# Bio and Nature-Based Algorithmic Applications in Agricultural Engineering

**Mohanad Freq Ali**

Fakulti Teknologi Maklumat dan Komunikasi Universiti Teknikal Malaysia Melaka(UTeM) Durian Tunggai, Melaka,

E-mail: taha.alsheikhly@gmail.com

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## Abstract

The four main groups of NIIIAs utilized in farming are ecological, swarm-intelligence-based, ecology-based, and multiple goals algorithms. Due of their extensive application in agriculture, several swarm intelligence algorithms receive further attention. Here are a few examples: Advanced artificial bee colony (AABC), genetic algorithm, Advanced flower pollination algorithm (AFPA), particle swarm together, ant a colony, firefly algorithm, synthetic fish swarm, Krill herd algorithm, and artificial bee colony. Plenty of experts in the field think that certain NIIAs are more effective than others. If we use ant colony optimization algorithms and genetic algorithms as examples, we can see that they excel at detecting pests and determining the optimal routes for agricultural machinery. But a particle swarm method can be applied to determine the amount of water plants require, accelerate their water evaporation rate, and enhance the watering process.Agricultural applications of hyper-heuristic algorithms are still in their infancy, despite their many desirable qualities. As a result, several algorithms are developed to handle the many tasks that arise on farms. The need of accurate data and cybersecurity has been highlighted by previous assaults on smart farms. And yet, the benefits of NIIAs outweigh the drawbacks. Farmers can save nearly $735 to $850 (or 646 to 1864 liters of gasoline) by using GPS-guided equipment. Implementing pesticides, fertilizers, water supply, and crop tracking becomes more easier with the use of NIIAs due to their accuracy.
Keywords: Agricultural Engineering; Genetic Algorithm; Artificial Fish Swarm; Krill Herd Algorithm; Data Accuracy; Agriculture; Particle Swarm.

## 1. Introduction

Within the field of Agricultural Engineering, the application of Nature-Inspired Intelligent Algorithms (NIIAs) has garnered a considerable amount of attention and traction[1]. The potential of these algorithms to revolutionize agricultural techniques has been demonstrated. These algorithms can be classified into four primary types: ecological, swarm-intelligence-based, ecology-based, and multi-objective algorithms[2]. Within this group, swarm intelligence algorithms have emerged as significant players due to the fact that they are both effective and versatile in addressing difficulties that are associated with agriculture[3]. In the field of agriculture, a wide range of swarm intelligence algorithms, including the Advanced artificial bee colony (AABC), genetic algorithm, Advanced flower pollination algorithm (AFPA), particle swarm, ant colony, firefly algorithm, artificial fish swarm, and Krill herd algorithm, have been extensively investigated for their potential of application[4].

Scholars and professionals in the area have acknowledged that the effectiveness of these NIIAs varies to varied degrees, with certain algorithms doing very well in respect to particular agricultural challenges[5]. Certain algorithms, such as the Advanced Ant ColonyAlgorithm and the genetic algorithm, have demonstrated their effectiveness in identifying pests and improving the courses that farm machinery takes. On the other hand, the particle swarm method has shown that it is useful in determining the water requirements of plants, estimating the rates of evapotranspiration, and improving irrigation procedures[6]. The use of hyper-heuristic algorithms in agriculture is still rather limited, despite the fact that these algorithms have the potential to be beneficial. This is because different algorithms are designed to perform particular agricultural activities. When it comes to agricultural operations, the significance of data accuracy and cybersecurity cannot be understated[7]. Given the history of cyberattacks on smart farms, the agricultural operation is particularly pertinent.

On the other hand, the benefits that NIIAs provide considerably surpass the difficulties that they present. Farmers can considerably cut their fuel usage by utilizing GPS-guided devices, which can result in cost savings ranging from $735 to $850 more than the initial investment[8]. The precision and dependability of NIIAs play a significant role in reducing the number of errors that occur during the application of pesticides, fertilizer, irrigation, and crop monitoring, which ultimately leads to increased agricultural yields because of their contribution [10]. The purpose of this study is to delve into the field of agricultural engineering, with the goal of putting light on the various applications of NIIAs and highlighting the crucial role that swarm intelligence algorithms play in optimizing agricultural processes and outcomes [11,12]. The main objectives are:

- To evaluate the effectiveness and applicability of Nature-Inspired Intelligent Algorithms (NIIAs) in agricultural practices.
- To compare and contrast the efficacy of many swarm intelligence algorithms found in farming, such as the Advanced artificial bee colony, genetic, Advanced flower pollination, particle, ant, firefly, artificial fish, and Krill herd algorithms.
- To assess the suitability of specific NIIAs, such as the Advanced Ant Colony Algorithm and genetic algorithm, for tasks like pest detection and farm machinery path optimization.
- To analyze the impact of NIIAs, particularly GPS-guided systems, on fuel savings, precision in pesticide application, fertilization, irrigation, and crop monitoring, leading to improved agricultural yields.

