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Development of an Arduino-based automated grading onion (Allium cepa, L.) machine for enhanced productivity

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Abstract

This study aimed to develop an Arduino-based automated grading onion machine for enhanced productivity. The researchers utilized an experimental research design in developing and testing the machine. The materials used in the study were the following: Arduino-Uno, MQ-135 gas sensor, conveyor, servo motor, battery power supply, weighing scale, camera, and jumper wires. The researchers encoded different programs in the machine's servo motor and camera to carry out their intended function. To gather the data, the researchers conducted an experiment of trials to test the machine's efficiency in terms of its performance, enhanced productivity, and the accuracy of the machine in grading and sorting the onions by size, texture, and quality. Based on the results and data gathered through experimenting and trials, it can be concluded that the machine is efficient, faster, and cost-efficient; has a long battery life; and is accurate in sorting and grading the onions. Moreover, the automated machine's grading function is consistently accurate when it comes to sorting onions with different sizes, and its performance when tested is proven more precise and faster than manual grading through observation; it was tested and proven by t-test and analysis of variance (ANOVA) on the data gathered by the researchers themselves. The researchers then recommend that future researchers further improve the device by enhancing the Arduino-based automated grading onion machine by optimizing its processing speed and expanding its grading capabilities to accommodate larger quantities of onions.

Keywords: automated grading onion machine, enhanced productivity, Arduino-Uno, MQ-135 gas sensor, experimental study

Development of an Arduino-based automated grading onion (Allium cepa, L.) machine for enhanced productivity

1. Introduction

The onion (*Allium cepa, L.*) is a plant species belonging to the Alliaceae family that has culinary and medicinal uses. It is rich in vital vitamins and minerals. Originating from Asia and the Middle East, it has been domesticated for over 5,000 years. It is seasonal production but requires yearly (Karthik et al., 2016). Onions have a significant role in human life on Earth. Domestically, it is farmed, exported for commercial gain, and utilized as a dietary supplement. Onions are in more demand than ever, and their quality has grown. After harvesting onions, their quality is crucial to the end user (Umani & Markson, 2020). San Jose, Occidental Mindoro, is one of the key onion-producing areas in the Philippines. However, the cost of onion farming in the region is significantly high, posing financial challenges to local farmers. According to San Jose's municipal agriculturist, Romel Calingasan, cultivating onions requires substantial investment, with expenses ranging from ₱250,000 to ₱300,000 per hectare. Even higher capital is needed for farmers who aim to expand their agricultural land. Despite the high production costs, farmers often face difficulty securing sufficient funds, making sustaining and improving their farming operations challenging (Dequina, 2023).

Grading onions is crucial for complying with industry standards and improving marketability. It is the primary source of income for farmers and traders. This grading system will help the farmers distinguish the good onions from the rotten. This will also prevent the farmers from having a low income. However, nowadays, especially in the provinces, most onion growers and traders conduct manual sorting; farmers dedicate hours, even days, to this task. This manual increases selling expenses and inconsistencies and reduces efficiency. Manual grading is less efficient and inconsistent as human perception differs from one person to another. It is also a laborious job and causes muscle fatigue and stress to the farmers. When grading products manually, a significant amount of energy is expended, and the product is managed multiple times, leading to increased waste and a drop in marketing value (Gayathri et al., 2016). Gunathilake et al. (2016) reported an appreciable difference in the market price of big onions according to the size of the bulbs. The immense size of graded onion bulbs fetches a higher price than ungraded onions. Inefficient grading is frequently the result of this manual and time-consuming procedure, mostly when inexperienced staff rely on subjective assessment. Although skilled laborers can grade up to 78 kg per hour by hand, workforce shortages during busy seasons lead to high expenses. Farmers must recruit more labor during harvest to meet market demand and command higher prices. Onion graders are sold online, but small-scale farmers cannot afford or use them since they are made for large-scale operations. Furthermore, repairs and maintenance are expensive because replacement parts are hard to come by for smaller grader machines imported from overseas. An appropriate, cost-effective, and agriculturally friendly onion grader that can effectively serve farmers' demands is required in this case (Caguay & Magboo, 2023).

