The development of onion sorting and grading machine

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Abstract: Onion cultivation is a vital part of Philippine agriculture, contributing to the nation's economy and rural employment. However, the small-scale onion farmers faced challenges in sorting and grading, including reliance on manual labor, lack of mechanized equipment, and postharvest losses due to manual handling. This paper aims to review and to analyze existing onion grading technology in both mechanical and automated to identify most efficient and cost-effective solutions suitable for small-scale farmers in the Philippines. While automated onion graders equipped with advanced sensors show higher accuracy (up to 99%) in size classification and defect detection, mechanical onion grader such as rotating cylindrical grader and divergent roller design can achieve up to 95% grading efficiency, reduce manual labor, and provide a practical, cost-effective solution for small onion farmers facing high postharvest losses. For the design conceptualization of mechanical onion grader for small scale farmer, factors such roller rpm (13 rpm to 15 rpm) and inclination (8^o to 13^o), and drum rpm (10 rpm to 15 rpm) and inclination (3^o to 4^o) must be considered to ensure higher grading efficiency and lower percent damage. In addition, finite element analysis and discrete event modeling must be conducted to predict the effects of drum inclination, rotational speed, and feed rate on throughput and grading accuracy.

Keywords: automated onion sorter, grading efficiency, mechanical onion sorter, onion sorting, throughput capacity

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1 Introduction

Onion cultivation is a vital part of Philippine agriculture, contributing to the nation's economy and rural employment. Considering the volume and value of production, onion is regarded as one of the high value crops by the Department of Agriculture. In 2018 the Philippines registered a total production of 172,665 metric tons produced in 17,904 ha (PSA, 2020). During on-season, onions were produced in November to December which are then harvested in March to April. The bulk of this produce are normally kept in cold storage facilities that constitute the supply requirements during the lean months of August to December (Flores et al., 2021).

In 2022, the country produced approximately 283,172 metric tons of red and yellow onions and shallots from a 29,728-hectare production area, underscoring the crop's substantial role in the agricultural sector (DA-AFID, 2023). This production volume reflects the importance of onions in meeting domestic demand and supporting food security. The industry provides livelihoods for numerous farmers, particularly in regions like Nueva Ecija, where onion farming is a primary source of income and employment (DA-PRDP, 2022). Major onion-

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producing regions in the Philippines include Nueva Ecija, often referred to as the "Onion Basket of the Philippines". This region, along with others like Mindoro and Ilocos Norte, contributes significantly to the country's onion supply. The five study sites in Nueva Ecija, namely Laur, Gabaldon, Bongabon, Rizal, and Talavera, have production areas of 411.9 ha, 1,587 ha, 2,695.5 ha, 1,107 ha, and 520 ha, respectively, with a total of 6,321.4 ha (Gavino et al., 2020).

The production process and postharvest processing of onions in the Philippines are significant aspects of the country's agricultural sector. The cultivation of onions is a major agricultural activity, especially among smallholder farmers (Mopera, 2016). The production process typically involves several stages, including land preparation, seed preparation, cultivation practices, and pest and disease management. These processes are crucial for ensuring the quality and quantity of the onions produced. Once the onions are harvested, they undergo several postharvest processes. These include field drying, harvesting, topping, curing, cleaning, grading, sorting, packaging, storage, and distribution. Each of these stages plays a vital role in keeping the quality of the onions and ensuring they reach the market in the best possible condition.

However, onion industry faces several challenges such as price volatility and competition from imports affect the stability of farmers' incomes (DOST - PCARRD, 2024). In addition, technological issues, including limited access to modern farming equipment and inadequate post-harvest facilities, further hinder productivity and profitability (DOST - PCARRD, 2018). Furthermore, substantial post-harvest losses of up to 50% have been recorded from the first harvesting, grading, packaging, and transportation from field to storage and distribution to the consumers. These losses are attributed to poor handling, distribution, storage, and consumption behavior (Yeshiwas et al., 2023). These factors can impact the demand, supply, and overall production of onions in the country (Santos et al., 2024). Recognizing these challenges, there is a need to enhance productivity and support onion farmers in terms of processing technology, aiming to stabilize supply and improve market conditions.

One of the main issues observed is the lack of appropriate technology for sorting and grading designed for small scale farmers. Most of the sorting and grading were done manually, which is labor-intensive and time-consuming. This manual process can lead to inconsistencies in the quality of the sorted and graded onions, affecting their market value. The sorting and grading practices in the onion industry in the Philippines face several challenges, particularly in relation to quality, standardization, and the technology currently used by Filipino onion farmers. To address these issues, there is a growing interest in developing affordable and efficient mechanical grading solutions tailored to the needs of local farmers (Mishra et al., 2020).

The main purpose of this review article is to provide a comprehensive overview of onion sorting and grading technology. This paper is structured into three (3) major sections: (1) practices in onion sorting and grading, (2) analysis of different technologies for onion grading, and (3) conceptualization of an onion grader machine for small-scale farmers in the Philippines. This review article also provides data on the important parameters to consider in the design of onion grading machines, offering valuable insights into the initial considerations for grading machine development.

2 Practices in onion sorting and grading

2.1 Traditional sorting and grading methods

Globally, traditional onion sorting and grading methods predominantly rely on manual labor, where workers visually assess and categorize onions based on size, shape, and quality attributes (Umani and Markson, 2020). This approach is labor-intensive and often leads to inconsistencies due to human error and fatigue. In the Philippines, similar manual practices are prevalent, with farmers sorting onions by hand to meet local market standards (Santos et al., 2024). Philippine

National Standard for Bulb Onion and Shallots (PNS/BAFPS 14:2004) has been established to provide guidelines for grading, aiming to improve consistency and quality in the market. Despite these standards, the lack of mechanized grading systems poses challenges in meeting quality benchmarks and market demands.