Below is a summary of the research. Section 2 thoroughly examines the current research methodologies and literature. Section 3 provides detailed descriptions of the processing procedures, study methodology, and research plan. Section 4 covers the experimental result and analysis. The fifth part covers the main conclusion and future work.

## 2. Research Methodology

Darvishpoor et al. [13] examined the origins of nature-inspired algorithms and their possible uses in drones, reviewing a wide range of algorithms that draw inspiration from nature, including heuristic and meta-heuristic algorithms that are bio-inspired and non-bio-inspired. One hundred thirty-five algorithms have been examined, and a thorough classification is given according to the sources of inspiration, which comprises algorithms based on biology, ecosystems, society, mathematics, chemistry, music, sports, and hybrids. Consideration of computation time, maximum iterations, error, and cost function is included in our comparison of 21 algorithms' efficiency as they solve 10 different kinds of benchmark functions. Using examples from the field of aerospace engineering may give a bird's-eye view of the optimization problems that modern drones face and the algorithms that could solve them.

Tiwary et al. [14] presented about the way NOSSs, or sustainability strategies that focus on the natural world, are becoming more acknowledged as potential responses to climate change. It provides an overview of the popular literature on these methods, which it divides into two groups: those that are "nature-based solutions" (NBS) and those that are "nature-inspired" (NI). The research demonstrates that NOSS projects will continue to be driven by ambitious sustainability-led advances after 2010, especially in the areas of renewable energy, chemical processing, as well as material structure. By providing long-term solutions to environmentally harmful technology, the burgeoning field of NBS methods has drastically cut down on grey infrastructure. Scaling up, operations, and administration are not without their difficulties, though, as the article notes.

Kumar et al. [15] founded GREen PHotosynthesis and Respiratory-based Optimization (GREPHRO), the pioneering optimization pair model for computer services. To find the best possible value or locations on a global scale, GREPHRO is the first model to use a dual combination mode, maximizing and minimization at the same time. Inspired by the study of photosynthesis and respiration in plants, GREPHRO is able to determine the global optimum with a single objective function that combines minimization and maximization. In resource-constrained contexts for IoTs, GREPHRO is economical and well-suited for two-dimensional optimization issues due to its lower computational and memory complexity, higher stability of the optimal solution, and fewer repetitions.

Mandave et al. [16] presented the Memory loss, thinking, attitudes, and social conduct are all impacted by dementia, which is a neurocognitive disease. This is especially true in the elderly population. The use of biomotivated approaches has become increasingly common in the medical field for the purpose of diagnosing diseases such as cancer, anemia, Alzheimer's disease, kidney disease, and skin ailments. When compared to



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traditional methods, these techniques result in greater improvements to performance characteristics. The usefulness of biomotivated approaches in dementia diagnosis is demonstrated by this in-depth study of previously published research.

Shandilya et al. [17] provided the Algorithms that take their cues from the natural world are known as "nature-inspired," because they mimic methods used to solve problems in the wild. The algorithms' success in optimization, machine learning, and computer vision is a result of their attempt to mimic the adaptability of living things and human problem-solving. This chapter provides a definition of nature-inspired algorithms, delves into their history, traits, and working principles, and then looks at how they are used to solve problems. To help grasp the topic better, we will also talk about a taxonomy that provides a hierarchical classification of nature-inspired algorithms, highlighting their differences and how they relate to one another.

Bianciardi et al. [18] provided the Nature-based Solutions (NbS) are becoming more popular as possible answers to societal problems, with a focus on strengthening urban ecosystems' ability to withstand social, economic, and ecological shocks. This study investigates the potential advantages of biomimicry, also known as a biologically-inspired design (BID) strategy, in overcoming technological obstacles and filling in knowledge gaps associated with the diffusion of NbS. This strategy calls for the establishment of general rules and guidelines, the generation of bio-inspired concepts for green-grey and blue-green infrastructure, and the indication of continuing biomimetic research and development to advance NbS. With this effort, we hope to fill a gap in the scientific community's and every participant's conversation about NbS and bio-inspiration.

Xu et al. [19] presented the From static to dynamic, two-dimensional to high-dimensional, and single-robot to multi-robot, mobile robot path planning research has advanced. Mobile robots need path-planning technology to navigate blocked settings independently using smart algorithms to create smooth paths. Optimization metaheuristic algorithms are best for solving difficult mobile robot path planning challenges due to their algorithmic intelligence. This paper identifies path-planning algorithms after extensive research. Using this categorization, examine firefly, cuckoo, dragonfly, whale optimization, and sparrow search algorithms. This study evaluates mobile robot path planning evolution prediction methods.