With these observations, the reconsideration should be made of designing an Arduino-based automated grading onion machine for enhanced production. This prototype utilizes a gas sensor (MQ-135) to detect gases emitted by rotten onions, guiding them to a "bad" section via a servo motor. Healthy onions are directed to the "good" section, ensuring accurate weighing. A weighing scale will be placed at the end of the conveyor, allowing the laborers to weigh the product if it reaches the desired weight. The researchers will also use a camera or image processing to identify the different sizes of the onions. The servo motor remains inactive when not sorting, conserving energy and optimizing performance. A battery will also supply the energy needed for the machine to work. The study of Digamber et al. (2022) presented a novel approach to automating the sorting of onions based on their quality, combining electronic gas sensing and image processing to identify and remove sprouted and rotten onions. They utilized a prototype with image processing and a sensory mechanism that automatically removes the sprouted and rotten onions. This allowed the system to differentiate between fresh, sprouted, and rotten onions. In addition, it focuses only on sorting the onions based on quality using gas sensing and image processing, while this study will focus on different variables—the quality, texture, and size of an onion. This study will also increase the speed based on Digamber et al.'s recommendations. Further, a weighing scale will be added to signal whether the onion bag is full. It will also use a camera to identify the varied sizes of an onion. The researchers consider the stated recommendations of Kokate Mahadeo Digamber, Wankhede Vishal Ashok, and Pawar Dhananjay Jagdish's work.

The grading machine will help the farmers in overcoming the manual approach, reducing the labor scarcity, improving uniformity and efficiency of grading, saving time and energy, minimizing costs, and most significantly, making the grading process more efficient, quicker, and more affordable for the farmer (Umani & Markson, 2020). 2020). This automated approach addresses the challenges of subjective grading and inefficiency and paves the way for a more sustainable and profitable agricultural industry. It is also designed to achieve outstanding speed and capacity. Such a high throughput will increase each company's profitability and productivity and decrease its reliance on the workforce. With as little waste as possible, the researchers will make every onion from your harvest count.

Statement of the Problem - This study aimed to develop and evaluate an Arduino-based automated grading onion machine to improve agricultural efficiency and reduce post-harvest losses. The outcome may contribute to more consistent sorting, reduced labor costs, and ultimately higher farmer profits. Specifically, it sought to answer the following questions: (1) What is the level of performance of the Arduino-based automated grading onion machine in terms of texture and quality of onions and size of onions? (2) Is there a significant difference between the Arduino-based automated grading onion machine and the manual sorting of onions in terms of speed, battery duration, and weight? (3) Does the Arduino-based automated grading onion machine affect the enhanced productivity of onions? (4) Does the Arduino-based automated grading onion machine affect the accuracy of storing onions?

Significance of the Study - In this study, the researchers seek to produce a machine to help onion farmers separate the onions into various sizes, qualities, and weights. The findings in this study may benefit specific individuals and groups of people, and the benefits they might gain are as follows: to local citizens of San Jose, Occidental Mindoro. The citizens of San Jose, Occidental Mindoro, will find a better and less expensive way to sort their onions at home. This study will also help those with onions at home, even though they do not own land for planting onion crops. The outcome of this study will benefit them in terms of their financial expenses because this machine aims to lessen the cost of paying numerous people to sort onions individually. The researchers aim to make their job easier with the help of our invention. To onion traders, their jobs may be lightened because of this automated onion sorting machine. This invention may help them exert less effort in terms of assessing the quality of onions that they may buy and sell. The machine may help facilitate the work of those in the agriculture section. This study will help future researchers who are also interested in studying automated onion sorting machines for agricultural efficiency. Most of the researchers only tackled sorting onions through camera detection, but the researchers are studying a deeper aspect of how to sort onions automatically and accordingly.

Scope and Delimitation of the Study - The main purpose of this study is to develop and evaluate an Arduino-based automated grading onion machine for enhanced production. This study is limited only to the local farmers of Purok III, Barangay Magbay, San Jose Occidental Mindoro, for 2024-2025, who were randomly selected by the researchers. The level of performance of the Arduino-based automated grading onion machine is limited only to the following variables: (a) texture and quality, (b) weight, (c) size, (d) speed, and (e) battery duration. The study is only focused on assessing the efficiency of the Arduino-based automated grading onion machine using good (no defect/damage) onions and damaged onions, as well as small-- and big-sized onions.