2.2 Manual labor challenges and productivity issues

The Philippine Onion Industry Roadmap 2021–2025 emphasizes the necessity for mechanization to boost productivity and maintain consistent quality standards (DA-BAR, 2022). However, the substantial costs associated with mechanized equipment present significant challenges for small-scale farmers, who often have limited financial resources. This economic barrier hinders the widespread adoption of modern agricultural technologies among these farmers. A study assessing the mechanization level of onion production in Nueva Ecija found that while land preparation, spraying, and irrigation utilize mechanical power, operations such as transplanting, crop establishment, and harvesting are performed manually, necessitating the hiring of additional laborers during peak seasons (Gavino et al., 2020). Moreover, most of the postharvest practices for onions, from harvesting to marketing, were done manually, making them tedious, laborious, and time-consuming (Calica and Cabanayan, 2018).

2.3 Quality impacts of non-mechanized practices

The major causes of postharvest losses in onions include rot, diseases and pests, drying, bruising, lack of credit to carry out operations at the right time, poor storage facilities, inadequate agricultural extension services to mitigate losses, poor transportation systems, and long distances to marketing centers (Falola et al., 2023). Non-mechanized practices in onion sorting and grading significantly impact the quality of the produce (Mushobozi, 2010). Manual methods often result in inconsistent sizing and grading due to human error and fatigue, leading to a heterogeneous product mix that can affect marketability (Wang and Li, 2014). Additionally, the physical handling of onions during manual sorting can cause mechanical damage, such as bruising or skinning, which not only diminishes visual appeal but also reduces shelf life and increases susceptibility to pathogens (Bahram-Parvar and Lim, 2018; Chakraborty, 2018; Osei et al., 2025). Furthermore, the lack of standardization in manual grading can result in batches that do not meet market or export standards, thereby limiting market access and potential revenue for producers (Giovannucci et al., 2001; Kitinoja and Kader, 2002; Sanyang, 2014). Implementing mechanized grading systems has been shown to improve grading accuracy and reduce physical damage, thereby enhancing overall product quality and market competitiveness (Alfatni et al., 2013; Londhe et al., 2013).

3 Analysis of different technologies for onion grading

Various research has been conducted for the development of onion sorting and grading machine. The results of these research vary depending on the level of technology applied in a local condition. Table 1 and Table 2 summarize the comparison of various technologies intended only for onion sorting and grading based on the principle of operation, factors for evaluation, & performance parameters such as grading/sorting efficiency, throughput capacity and percent damage. The technology for onion sorting and grading could be classified into two major groups, the mechanical systems, and automated systems. Across the available literature on technology for onion sorting and grading, manual grading methods remain labor-intensive, inconsistent, and time-consuming, contributing to high post-harvest losses, reduced profitability, and inefficiencies. Research gaps are evident in the limited availability of affordable, scalable, and efficient mechanized solutions, particularly for small and medium-scale farmers.

Table 1 Specification and performance of different mechanical onion grading machines

Author	Mechanisms for grading	Factors for evaluation	Onion variety and grading systems	Grading efficiency	Throughput capacity	Percent damage
(Bisen et al., 2022)	Onion grading is achieved through a rotating perforated cylindrical drum, where onions fed from a hopper are separated by size as they pass through appropriately sized apertures.	Rotating speed (3, 5, 10, 15, and 17 rpm) Slope (1.1%, 2%, 4%, 6%, and 6.8%). Best Setting: Rotating speed of 10 rpm and Slope: 4%.	Bhima Raj Size: Small (< 40 mm), Medium (40–60 mm), & Large (> 60 mm).	82.79% to 92.99%	20 tons day^{-1} (approx. 3 tons hr^{-1})	No data
(Tafa and Olaniyan, 2023)	Onions pass through rotating concentric cylindrical sieves with varying bar spacings for size-based grading into three categories: small, medium, and large.	Rotating speed (62.5, and 87.5 rpm) Feed rate (10, 20, and 30 kg min^{-1}). Best Setting: Rotating speed of 87.5 rpm and feed rate: 20 kg min^{-1}.	Bombay Red Size: Small (<40 mm), Medium (40–60 mm) & Large (>60 mm)	87.32% to 96.04%,	583.23 kg hr^{-1} to 1488.43 kg hr^{-1}	0.34% to 1.20%,
(Caguay and Magboo, 2023)	Onions are fed into a rotating cylindrical grader with slatted openings of varying sizes, where they are sorted into four size categories as they fall through the corresponding openings.	Shaft rotating speeds (10, 20, and 30 rpm) Best Setting: Shaft rotating speed of 10 rpm.	Red Onion Size: Super Small (<15 mm), Small (15–30 mm), Medium (31–50 mm), & Large (>50 mm)	87.01% to 95.45%	583.23 kg hr^{-1} to 1,272.74 kg hr^{-1}	With report of visual observation of onion damage
(El-Rahman and Magda, 2011)	Onion sets are fed into a rotating cylindrical grader with riddles of varying mesh sizes, where they are sorted by diameter and collected into different classification based on size.	Rotating Speeds (35, 45, 55, and 65 rpm) Feeding Rates (75, 100, 125, and 150 kg h^{-1}) Best Setting: Rotating speed of 55 rpm, and Feeding rate of 125 kg h^{-1}.	Seds-6 Size: Large (Grade 1 of >20 mm), Medium (Grade 2: 16–20 mm), Small (Grade 3: 8–16 mm) & Very Small (Grade 4: <8 mm)	94.32%	45.4 kg hr^{-1} to 121.3 kg hr^{-1}	2.26% to 7.93%
(Gunathilake et al., 2016)	Onions are fed into a rotating grading cylinder with an adjustable inclination, where openings sort them into three size categories by diameter, with each grade collected in separate outlets.	Inclination Angle (2°, 3°, and 4°) Rotational Speeds (10, 15, and 20 rpm) Best Setting: Inclination angle at 3°, and Cylinder speed of 15 rpm	Variety was not specified Size: Small (<4 cm), Medium (4–6 cm) & Large (>6 cm)	84.47% to 90.14%	630 kg hr^{-1}	No data
(Umani and Markson, 2020)	Onions are loaded into a hopper and pass through a rotating cylindrical grader with openings, which sorts them into three different sizes	Protection (with and without cushion) Feed gate opening (Half Open and Full Open) Rotational Speed (20, 40, 60, 80, and 100 rpm) Best Setting: With Cushion, with half-open feed gate using under 60 rpm	Red Onion Size: Small (≤40 mm) Medium (41–60 mm) Large (>60 mm)	62.00% to 80.00%	97.09 kg hr^{-1} to 297.9 kg hr^{-1}	With report of visual observation of onion damage
(Karthik and Palanimuthu, 2018)	The grader features a tubular grading unit with diverging PVC pipes for size-specific sorting and a manual oscillation mechanism to ensure the flow of onions through the grading unit.	Slope (13°, 15°, and 18°) Feed Rate (300, 450, 600 kg h^{-1}) Best Setting: slope of 13° and 300 kg h^{-1} feed rate for all onion varieties	Satara Garva Variety & ArkaKalyan Variety Sizes: (<40 mm, 40–50 mm, 50–60 mm, >60 mm) Bangalore Rose Variety Sizes: (<30 mm, >30 mm)	89.9% to 94.8%,	268 to 285 kg h^{-1}	0.327% to 1.425%

