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Advancements in Artificial Intelligence (AI) for enhanced insights and automation in rice agriculture: A systematic review

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Abstract

With the rising global demand for rice, improving production efficiency through advanced technologies like artificial intelligence (AI) is crucial. This systematic review gathered recent literatures on learning algorithm models applied to automate rice agriculture tasks. The objectives were to analyze the performance accuracy of different machine learning algorithms for rice classification and determine the most effective models. The 116 studies from 2016-2023 were screened and 70 were included. The algorithms were evaluated by weighted mean accuracy percentage across studies while maintaining consideration to sample sizes. The results showed the DenseNet121 deep convolutional neural network achieved the overall highest accuracy of 99.98%, also topping rice disease detection. For variety classification, Deep Neural Networks reached 99.95% accuracy by learning complex visual differences. Adaptive Neuro-Fuzzy Inference System led in grading quality of 98.6% by discerning grain features. Larger datasets improved accuracy indicating that the more training data has, it enhances model accuracy. The review demonstrates AI's significant potential to automate essential aspects of rice production. Further research expanding standardized algorithm evaluations is recommended to strengthen the evidence-base and support integration of AI for intelligent, sustainable rice agriculture.

Keywords: Artificial Intelligence; Machine Learning; Algorithm; Rice Agriculture; Literature Review

1. Introduction

For billions of people rice is more than just a food especially in Asia, Africa and South America [1]. Nearly half of the world's population depends on rice as their dietary requirements. Each year, throughout the world nearly 510 million metric tons of rice are produced according to the Statista [2, 3]. Currently, rise in demand for rice is happening especially to places that are not a rice growing region and need a vast rice production to meet day to day food supply.

Agricultural research and innovation in rice production is crucial. It needs to be developed and advanced to increase output and keep up with the rising demand for rice driven by population growth and surge in food consumption. The deployment of advanced technology for rice production makes procedures in production faster and accurate.

Over the years Artificial Intelligence (AI) offers solutions that will help in farming and produce more with fewer resources, increase crop quality and quick production [4]. Technology in artificial intelligence is responsible for different objectives including vision, learning and decision making. AI improves as it is constantly learning, applying its components such as Machine Learning and Deep Learning. Under those components there are different algorithms or architectures that are used to understand and process information similarly as the human brain operates [5]. With that, those advancements are more utilized in the field of agriculture to enhance the automation of the productions.

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Advancements in artificial intelligence for rice production were already applied and executed by many other researchers. However, literature reviewing of the use of artificial intelligence in rice agriculture remains overlooked. Considering the above statement, this review aims to gather recent advancements in rice production using artificial intelligence and existing literature regarding the application of technology to rice agriculture. More specifically, rice technology in automated rice classifications to improve the process of rice production. Furthermore, the purpose of this review is to synthesize learnings about the performance accuracy of the applied AI algorithm in a study and conclude the most efficient and successful AI model/algorithm for future outlooks and applications.

2. Material and methods

In this section, it contains the discussion of detailed methods in gathering, evaluating, and analyzing existing literature and articles which will be potentially applied and adapted for future outlooks.

2.1. Selection of Studies

Searches for studies were conducted in selecting and reviewing studies in several journals, inputting keywords regarding the application of artificial intelligence in rice production, more specifically automated classifications for rice. Gathering a total of 116 studies were screened and evaluated if it is eligible and meets the criteria of the study objectives. Considering the publication year within the span of 2016 to 2023, relevance of the artificial intelligence algorithm used, completeness of data indicating the performance accuracy of the model/algorithm, and applicability in the field of rice production. After a full-text screening a total of 70 studies were decided to be included in the systematic review and 46 were excluded. The data gathered was presented in Table 2 indicating the important information that will be used for the review, which includes: Lead Author & Year, Title, Findings (Performance Accuracy %), Number of Image Samples Used, Learning Algorithm model.

2.2. Data Analysis

To synthesize and analyze the data gathered to determine the most efficient artificial intelligence algorithm used and its ranking, the method used is the weighted mean. Weighted mean is computed based on the following formula [6];

$$Weighted\ mean = \frac{Sum\ of\ (data\ point\ x\ weight)}{Sum\ of\ weights}$$

The weighted mean considers the different sample sizes of each article for each algorithm's performance evaluation. This is utilized by multiplying the algorithm's scores by the sample size used for that measurement, which is then divided by the total sample size to calculate the weighted average accuracy score for each algorithm [6]. This allows us to rank the algorithms while maintaining consideration of the difference in sample sizes.

Using this method provides a quantitative way to account for the different sample sizes used for each accuracy percentage. The weighted mean allows us a more precise ranking system by giving more influence to measurements with larger sample sizes and simplifies comparing the algorithms. The weighted mean consolidates the performance ratings into a combined accuracy benchmark.

3. Literature Review

This section comprises the existing systematic reviews about the advancements in technology applied in the field of agriculture. Several systematic reviews were gathered to synthesize the reviews of every paper and highlight the importance of adapting advanced technology in agriculture.

Surge of demand in securing the proper methods of food production calls information technology as a solution for the development in agricultural production [7]. Agricultural researchers should provide more synthesized learnings and systematic reviews about the adoption of technology in agriculture, specifically, artificial intelligence. By using artificial intelligence, it will help farmers to have an improved farming process and efficiencies, waste reduction in biofuel and food production which will be non-destructive to the environment [4].