2. Methodology

Research Design - This study explores practical implementation through applied research to develop new onion grading procedures to guarantee reliable, consistent, and effective results. The researcher attempts to get answers to the problem and to justify and satisfy the objectives of the study. Likewise, it also tries to know and determine the cause-and-effect relationship of the variables. The researchers used experimental quantitative research to make this study well-aimed and successful. Therefore, the experimental research design plays a critical role in developing the Arduino-based automated onion grading machine. Using this approach, the machine's components would be systematically tested and optimized to achieve the targeted performance standards. The research design’s emphasis on observation and modification would support its objective of creating an excellent automated onion grading system.

Data Gathering Procedure - The data-gathering procedure began with researchers setting up the onion grading machine, ensuring that it was fully operational and ready for observation. The researchers examined the product themselves. Before beginning, the machine's purpose and functionality were described. Researchers note any initial impressions or reactions to the machine, which may indicate initial usability concerns. Researchers would observe discreetly while using the machine, focusing on features such as ease of use, efficiency, and accuracy. This phase helped determine whether the machine performs effectively in real-world conditions. Any issues, such as operational errors or challenges encountered, were recorded to highlight potential areas for improvement. Researchers also note signs of satisfaction or dissatisfaction, as these may provide insight into the device's alignment with practical needs. Following each observation, informal input was solicited to record any specific insights on the machine's performance. This information can assist researchers in identifying specific challenges or benefits observed during use. Once all sessions had concluded, researchers assembled and evaluated the data to uncover patterns in usability, efficiency, and necessary changes. The data were synthesized into a report that summarized the machine's overall performance and made recommendations for future improvements. The researchers gathered the data in 20 days.

Research Process: Stage 1 Preparation and Gathering of Materials - In the initial stage of the research, the necessary materials and components were identified and acquired for the automation system. The researchers comprehensively reviewed the required hardware and software tools to ensure that each element met the project's specifications. These are the materials needed to build the Grading Onion Machine: MQ-135 Gas Sensor, Conveyor, Servo Motor, 12V Battery, Weighing Scale, Camera, Arduino Uno, Jumper Wires, and Plywood. B. These are the software tools needed to create the code for the Grading Onion Machine: Python and Arduino IDE. Each component was selected based on its functionality and compatibility with the overall automation system. The MQ-135 Gas Sensor was chosen for its ability to detect gases, while the conveyor and servo motor facilitated the movement and sorting process. The weighing scale and camera module enabled the precise classification of onions, ensuring accurate data collection. Arduino Uno was used as the microcontroller for system operation, with jumper wires and plywood as essential supporting materials. The system utilized free and open-source software for automation development, including Python and Arduino IDE. These tools were chosen due to their flexibility, efficiency, and ease of integration with hardware components.

Stage 2: Building and Development of the Project - Once the materials are collected and ready, programming for the Arduino board will begin. In this study, the researchers utilized Arduino IDE to create the code within 7 days, which can accurately control every part of the system. When the code is done, it is transferred to the Arduino board, where it undergoes intensive testing to ensure that the different parts of the program run as intended. After verification, the Arduino board is related to all the other hardware components. Each component, such as the servo motor, camera, and conveyor, was attached to the designated pins on the board according to system requirements. A reliable power source was also connected to supply power to the machine. When the machine is switched on, a close observation is conducted to track how the machine performs. Its execution was watched to ensure it met the expectations of the researchers.