Author	Mechanisms for grading	Factors for evaluation	Onion variety and grading systems	Grading efficiency	Throughput capacity	Percent damage
(Vinay et al., 2017)	The grader uses a rotary disc to generate centrifugal force, guiding fruits and vegetables along a gauge belt with increasing clearance for size-based separation.	Rotary Disc Speeds (10, 30, 50, 70 rpm) Best Setting: Rotary Disc Speeds of 10 rpm	Variety was not specified Sizes: (Small, medium & large)	70%	700 kg hr^{-1}	With report of visual observation of onion damage
(Gayathri et al., 2016)	Onions are fed into a manually oscillating tray with perforated sieves, where they pass through size-specific slots and are collected in cushioned trays for three categories	Slope (0°, 2°, and 4°) Feed Gate Opening (1/3 open, 2/3 open, and full open) Swing Direction (Lengthwise and widthwise) Best Setting: Swing direction of widthwise, tray slope of 4° and full open of feed gate	Arka Bindu Size: Large (Grade I): >30 mm, Medium (Grade II): 25–30 mm & Small (Grade III): <25 mm	64.5% to 81.97%	44.9 kg hr^{-1} to 617.38 kg hr^{-1}	With report of visual observation of onion damage
(Dabhi and Patel, 2016)	Onions are fed into a hopper and sorted by size as they pass through divergent rollers with adjustable gaps, which rotate at controlled speeds, directing them into separate compartments through graded openings.	Roller Speeds (5, 7, 9, 11, 13, 15 rpm) Roller Inclination Angles (4°, 8°, 12°) Best Setting : Roller speed of 15 rpm & Roller inclination of 8°	Talaja Red Size: Grade A (<40 mm), Grade B (40–60 mm), & Grade C (>60 mm).	70.02% to 91.69%,	211.04 kg hr^{-1} to 751.38 kg hr^{-1}	With report of visual observation of onion damage
(Mostafa and Bahnasawy, 2009)	Onions are fed onto a conveyor belt with adjustable longitudinal and side angles, where they are sorted into three size categories through specific outlet openings based on diameter.	Belt speeds (0.10, 0.17, 0.23, 0.30 m s^{-1}) Side angles (10°, 20°, 30°) Longitudinal angles (0°, 10°, 20°) Best Setting: Belt speed of 0.23 m s^{-1}, side angle of 10°, & longitudinal angle of 10°	Variety was not specified Size: Small (<40 mm), Medium (40–70 mm), & Large (>70 mm)	85.6% to 95.2%	0.58 t h^{-1} to 1.72 t h^{-1}	Not explicitly detailed

Table 2 Specification and performance of different automated onion grading machines

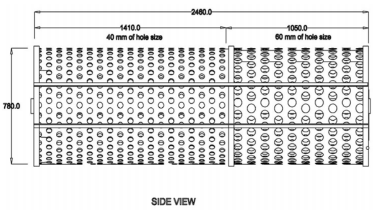
Author	Mechanisms for grading	Sensor technology	Factors for evaluation	Onion variety and grading systems	Grading efficiency	Throughput capacity	Percent damage
(Aboamera et al., 2011)	Onions pass through a conveyor equipped with an optical sensor system (photoresistors and LEDs). Light blocking determines bulb dimensions, and the control unit assigns each bulb to size-based bins using a distributing motor.	photoresistors and LEDs for size detection DC motors for bulb distribution.	Conveyor chain velocity (0.10–0.25 m s^{-1}) Stopping time (1–2.5 sec) Bulb sphericity (<100%, 100–105%, >105%) Best setting: 0.20 m s^{-1} chain velocity, 1.5 sec stopping time	Giza variety Size-based sorting categorized by bulb dimensions (small, medium, large)	78.96% to 92.28%	130 kg h^{-1} to 325 kg h^{-1}	3.2% to 14.7%
(Tollner et al., 2005)	The X-ray machine scans onions on a conveyor belt, using morphological and threshold algorithms to identify voids and defects within the onion tissue. Defective onions are marked or removed using an integrated reject mechanism.	X-ray imaging with morphological algorithms for defect analysis.	Fix Setting Belt speed (0.6 m s^{-1}) and machine sensitivity were key factors affecting accuracy and false positives	Vidalia sweet onion Classified into good and defective onions based on internal defects such as voids, fungal infections, or bacterial rots	85% to 97% (for defect detection)	25 bags/hour (50 onions per bag) per lane, with scalability up to 15 lanes for higher throughput	Not explicitly specified