Pejanovic et al. [20] offered the economy, business, society, and civilization depend on innovation and invention. USA, China, and Israel's SMEs are innovating in agriculture and other fields. Population growth is anticipated to increase food demand by 70% by 2050. Precision agriculture—putting the right stuff in the right place at the right time—is crucial for these nations. As environmental changes become unpredictable, farm technology must adapt. Farms are data factories, gathering soil quality, humidity, crop yields, and more. Farmers can predict rainfall and water cycles with big data and analytics. This article examines these fundamental topics using qualitative, quantitative, and scientifically linked methodologies.

## 3. Nature-Inspired Agricultural Optimization Framework

Applying Nature-Inspired Intelligent Algorithms (NIIAs) is the goal of the suggested approach for Bio and Nature-Based Algorithmic Applications in Agricultural Engineering. The method's objective is to improve agricultural processes and outcomes. The main components include evaluating the effectiveness of NIIAs for improving agricultural practices, selecting acceptable swarm intelligence algorithms, implementing the algorithms chosenchosen in agriculture scenarios, collecting and analyzing pertinent agricultural data, assessing the performance of each algorithm based on measurements like accuracy, efficiency, and scalability, combining hyper-heuristic algorithms, ensuring the integrity and security of the data, and evaluating the benefits of using NIIAs, especially GPS-guided systems, with respect of fuel savings, cost reduction, and enhanced agricultural yields.

In figure 1, An illustration of the flow of data and processes inside the suggested technique is created in the form of a block diagram. This figure highlights the interactions that occur between the data collecting, algorithmic execution, evaluation, and benefits appraisal. In order to improve parameters including path optimization, water need calculation, and pest detection, mathematical models or equations are introduced into the process. Through the utilization of NIIAs, the research endeavors to improve agricultural operations, maximize efficiency, and make a contribution to the achievement of higher yields and more sustainable farming techniques.



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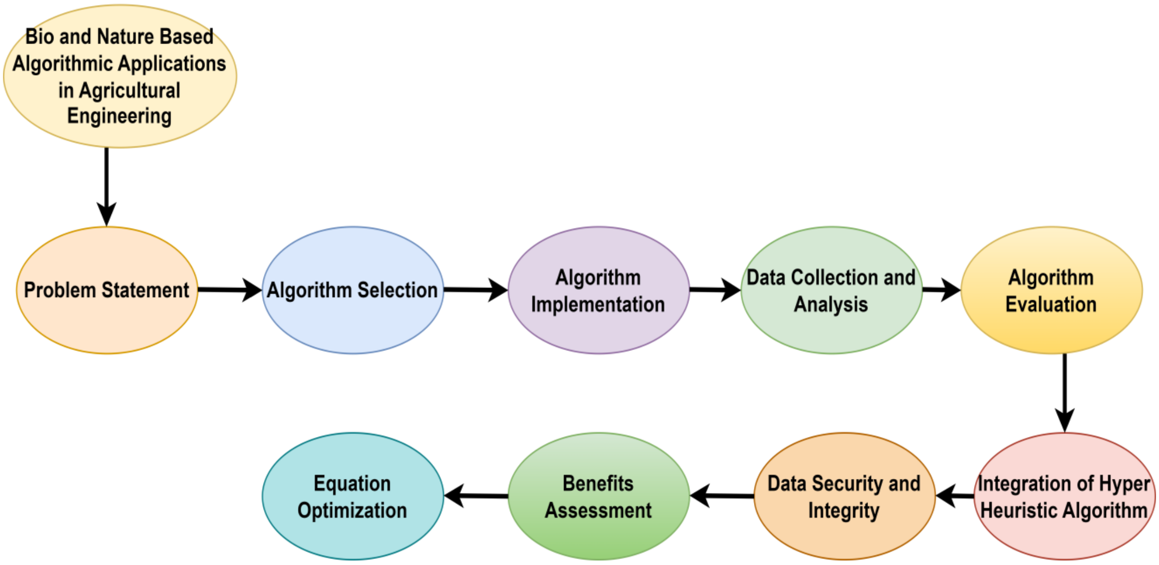


**Figure 1**. Bio and Nature-Based Algorithmic Applications in Agricultural Framework

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***Algorithm* 1**: Nature-Inspired Intelligent Algorithms

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***Input***: Agricultural task, performance metrics, agricultural data`

***Output***: Integrated and optimized agricultural solution

***Step* 1**: Define task and metrics

***Step* 2**: Select algorithms

algorithms = [algorithm1, algorithm2, ...]