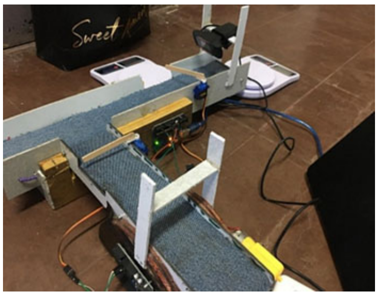

Figure 1. Actual Product of Grading Onion Machine

Stage 3: Experimental Stage, Observation, and Data Recording - At this stage, the machine was tested and observed for reliability and accuracy in detecting and sorting onions. The detection of rotten onions using the gas sensor and their emitted gases was appropriately observed. As the onions passed through the sorting machine, the researchers checked on the effectiveness of the servo motor in taking each onion to the right section. Additionally, the machine's speed and lifespan were monitored, as well as the weighing scale, ensuring consistency in the weight of the sorting bag when the sorting process is complete. Finally, the camera's ability to detect the onions' sizes was also tested. This testing phase enables the researchers to collect data that explicitly identifies machine functionality irregularities. At each phase of the sorting process, the researchers studied any inconsistencies to refine the building of an Arduino-based onion-sorting machine. The researchers took 20 days for the experimental stage, observation, and data recording.

Statistical Treatment of the Data - The researchers used a T-test for statistical data analysis in conducting this study to determine if there is a significant difference between the proposed product and the manual onion grading machine. The researchers used regression analysis to investigate the relationship between the accuracy and the enhanced productivity of onions and the proposed product. Researchers also calculated the weighted mean and average to describe the grading machine's performance level

3. Results and Discussions

Table 1

Level of performance of the Arduino-Based Automated Grading Onion Machine, in terms of Texture and Quality of Onions

Good (No damage/defect) Onions					
No. of Trials	1	2	3	4	5
Number of Good Onions Tested	10	10	10	10	10
Accurate Results	10	10	10	8	9
Average Accuracy: 94% (Very High)					
Damaged Onions					
No. of Trials	1	2	3	4	5
Number of Damaged Onions Tested	10	10	10	10	10
Accurate Results	3	5	3	4	6
Average Accuracy: 42% (Moderate)					

Legend: 80-100% Very High, 60-80% High, 40-60% Moderate, 20-40% Low Accuracy

Table 1 presents the level of performance of the Arduino-based automated grading onion machine in terms of the texture and quality of onions. To test the accuracy of the machine, the researchers used ten good (no damage/defect) and ten with damage/defect samples of onions and conducted five trials. The researchers used a legend to identify if the level of performance of the Arduino-based Automated Grading Onion Machine, in terms of texture and quality of onions, is accurate. The highest accuracy gathered in testing the good samples is 100% from. Once the onions are placed on the conveyor, the servo motor will not move 90°, giving way to the onions at the next conveyor, which will be sorted by size. The lowest was about the MQ135 gas sensor detecting gas emitted by the onions, leading the onion into the damaged section with an accuracy of 80%. Based on the observations of the researchers, with an overall accuracy of 94%, the Arduino-based Automated Grading Onion Machine has a very high level of performance that would be helpful to consumers and farmers. In terms of testing rotten onions, the highest accuracy gathered is 60%. Once the onions are placed at the conveyor, the servo motor will move 90°, leading the defective onions into the defect section. The lowest was the MQ135 gas sensor, which has a delayed response time upon placing the damaged onions on the conveyor, with an accuracy of 30%. With a total accuracy of 42%, the researchers found that the MQ135 has a delayed response rate. To support how automation helped the farmers and consumers, as stated by Umani and Markson (2020), the machine will assist farmers in overcoming the manual approach, reducing the lack of labor, improving grading uniformity and efficiency, saving time and energy, minimizing costs, and making the grading process more efficient, quicker, and most importantly affordable. To support how MQ135 affects the accuracy of sorting onions, as stated by Digamber et al. (2022), the speed of the detection of gases depends on the chamber housing of the sensor. Teflon was also used to lessen the possibility of contamination from sample odors inside the chamber. In this study, the researchers did not use any chamber housing, leading to a total accuracy of 42%.

Table 2 shows the level of performance of the Arduino-based automated grading onion machine in terms of the texture and quality of onions. The response of small and big sizes of onions with the image processing tool is being tested. The researchers conducted five trials with five onions each to test if the Arduino-based automated grading onion machine's level of performance in terms of sizes of onions is accurate. For the small sizes of onions, in the first, third, and fourth trials, four onions were sorted correctly, with an accuracy of 80%. The second trial resulted in an accuracy of 60%, with three out of five onions correctly sorted. Lastly, for the final trial, the results showed 100% accuracy because all the onions tested were sorted accurately. With an overall accuracy of 80%, the Arduino-based automated grading onion machine has an accurate level of performance.