Author	Mechanisms for grading	Sensor technology	Factors for evaluation	Onion variety and grading systems	Grading efficiency	Throughput capacity	Percent damage
(Dorokhov et al., 2021)	Onions are transferred through a conveyor system with vision camera to scan and classify onions by size, shape, and damage. Actuators separate defective and healthy products.	Image recognition camera (vision-based control system) Actuators controlled by microcontrollers (Arduino Mega 2560)	Conveyor speed (0.8 to 1.2 m s^{-1}) Feed rate (4 to 8 kg s^{-1}), Actuator response time (1 to 3 seconds). Best Setting: Conveyor speed of 1.2 m s^{-1}, feed rate of 6.5 to 6.9 kg s^{-1}, and actuator response time: 1.9–2.3 seconds.	Not explicitly specified Size-based sorting using dimensional characteristics and recognition of damaged and substandard products.	91%	4 kg s^{-1} to 8 kg s^{-1}	2.2%
(Digamber et al., 2022)	Onions are loaded onto a conveyor belt, pass through an image processing unit to detect sprouted onions, and then through a gas sensing chamber to detect rotten onions. Actuators separate defective onions from healthy ones.	RGB cameras (for image processing) MQ6/MQ135 gas sensors (for detecting volatile compounds)	Fixed setting with camera resolution (1280x720 pixels) and gas sensor with distance for sensing: 3 cm at ambient temperature: 31°C	Not explicitly specified Identifies and separates sprouted and rotten onions based on visual (color and texture) and chemical (gas emissions) attributes	87% (efficiency for sprouted onions using image processing) 80%–93% (efficiency for determining rotten onions using gas sensors)	Not explicitly specified	Not explicitly specified
(Deplomo et al., 2020)	The system captures images of onions placed on a platform using a camera. Digital image processing algorithms analyze RGB values, texture, and pixel-per-metric ratios to classify onions by size and detect quality issues.	RGB cameras for image capture Blob detection algorithms for analysis	Fixed setting with lighting conditions standardized for consistent image quality. Algorithms used was blob detection for size and RGB analysis for texture and quality grading.	Not explicitly specified Grading based on size (small, medium, large) quality (color and texture) as per Philippine National Standards.	91.2% for size classification 89.6% for quality grading	Not explicitly specified	Not explicitly specified
(Wang and Li, 2015)	Onions are placed on a motorized linear slider and sequentially scanned using RGB-D, hyperspectral, and X-ray imaging sensors. Custom algorithms analyze size, volume, density, and detect internal/external defects.	RGB-D, hyperspectral, and X-ray sensors. Integrated with LabVIEW software for synchronization and data acquisition.	Size/geometric shape of onion External & Internal defects	Granex type Size (diameter), volume, density, and defects (external and internal).	88.9% Quality classification (healthy vs defective)	One onion per minute in a laboratory setup	Not explicitly specified
(Wang and Li, 2014)	The RGB-D sensor captures depth and color images of onions from multiple orientations. Depth images are used to estimate the maximum diameter, volume, and density of onions using a point	RGB-D sensors Software for depth and image analysis.	Evaluated single vs. multiple scans, color image vs. depth image; depth image provided the best accuracy and robustness to orientation changes.	Granex type Size: Colossal: ≥101.6 mm, Jumbo: 76.2–101.6 mm, Medium: 50.8–76.2 mm.	99.14% (diameter estimation accuracy) volume estimation accuracy ranged from 96.3%	30 onions per second per lane	Not explicitly specified

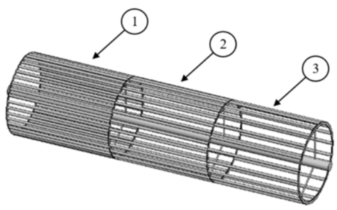
Author	Mechanisms for grading	Sensor technology	Factors for evaluation	Onion variety and grading systems	Grading efficiency	Throughput capacity	Percent damage
	cloud and ellipsoidal models.			Geometric Measurement: Diameter, Volume & Density	(single scan) to 97.9% (multiple scans)		
(Shahin et al., 2002)	X-ray images are processed to detect internal defects like leaf decay and sprouting using spatial and transform features. Neural and Bayesian classifiers analyze image features for defect classification.	X-ray imaging, edge detection, DCT feature extraction Artificial intelligence (AI) classifiers.	Optimal imaging and classification: X-ray line scan with 120 kV and 390 mA; 12 image features (spatial and DCT coefficients) were selected for classification.	Sweet Vidalia onions Binary classification: Good (defect-free) and Defective (internal decay, sprouting).	90% (Neural network) 84% (Bayesian classifier)	10 onions scanned every 6 seconds (off-line research setup)	Not explicitly specified

3.1 Mechanism and sensor technology for grading of onion

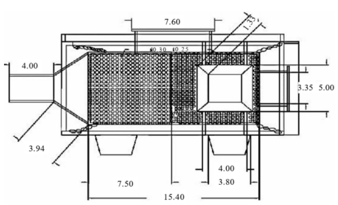
There are various mechanisms employed for onion sorting and grading. Common designs include mechanical systems, such as rotating perforated cylindrical drum (Figure 1a) with different sized apertures for onion grading and separated based on size by falling through respective apertures (Bisen et al., 2022). Another variation includes a rotating cylindrical grader (Figure 1b) divided into sections with slatted openings of varying sizes, where onions are sorted into different categories as they fall through the corresponding openings (Caguay and Magboo, 2023; El-Rahman and Magda, 2011; Gunathilake et al., 2016; Tafa and Olaniyan, 2023; Umani and Markson, 2020). In addition, a mechanism that includes an oscillating tray with perforated sieves (Figure 1c) allows onions to pass through size-specific slots and be collected in trays for different size categories (Gayathri et al., 2016). Other designs include divergent roller systems (Figure 1d), where onions are fed into a hopper, pass through divergent rollers with adjustable gaps that rotate at controlled speeds, and fall through graded openings based on size into separate compartments (Dabhi and Patel, 2016; Karthik and Palanimuthu, 2018).These systems offer simplicity and ease of operation but often fall short in addressing more complex grading needs, such as detecting quality defects or handling delicate onions without damage.