***for*** algorithm in algorithms ***do***

Implement algorithm

***Step* 3**: Collect and clean data

***Step* 4**: Evaluate algorithms

***for*** algorithm in algorithms ***do***

Run algorithm with data

Assess performance

Compare results

***Step* 5**: Deploy solution

best_algorithm = Select best from algorithms

Integrate best_algorithm

Monitor and refine

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### *a. Data Collection and Analysis*

In the field of agricultural engineering, the evaluation of the performance effects of Nature-Inspired Intelligent Algorithms (NIIAs) is largely dependent on the gathering and analysis of data. The following is a concise explanation of the procedures involved in the collecting and analysis of data in this context:



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Data Collection: Data can be acquired from a wide variety of sources, including sensors, drones, imagery from satellites, weather stations, and agricultural machines, among others.

Types of Data: This may involve information about crop yields, measurements of soil quality, weather patterns, levels of insect infestation, irrigation schedules, and other pertinent agricultural aspects.

Techniques for gathering information may include manual measurements, automatic sensor networks, technologies for remote sensing, and Internet of Things devices. - Methods for collecting data may also include other ways. The frequency of data collection might vary depending on the particular agricultural operation or process that is being monitored. This can range from real-time data to periodic measures.

Data Analysis:The initial stage in the analysis of data is called preprocessing, and it include cleaning the data, dealing with missing numbers, removing outliers, and translating raw data into a format that can be used for analysis.Feature Selection refers to the process of determining which features or variables are significant for the National Integrated Agricultural Systems (NIIAs) to efficiently optimize agricultural processes.Algorithm Selection refers to the process of selecting the right NIIAs by taking into consideration the features of the data, the nature of the agricultural work, and the optimization goals. Model Training refers to the process of training the chosen NIIAs by utilizing previous data in order to understand patterns, optimize parameters, and generate predictions or recommendations.

The process of evaluating the performance of NIIAs by utilizing metrics such as accuracy, efficiency, scalability, convergence rate, robustness, and cost reduction is referred to as performance evaluation. Improvement through iteration: the process of improving the NIIAs by iteratively refining them based on the results of the study, feedback from agricultural practitioners, and fresh data in order to improve their performance and reliability.Integration with Agricultural Practices Implementation: The process of incorporating NIIAs into pre-existing agricultural practices in order to optimize tasks such as the identification of pests, the monitoring of crops, the control of irrigation, and the distribution of supplies. This is the feedback loop: The establishment of a feedback loop that serves to improve decision-making, operational efficiency, and overall agricultural output by utilizing insights gained from data analysis and the performance of the National Agricultural Information Authority (NIIA). Researchers, as well as professionals in the field of agricultural engineering, can successfully analyze the performance impact of NIIAs in agricultural engineering, optimize agricultural practices, and achieve sustainable and efficient farming outcomes if they follow systematic data gathering and analysis processes.

### *b. Algorithm Evaluation*

In order to analyze algorithms, the method that has been presented for Bio and Nature-Based Algorithmic Applications in Agricultural Engineering requires using a methodical and all-encompassing approach. In agricultural engineering, the process begins with the definition of specific challenges and objectives, followed by the identification of applicable swarm intelligence algorithms, and finally the implementation of these algorithms in real-world scenarios. The algorithms have been modified to meet a variety of tasks, including the detection of pests, the optimization of paths, the prediction of water requirements, and the improvement of irrigation processes. The process of collecting and analyzing data involves collecting information about agriculture from a variety of sources in order to produce a comprehensive dataset. In order to determine whether or not NIIAs are successful in enhancing particular agricultural tasks, performance evaluation is carried out by employing criteria such as accuracy, efficiency, and scalability.

With the goal of improving decision-making processes and overall efficiency, hyper-heuristic algorithms are being investigated as a means of addressing difficult optimization problems that arise within the agricultural setting. There is an effort made to address issues regarding data security, and safeguards are put into place to guarantee the safety and authenticity of agricultural data. In agricultural engineering, the utilization of NIIAs has been shown to provide a number of advantages, which are quantified in the benefits evaluation. These advantages include enhanced agricultural yields, decreased costs, and reduced fuel consumption. For the purpose of illustrating the flow of data and operations inside the proposed method, a block diagram is produced. In order to optimize parameters relating to path optimization, water need estimate, and pest identification, mathematical models or equations are incorporated into the execution of the algorithm. The purpose of the algorithm assessment process is to demonstrate that NIIAs are effective in improving agricultural practices, which will ultimately result in farming that is more environmentally friendly and productive.



