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A Survey on AI-Driven Bio-Inspired Algorithms in Agriculture

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Abstract
Bio-inspired algorithms are now considered to be highly effective computational methods for resolving difficult agricultural optimization issues. Inspired by natural processes like evolution, swarm intelligence, and neural systems, these algorithms have been widely used in agriculture. This work presents the comprehensive analysis of bio-inspired algorithms, such as, Ant Colony Optimization (ACO), Genetic Algorithms (GA), Particle Swarm Optimization (PSO), Artificial Bee Colony (ABC), Flower Pollination algorithm (FPA) focusing on their uses and performance in agricultural problem solving. To increasing the yields, the precision of Bio inspired algorithms (BIAs) reduced the possibility of failures in the application of fertilizer, pesticides, irrigation and crop monitoring. This study presents review of different Bio-Inspired Algorithms employed in agriculture and also compares various Bio-Inspired algorithms to make it more computationally useful for farming in the future.

Keywords: *Bio-inspired Algorithms (BIAs), Ant Colony Optimization (ACO), Particle Swarm Optimization (PSO), Artificial Bee Colony (ABC), Genetic Algorithms (GA).*

1. Introduction
Agricultural is essential to both economic stability and global security. Computational intelligence is becoming crucial for agricultural process optimization due to the growing demand for precision agriculture and sustainable farming methods [1]. Problem with traditional farming practices include pest infestations, climate variability, and resource inefficiency. Bio inspired algorithms offers solutions to these issues which are based on natural events. These algorithms simulate the behaviour of living organisms to addressing the challenging optimization problems. These algorithms are inspired by natural processes including evolution, swarm intelligence and biological adaption such as, Artificial Bee Colony, Ant Colony Optimization, Genetic Algorithms and Particle Swarm Optimization [2]. These algorithms have demonstrated potential in optimizing a number of agricultural aspects. The significance of bio inspired algorithms in smart agriculture has been further increased by their modern innovations such as, machine learning, remote sensing and Internet of Things (IoT). Predictive analytics, resource optimization and real time decision-making are made possible by these algorithms, which increase sustainability and efficiency. In Agriculture, the application of AI-powered BIAs has resulted in the creation of intelligent farming systems that maximize output while reducing resource waste. The PSO enhances soil analysis and crop planning, ACO improves pest detection and autonomous farming, Artificial Neural Network (ANN) enable precise yield predictions and disease diagnosis, and Genetic Algorithms optimize the breeding selection and irrigation scheduling [3]. By enabling farmers to make data-driven decisions, these approaches minimize the dependency on conventional farming methods, which frequently contribute resource inefficiency. The wide availability of graphical interfaces, which are perfect for computational modelling in smart farms, healthcare, and manufacturing, as well as advancements in computing technology, can be partially attributed to the widespread application of IoT, Deep Learning (DL), and Machine Learning

(ML) in agriculture. In this survey of BIAs applied in smart agriculture to analysing their functionalities and the role of AI in optimizing farming practices [4]. Different bio-inspired algorithms have been created using a variety of bio-inspiration. The two most popular types of algorithms are Swarm-based and Evolution-based, which receive the inspiration from the collective behaviour of animals and natural evolution, respectively. Even though the majority of current bio-inspired algorithms are come under these two categories. Evolutionary algorithms encompass three categories such as genetic algorithm, flower pollination algorithm, and paddy field algorithm. (Figure 1)