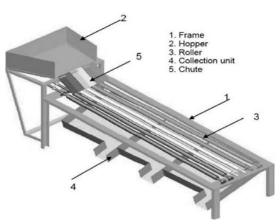
(a) Rotating perforated cylindrical drum



(b) Rotating slatted cylindrical grader



(c) Oscillating tray with perforated sieves



(d) Divergent roller systems

Figure 1 Different design of mechanisms for onion sorting and grading

Automated onion grading systems employ various mechanical and sensor-based mechanisms to classify onions by size, shape, and quality. Optical-based systems, such as photoresistor-LED arrays utilize light-blocking principles to measure bulb dimensions, with distributing motors directing onions into size-specific bins (Aboamera et al., 2011). Another example is conveyor-driven designs with integrated vision cameras to capture dimensional and surface characteristics of onions, coupled with microcontroller-actuated arms for real-time onion sorting (Dorokhov et al., 2021). In addition, X-ray systems employ line-scan imaging and morphological algorithms to detect internal defects, with reject mechanisms triggered by spatial and transform feature analysis (Shahin et al., 2002; Tollner et al., 2005). Furthermore, an onion grader with combine RGB cameras for visual sprout detection with gas sensors to identify volatile compounds emitted by rotten onions, enabling multi-attribute separation (Digamber et al., 2022). Advanced imaging systems, including RGB-D sensors (Wang and Li, 2014), generate 3D point clouds and ellipsoidal models to estimate geometric parameters, while hyperspectral and X-ray fusion (Wang and Li, 2015) enables multi-modal defect analysis through synchronized data acquisition. Simpler platforms, like Key mechanical elements include adjustable conveyor speeds, actuator response systems, and modular sorting lanes, with AI-driven classifiers (Shahin et al., 2002) enhancing defect recognition robustness. Despite advancements, gaps remain in various automated onion grading technologies such as accessibility for small-scale farmers due to high costs, technical complexity, infrastructure demands, and off-grid conditions.

3.2 Grading efficiency of onion grading machines

Grading efficiency refers to the effectiveness of a system in accurately classifying produce into designated categories based on specific attributes such as size, shape, color, and quality which is quantified by comparing the number of correctly sorted items to the total number of items processed, often expressed as a percentage (Londhe et al., 2013). The efficiency of mechanical systems of onion sorting and grading varies significantly, influenced by parameters such as drum speed, feed rate, and slope. For example, a rotating perforated cylindrical drum mechanism, achieved grading efficiencies ranging from 82.79% to 92.99%, with the highest efficiency (92.99%) recorded at the optimal settings of 10 rpm drum speed and a 4% slope for effective size-based sorting with minimal damage to the onions. Various rotating slatted cylindrical graders achieved grading efficiencies ranging from 68% to 96.04%, with performance influenced by factors such as cylinder rotational speed, feed rate, inclination angle, and feed gate opening (Caguay and Magboo, 2023; El-Rahman and Magda, 2011; Gunathilake et al., 2016; Tafa and Olaniyan, 2023; Umani and Markson, 2020). In terms of divergent rollers mechanism and perforated sieves for onion grading, the efficiencies ranged from 66.64% to 94.8%, influenced by factors such as grading slope, feed rate, roller speed, and feed gate opening (Dabhi and Patel, 2016; Gayathri et al., 2016; Karthik and Palanimuthu, 2018).

Automated onion grading systems achieve efficiencies ranging from 78.96 to 99.14%, influenced by the types of sensors, implemented algorithms, and actuators. Optical systems (Aboamera et al., 2011) using photoresistor-LED arrays attain 92.28% size-sorting efficiency at optimal conveyor speeds, while vision-based systems (Dorokhov et al., 2021) with cameras and actuators reach 91% accuracy in combined defect and size grading. X-ray technologies were able to classify onion in terms of in internal defect detection with 85% to 97% accuracy (Shahin et al., 2002; Tollner et al., 2005). Advanced platforms integrating RGB-D, hyperspectral, and X-ray sensors achieve near-perfect geometric estimations (99.14% diameter accuracy) and 88.9% defect classification, although constrained to lab-scale throughput (Wang and Li, 2014, 2015). Simpler setups using blob detection (Deplomo et al., 2020) and hybrid gas-RGB sensors (Digamber et al., 2022) have an efficiency (80%–93%) and practicality, though variability in lighting, onion geometry, and algorithm robustness remains a challenge for universal adoption.

Despite achieving high grading efficiencies, automated onion sorting systems face challenges such as high costs, technical complexity, and limited adaptability, hindering their practical applications, particularly for small to medium scale onion farmers. On the other hand, mechanical onion graders provide a low-cost, and accessible alternative to automated technologies, ideal for small to medium scale farmers due to their minimal maintenance requirements, and independence from complex operation though they lack the precision and defect-detection capabilities of sensor-based systems.

3.3 Percent damage of onion grading machines

Mechanical graders, using rotating drums or sieves, show low damage percentages between 0.34% to 1.20% when optimized for parameters such as rotational speed (e.g., 10–15 rpm) and slope (e.g., 4%) (Karthik and Palanimuthu, 2018; Tafa and Olaniyan, 2023). However, higher percent damage between 2.26% to 7.93%, occurs in systems with unoptimized settings, such as elevated feeding rates or steeper inclinations (El-Rahman and Magda, 2011). Automated systems, integrating sensors (e.g., RGB cameras, X-ray) and actuators, exhibit varying percent damage ranging from 2.2 to 14.7%, which is mainly influenced by conveyor speeds, actuator precision, and contact intensity during sorting (Aboamera et al., 2011; Dorokhov et al., 2021). While mechanical systems prioritize throughput with minimal damage, automated solutions trade-off higher accuracy against potential mechanical abrasion or sensor-induced impacts. Notably, many studies for onion grading machine lack explicit damage quantification, underscoring the need for standardized reporting to balance efficiency and postharvest quality in grading technology development.