Table 2

Level of performance of the Arduino-Based Automated Grading Onion Machine, in terms of Sizes of Onions

Small Onions					
No. of Trials	1	2	3	4	5
No. of Small Size Onions Tested	5	5	5	5	5
Accurate Results	4	3	4	4	5
Average Accuracy: 80% High					
Big Onions					
No. of Trials	1	2	3	4	5
No. of Big Size Onions Tested	5	5	5	5	5
Accurate Results	4	5	5	4	5
Average Accuracy: 92% Very High					

Legend: 80-100% Very High, 60-80% High Accuracy, 40-60% Moderate, 20-40% Low

The data gathered suggests that the accuracy of the image processing tool varied across trials. For the big-sized onions, the first and fourth trials had an accuracy of 80% because four out of five onions were correctly sorted. For the second, third, and fifth trials, five onions were sorted accurately with an accuracy of 100%. With a total accuracy of 92%, the researchers found that an image processing tool can accurately determine the size of big onions. The researchers also discovered the success of a camera programmed through Arduino to identify small onions. As stated by Dorokhov et al. (2021), using the appropriate technical activities throughout the sorting process, including splitting and sorting the onions into fractions according to their size and quality, is one way to achieve high-quality production in grading machines. Classifying agricultural items into the appropriate categories will also lessen quality losses in certain crops, particularly onions.

Table 3

Difference between the Arduino-Based Automated Grading Onion Machine and the Manual Sorting of Onions in Terms of Speed

No. of Trials	Number of Onions Sorted	Variable 1 Mini Conveyor Sorting (in seconds)	Variable 2 Manual Sorting (in seconds)
1	10	54	65
2	10	50	65
3	10	52	65
4	10	53	65
5	10	51	65
AVERAGE		52	65

Legend: Variable 1 – Mini Conveyor Sorting, Variable 2 – Manual Sorting

Table 3 differentiates the sorting speed of the mini conveyor from that of manual sorting. The mini conveyor averages 52 seconds, while manual sorting takes 65 seconds, showing a difference in productivity. This indicates that the mini conveyor processes onions faster than manual sorting in all trials.

Table 4

T-Test Results of the Difference between the Arduino-Based Automated Grading Onion Machine and the Manual Sorting of Onions in terms of Speed

t-Test: Two-Sample Assuming Unequal Variances		
	Variable 1 Mini Conveyor Sorting (in seconds)	Variable 2 Manual Sorting (in seconds)
Mean	52	65
Variance	2.5	0
Observations	5	5
Hypothesized Mean Difference	0	
df	4	
t Stat	-18.38477631	
P(T<=t) one-tail	2.57496E-05	
t Critical one-tail	2.131846786	
P(T<=t) two-tail	5.14992E-05	
t Critical two-tail	2.776445105	

Legend: P-value ≤ 0.05 Significant; reject H0

Table 4 shows the grading times for the mini conveyor (52 sec avg.) and manual sorting (65 sec avg.) across five trials. To check if the time difference is statistically significant, a t-test was performed in Table 4. The results show a very low p-value (5.14992E-0 two-tail), which means that the difference is statistically significant. This confirms that the mini conveyor grades onions much faster than manual sorting. According to O'Brien (2014), farming must speed up to keep up with the rising demand for food. A power-driven rotary grader sorted onions with an efficiency of 92.99%, as demonstrated by Bisen et al. (2021), indicating that machines help in sorting. A conveyor speed of 1.2 m/s produced 91% sorting accuracy, according to Dorokhov et al. (2021), demonstrating that speed enhances sorting quality. These studies prove that farming is more productive and efficient when using faster machinery.