Table 1 Review of related literatures

Lead Author & Year	**Title**	**Journal**	**Total of Studies Included**	**Area of Focus (Objective)**	**Findings**
Alfred R. 2021 [8]	Towards Paddy Rice Smart Farming: A Review on Big Data, Machine Learning and Rice Production Tasks	IEEE Access	Not Specified	A survey of the latest research on intelligent data processing technology in rice agriculture.	The efficient and effective integration of Big Data (BD), Machine Learning (ML) and Internet of Things (IoT) are crucial to transform traditional rice production to rice precision agriculture.
Ambong R. M. A. 2022 [9]	Methods of Rice Technology Adoption Studies in the Philippines and Other Asian Countries: A Systematic Review	Research on World Agricultural Economy	22	Reviewing the adoption of rice technologies and practices in the Philippines and other ASEAN Countries.	The adoption of rice technologies improved crop management practices and farmers' capacity and capability leading to increased net income and benefit-cost ratio which are greatly influenced by institutional factors.
Amur M. 2020 [10]	Rice Disease Detection by using techniques of machine learning, Image Processing, and AI: A Systematic Literature Review	Research Gate	31	A comparison of rice disease detection methods based on different performance measures.	There are limitations in machine learning, image processing, and AI which include the current lack of standardized datasets, sufficiently robust algorithms, integration of diverse data sources, and development of accessible user-friendly systems in the field.
Dominic N. 2023[11]	Systematic Literature Review on Statistics and Machine Learning Predictive Models for Rice Phenotypes	Procedia Computer Science	17	Comparison of different machine learning predictive models to determine performance, important rice phenotypes and predictors for yield prediction.	Support Vector Machine, Multi-layer Perceptron, and regression are the top three predictive models for rice phenotypes.
Eli-Chukwu N. C. 2019 [12]	Applications of Artificial Intelligence in Agriculture: A Review	Engineering, Technology & Applied Science Research	54	Reviewing applications of artificial intelligence in various aspects of agriculture, discussing the limitations of AI in agriculture, and future prospects of this emerging field.	Findings show that artificial intelligence has been used to optimize soil performance, improve crop yield, used to monitor weed growth and to diagnose and manage diseases using different technology systems.
Gupta A. 2023 [13]	Machine Learning Applications in Agriculture: A Review for Opportunities, Challenges, and Outcomes	International Journal for Research Trends and Innovation	24	Comparison of various machine learning algorithms in different aspects of agricultural management and provide detailed information about various techniques that can be used to improve production and sustainability.	Machine learning provides various benefits for agriculture but requires further study and data availability in order to merge with other technologies to create more efficient and intelligent solutions.

Patrício D. 2018 [7]	Computer vision and artificial intelligence in precision agriculture for grain crops: A systematic review	Computers and Electronics in Agriculture	25	Identifying the applicability of computer vision and artificial intelligence in precision agriculture of five major grains in the world.	Using computer vision systems and artificial intelligence in agricultural and industrial food production for automation tasks in the field showed that there are gaps in the development of intelligent devices but there are alternatives for future improvement.

4. Results

4.1. Extracted data of the included studies

The included studies for the review, shown in Table 2, contains the information that will be synthesized to come to a conclusion of determining the most efficient artificial intelligence algorithm applied in rice production. From all the gathered data, the researchers come up with a way to determine which learning algorithm model has the highest performance accuracy ranking them from lowest to highest accuracy percentage and combine the learnings from all the studies included. Thus, this systematic review of gathering several studies related to the application of artificial intelligence in automated classifications of rice properties, to improve and hasten rice production, was conducted.

Table 2 Application of Artificial Intelligence in Classification of Rice Properties

Lead Author & Year	Title	Findings (Performance Accuracy %)	Number of Image Samples Used	Learning Algorithm Model
Abbas K. 2022 [14]	Identification of Rice Purity Level from Mixed Rice Varieties Using Deep Learning	89.88%	2953	Convolutional Neural Network (CNN)
Ahmed T. 2020 [15]	Rice Grain Disease Identification Using Dual Phase Convolutional Neural Network-Based System Aimed at Small Dataset	88.07%	419	Convolutional Neural Network (CNN)
Appalanaidu M. V. 2022 [16]	Nutrient Deficiency Classification in Rice Plants Using DenseNet121	99.98%	1200	DenseNet121 (Dense Convolutional Network)
Atole R. R. 2018 [17]	A Multiclass Deep Convolutional Neural Network Classifier for Detection of Common Rice Plant Anomalies	91.23%	600	AlexNet
Bashir K. 2019 [18]	Detection and Classification of Rice Diseases: An Automated Approach Using Textural Features	94.16 %	300	Support Vector Machine (SVM)

Biradar V. G. 2022 [19]	Rice Leaves Disease Classification Using Deep Convolutional Neural Network	93%	3000	Convolutional Neural Network (CNN)
Chatnuntawech I. 2018 [20]	Rice Classification Using Spatio-Spectral Deep Convolutional Neural Network	86.41% - VGGNet 88.23% - ResNet 91.09% - ResNet-B 93.27% - Ensemble of VGGNet, ResNet, and ResNet-B	3048	Visual Geometry Group Network (VGGNet) Residual Network-B (ResNet-B) Ensemble of VGGNet, ResNet, and ResNet-B
Chen W. 2022 [21]	Evaluation of Rice Degree of Milling Based on Bayesian Optimization and Multi-Scale Residual Model	96.90% - IRBOA 95.55% - ResNet34 92.93% - VGG16 92.30% - AlexNet 89.49% - BPNN	17400	InceptionResNet–Bayesian optimization algorithm (IRBOA) Residual Network 34 (ResNet34) VGG16 (Visual Geometry Group 16) AlexNet Back Propagation Neural Network (BPNN)
Cinar I. 2019 [22]	Classification of Rice Varieties Using Artificial Intelligence Methods	93.02% - LR 92.86% - MLP 92.83% - SVM 92.49% - DT 92.39% - RF 91.71% - NB 88.58% - K-NN	10824	K-Nearest neighbor (K-NN) Decision tree (DT) Logistic regression (LR) Multilayer Perceptron (MLP) Naive Bayes (NB) Random forest (RF) Support vector machine (SVM)
Cinar I. 2022 [23]	Identification of Rice Varieties Using Machine Learning Algorithms	99.91% - MLP 99.88% - RF 99.85% - SVM 99.80% - K-NN 99.79% - LR 99.69% - DT	75000	K-Nearest neighbor (K-NN) Decision tree (DT) Logistic regression (LR) Multilayer Perceptron (MLP) Random forest (RF) Support vector machine (SVM)
Crisóstomo de Castro Filho H. 2020 [24]	Rice Crop Detection Using LSTM, Bi-LSTM, and Machine Learning Models from Sentinel-1 Time Series	99.14% - Bi-LSTM 98.86% - LSTM 98.39% - RF 98.28% - SVM 97.71% - K-NN	4000	Bidirectional Long Short-Term Memory (Bi-LSTM) Long Short-Term Memory (LSTM) Random Forest (RF) Support Vector Machines (SVM)