3.4 Throughput capacity of onion grading machines

Throughput capacity refers to the total amount of material processed or produced by a system within a given time frame (Qarahasanlou et al., 2022). The throughput capacity of mechanical and automated onion sorting and grading machines varies depending on the intended end users, the purpose of the research, and the stage of technology development. Nonetheless, this information provides insight into the future development of the machine, considering the relationship between throughput capacity, percentage of damage, and grading efficiency. Mechanical systems achieve throughputs from 45 kg hr^{-1} (Gayathri et al., 2016) to 3 tons hr^{-1} (Bisen et al., 2022), with cylindrical sieve-based designs reaching 1,273–1,488 kg hr^{-1} at optimal rotational speeds (Caguay and Magboo, 2023; Tafa and Olaniyan, 2023).

Automated systems show wider variability compared to mechanical systems. For example, optical sensors manage 130–325 kg hr^{-1} (Aboamera et al., 2011), while high-speed vision-based conveyors scale to 14,400–28,800 kg hr^{-1} (Dorokhov et al., 2021), rivaling industrial demands. Advanced sensor systems prioritize precision over speed, such as X-ray (Tollner et al., 2005) and hyperspectral setups (Wang and Li, 2015), which process 10 onions/6 seconds or 30 onions/second per lane, respectively, but lack scalability. Mechanical graders excel in cost-effective, moderate-throughput applications (211–751 kg hr^{-1}), while automated solutions suit high-volume, quality-focused operations despite higher complexity. Trade-offs persist between speed and precision, with mechanical systems favoring bulk sorting and automated technologies enabling defect-sensitive grading. The choice hinges on operational scale, with mechanical designs ideal for small-to-medium farms and automated systems catering to large-scale, precision-dependent markets.

3.5 Treatments for evaluation of mechanical onion grading machine

The treatment commonly used for performance evaluation of mechanical onion grading machines are rotational speed, inclination angle, feed rate and sorting mechanism. Rotational speed plays an important role in refining grading performance specially with rotating drum equip with either perforated sheet or slatted bar, with studies suggesting optimal speeds ranging from 10 rpm (Caguay and Magboo, 2023; Vinay et al., 2017) to 87.5 rpm (Tafa and Olaniyan, 2023). Inclination angle impacts onion movement through grading apertures, with optimal settings reported at 3° (Gunathilake et al., 2016) and 4° (Gayathri et al., 2016) to improve sorting accuracy. Feed rate significantly affects throughput and grading efficiency, with ideal values shown at 20 kg min^{-1} (Tafa and Olaniyan, 2023) and 300 kg h^{-1} (Karthik and Palanimuthu, 2018). Lastly, the sorting mechanism varies across designs, including rotating cylindrical graders (El-Rahman and Magda, 2011), divergent rollers (Dabhi and Patel, 2016), and conveyor belts (Mostafa and Bahnasawy, 2009), each requiring specific parameter optimizations to maximize accuracy and reduce damage.

In terms of automated onion grading machine, the commonly used factors for evaluation in onion sorting and grading systems with sensor technology include conveyor speed, feed rate, image processing resolution, defect detection accuracy, and actuator response time. Conveyor speed is a critical factor influencing throughput and classification accuracy, with optimal values ranging from 0.10 m s^{-1} (Aboamera et al., 2011) to 1.2 m s^{-1} (Dorokhov et al., 2021). Feed rate, affecting system efficiency and sorting precision, was optimized between 4 to 8 kg s^{-1} in vision-based systems (Dorokhov et al., 2021). Image processing resolution and sensor quality, particularly in RGB and hyperspectral imaging systems, impact defect detection and size classification (Deplomo et al., 2020; Wang and Li, 2015). Defect detection accuracy, using X-ray or gas sensors, is influenced by sensor sensitivity and imaging techniques, with AI classifiers improving internal defect identification (Digamber et al., 2022; Shahin et al., 2002). Lastly, actuator response time determines sorting efficiency, with optimal settings between 1.9 and 2.3 seconds (Dorokhov et al., 2021). These factors were commonly used for optimization of mechanical onion grading machine settings to enhance efficiency, minimize product loss, and improve onion grading performance.

4 Conceptualization of onion grader machine for small scale farmers in the Philippines

Small onion farmers often cite the high cost of mechanized equipment which is not affordable to farmers who have small farm sizes in the Philippines (Gavino et al., 2020). Postharvest practices of producing bulb onions were laborious and manually done. A result of a postharvest loss study in the Philippines revealed that the industry was incurring postharvest physical losses of 31.49% and quality losses of 32.41% (Calica and Cabanayan, 2018). Based on the conducted review on mechanical and automated onion grading system, a rotating cylindrical grader design and divergent roller design is the suggested mechanism for the design of mechanical onion grader which could offer by up to 95% grading efficiency in terms of onion size. Compared to advanced sensor-based or fully automated systems, it requires lower capital outlay and simpler training for operators. Its minimal power requirements suit remote or limited-electrification areas, where a small engine can drive the drum if electricity is unavailable. In terms of rotating cylindrical grader, whether perforated or slatted, the major design parameters that could affect grading efficiency, percent damage, & throughput capacity, the optimum drum speed is commonly around 10 rpm to 15 rpm and inclination of 3^{o} to 4^{o}. For divergent roller design, optimum setting in terms of rolling speed ranging from 13 rpm to 15 rpm and bed inclination of 8^{o} to 13^{o} gives best grading efficiency. These two design of mechanical grader could achieve consistent size-based separation aligned with the Philippine National Standard for Bulb Onion and Shallots (PNS/BAFPS 14:2004) and offers a practical and cost-effective approach for improving onion sorting and grading process in the Philippines.

For the performance evaluation, grading efficiency, throughput capacity, and percent damage, along with energy consumption and labor savings must be included to ensure that the machine will be evaluated comprehensively. These parameters provide quantitative benchmarks to compare different machine settings in terms of rotating drum rpm, rolling drum rpm and angle of inclination. In addition, 3D modeling and, software simulations such as finite element analysis (FEA) for machine structural component response to different loadings and discrete event modeling (DEM) to predict how design parameters—such as drum inclination, rotational speed, and feed rate—impact throughput, and overall accuracy of grading in terms of size must be conducted before the construction. Furthermore, a techno-economic analysis of the machine should factor in capital investment costs (materials, manufacturing, and assembly), operating costs (energy, labor, maintenance), and potential revenue gains derived from improved grading accuracy, reduced postharvest losses, and increased marketability.