Table 5

Difference between the Arduino-Based Automated Grading Onion Machine and the Manual Sorting of Onions in Terms Battery Duration

Sorting Method	Power Source	Trials	Total Operation Time Before Recharge/Reset
Arduino Onion Sorting Machine	5 x 12V Batteries	5	23.25 hours
Smart Onion Sorting Machine	12V DC Battery	Not Specified	18.5 hours

Legend: Variable 1 - Battery Duration of Mini Conveyor, Variable 2 - Battery Duration of Smart Onion Sorting Machine.

Table 5 shows that the Arduino-based onion sorting machine, powered by 5x12V batteries, operates longer with an average of 23.25 hours per charge. The Smart Onion Sorting Machine, as stated by Digamber et al. (2022), which uses a 12V DC battery, operates for 18.5 hours per charge. Due to its increased power capacity from 5x12V batteries, the Arduino-based onion sorting machine, which is set with a gas sensor and image processing, has a longer lifespan. Because a single 12V DC battery powers it, the Samet Onion Sorting Machine runs shorter, even though it uses similar technologies.

Table 6

T-Test Results of the Difference between the Arduino-Based Automated Grading Onion Machine and the Manual Sorting of Onions in Terms of Battery Duration

t-Test: Two-Sample Assuming Unequal Variances	Variable 1 (Battery Duration of Mini Conveyor)	Variable 2 (Battery Duration of Smart Onion Sorting Machine)
Mean	14.125	7
Variance	166.5313	8
Observations	2	2
Hypothesized Mean Difference	0	
df	1	
t Stat	0.762717	
P(T<=t) one-tail	0.292592	
t Critical one-tail	6.313752	
P(T<=t) two-tail	0.585185	
t Critical two-tail	12.7062	

Legend: P-value ≤ 0.05 Significant; reject H0

Table 6 presents the computation of the battery duration data using the T-test variance model. Based on Table 5, the machine runs 23.25 hours, while manual sorting lasts 8–10 hours. The t-test compares battery duration from two trials, with one having 14.125 hours and the other 7 hours. The p-values (0.292592 one-tail, 0.585185 two-tail) show no difference. This means the battery lasts long enough, keeping the machine running longer than manual sorting. Linga (2022) stated that battery duration is how long it gives power before running out. The Onion Grading Machine's battery lasts 14.125 hours on average, meaning it is a long-duration battery since it exceeds 8 hours. The t-test shows a big difference between trials, proving the battery gives steady power. This supports the study, as longer battery life helps machines run longer, making grading more efficient.

Table 7

Difference Between the Arduino-Based Automated Grading Onion Machine and the Manual Sorting of Onions in Terms of Weight

Automated Grading Machine					
Time in Seconds	54	52	52	51	50
No. of Onions Sorted	10	10	10	10	10
Total Weight in Grams	1775g	1500g	1625g	1700g	2000g
Total Weight: 8600g					
Manual Sorting					
Time in Seconds	54	52	52	51	50
No. of Onions Sorted	7	7	8	8	8
Total Weight in Grams	1250g	1050g	1300g	1360g	1600g
Total Weight: 6560g					

Legend: Seconds: Time consumed per trial; Onions Sorted: Individually vary in size; Weight of Each Onion: Individual weight of onions; Total Weight: Summary of gathered individual weight

Table 7 shows the difference between the Arduino-based automated grading onion machine and the manual sorting of onions in terms of weight. The manual grading machine was able to sort in the same time as the automated one, while the automated grading machine was able to sort more onions in the same time as the manual technique. The data obtained to come up with this table was derived from the researchers' actual observations. Five trials were made accordingly on the manual and automated grading onion system to compare the performance and productivity of each technique.

Table 8

T-Test Results of the Difference between the Arduino-Based Automated Grading Onion Machine and the Manual Sorting of Onions in Terms Weight

t-Test: Two-Sample Assuming Unequal Variances	Variable 1 (Automated)	Variable 2 (Manual)
Mean	1360	1312
Variance	430812.5	39470
Observations	5	5
Hypothesized Mean Difference	0	
df	5	
t Stat	0.156511708	
P(T<=t) one-tail	0.440876482	
t Critical one-tail	2.015048373	
P(T<=t) two-tail	0.881752964	
t Critical two-tail	2.570581836	