		97.46% - NB		k-Nearest Neighbors (k-NN) Normal Bayes (NB)
Dabaghi A. 2020 [25]	Identification the Appearance Quality of Rice Kernels by Vision Technology and Neural Network Classifier	97.33%	1500	Artificial Neural Network (ANN)
Dar R. A. 2022 [26]	Classification of Rice Grain Varieties Using Deep Convolutional Neural Network Architectures	94% - RiceNet 84% - InceptionV3 81.33% -InceptionResNetV2	4898	RiceNet InceptionV3 InceptionResNetV2
Deng R. 2021[27]	Automatic Diagnosis of Rice Diseases Using Deep Learning	91%	33026	Ensemble of DenseNet-121, ResNeSt-50, and SE-ResNet50
Dharmik R. C. 2022 [28]	Rice Quality Analysis Using Image Processing and Machine Learning	92.36%	Not Specified	Recurrent Neural Network (RNN)
Dhiman M. 2023 [29]	Deep Learning-Based Classification of Rice Varieties from Seed Coat Images	99.76%	Not Specified	Convolutional Recurrent Neural Network (CRNN)
Díaz-Martínez, V. 2023 [30]	A Deep Learning Framework for Processing and Classification of Hyperspectral Rice Seed Images Grown under High Day and Night Temperatures	91.33% - 3D-CNN 94.83% - DNN	40	3D Convolutional Neural Network (3D - CNN) Deep Neural Network (DNN)
Gao T. 2021 [31]	HyperSeed: An End-to-End Method to Process Hyperspectral Images of Seeds	97.5%	200	3D Convolutional Neural Network (3D - CNN)
Gopalakrishnan, K. 2022 [32]	Rice Grain Classification Using Image Processing Technique	96.63%	1200	Support vector machine (SVM)
Gulzar Y. 2020 [33]	A Convolution Neural Network-Based Seed Classification System	99%	6840	Convolutional Neural Network (CNN)
Hamzah A. S. 2020 [34]	Classification of White Rice Grain Quality Using ANN: A Review	96%	200	Artificial Neural Network (ANN)
Hazra S. 2023 [35]	Deep Learning-Based Classification Of Rice Varieties: A Comprehensive Study	99.80% - Inception V3 99.31% - ResNet50 98.79% - VGG19 99.41% - VGG16	75000	VGG16 (Visual Geometry Group 16) VGG19 (Visual Geometry Group 19) Residual Network 50 (ResNet50) InceptionV3
He Y. 2023 [36]	Rapid Appearance Quality of Rice Based on Machine Vision and Convolutional Neural	92.3%	50	VGG19 (Visual Geometry Group 19)

	Network Research on Automatic Detection System			
Hidayat S. S. 2023 [37]	Determining the Rice Seeds Quality Using Convolutional Neural Network	88.3%	2000	Convolutional Neural Network (CNN)
Hruthik Chandra R. 2022 [38]	Rice Disease Detection and Classification Using Artificial Intelligence	88.6%	500	Convolutional Neural Network (CNN)
Huang K. Y. 2017 [39]	A Novel Method of Identifying Paddy Seed Varieties	95.56%	3506	Back Propagation Neural Network (BPNN)
Ibrahim S. 2019 [40]	Rice Grain Classification Using Multi-Class Support Vector Machine (SVM)	92.22%	90	Multi-class Support Vector Machine (SVM)
Jeyaraj P. R. 2022 [41]	Computer-Assisted Real-Time Rice Variety Learning Using Deep Learning Network	98.2%	2165	Convolutional Neural Network (CNN)
Kiratiratanapruk K. [42]	Development of Paddy Rice Seed Classification Process using Machine Learning Techniques for Automatic Grading Machine	83.9% - SVM 95.14% - InceptionResNetV2	49000	Support vector machine (SVM) InceptionResNetV2
Koklu M. 2021 [43]	Classification of rice varieties with deep learning methods	99.87% - ANN 99.95% - DNN 100% - CNN	75000	Artificial Neural Network (ANN) Deep Neural Network (DNN) Convolutional Neural Network (CNN)
Kumar K. 2022 [44]	Detection of Rice Plant Disease Using AdaBoostSVM Classifier	98.8%	120	Adaptive-Boosting-Support Vector Machine (AdaBoostSVM)
Sethy P. K. 2020 [45]	Rice (Oryza Sativa) Panicle Blast Grading using Support Vector Machine based on Deep features of Small CNN	89.3% - ShuffleNet + SVM 90.66% - MobileNetV2 + SVM 86.17% - ShuffleNet 86.91% - MobileNetV2 88.7% - LBP + SVM 82.3% - GLCM + SVM 76% - HOG + SVM 60.3% - Color Feature + SVM Overall, considering the computational time and based on deep learning approach ShuffleNet plus SVM is statistically superior to other models with an accuracy of	1200	Support Vector Machine (SVM)

		89.37%, 14.9s computational time and sensitivity (89.37%), specificity (94.68%)		
Latif G. 2022 [46]	Deep Learning Utilization in Agriculture: Detection of Rice Plant Diseases Using an Improved CNN Model	96.08%	2370	VGG19 (Visual Geometry Group 19)
Liang W. 2019 [47]	Rice Blast Disease Recognition Using a Deep Convolutional Neural Network	95.82% - CNN + SVM 95.83% - CNN + Softmax	2906	Convolutional Neural Network (CNN)
Lin P. 2018 [48]	A Deep Convolutional Neural Network Architecture for Boosting Image Discrimination Accuracy of Rice Species	The results showed that DCNN gives the best accuracy rate which is 95.5% for classification of rice kernel	16500	Convolutional Neural Network (CNN)
Lu Y. 2017 [49]	Identification of Rice Diseases Using Deep Convolutional Neural Networks	95.48%	500	Convolutional Neural Network (CNN)
Macalalad C. L. 2019 [50]	Morphological Based Grain Comparison of Three Rice Grain Variety	80%	60	Fuzzy Logic
Mandal D. 2018 [51]	Adaptive Neuro-Fuzzy Inference System Based Grading of Basmati Rice Grains Using Image Processing Technique	98.6%	600	Adaptive Neuro-Fuzzy Inference System (ANFIS)
Mathulaprangsan S. 2021 [52]	Rice Disease Recognition Using Effective Deep Neural Networks	98.62%	12223	DenseNet161 ((Dense Convolutional Network)
Mohan D. 2020 [53]	Quality Analysis of Rice Grains Using ANN and SVM	91% - SVM 83% - ANN	Not Specified	Support Vector Machine (SVM) Artificial Neural Network (ANN)
Naik N. K. 2023 [54]	Hybrid Enhanced Featured AlexNet for Milled Rice Grain Identification	99.63%	112000	AlexNet
Patil R. R. 2021 [55]	Predicting rice diseases across diverse agro-meteorological conditions using an artificial intelligence approach	92.15%	1634	Artificial Neural Network (ANN)
Patil R. R. 2022 [56]	An Artificial-Intelligence-Based Novel Rice Grade Model for Severity Estimation of Rice Diseases	96.43%	1200	Faster-Region-Based Convolutional Neural Network (FRCNN)
Prajapati H. B. 2018 [57]	Detection and Classification of Rice Plant Diseases	73.33%	120	Support Vector Machine (SVM) K-means clustering