5 Conclusion

The review of existing onion sorting and grading technologies reveals that both mechanical and automated systems have distinct advantages and limitations. Mechanical graders, particularly those using rotating cylindrical and divergent roller designs, offer a cost-effective solution with grading efficiencies reaching up to 95%, making them highly suitable for small-scale Filipino farmers who face labor and capital constraints. In contrast, automated systems equipped with advanced sensors can achieve accuracies as high as 99% in defect and size classification, although at a higher cost and operational complexity. For the design conceptualization of mechanical onion grader for small scale farmer, factors such roller rpm (13 rpm to 15 rpm) and inclination (8^o to 13^o), and drum rpm (10 rpm to 15 rpm) and inclination (3^o to 4^o) must be considered to ensure higher grading efficiency and lower percent damage. Future work should be validated which factors is critical using simulation analysis such as motion analysis (MA) and discrete element method (DEM) alongside a comprehensive techno-economic evaluation to ensure that the designed solutions are both effective and accessible for local small-scale onion farmers.

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Reference

Aboamera, M., G. Gamea, and M. Mohmed. 2011. Onion Grading Prototype Based on the Dimensions of the Bulb Using Photoresistors. *Misr Journal of Agricultural Engineering*, 28(2): 487–504.

Alfatni, M. S. M., A. R. M. Shariff, M. Z. Abdullah, M. H. B. Marhaban, and O. M. B. Saaed. 2013. The application of internal grading system technologies for agricultural products–Review. *Journal of Food Engineering*, 116(3): 703–725.

Bahram-Parvar, M., and L. T. Lim. 2018. Fresh-cut onion: A review on processing, health benefits, and shelf-life. *Comprehensive Reviews in Food Science and Food Safety*, 17(2): 290–308.

Bisen, R. D., P. H. Bakane, and S. R. Sakkalkar. 2022. Design, development and performance evaluation of rotary onion grader. *Journal of Food Science and Technology*, 59(6): 2370–2380.

Caguay, M., and A. M. Magboo. 2023. Development and Evaluation of an Onion Bulb Size Grading Machine: A Promising Solution to Enhance Efficiency and Reduce Costs for Local Onion Farmers. *Journal of Engineering and Emerging Technologies*, 2(1): 12–24.

Calica, G. B., and Z. L. L. Cabanayan. 2018. Assessment of the Postharvest Systems and Losses of Bulb Onions in Nueva Ecija, Philippines. *Asian Journal of Postharvest Mechanization*, 1(1): 47–55.

Chakraborty, A. C. 2018. Pre-and post-harvest losses in vegetables IVI. In *Advances in Postharvest Technologies of Vegetable Crops*, eds. B. Singh, and S. Singh, ch. 2, 25–87. Boca Raton, FL, USA: Apple Academic Press.

DA-AFID. 2023. ORION Program targets to perk up Phl onion industry, increase domestic supply. Official Portal of the Department of Agriculture. Available at: https://www.da.gov.ph/orion-program-targets-to-perk-up-phl-onion-industry-increase-domestic-supply/. Accessed January 31, 2023.

DA-BAR. 2022. Philippine onion industry roadmap 2021–2025. Quezon City, Philippines: Department of Agriculture - Bureau of Agricultural Research through the UPLB Foundation, Inc. in collaboration with the Philippine Council for Agriculture and Fisheries.

Dabhi, M. N., and N. C. Patel. 2016. Design and Development of Onion Grader. *Journal of Agricultural Engineering (India)*, 53(1): 27–32.

DA-PRDP. 2022. Top onion-producing municipality breaks ground for cold storage subproject | Philippine Rural Development Project. Available at: http://prdp.da.gov.ph/top-onion-producing-municipality-breaks-ground-for-cold-storage-subproject/. Accessed February 3, 2023.

Deplomo, B. N. I., J. C. Dela Cruz, and J. R. Balbin. 2020. Classifying Quality Grading and Size of Allium Cepa Using Digital Image Processing Algorithms. In *2020 International Conference on Communications, Information System and Computer Engineering (CISCE)*, 123–126. Kuala Lumpur, Malaysia, 3-5 July.

Digamber, K. M., W. V. Ashok, and P. D. Jagdish. 2022. Development of smart machine for sorting of deceased onions. *Indonesian Journal of Electrical Engineering and Computer Science*, 25(1): 191-199.

Dorokhov, A., A. Aksenov, A. Sibirev, N. Sazonov, M. Mosyakov, and M. Godyaeva. 2021. Results of laboratory studies of the automated sorting system for root and onion crops. *Agronomy*, 11(6): 1257.

DOST - PCARRD. 2018. DOST-PCAARRD leads discussion on onion and garlic S&T gaps. Available at: https://pcaarrd.dost.gov.ph/index.php/quick-information-dispatch-qid-articles/dost-pcaarrd-leads-discussion-on-onion-and-garlic-s-t-gaps?utm. Accessed February 3, 2023.

DOST - PCARRD. 2024. Onion Production Surge: Market Impact, Importation Ban, and Support Initiatives for Farmers in the Philippines – Industry Strategic Science and Technology Plans (ISPs) Platform. Available at: https://ispweb.pcaarrd.dost.gov.ph/onion-production-surge-market-impact-importation-ban-and-support-initiatives-for-farmers-in-the-philippines/. Accessed December 5, 2024

El-Rahman, A., and M. Magda. 2011. Development and performance evaluation of a simple grading machine suitable for onion sets. *Journal of Soil Sciences and Agricultural Engineering*, 2(2): 213–226.

Falola, A., R. Mukaila, R. O. U. Iı, C. O. Ajewole, and W. Gbadebo. 2023. Postharvest losses in onion: Causes and determinants. *Kahramanmaraş Sütçü İmam Üniversitesi Tarım ve Doğa Dergisi*, 26(2): 346–354.