Legend: P-value ≤ 0.05 Significant; reject H0

Table 8 shows the data using the T-test variance model computation for the difference between automated and manual sorting, which helps the researchers to conclude that there is a significant difference between the automated onion grading machine and the manual sorting of onions in terms of weight. The value of Significance F is 0.881752964, and the value of F (critical or tabular value) is 2.570581836. Since the computed F value is less than the critical or tabular value, 0.881752964 < 2.570581836, there is evidence that the null hypothesis should be accepted. Therefore, the alternative hypothesis is rejected. Hence, the Arduino-based automated grading onion machine affects the enhanced productivity of onions. When it comes to the automated onion grading machine, the machine provides an accurately graded onion as it carefully studies each onion's size before sorting it. It weighs the onions precisely on the final weighing scale before bagging it. While on the manual sorting of onions, the traditional way makes little to moderate mistakes when grading onions because onions' size is sometimes tfor them to identify

Furthermore, onions should be well studied before throwing them on the right weighing scale and packing up. In a study by Sari et al. (2022), an automated grading machine was utilized to sort tomatoes by weight, ensuring uniform size for each fruit. The automation in the post-sorting and grading process helps save time and resources. The researchers proposed a sorting system that categorizes tomatoes based on color, size, and weight, aiming to provide farmers with uniformly sized tomatoes for the market. This method enhances both the quality and efficiency of post-harvest handling.

Table 9

Raw Data of Speed of Manual Sorting and the Arduino-Based Automated Grading Onion Machine

No. of Trials	Number of Onions Sorted	Mini Conveyor Sorting (in seconds)	Manual Sorting (in seconds)
1	10	54	65
2	10	50	65
3	10	52	65
4	10	53	65
5	10	51	65
AVERAGE		52	65

Legend: No. of Onions Sorted: 10; Mini Conveyor Sorting: Time onions were sorted in seconds; Manual Sorting: Time onions were sorted in seconds

Table 9 presents the raw data that the researchers used in identifying whether the Arduino-based automated grading onion machine affects the enhanced productivity of onions. The data was gathered through five experimental trials, with each trial having ten sample onions. The time it took to sort the onions using both methods was measured in seconds during five trials. Furthermore, the sorting machine had an average sorting time of 52 seconds, compared to the 65-second average sorting time of manual sorting. The results indicate that the automated machine is faster than manual sorting. In conclusion, the data was collected through experimental trials to assess the time required for sorting onions using both automated and manual methods, and the regression analysis was used to compare sorting speeds.

Table 10

Analysis of the Speed of Manual Sorting and the Automated Grading Onion Machine

Regression Statistics					
Multiple R	0.82789504				
R Square	0.685410197				
Adjusted R Square	0.580546929				
Standard Error	1.024027674				
Observations	5				
ANOVA	*df*	*SS*	*MS*	*F*	*Significance F*
Regression	1	6.854101966	6.854101966	6.53622771	0.083460689
Residual	3	3.145898034	1.048632678		
Total	4	10			

Legend: P-value ≤ 0.05 Significant; reject H0

Table 10 presents the regression analysis of the speed of manual sorting and the Automated Grading Machine. The value of significance F is 0.083460689, and the value of F (critical or tabular value) is 6.5362277. Since the computed F value is less than the critical or tabular value, 0.083460689 < 6.5362277, there is evidence that the null hypothesis should be accepted; therefore, the alternative hypothesis should be rejected. Hence, the Arduino-based automated grading onion machine affects the enhanced productivity of onions. Caugay and Magboo (2023) and Karthik et al. (2018) studied the creation of automated onion grading machines to lower labor costs and increase efficiency. An on-farm onion grader with an 85% efficiency rate and a 500 kg/hr processing capacity was created by Karthik et al. (2018), proving its usefulness for small-scale farmers. Similarly, Caugay and Magboo (2023) developed a machine that graded the size of onion bulbs with a 95.45% efficiency rate and a 583.23 kg/hr capacity, demonstrating its cost-effectiveness with a 204.85% return rate and a 0.32-year payback period. These results bolster the current study, highlighting how automation may optimize onion grading, increase accuracy, and boost production in agricultural processing.