Prakash N. 2022 [58]	Image Classification for Rice varieties using Deep Learning Models	99.5% - VGG16 95.3% - VNN	75000	Convolutional Neural Network (CNN) Vanilla Neural Network (VNN) Visual Geometry Group (VGG16)
Priyangka, A. A. JE Veggy 2021[59]	Classification Of Rice Plant Diseases Using the Convolutional Neural Network Method	95.24%	105	VGG19 (Visual Geometry Group 19)
Qadri S. 2021 [60]	A Machine Vision Approach for Classification the Rice Varieties Using Statistical Features	97.4%	600	LMT Tree (LMT-T)
Qui Z. 2018 [61]	Variety Identification of Single Rice Seed Using Hyperspectral Imaging Combined with Convolutional Neural Network	87%	3000	Convolutional Neural Network (CNN)
Quraishi Md. I. 2022 [62]	A Model for Classifying Rice Varieties Grown in Turkey Using Image-Based Morphological Features and Machine Learning	93.57%	3810	Support vector machine (SVM)
Rathore Y. K. 2023 [63]	Detection of rice plant disease from RGB and grayscale images using an LW17 deep learning model	93.75%	3000	Light Weight 17 (LW17)
Rayudu M. S. 2023 [64]	An Automatic Rice Grain Classification for Agricultural Products Marketing	99.24% - RF 99.20% - DT 95.40% - K-NN 78.01% - LR 76.27% - GNB	1500	Random forest (RF) Decision Tree (DT) K-Nearest neighbor (K-NN) Logistic Regression (LR) Gaussian Naive Bayes (GNB)
Ruslan R. 2022 [65]	Weedy Rice Classification Using Image Processing and a Machine Learning Approach	97.9%	7530	Logistic Regression (LR)
Saad A. M. 2023 [66]	Rice Classification Using ANN	100%	18188	Artificial Neural Network (ANN)
Sampath Kumar S. 2023 [67]	Classification of Rice Varieties Using Machine Learning Techniques for Agricultural Applications	90% - SVM 99% - RF 99% - BB 61% - AB	3810	Support vector machine (SVM) Random forest (RF) Bagging Boost (BB) Ada Boost (AB)
Satoto B. D. 2022 [68]	Rice Seed Classification Using Machine Learning and Deep Learning	99.92%	1000	Convolutional Neural Network (CNN)

Saxena P. 2022 [69]	Rice Varieties Classification Using Machine Learning Algorithms	99.85% - RF 99.68% - DT	75000	Random Forest (RF) Decision Tree (DT)
Setiawan A. 2023 [70]	Rice Foreign Object Classification Based on Integrated Color and Textural Feature Using Machine Learning	96.83% - SVM 87.31% - DT 82.54% - NB	80	Support vector machine (SVM) Decision Tree (DT) Naive Bayes (NB)
Shivamurthaiah M. M. 2023 [71]	Non-destructive Machine Vision System Based Rice Classification Using Ensemble Machine Learning Algorithms	99.60%	500	Extreme Gradient Boosting (XGBoost)
Singh H. 2023 [72]	Rice Kernels Classification with Deep Learning using a Modified Dataset Mimicking Real-World Conditions	100%	75000	Residual Network 50 (ResNet50)
Singh K. R. 2016 [73]	Efficient technique for rice grain classification using back-propagation neural network and wavelet decomposition	96%	12	Back Propagation Neural Network (BPNN)
Sokudlor N. 2023 [74]	Enhancing Milled Rice Qualitative Classification with Machine Learning Techniques Using Morphological Features of Binary Images	99.50%	400	Random Forest (RF)
Son N. 2019 [75]	Deep Learning for Rice Quality Classification	93.85% - CNN 85.06% - SVM+HOG 84.30% - K-NN	2000	Convolutional Neural Network (CNN) Support Vector Machine (SVM) K-Nearest neighbor (K-NN)
Sowmyalakshmi R. 2021[76]	An Optimal Classification Model for Rice Plant Disease Detection	94.2%	115	Convolutional Neural Network-based inception with ResNset v2 model and Optimal Weighted Extreme Learning Machine (CNNIR - OWELM)
Sujatha K. 2023 [77]	Innovation in Agriculture Industry by Automated Sorting of Rice Grains	97% - DT 96% - SVM 96% - NB	920	Artificial Neural Network with Black Widow Optimization Algorithm and Mayfly Optimization Algorithm (ANN-BWO-MA) Decision Tree (DT) Naive Bayes (NB) Support vector machine (SVM)
Suneetha E. 2023 [78]	Nutrients Estimation in Rice Grains using Artificially Intelligent (AI) Sensors	95.92%	Not Specified	Artificial Neural Network (ANN)

Tejaswini P. 2022 [79]	Rice Leaf Disease Classification Using Cnn	78.2%	1600	5-Layer CNN (Convolutional Neural Network)
Vu H. 2016 [80]	Spatial and spectral features utilization on a Hyperspectral imaging system for rice seed varietal purity inspection	84% - RF 74% - SVM	Not Specified	Random Forest (RF) Support vector machine (SVM)
Wang X. 2023 [81]	ECA-ConvNeXt: A Rice Leaf Disease Identification Model Based on ConvNeXt	94.82%	6000	ECA-ConvNeXt
Wang Y. 2021 [82]	Rice Diseases Detection and Classification using Attention Based Neural Network and Bayesian Optimization	94.65%	3000	Attention-based Depthwise Separable Deep Neural Network with Bayesian Optimization (ADSNN - BO)
Zareiforoush H. 2016 [83]	Qualitative Classification of Milled Rice Grains Using Computer Vision and Metaheuristic Techniques	98.72%	1280	Artificial Neural Network (ANN)

4.2. Summary result of all the analyzed learning algorithm models

The collected data has been analyzed and evaluated in terms of getting its weighted average in accuracy percentage per learning algorithm of each study. All the collected learning algorithms were ranked from lowest to highest to conclude which has the best performance that can be applied in rice production which is shown below (Figure 1). Additionally, not all the extracted learning algorithms had more than one supporting studies, some still lack evidence and foundation for it to be applied practically and so the data were separated into two: algorithms applied in more than 1 study (Figure 2) and algorithms applied in only 1 study (Figure 3), which is ranked respectively.