Flores, E. D., R. G. Idago, M. C. R. Antolin, and D. R. Miranda. 2021. Protected Cultivation of Off-Season Bulb Onion (Alium Cepa) Under Low Plastic Tunnel. *Asian Journal of Postharvest and Mechanization*, 4(1): 36.

Gavino, R. B., V. E. B. Camaso, and C. C. Tiw-an. 2020. Assessment of Mechanization Level of Onion Production in Nueva Ecija. *CLSU International Journal of Science & Technology*, 4(1): 82–99.

Gayathri, G., K. V. Harshanjali, K. Rupavathi, D. V. Kumar, G. S. Kumaran, A. C. R. Kumari, and M. Ramana. 2016. Design, development and evaluation of a manually operated onion grader for Rose onion. *International Journal of Agricultural Engineering*, 9(2): 121-129.

Giovannucci, D. P., P. A. Sterns, M. Eustrom, and H. Haantuba. 2001. The impact of improved grades and standards for agricultural products in Zambia. *PFID-F&V Report No. 3*. East Lansing, MI: Michigan State University and United States Agency for International Development (USAID).

Gunathilake, D. M. C. C., W. M. C. B. Wasala, and K. B. Palipane. 2016. Design, development and evaluation of a size grading machine for onion. *Procedia Food Science*, 6: 103–107.

Karthik, S., and V. Palanimuthu. 2018. Design and development of on-farm onion grader. *International Journal of Current Microbiology and Applied Sciences*, 7(Special Issue 6): 2907–2914.

Kitinoja, L., and A. A. Kader. 2002. *Small-scale postharvest handling practices: A manual for horticultural crops*. 4th ed. Postharvest Horticulture Series No. 8E. Woodland, California: University of California, Davis, Postharvest Technology Research and Information Center.

Londhe, D. H., S. M. Nalawade, G. S. Pawar, V. T. Atkari, and S. V. Wandkar. 2013. Grader: A review of different methods of grading for fruits and vegetables. *CIGR Journal*, 15(3): 217–230.

Mishra, A., S. K. Jha, and S. Shrestha. 2020. Performance Evaluation of Onion Grader. *International Journal of Scientific and Research Publications*, 10(1): 434-438.

Mopera, L. E. 2016. Food loss in the food value chain: The Philippine agriculture scenario. *Journal of Developments in Sustainable Agriculture*, 11(1): 8–16.

Mostafa, H., and A. H. Bahnasawy. 2009. Development of affordable machine for sizing Egyptian onion. *CIGR Journal,* 11, Manuscript FP 1179.

Mushobozi, W. L. 2010. Good Agricultural Practices on horticultural production for extension staff in Tanzania. Rome,Italy: FAO.

Osei, M. K., J. Adjebeng-Danquah, I. Osei-Bonsu, F. O. A. Andoh, B. Amoabeng, F. Okyere, L. D. Melomey, and R. Y. Agyare. 2025. Integrated Management Strategies for Shelf-life and Postharvest Diseases in Vegetable Cultivation. In *Plant Diseases and Their Management*, eds. D. Srivastava, R. K. Gaur, and A. K. Tiwari, ch. 1, 1–43. New York, USA: Apple Academic Press.

Philippine Statistics Authority. (2020). *Crops statistics of the Philippines, 2015-2019*. https://psa.gov.ph.

Qarahasanlou, A. N., A. Hazrati, A. Barabdi, A. Khodayari, and M. Mokhberdoran. 2022. Industrial Equipment's Throughput Capacity Analysis. In *International Congress and Workshop on Industrial AI 2021*, eds. R. Karim, A. Ahmadi, I. Soleimanmeigouni, R. Kour, and R. Rao, 99–111. Switzerland: Springer International Publishing.

Santos, M., J. D. Jesus, A. V. Villanueva, M. Fernandez, C.

Saturno, M. Fuentes, R. Pestano, J. Miller, and J. Martin. 2024. Traditional Sibuyas (Onion) Farming in the Philippines: An Ethnographic and Biomechanical Perspective. *Universal Journal of Agricultural Research*, 12(2): 356–368.

Sanyang, S. E. 2014. Market oriented study on onion production through value chain approach in agricultural regions of the Gambia. *World Journal of Agricultural Sciences*, 10(6): 279–293.

Shahin, M. A., E. W. Tollner, R. D. Gitaitis, D. R. Sumner, and B. W. Maw. 2002. Classification of sweet onions based on internal defects using image processing and neural network techniques. *Transactions of the ASAE*, 45(5): 1613.

Tafa, W., and A. M. Olaniyan. 2023. Design and Development of an Engine Driven Onion Grading Machine. *American Journal of Food Science and Technology*, 2(2): 1–13.

Tollner, E. W., R. D. Gitaitis, K. W. Seebold, and B. W. Maw. 2005. Experiences with a food product X-ray inspection system for classifying onions. *Applied Engineering in Agriculture*, 21(5): 907–912.

Umani, K. C., and I. E. Markson. 2020. Development and performance evaluation of a manually operated onions grading machine. *Journal of Agriculture and Food Research*, 2: 100070.

Vinay, B. J. V. S., L. Edukondalu, S. Kumar, and G. V. Prasad. 2017. Development and Evaluation of a Grader for Round Fruits and Vegetables. *The Andhra Agricultural Journal*, 64(4): 891-895.

Wang, W., and C. Li. 2014. A multimodal quality inspection system based on 3D, hyperspectral, and X-ray imaging for onions. ASABE Paper No. 141900673. St. Joseph, Michigan: ASABE.

Wang, W., and C. Li. 2015. A multimodal machine vision system for quality inspection of onions. *Journal of Food Engineering*, 166: 291–301.

Yeshiwas, Y., M. Alemayehu, and E. Adgo. 2023. The rise and fall of onion production; its multiple constraints on pre-harvest and post-harvest management issues along the supply chain in northwest Ethiopia. *Heliyon*, 9(5): e15905.