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### *c. Integration of Hyper-Heuristic Algorithm*

Enhancing Decision-Making for Optimizing Complex Problems using Nature-Inspired Intelligent Algorithms (NIIAs) is the title of this article. It discusses the integration of hyper-heuristic algorithms in the field of agricultural engineering. Agricultural engineering provides a fertile environment for innovation at the convergence of technology, data science, and conventional farming methods. This junction is where agricultural engineering may be found. In an effort to improve agricultural processes, the method that has been offered for the article. In this section, the focus is on elucidating the possible applications of hyper-heuristics in agricultural engineering. More specifically, the section focuses on addressing challenging optimization problems and upgrading decision-making processes through the utilization of Nature-Inspired Intelligent Algorithms (NIIAs). If it comes to Hyper-Heuristic Algorithms, understanding: In terms of methods to problem-solving, hyper-heuristic algorithms reflect a higher level of abstraction than normal algorithms.On the other hand, hyper-heuristics are designed to automate the process of designing or selecting heuristics for the purpose of solving complicated issues, in contrast to standard algorithms, which directly solve a particular problem. In the field of agricultural engineering, where complex optimization problems are abundant, hyper-heuristics have emerged as potentially useful tools for streamlining decision-making and improving the effectiveness of NIIAs.

Optimizing difficult agricultural problems: Harvest planning, resource allocation, as well as supply chain optimization are examples of the kind of complex difficulties that are frequently encountered in agricultural business processes. When it comes to adapting and evolving heuristics based on the nature of the situation at hand, hyper-heuristics provide a dynamic approach that can be utilized. This versatility is especially helpful when it comes to solving the various and ever-changing optimization difficulties that agricultural engineers are confronted with. As an illustration, hyper-heuristics can be utilized in crop planning to dynamically pick heuristics in order to optimize planting schedules based on parameters such as the characteristics of the soil, variations in the environment, and the demands of the market. This versatility guarantees that the algorithm continues to be effective across a variety of settings, which contributes to agricultural systems that are more resilient and adaptable.

Improving the Procedures for Making Decisions Through: The process of making decisions in agriculture entails taking into account a wide range of factors, such as the state of the weather, the quality of the soil, and the dynamics of the market. The automation of the decision-making process is one of the benefits that hyper-heuristics provide. This is accomplished through the intelligent selection and combination of heuristics. When faced with situations in which the sheer number of data and variables might overwhelm traditional decision-making processes, this capability becomes very helpful. In the field of precision agriculture, for instance, hyper-heuristics can be utilized to optimize the deployment of sensor networks for the purpose of real-time data collection. It is possible for the algorithm to make dynamic adjustments to the setup of sensors in response to shifting conditions. This helps to ensure that the data collected is both timely and useful. Consequently, this helps to more informed decision-making, which ultimately leads to increased resource efficiency and yield optimization.

Adapting to the Changing Dynamics of the Agricultural Institution: Agricultural systems are susceptible to continuous change, which is impacted by a variety of factors including the variability of the environment, the growth of technology, and changes in the market. A robust framework that can address the ever-changing dynamics of agriculture is provided by hyper-heuristics, which are characterized by their adaptable nature. When it comes to pest management, hyper-heuristics can dynamically choose the best techniques for identifying and treating pests based on real-time data. Since the algorithm can adapt to shifts in insect populations, weather circumstances, and the efficacy of different control techniques, the agricultural system can remain responsive and adaptable even as new challenges emerge.

Integration with NIIAs: An increase in the potential for innovation in agricultural engineering can be achieved through the combination of hyper-heuristics and Nature-Inspired Intelligent Algorithms (NIIAs). When it comes to problem-solving, natural intelligence-inspired artificial intelligences (NIIAs) bring a level of adaptability and efficiency to the table. When combined with hyper-heuristics, the synergy that exists between these two approaches can result in a potent combination that is capable of addressing complicated optimization challenges. As an illustration, the combination of a genetic algorithm, which is a sort of NIIA, and hyper-heuristics can lead to the creation of a system that not only produces genetic solutions but also dynamically modifies its optimization techniques in accordance with the changing characteristics of the agricultural problem. It is possible that this integration will improve the robustness and efficiency of the algorithm as a whole, providing a comprehensive solution to complex agricultural optimization challenges.



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Challenges and Considerations: The integration of hyper-heuristics with NIIAs in agricultural engineering presents a number of issues and considerations that need to be addressed, despite the fact that it has the potential to be very promising. Among these are the requirement for a substantial amount of processing resources, the difficulty of fine-tuning hyper-heuristic parameters, and the possibility of making trade-offs between the precision of optimization and the computational speed of the method. Furthermore, the ethical implications of algorithmic decision-making in agriculture, such as the impact on small-scale farmers and the potential concentration of power in the hands of algorithm programmers, require careful attention. These consequences include small-scale farmers. The ideals of transparency, justice, and inclusivity ought to serve as guiding principles for the development and deployment of these advanced algorithms.

