.3389/frai.2024.1477044
[39] AI. AI sugar factory automation, 2025. Available at: https://aimlprogramming.com/services/ai-sugar-factory-automation/ (accessed on 30 April 2025).
[40] eSided. Real-Time AI supply chain monitoring transforms sugar mill operations, 2025. Available at: https://esided.com/case-studies-ai-supply-chain-monitoring-sugar-mill-transformation/ (accessed on 30 April 2025).
[41] Farming F. Harvesting sugar cane more efficiently with AI and IoT, 2019. Available at: https://www.futurefarming.com/smart-farming/harvesting-sugar-cane-more-efficiently-with-ai-and-iot/ (accessed on 30 April 2025).
[42] ETV. Artificial intelligence proving to be a boon for sugarcane farmers in maharashtra, 2025. Available at: https://www.etvbharat.com/en/!state/artificial-intelligence-proving-to-be-a-boon-for-sugarcane-farmers-enn25041102394 (accessed on 30 April 2025).

[43] Yee CM. Chasing peak sugar: India's sugar cane farmers use AI to predict weather, fight pests and optimize harvests, 2025. Available at: https://news.microsoft.com/source/asia/features/chasing-peak-sugar-indias-sugar-cane-farmers-use-ai-to-predict-weather-fight-pests-and-optimize-harvests/ (accessed on 30 April 2025).
[44] CropGPT. AI-powered sugarcane farming revolutionizes indias sugar industry, 2025. Available at: https://cropgpt.ai/ai-powered-sugarcane-farming-revolutionizes-indias-sugar-industry (accessed on 30 April 2025).
[45] Ahmed MO, Idris AM, Enahoro-Ofagbe FE, Iwuozor KO. Impact of irrigation management on sugarcane during stress. In Sugarcane Cultivation and Management: Apple Academic Press; 2024. p. 53-71. DOI: 10.1201/9781003504122-3
[46] Felipe B. Brazil Sugarcane farm uses AI detection to mitigate wildfire risks: Roboticscats, 2023. Available at: https://roboticscats.com/2023/07/11/brazil-sugarcane-farm-uses-ai-detection-to-mitigate-wildfire-risks/ (accessed on 30 April 2025).
[47] Phol M. Mitr phol pioneers AI to modernize thai sugar industry, 2019. Available at: https://sugar-asia.com/mitr-phol-pioneers-ai-to-modernize-thai-sugar-industry/ (accessed on 30 April 2025).
[48] Saengprachatanarug K, Chea C, Posom J, Saikaew K. A review on innovation of remote sensing technology based on Unmanned Aerial Vehicle for sugarcane production in tropical region. In Remote Sensing Application: Regional Perspectives in Agriculture and Forestry, 2022, 337-350. DOI: 10.1007/978-981-19-0213-0_12