Table 11

Accuracy of Sorting Good (Big) and Damaged (Small) Onions

Good Onions					
No. of Trials	1	2	3	4	5
Number of Good Onions Tested	10	10	10	10	10
Accurate Results	10	10	10	8	9
Average Accuracy: 94%					
Damaged Onions					
No. of Trials	1	2	3	4	5
Number of With Damaged Onions Tested	10	10	10	10	10
Accurate Results	3	5	3	4	6
Average Accuracy: 42%					

Legend: Y Range—Range-—Good Onions, X Range—Damaged Onions

Table 11 shows the accuracy of sorting onions. The researchers conducted a series of trials using the Arduino-based Automated Grading Onion Machine to assess its accuracy in sorting onions based on texture and quality. They prepared two categories of onion samples: good (big) and damaged (small onions), ensuring that each category contained 10 samples per trial. The machine was programmed to analyze and classify the onions, and the researchers carefully recorded the number of correct classifications for both good and bad onions in five separate trials.

Table 12

Regression Analysis of the Accuracy of Sorting Good (Big) and Damaged (Small) Onions

Regression Statistics					
Multiple R	0.3001225				
R Square	0.0900735				
Adjusted R Square	-0.213235				
Standard Error	0.0985184				
Observations	5				
ANOVA	df	SS	MS	F	Significance F
Regression	1	0.002882353	0.002882	0.29697	0.623688851
Residual	3	0.029117647	0.009706		
Total	4	0.032			

Legend: P-value ≤ 0.05 Significant; reject H0

Table 12 presents the regression analysis of the accuracy of sorting good (big) and damaged (small) onions.

The value of significance F is 0.623688851, and the value of F (critical or tabular value) is 0.29697. Since the computed F value is greater than the critical or tabular value, 0.623688851 > 0.29697, there is evidence that the null hypothesis should be rejected; therefore, the alternative hypothesis should be accepted. Thus, the Arduino-based automated grading onion machine affects the accuracy of sorting onions. The study of Digamber et al. (2022) defined the importance of automation in sorting onions through gas sensors and image processing. The latter highlights its crucial role in differentiating onions based on their size, quality, texture, and freshness, aiming to improve sorting accuracy. Using the MQ-135 gas sensor and the camera ensures that the machine can accurately classify the different types of onions based on various factors. Furthermore, Caguay and Magboo (2023) highlight the importance of automation in efficiency and cost-effectiveness. Their machine achieved a 95.45% grading efficiency, similar to the Arduino-based machine's accuracy in grading onions. The findings encourage that automation improves productivity and enhances sorting accuracy.

4. Conclusions

The automated grading onion machine demonstrated high accuracy and efficiency in grading and sorting the onions. The performance shows the machine's potential to reduce time and labor while maintaining high accuracy. Sorting onions by size and weight allows for a consistent grading speed since uniform weights go quickly through the system. In contrast, varying weights slow down the process since sorting modifications take longer. The Onion Grading Machine uses advanced automation to sort onions with greater precision and speed, reducing the need for constant human intervention. Its durable design and energy-efficient technology allow it to run for extended periods without requiring frequent recharges or maintenance.

Recommendation - In light of the work completed during this research and the previously stated conclusions, the following suggestions are made: The researchers recommend to the users to use chamber housing for the MQ135 gas sensor to prevent the air from dragging away the gas emitted by the onions and to increase the speed of the detection of rottenness, resulting in more accurate results. The users may use a bigger battery for longer use, and a stronger motor can make it even faster. More trials can help see how long the battery lasts in different conditions. For agricultural programs or organizations, the researchers recommend enhancing the Arduino-based automated grading onion machine by optimizing its processing speed and expanding its grading capabilities to accommodate larger quantities of onions. Future studies may explore the integration of advanced sensors and machine learning algorithms to improve the machine’s adaptability to different onion sizes and conditions. For academic purposes, schools are encouraged to integrate the Automated Onion Grading Machine into their curriculum to enhance students' understanding of automation, technology, and agricultural processing through hands-on learning experiences. For future researchers, this grading machine is also recommended for defective product detection, as it can identify irregularities in packaged goods through its advanced sensor system.

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