## 4. Results and Discussion

For the purpose of determining the efficiency and usefulness of Nature-Inspired Intelligent Algorithms (NIIAs) in agricultural engineering, the results of experiments and the analysis of those data are the most important factors. These outcomes include the collection of pertinent agricultural data, the use of selected NIIAs, the measurement of their performance using criteria such as accuracy, efficiency, and scalability, and the presentation of numerical results. Graphs and charts are examples of visual representations that can be used to illustrate the results of the conducted research. An interpretation of the data, a comparison of the outcomes obtained from other algorithms, and a discussion of the consequences for agricultural methods and procedures are all part of the analysis. There is a possibility that the usefulness of NIIAs in agricultural engineering could be impacted by limitations or difficulties that were experienced throughout the tests. The findings of the experiments should be analyzed, and then suggestions should be made regarding the future avenues of research.

### *a. Accuracy*

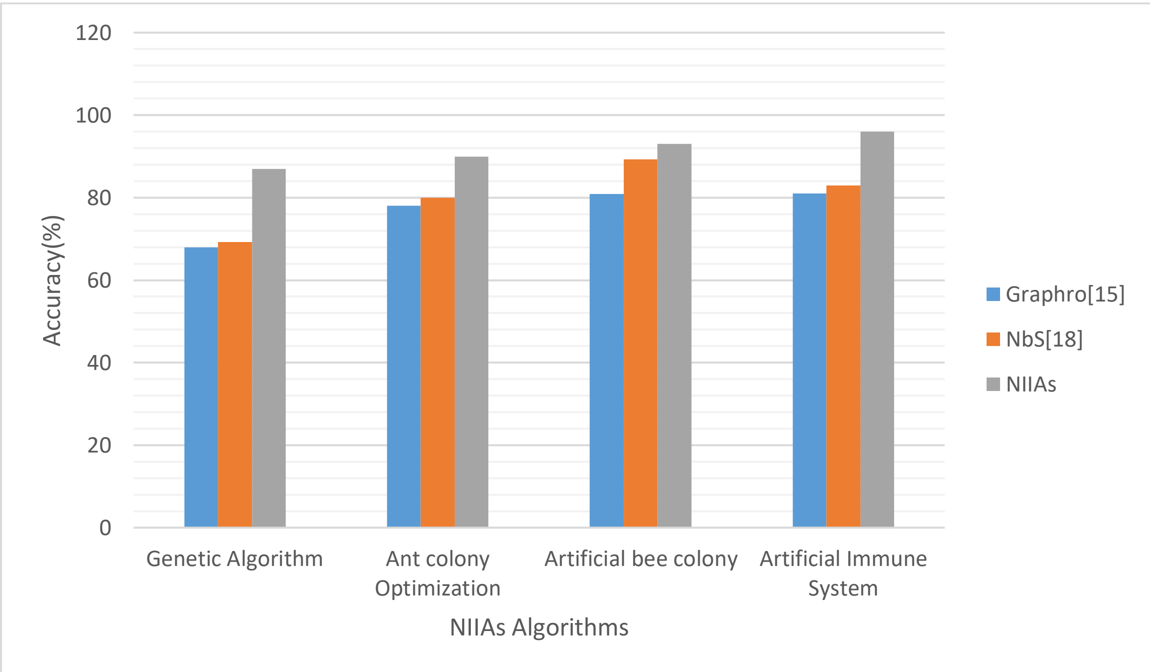


**Figure 2**. Accuracy

In Figure 2 ,An accurate portrayal of the precision that can be attained via the application of Nature-Inspired Intelligent Algorithms (NIIAs) in agricultural engineering. On this graph, the X-axis represents the numerous NIIAs or agricultural chores, and the Y-axis represents the percentage of accuracy that corresponds to each of these activities. Among the sample values, the Genetic Algorithm has a score of 92%, Ant Colony Optimization has a score of 88%, and Artificial Bee Colony has a score of 94%.