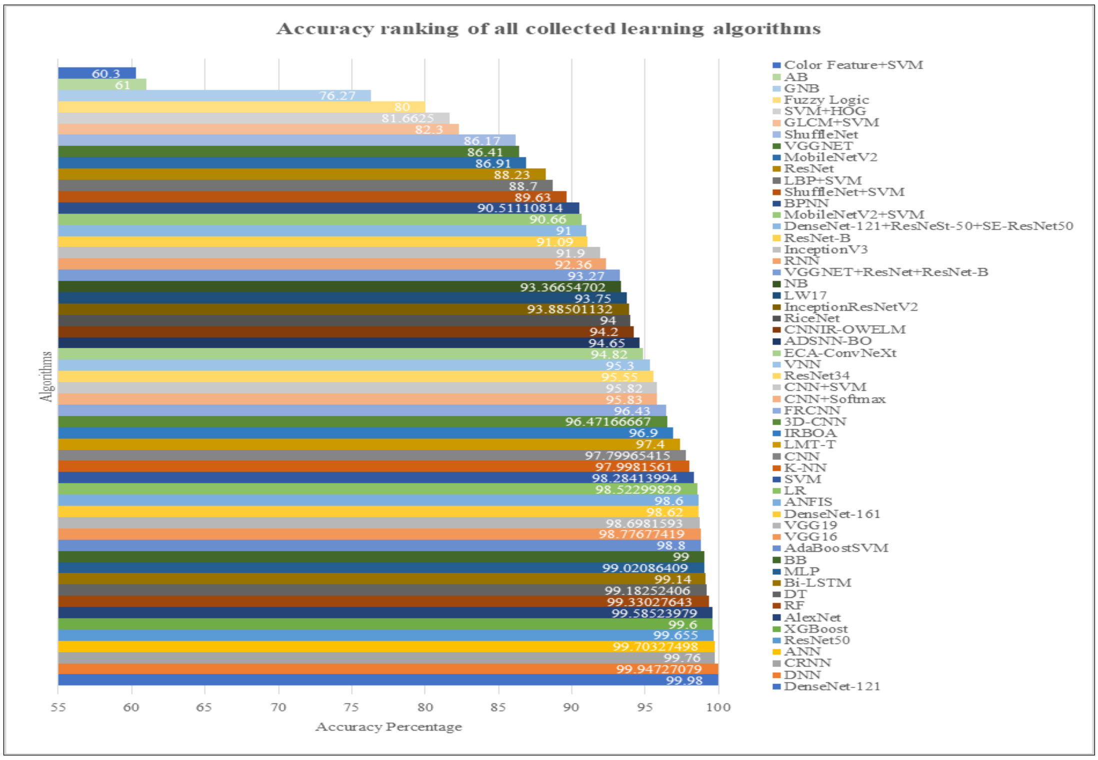

Figure 1 Accuracy ranking of all collected learning algorithms

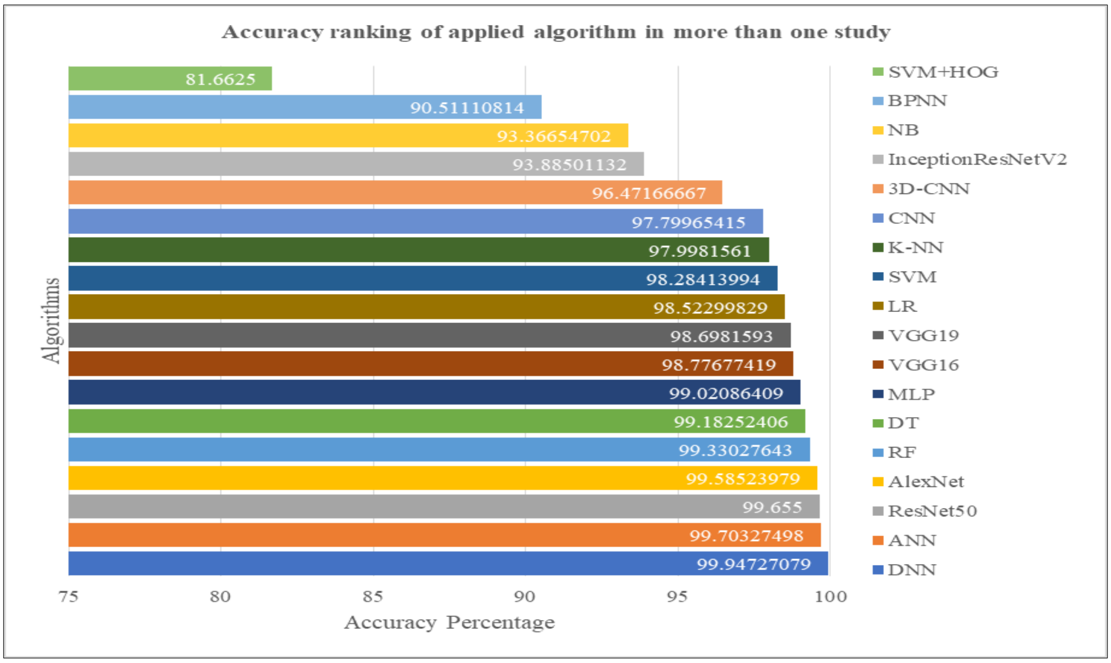

Figure 2 Accuracy ranking of applied algorithm in more than one study

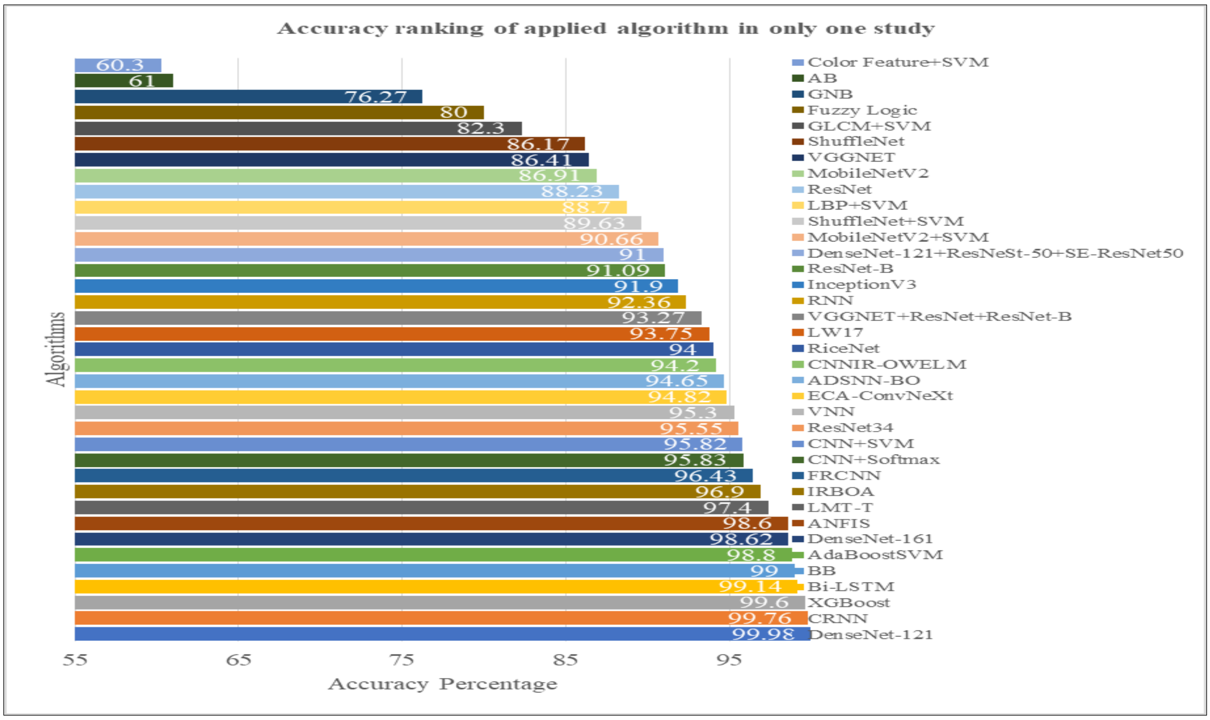

Figure 3 Accuracy ranking of applied algorithm in only one study

4.3. Analyzed learning algorithm models segmentation into their respective categories

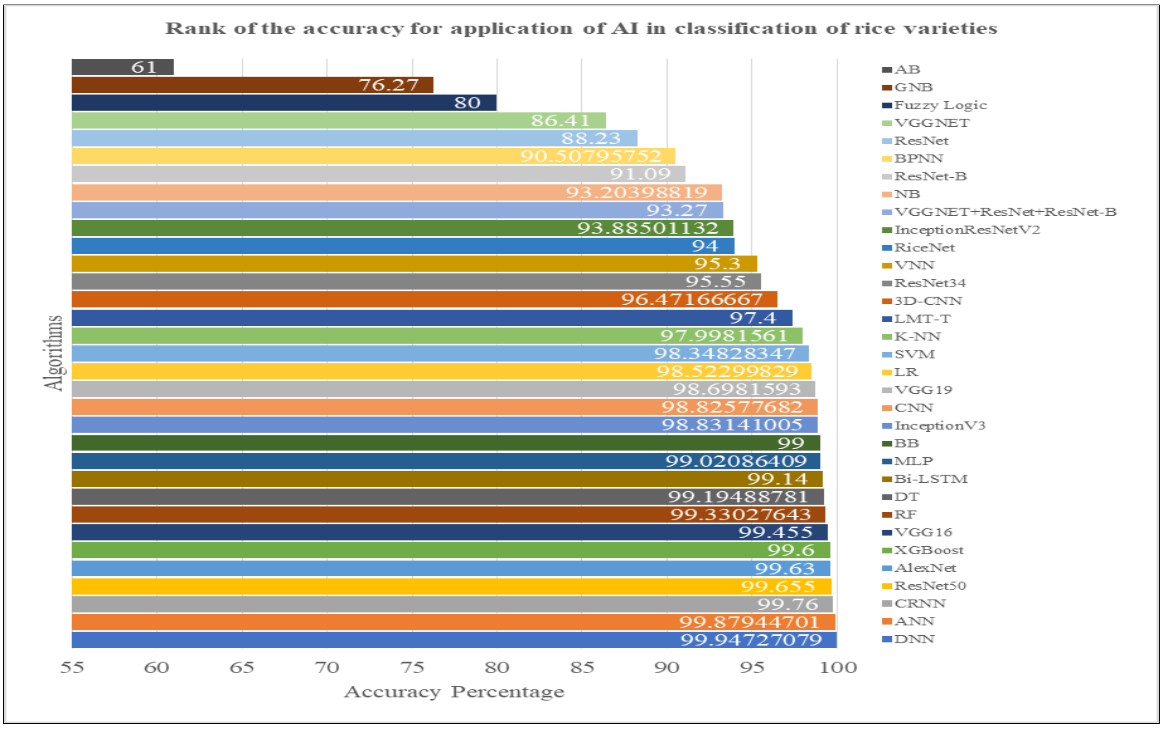

Figure 4 Rank of the accuracy for application of AI in classification of rice varieties

From the analyzed data it was observed that the studies related to rice production provide different purposes as rice production is a broad topic. The researchers decided that depending on the rice production category in which a study focuses, data will be segmented into categories: rice varieties, rice health/diseases, and rice quality or grading. The graphs provided below will present the rank of the accuracy for application of AI in classification of rice varieties (Figure 4), rice health and disease detection (Figure 5), and rice quality/grading (Figure 6). Segmentation of the data will provide more specific information regarding the efficiencies of application of AI in rice agriculture. The review would broaden knowledge and yield an exact ranking of the application of different learning algorithm models per rice production category that would explain which is best to use in a specific rice production.

