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Advancements in Grain Adulteration Detection and Quality Assessment - A Survey

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Abstract: Food security and public health are severely compromised by food adulteration and quality deterioration, which have become pressing concerns. Unfavourable food quality is caused by a multitude of factors, including but not limited to the widespread adulteration of food. Food quality is heavily influenced by environmental variables, such as poor storage conditions, pest infestations, and contaminant exposure. Furthermore, food products may be exposed to adverse circumstances due to the complexities of transportation and distribution, which can result in microbial spoilage and a loss of nutritive value. Consumers are thereby subjected to a decreased level of nutritional quality from their diet in addition to health hazards. In the context of food grains, such as rice and wheat, the challenges are particularly noteworthy. As these grains form the essence of sustenance in regions like India, ensuring their quality is paramount. Grain quality evaluation has traditionally been done by hand using labour-intensive, human error-prone procedures. However, the prospect of automation and computer vision gives a glimmer of optimism in today's technologically advanced society. Systemic research and developments concerning the evaluation of grain quality have demonstrated that image processing techniques may be employed to automate the procedure. Such advancements give rise to the potential for more accurate, efficient, and scalable grain quality assessment.
***Keywords:** Adulteration, Automation, Computer Vision, Contaminant Exposure, Grain Quality, Image Processing.*

I. INTRODUCTION

Food grains have intricately woven themselves into the rich tapestry of India's culinary heritage, acting as the very foundation of sustenance that has nurtured generations and established the core of India's dietary culture. This is reflected in the Economic Survey for the fiscal year 2022-23, which was formally presented to the Parliament by the Union Minister of Finance and Corporate Affairs, Smt. Nirmala Sitharaman, on January 31st, 2023 [18]. The Economic Survey highlighted a significant achievement despite the formidable challenges posed by climate change. In the agricultural year 2021-22, India reached a milestone by achieving a record production of food grains, totalling 315.7 million tonnes [18]. Moreover, the Second Advance Estimates [23], released by the Ministry of Agriculture and Farmers Welfare in February 2023, offer valuable insights into the projected production of major crops for the fiscal year 2022-23. These estimates are illustrated in Fig. 1.[22]

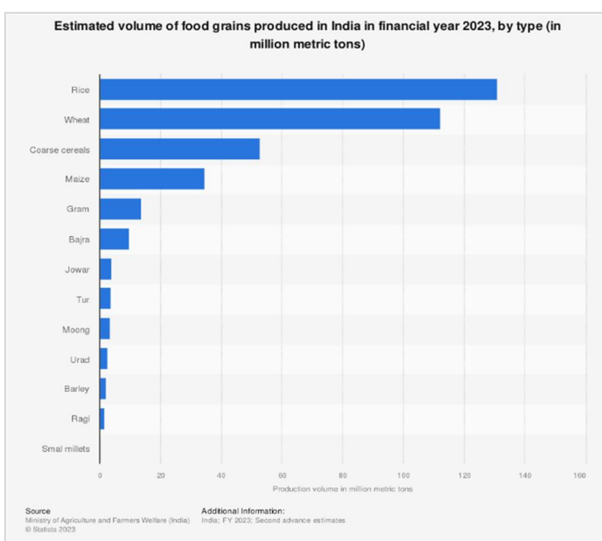

Fig. 1 Estimated volume of food grains produced in India (2023) by type (in million metric tons)

Amidst the widespread and consistent consumption of food grains, the compromise in their quality emerges as an increasingly pressing concern. This concern is further exacerbated by a multitude of factors, with the most disconcerting being the pervasive adulteration of grains, which poses a significant threat to the integrity of food supply. Food adulteration, defined as the deliberate act of introducing substandard, dangerous, or deceptive components into food items, has been a subject of meticulous exploration by Momtaz et al, as documented in their work [17]. This comprehensive analysis has shed light on various techniques employed in the insidious practice of food adulteration and, perhaps even more critically, the corresponding health implications borne by unsuspecting consumers. Unscrupulous elements have infiltrated dietary staples, adversely affecting the health of consumers. What makes this issue even more alarming is that its reach extends far beyond the boundaries of food grains, seeping into the very heart of India's food supply chain, causing a ripple effect across the nation's food security and public health.

Rice and wheat, as the cornerstones of India's dietary culture, hold profound significance. They provide essential sustenance to millions of individuals, making their quality paramount. However, the challenges facing these grains go beyond the realm of adulteration, encompassing environmental factors, such as changing climate patterns, which play a significant role in shaping the conditions under which rice and wheat are cultivated.

Storage practices represent another facet of this issue. Suboptimal storage conditions can compromise the quality of rice and wheat, leading to a gradual degradation of nutritional value. Unforeseen circumstances, such as natural disasters or disruptions in transportation, further exacerbate the challenges faced by the grains in their journey from farm to table.