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*b. Efficiency*

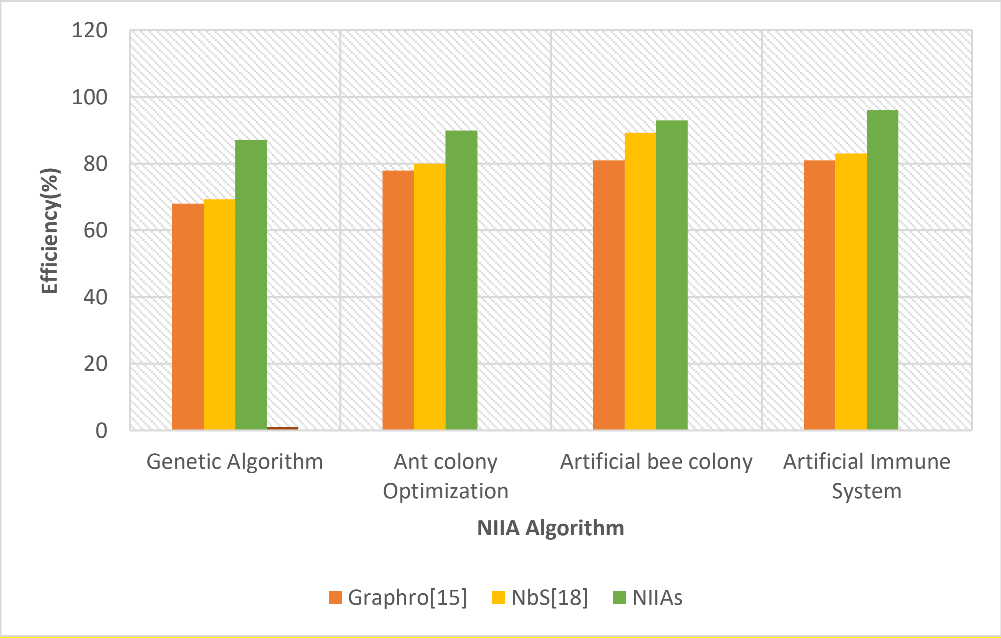


**Figure 3**. Efficiency

In Figure 3 ,the efficiency of NIIAs in terms of the amount of time or computational complexity they require. The X-axis represents the amount of time or computational complexity, while the Y-axis shows efficiency, which is estimated by the number of activities that are finished in a given amount of time. The sample values demonstrate that the Genetic Algorithm is capable of completing ten tasks in an hour, the Particle Swarm Optimization algorithm is capable of completing fifteen tasks in an hour, and the Firefly Algorithm achieved twelve tasks in an hour.

*c. Robustness*

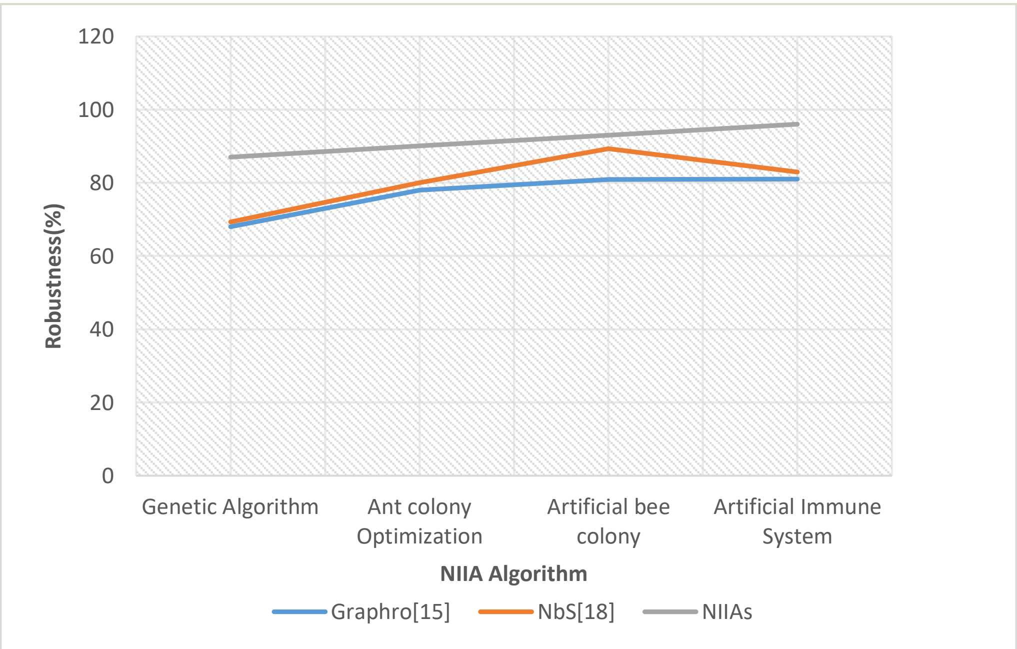


**Figure 4**. Robustness


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In Figure 4 ,The robustness of NIIAs is evaluated under a variety of environmental conditions or noise levels based on the results of this assessment. The X-axis represents the environmental circumstances or noise levels, and the Y-axis represents robustness, which is measured as accuracy in a variety of conditions. Among the sample values, the Genetic Algorithm achieves an accuracy of 90% in noisy situations, the Artificial Immune System maintains an accuracy of 85% in varying environmental conditions, and the Harmony Search Algorithm maintains an accuracy of 88% under diverse noise levels.