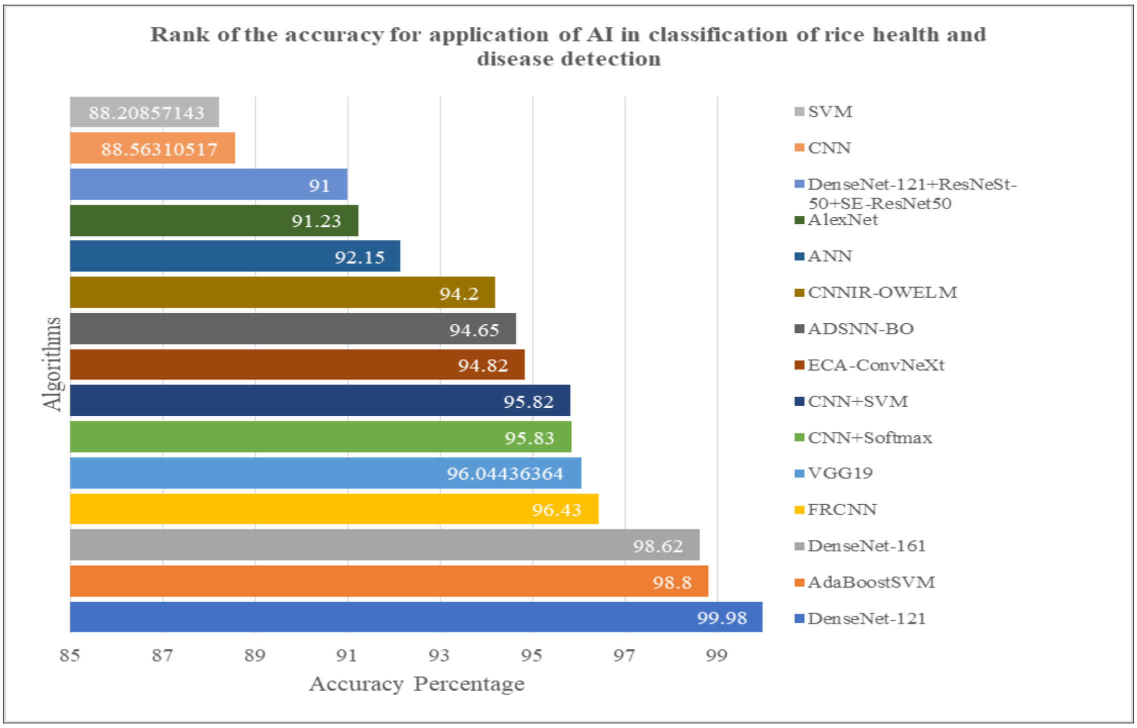

Figure 5 Rank of the accuracy for application of AI in rice health and disease detection

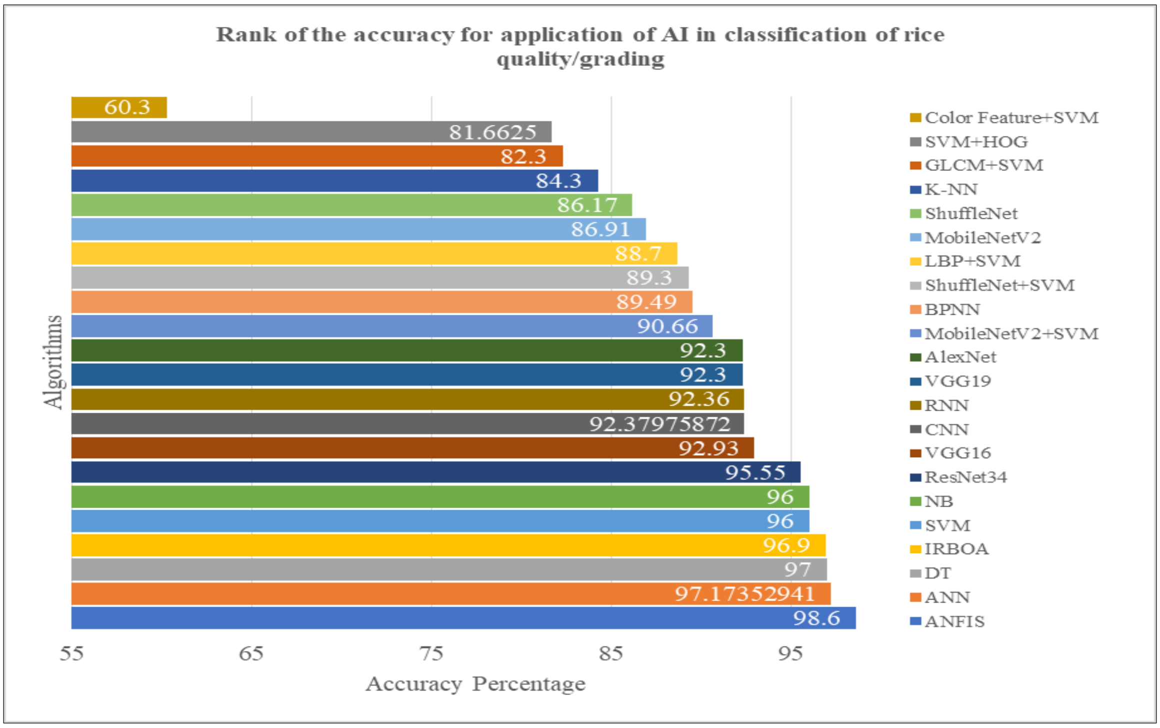

Figure 6 Rank of the accuracy for application of AI in rice quality/grading

5. Discussion

The result from the analyzed data of showing the overall average accuracy ranking of all collected learning algorithm models displayed (Figure 1) that the DenseNet-121 got the best accuracy percentage of all and in contrast Color Feature + SVM was the lowest. With a further learning after the overall ranking as the data were separated, considering if a learning algorithm has only one or more than one supporting study the results of ranking are shown below, respectively.

5.1. Accuracy ranking of applied algorithm in more than one study

In the analyzed data the lowest average accuracy percentage with more than one study was the SVM + HOG. Histogram of Oriented Gradients with Support Vector Machine (SVM + HOG) is a traditional image classification method which is proposed in 2005 by Dalal and Triggs [84]. In the study of Sethy et. al., SVM + HOG was included to be examined for grading the rice panicle blast which achieved an accuracy of 76% [45]. Moreover, this method was also used for rice quality classification obtaining an accuracy of 85.06%. Combining these studies which applied SVM + HOG to classification of rice properties, considering the number of data samples included, results an average accuracy percentage of 81.62%. This method was originally the basis of pedestrian detection in which HOG characterizes object appearance based on the information of local intensity gradients or edge directions and the combined feature vector will then be classified by SVM [84]. However, it should be pointed out that this traditional method contains simpler operations which leads to slow computational speed and its application to real-time system is limited due to that. With some modifications to the SVM + HOG or applying other algorithms may enhance the effectiveness of it.