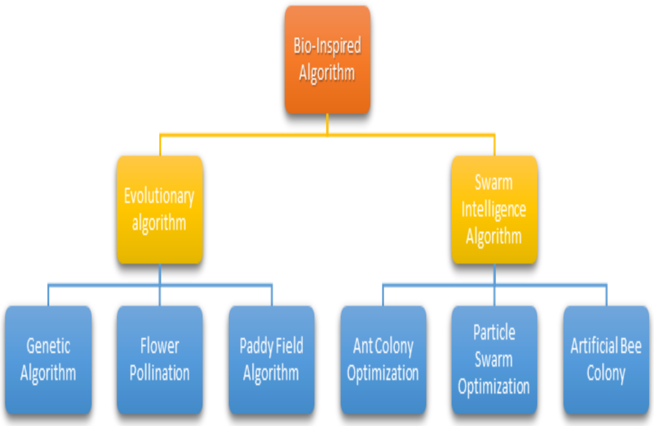

Figure 1 Classification of Bio-Inspired Algorithms

The swarm-based algorithm can be classified into three categories like Ant colony optimization, Artificial Bee Colony and particle swarm optimization [5]. These algorithms are categorized according to their biological inspiration source. The primary benefit of this classification algorithm is that, within a class of algorithms, the terms used to describe how the algorithms work is connected and generally remain constant. Classifications of bio-inspired algorithms are shown in the figure 1.

2. Literature Review

Bio-Inspired Algorithms in Agriculture, these algorithms use biological processes, including evolution, self-organization, and swarm intelligence, to solve complicated agricultural problems. They are extremely flexible and effective in addressing actual agricultural problems. In this paper, the algorithms are categorized according to their biological inspiration source. By simulating biological processes, these algorithms address difficult, practical agricultural problems like insect control, crop disease prediction, autonomous farming, and precision agriculture. A new phase of smart farming has emerged in agriculture through the integration of AI-driven Bio-inspired techniques, where automation and data-driven decision-making improve sustainability and productivity. Here are a few significant fields where BIAs can develop agriculture: predicting crop yield, managing irrigation and detecting pests and diseases.

2.1. Crop Yield Prediction

Huang et.al., have implemented in crop yield prediction, AI powered bio-inspired methods like Artificial Neural Network (ANN), Particle Swarm Optimization (PSO) and Genetic Algorithms are widely utilized. To predict crop performance, these methods have been used to enhance the accuracy. Artificial Neural Network has performed well in yield prediction, climate and remote sensing data. ANN models could forecast wheat production with an accuracy of more than 90%. In particularly, Genetic Algorithms (GA) optimizes the choice of input parameters, to ensure the specific characteristics are to be considered. GA algorithms improve the prediction process to increase the accuracy and computational cost [6]. This method has specifically used for large-scale farming. Additionally, PSO has been used to optimize yield prediction models by the fine-tuning of machine learning algorithm parameters. When predicting rice yield in a variety of climate situations, PSO-based models have been proven to perform better than conventional regression techniques. PSO flexibility makes it compatible with dynamic agricultural environments. Although the progress and issues with yield prediction models like as quality of data and computational complexity seem to be significant issues. In order to overcome these issues, hybrid strategies that integrate a number of bio-inspired algorithms with machine learning methods have showed potential. To increase forecast accuracy and

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ensure model adaptability across various agricultural environments, Artificial Neural Network can be integrated with GA and PSO [7]. Crop yield prediction models are getting more accurate by utilizing bio-inspired algorithms, which allows farmers to optimize the components and improve overall agricultural production [8]. The above models will be further enhanced by continuing AI-driven bio-inspired algorithms, which will support sustainable agricultural methods and global food security. The performance of BIAs in crop yield prediction can be shown in the (Table 1).

Table 1 Evaluation of Bio-Inspired Algorithm Performance in Crop Yield Prediction

Algorithm	Accuracy (%)	Computational complexity	Adaptability to different crops
ANN	96.4	High	High
GA	92.1	Medium	Medium
PSO	94.5	Fast	High
ACO	90.8	Slow	Medium
Hybrid Models (ANN+ PSO)	97.6	High	Very High

2.2. Irrigation Management

Mahidar et.al., have been suggested that one of the major problems facing agriculture is water constraint, which requiring for effective irrigation management. Water distribution has been optimized using PSO and ACO to adapt current weather and soil moisture levels. These algorithms offer efficient irrigation, minimizing water waste while preserving crop health. By determining the most efficient pesticide application techniques, GA maximizes pest control. By doing this, the environmental impact is reduced and the pests are effectively controlled. ACO is a technique used in autonomously pest monitoring systems where robotics and drone systems locate pest hotspots and determine the best pathways for applying pesticides by imitating the behaviors of Ants [9]. PSO has been used in real-time pest prediction models, which forecast pest infestation by analyzing weather, crop type and pest infestation history. Modern agriculture could shift to more sustainable pest control practices by including these bio-inspired approaches, which will improve crop health and minimize dependency on toxic pesticides. AI-driven pest identification enhances environmental friendly pest management techniques, which not only increases efficiency but also supports sustainable agriculture practices [10].