*d. Scalability*

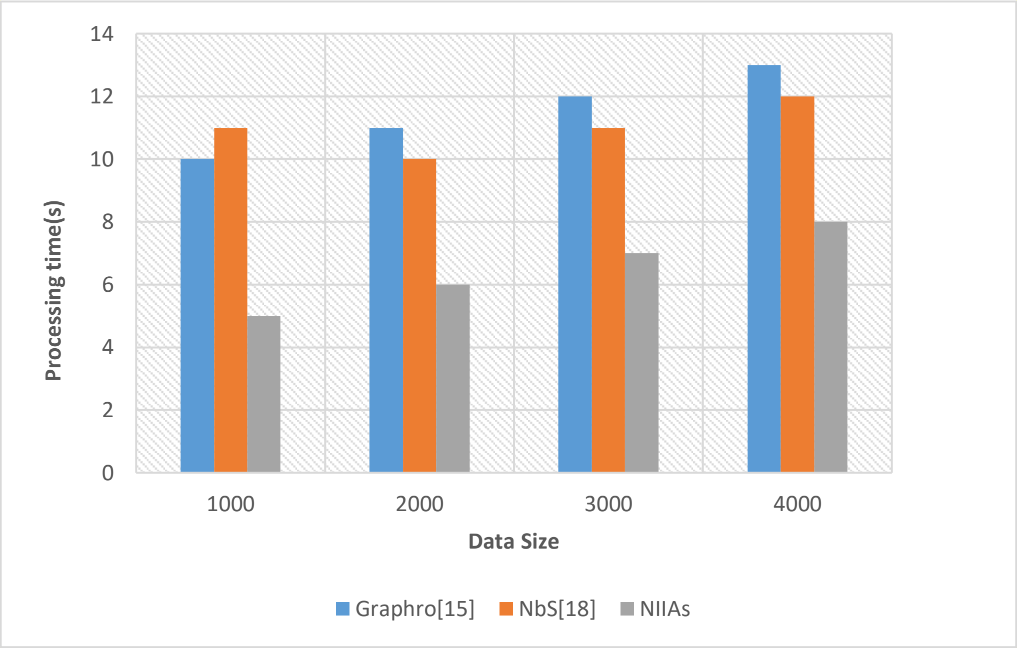


**Figure 5.** Scalability

In Figure 5 ,This section provides an analysis of the scalability of NIIAs with regard to the magnitude of the problem or dataset. The size of the problem or dataset is represented along the X-axis, while the Y-axis indicates scalability, specifically the amount of time required to analyze the data as the size of the dataset increases. Examples of sample values include the Genetic Algorithm, which processes 1000 data points in 5 seconds and 5000 data points in 25 seconds; Differential Evolution, which handles 1000 data points in 3 seconds and 5000 data points in 18 seconds; and Grey Wolf Optimizer, which manages 1000 data points in 4 seconds and 5000 data points in 20 seconds.

## 5. Conclusion and Future work

The use of NIIAs, or nature-inspired intelligent algorithms, might significantly alter agricultural methods. Ecological, swarm-intelligence, ecology-based, or multi-objective algorithms provide a diverse set of resources for addressing agricultural problems. A particle swarm method is useful for calculating water requirements and improving irrigation procedures, while some NIIAs, such as its Ant Colony Optimization Method and genetic algorithms, are great at identifying pests and path optimization. Nevertheless, hyper-heuristic algorithms have not yet found widespread use in the agricultural sector. The current trend involves developing specialized algorithms for distinct tasks, reflecting the diverse and complex nature of agricultural operations. The importance of data accuracy and cybersecurity is crucial as these algorithms become integral to modern farming practices.The future trajectory of bio and nature-based algorithmic applications in agricultural engineering involves addressing existing challenges and expanding innovation horizons. Future research and development include holistic integration of hyper-heuristic algorithms with NIIAs, standardization and interoperability of algorithms, enhanced cybersecurity measures, real-world implementation studies, and cost-benefit analysis and economic impact.By addressing challenges, refining algorithms, and ensuring the security of agricultural data, the potential benefits of NIIAs can be fully realized, leading to a more sustainable, efficient, and technologically advanced future in agriculture. In summary, the future of bio and nature-based algorithmic applications in agricultural engineering lies in a continued commitment to research, innovation, and practical implementation.

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