Deep Neural Network (DNN) gained the highest accuracy percentage in all the learning algorithms applied in more than one supporting studies. A recent study about a pixel-based rice seed classification which implements DNN found that in high temperature grown rice seed HSI DNN can achieve an accuracy of 94.83% and the average accuracy in five different treatments at each exposure times and six different temperature treatment was 91% using DNN [30]. Another study conducted implementing DNN was for the classification of rice varieties. The study concluded that one of the classification successes was from the model of DNN with an accuracy of 99.95% which is one of the highest among the other models tested [43]. Summing up the existing studies that have been gathered in this review the result showed that the average accuracy percentage of DNN was 99.95%. In different areas of artificial intelligence, DNN has been successfully used in many machine learning applications, taking note that the multi-layer structure was the foundation architecture of DNN [85]. The more hidden layers and neurons, it will allow DNN's capacity to extract complex features leading to a better algorithm for accurate classification of DNN in some cases. The findings suggest that DNN would be a successful method for rice properties classification in rice production.

5.2. Accuracy ranking of applied algorithm in only one study

The traditional image classification method with the lowest accuracy in the analyzed data was Colour Feature + SVM, with an accuracy of 60.3% based on a single study [45]. Colour Feature + SVM refers to using colour features extracted from images along with a Support Vector Machine (SVM) classifier for image classification. SVM is a machine learning algorithm commonly used for classification tasks [84]. In the study by Sethy et al. [45], Colour Feature + SVM was one of the traditional image classification methods examined for grading rice panicle blast severity. It achieved an accuracy of only 60.3%, lower than more advanced methods like ShuffleNet [45]. This indicates that colour features alone are not robust enough for accurately discriminating between panicle blast severity levels. Other methods using more sophisticated feature extraction and learning algorithms were able to capture more meaningful features that helped improve classification accuracy significantly. Relying only on colour features limits the representational power of the model.

In the analyzed studies, the DenseNet-121 model achieved the highest accuracy among all learning algorithms, in a single study. DenseNet-121 is based on deep convolutional neural networks (DCNNs), which are a type of artificial neural network that utilizes deep learning. DCNNs have emerged as one of the most promising neural network architectures and now dominate nearly all recognition and detection tasks [87]. DCNNs are a specialized class of deep neural networks designed for processing grid-like topology data like images. Their architecture of convolutional, pooling and fully connected layers allows efficient feature extraction and learning from visual data [86]. By using DCNN, DenseNet-121 is able to effectively analyze images and perform recognition tasks with high accuracy of 99.98% [16]. The exceptional performance of DenseNet-121 highlights the capabilities of DCNN models for image classification.

5.3. The best learning algorithm model applied in classification of rice varieties, rice health and disease detection and rice quality

Classification of rice varieties takes the difference of each varieties features such as texture, shape, and color. With the help of classification machines, it would be easier to determine its qualities. In this rice production method, from the analyzed data it resulted that Deep Neural Network (DNN) achieved the highest average accuracy of 99.95% (Figure 4) in classification of rice varieties. In an existing study, DNN obtained a high classification success (99.95%) considering 75000 data set in classifying rice varieties because in large data sets, wide range of learning could be performed in this method [43]. This method is also effective in hyperspectral rice seed classification, more importantly, in high temperature grown rice seed HIS [30]. Considering the synthesized learnings, it is proven that DNN can be applied successfully in classification of rice varieties.

Ensuring rice health in rice production is essential to achieve the best quality of rice. Applying artificial intelligence in this field would improve the detection of the rice disease and evaluate the rice health. According to the analyzed data (Figure 4) DenseNet121 (Dense Convolutional Network) approach achieved the highest average accuracy (99.98%) in rice health and disease detection. More specifically, the supporting study that proves the efficiency of this method concludes that with purpose of classifying the nutrient deficiency of rice, an accuracy of 99.98% was obtained. The reason behind for the high-performance accuracy of DenseNet121 is that additional new layers were inserted, early stopping, model check points and five-fold cross validation was conducted [16].

Many instances that rice quality is not secured and not accurately graded accordingly to its respective class quality was put on sale have occurred due to several reasons one of it was lack of advancements in production. Adaptive Neuro-Fuzzy Inference System (ANFIS) which obtained the highest average accuracy percentage of 98.6% (Figure 5) in the field or rice grading outperformed other machine learning algorithms. This method accurately classified broke and whole grain to determine the quality of the rice. Surge of using advanced rice quality classifier has become a new research trend which gradually applies to the development of AI in agriculture.

6. Conclusion

This systematic review aimed at gathering recent artificial intelligence advancements in rice production. The goal is to analyze their performance accuracy for determining the most efficient learning algorithm models for future real-world applications. The findings showed that DenseNet121 deep learning architecture has the highest performance accuracy of 99.98% in all the reviewed articles. Specifically, this DenseNet121 also is the top algorithm for rice health and disease detection. The deep convolutional neural network allowed for a robust feature extraction and learning capability which is effective for classifying rice diseases. For the rice variety classification, Deep Neural Networks (DNNs) are the most accurate with a 99.95% performance accuracy. The multi-layer processing of DNNs allows for complex differentiation between rice varieties based on texture, shape, and color. In terms of rice quality and grading, the Adaptive Neuro-Fuzzy Inference System (ANFIS) is the top-performing learning algorithm model with 98.6% accuracy by discerning whole and broken grains.

The analysis showed that with greater dataset sizes, comes with greater algorithm accuracy across most studies. By using more training data, the learning algorithm models can have more performance accuracy. Overall, this review demonstrates the significance of artificial intelligence in automating and enhancing the various aspects of rice production. Although DenseNet121 and DNNs are already leading in performance, there is room for more accuracy and efficient rice variety classification, disease detection, and quality grading. These will be beneficial for improving crop yields of farmers, ensuring rice quality for consumers, and optimizing production. Expanding the evidence-base by evaluating more algorithms on larger standardized datasets is recommended. Some specific focus areas may include early disease prediction and integrating spectral imaging for a holistic view of rice properties. This will lead to more intelligent artificial intelligence, more sustainable rice production, and trusted rice agriculture practices.

Compliance with ethical standards

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Disclosure of conflict of interest

The authors report that there are no other competing interests to declare.

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