The repercussions of these challenges are profound, adversely affecting the nutritional value of these grains and exacting a heavy toll on the health and livelihoods of those who depend on them.

In the realm of food safety and quality assurance, the Food Corporation of India (FCI) operates a comprehensive network of testing laboratories strategically positioned across the nation [21]. These laboratories serve as the frontline guardians, meticulously monitoring the quality of food grains that traverse the intricate web of the food supply chain. To ensure a rigorous adherence to standards, the Warehousing Development and Regulatory Authority (WDRA) has established a stringent standard operating procedure [19] for sampling, dictating that authorized representatives of both the depositor and the warehouseman or their appointed proxies partake in the systematic collection of grain samples. This meticulous sampling process serves as the initial step in a series of checks and balances aimed at upholding the integrity of the food supply chain. However, the traditional methods employed for the assessment of grain quality have been marked by manual, labor-intensive approaches, susceptible to human errors and inefficiencies. The Food Safety and Standards Authority of India (FSSAI), cognizant of the evolving challenges, has set forth exacting quality standards, underscoring the need for precision to safeguard consumers and uphold the authenticity of food products [20].

In this rapidly evolving landscape, developments involving automation and computer vision emerge as a beacon of hope, ushering in a new era of innovation poised to address these pressing concerns. Beyond merely reducing human error, automation holds the potential to elevate efficiency, scalability, and the overall quality of grain and food assessments. The integration of image processing techniques, a pivotal component of these technological advancements, promises not only increased accuracy but also enhanced efficiency and scalability in the evaluation of grain quality. The impact of these technological advancements transcends mere promises, serving as a compelling testament to the urgent need for automated solutions that overcome the limitations inherent in manual inspection methods. In an era where precision and reliability stand as paramount pillars, these technological strides not only enhance the standard of food products but also reinforce the safety and authenticity of the entire food supply chain. This ripple effect extends to consumer welfare, fostering trust in the industry and solidifying the commitment to unwavering quality standards.

The application of innovative solutions to the meticulous process of food quality assessment signifies a paradigm shift in ensuring food safety. This integration paves the way for a future where innovation aligns seamlessly with precision. The symbiosis of human expertise and technological prowess emerges as a safeguard for both the sanctity of the food supply chain and the trust placed by consumers in the industry's commitment to unparalleled quality standards.

II. LITERATURE REVIEW

This section furnishes a comprehensive overview of recent advancements and research predominantly centred on automated grain quality analysis. In its scope, the review extends beyond grains to encompass various sectors, incorporating the detection of undesirable elements in soft foods and the assessment of apple ripeness, among other applications. The primary objective is to establish a thorough comprehension of methodologies, challenges, and technological advancements within diverse food products and agricultural domains. Delving into each study's methodologies and limitations, the study aims to provide insights into prevailing technological trends, fostering an understanding of the current landscape and encouraging further research in the domain.

The systematic review also endeavours to identify prevalent trends, challenges, and potential gaps in the existing body of knowledge, contributing to a pragmatic understanding of the subject matter.

Some of the studies that have been examined in the literature review are as follows. In Paper [1], a methodology is proposed for detecting rice adulteration utilizing Tetrahertz Spectroscopy and various pattern recognition algorithms. A similar objective is pursued in Paper [2], which also involves the identification of rice varieties. This study employs headspace gas spectrometry to achieve its goals. In Paper [5], an artificial neural network model is utilized to classify rice samples into 15 commercial rice types. Paper [8] concentrates on quality inspection in rice grains, specifically addressing chalkiness. The detection of chalkiness is enhanced using a Gradient-weighted Class Activation Mapping model with a ResNet-101 backbone. Authors in Paper [9] focus on real-time grading of rice varieties, employing the AlexNet architecture. Another aspect affecting rice quality is mold development on its surface, which is addressed in Paper [13] through the application of YOLO-v5 models to detect mildew regions in rice grain images. Paper [7] improves ResNet models to detect damaged wheat kernels from images of wheat grains. A similar objective is pursued in Paper [12], where the YOLOv5 model is enhanced to achieve the detection of damaged wheat kernels. Notably, Paper [14] evaluates damaged wheat kernels using hyperspectral images.

The Table I summarizes recent contributions to the field to provide an understanding of work that has been done including limitations and potential areas for future improvement.