2.3. Pest and Disease Detection

Chrysanthos Maraveas et. al., have proposed to reduce the crop loss, early detection of pests and plant disease is essential. Artificial Neural Network can handle complicated image data and identify minor changes in plant symptoms have led to its widespread application in disease detection. ANN models trained on large datasets of plant leaf images have been shown to attain classification accuracies above 95% for identifying diseases like bacterial leaf blight rice and powdery mildew in wheat. Utilizing image processing techniques, Convolutional Neural Networks (CNN), a specialized type of ANN, proved especially useful for understanding patterns on plant leaves. CNN models accurately identify a variety of plant disease by extracting hierarchical features from leaf images. CNN based disease detection systems perform better that traditional machine learning models, with higher accuracy and faster processing times [13]. Support Vector Machine (SVM) has been used to classify diseases. Using extracted properties like color, texture, and form, SVM models categorize

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plants as either healthy or sick using kernel functions. Compared to deep learning techniques, SVM classifiers can reliably identify diseases with less training data [11]. Moreover, to improve feature selection and classification performance, swarm intelligence techniques like ACO and PSO have been combined with machine learning models. These hybrid approaches optimize the selection of significant image feature, lowering computational complexity while increasing disease detection accuracy. Although these developments, issues with model generalization, environmental variability, and dataset availability continue to be major obstacles to the widespread use of AI-driven diseases detection systems. By improving early intervention, minimizing pesticide use and increasing crop resilience, the use of bio-inspired algorithms in disease detection has changed traditional methods of agriculture [12]. AI-driven methods have huge potential to transform plant health management and ensure global food security as they improve further.

3. Results and Discussion

In precision agriculture, the BIAs can apply in various aspects including, pest detection, crop yield prediction and irrigation management. These algorithms have unique benefits, which influence their suitability for different agricultural tasks. Genetic Algorithms is frequently used to solve optimization issues like crop breeding and irrigation scheduling. For real-time optimization tasks like resource allocation and precision planting, Particle Swarm Optimization (PSO) is effective. ACO is frequently used in path optimization for pest control and self-sufficient farming equipment. Hybrid models that combine several algorithms typically provide better performance by overcoming of shortcomings of each individual approach. The combination of PSO and ANN increases the accuracy, which makes it suitable for large-scale farming applications. The comparison of different BIAs is shown in Table 2

Table 2 Comparative Analysis of Bio-Inspired Algorithms

Algorithm	Application	Advantages	Challenges
GA	Irrigation, Breeding Selection	Adaptive, Robust	High Computational Cost
PSO	Soil Quality, Precision Seeding	Fast Convergence	Requires Parameter Tuning
ACO	Pest Control, Supply Chain	Efficient Path Finding	Complex Implementation
ABC	Pollination, Precision Fertilization	Energy-Efficient	Sensitive to Colony Size
Hybrid Models (ANN + PSO)	Yield Optimization, Precision Planting	Effective in Multi-Objective Problems	Requires Parameter Tuning

Conclusion

Smart agriculture has been transformed by the use of AI-driven bio-inspired algorithms, which optimize irrigation management, insect detection, and crop production prediction. According to the results, hybrid AI models perform better than traditional AI models, which make them appropriate for use in daily life. However, the hybrid models (ANN+PSO) can be implemented on a large scale, the issues like data dependency and computational complexity must be resolved. Through the use of several bio-inspired techniques, agricultural efficiency and precision can be improved. In future, in order to improve the real-time agricultural monitoring through the use of IoT sensors and AI-powered decision-making. AI-driven bio-inspired computing can make an important contribution to the future of precision and sustainable agriculture by resolving these issues and encouraging innovation.

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