TABLE I SUMMARIZED WORKS

Sl No.	Title	Journal	Methodology	Outcome	Limitations/Future Scope
[1]	Analysis and Identification of Rice Adulteration Using Terahertz Spectroscopy and Pattern Recognition Algorithms Published in January 2020	IEEE	Terahertz spectroscopy and pattern recognition algorithms were employed to detect and analyze adulterated rice at five levels with varying mixing proportions. Principle Component Analysis (PCA) was performed to assist in feature extraction.	It was found that the support vector machine (SVM) model which utilized the absorption spectra with a first derivative pretreatment presented an accuracy of 97.33%.	The research was constrained to high-quality, low-cost rice. Enhancements in the study could involve considering additional rice varieties to create a more effective and realistic system.
[2]	Identification of Rice Varieties and Adulteration Using Gas Chromatography-Ion Mobility Spectrometry Published in January 2021	IEEE	Headspace-gas chromatography-ion mobility spectrometry (HGC-IMS) was employed to analyze volatile compounds in five types of rice. A semi-supervised generative adversarial network (SSGAN) was applied to identify unique ion migration fingerprints for these rice types, enabling accurate classification of HCG-IMS images.	The proposed model was found to exhibit an accuracy of 98% in recognizing the rice types and 97.30% in recognizing adulteration in rice.	The proposed method could be applied to identify food crops apart from rice.

[3]	High-throughput soybean seeds phenotyping with convolutional neural networks and transfer learning Published in May 2021	BMC	A hybrid simulated/real dataset for training and evaluating high throughput soybean seeds was developed. The synthetic image dataset was used for transfer learning with Mask R-CNN to perform high throughput soybean seeds instance segmentation.	The proposed synthetic image generation and augmentation method and the use of transfer learning methods achieved the objective of automated soybean seeds phenotyping.	The suggested system employed 2D images, resulting in a deficiency of information derived from depth analysis. There is room for enhancement in reducing the computational cost associated with training the segmentation model. The technique for generating synthetic images and performing augmentation is centred on a single-class object. This methodology could be expanded to include the synthesis of objects belonging to multiple classes.
[4]	Safety of Food and Food Warehouse Using VIBHISHAN Published in September 2021	Hindawi	An automated robot, VIBHISHAN, was built to ensure warehouse safety as well as to identify the food conditions. A machine learning model for detecting the food was developed by using CNN. After training.	The CNN based model exhibited an accuracy of 96.30%	–
[5]	Computer Vision and Machine Learning Analysis of Commercial Rice Grains: A Potential Digital Approach for Consumer Perception Studies Published in September 2021	MDPI	An Artificial Neural Network (ANN) model was developed using nine morpho-colorimetric parameters to classify the rice samples into 15 commercial rice types.	Results showed that the best classification accuracy was obtained using the Bayesian Regularization (BR) algorithm of the ANN with ten hidden neurons at 91.6% % (MSE = < 0.01) and 88.5% (MSE = 0.01) for training and testing stages, respectively, with an overall accuracy of 90.7%. Deployment also	Connections could be established between the readily accessible parameters with key traits in rice. The proposed method can be applied in the industry to develop a cloud-based smartphone application for real-time assessment of rice quality.

				showed high accuracy (93.9%) in the classification of the rice samples.	
[6]	Detection of Foreign Bodies in Soft Foods Employing Tactile Image Sensor Published in December 2021	Frontiers	Cylindrical tactile image sensor was used to detect shell fragments left on the surface of raw shrimp and bones left in fish fillets.	Tactile image sensor was used to successfully detect hard objects in three types of soft food.	The system could be applied to various other food items in the real world. The proposed method is successful in detecting shells only on the front side of the shrimp. Shells located at the back remain undetected. The force exerted on the food, varied from 2 to 7 N for optimal foreign matter detection. Future work could include adding a mechanism to maintain a constant force for consistent inspection conditions.
[7]	Detection of Wheat Unsound Kernels Based on Improved ResNet Published in January 2022	IEEE	Improved ResNet models were developed to detect unsound wheat kernels from wheat grains images.	The Res24_D_CBAM_Atrous model was found to perform the best with an accuracy of 94%.	Future work could include enhancements in testing equipment automation. Stable image acquisition scenes and a robust unsound kernel dataset could be established for heightened standardization. A detection standard for the unsound kernel rate based on mass ratio could be established.
[8]	Deep learning based high-throughput phenotyping of chalkiness in rice exposed to high night temperature. Published in January 2022	BMC	Convolutional Neural Networks (CNNs) and Gradient-weighted Class Activation Mapping (Grad-CAM) were used to detect chalkiness in rice grain images.	The Grad-CAM model with ResNet-101 as a backbone can be used to accurately detect chalkiness in images of rice grains. Detection was found to be easier in polished rice compared to unpolished rice.	The proposed system draws the line at regular white rice and may not work efficiently for coloured rice. The study shows that transferring models trained on polished rice to unpolished rice is

					ineffective, highlighting the need for specific models tailored to different rice varieties. The study focused on non-contacting seeds, and the tool's ability to assess chalkiness without physical grain separation wasn't tested. Additional training is needed for accurate quantification under varying grain overlap.
[9]	Computer-Assisted Real-Time Rice Variety Learning Using Deep Learning Network Published in September 2022	Rice Science	AlexNet architecture was used to develop an automated rice grading system. Real-time processing was provided by using a NI-myRIO with a high-resolution camera and user interface.	Using AlexNet architecture, an average accuracy of 98.2% with 97.6% sensitivity and 96.4% specificity was obtained.	_
[10]	Vision-Based Defect Classification and Weight Estimation of Rice Kernels Published in November 2022	IEEE	The proposed system assessed rice kernel quality and classified the grains based on their flaws. By calculating the weight ratios of kernels in the image using a pixel area-based metric. A multi-stage workflow was designed for division of kernel flaws.	The model exhibited a precision of over 85% for recognition of all six kernel flaws and a precision of over 90% for sound, broken, yellow-coloured and spotted kernels.	Exploration of methods to reduce the requirements for both the quantity and quality of training data could be considered. Acknowledging the challenges associated with obtaining professionally labelled data, it is crucial to enhance the network model's resilience to labelled data.
[11]	Apple Fruit Quality Detector Using Fiber Optics and Color Sensor Published in November 2022	IEEE	A portable system, consisting of a colour sensor and optical fiber has been proposed, that takes into account the amount of light reflected from apples to determine their mellowness.	The system was found to detect ripeness with an accuracy of 97%	Subsequent research could entail extending the application of the proposed system to detect the ripeness of various types of fruits. Efforts could be directed towards enhancing performance to attain a 100% accuracy rate.

[12]	Fast and accurate wheat grain quality detection based on improved YOLOv5 Published in November 2022	Computers and Electronics in Agriculture	Wheat quality detection was done by developing a model by implementing improvements to YOLOv5. The approach seeks to address degradation concerns through the utilization of sparse network pruning and a hybrid attenuation module.	A benchmark wheat grain dataset has been constructed. The proposed model was found to perform with an accuracy of 97%.	Subsequent research endeavors could concentrate on improving performance by merging the speed of visible image acquisition devices with the precision of hyperspectral image acquisition devices.
[13]	Study on Rice Grain Mildewed Region Recognition Based on Microscopic Computer Vision and YOLO-v5 Model Published in December 2022	MDPI	Three YOLO-v5 models, for each mould variety, were built for recognizing regions of mildew in microscopic mouldy rice grain images.	Accuracies of identifying the mildewed regions with contamination of A. niger, P. citrinum, and A. were found to be 89.26%, 91.15%, and 90.19%, respectively.	The proposed system identifies mouldy regions on individual rice grains and suggests the possibility of developing recognition models for grouped rice samples through transfer learning. To broaden the detection capability to include other types of mold, it is essential to acquire a more comprehensive collection of mildew rice grains.
[14]	Machine Learning Analysis of Hyperspectral Images of Damaged Wheat Kernels Published in March 2023	MDPI	Hyperspectral Imaging (HSI) was done to evaluate the damage done by the fungus Fusarium graminearum in wheat kernels. Machine Learning models were evaluated to ascertain which of them was more accurate.	G-Boost was found to perform the best with an accuracy of 97% in classifying wheat kernels into different severity levels.	The research employed images capturing only one side of the kernels. Enhancing model performance could be achieved by scanning both sides.
[15]	Application of Machine Learning for Insect Monitoring in Grain Facilities Published in March 2023	MDPI	An insect detection system consisting of a manual-focus camera and a Jetson Nano, running a trained deep-learning model was developed. The model	An accuracy of 70-85% was obtained using side-by-side comparison.	A platform centered on cloud services could be incorporated for the storage and retrieval of data. A mobile platform,

			used live feed video to detect small insects.		designed with processing and communication capabilities to send data to a server for additional processing and user feedback, may be developed.
[16]	Wheat Spikes Height Estimation Using Stereo Cameras Published in June 2023	IEEE	A method utilizing stereo cameras to measure wheat plant height was designed using mask region-based convolutional neural networks to localize and differentiate spikes in captured images, achieving spike localization through object detection and instance segmentation models.	The proposed method predicted wheat height with mean absolute percentage error values of 0.75% and 0.67% at the spike and plot levels, respectively.	The method could be implemented using standard RGB images.

III. CONCLUSION

This paper has delved into diverse methodologies employed for grain quality detection, examining the dynamic landscape of the field. Through an exploration of both strengths and limitations, the study highlights the evolving nature of these techniques, emphasizing the continuous demand for research. The identified constraints provide valuable insights, guiding future investigations and innovations within the broader spectrum of grain quality assessment methodologies.

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