Review Article

Advances in Multi-Fruit and Vegetable Grading: A Comprehensive Review

Abstract

This review paper provides an overview of the various methods and technologies used for grading fruits and vegetables. The paper begins by discussing the importance of grading in ensuring the quality of produce and meeting consumer demands. The review then delves into the different grading criteria used for fruits and vegetables, including size, shape, color, texture, and defects.

The paper explores traditional grading methods, such as visual inspection and manual sorting, as well as newer technologies, including computer vision and machine learning. It also discusses the use of spectroscopy and hyper spectral imaging for non-destructive quality assessment.

The review highlights the advantages and limitations of each grading method and technology and emphasizes the need for a holistic approach that considers multiple factors in grading produce. It also discusses the impact of grading on the economic and environmental sustainability of the produce industry. Overall, this review paper provides a comprehensive understanding of the current state of fruit and vegetable grading and the opportunities for future development in this field.

Keywords: Grading, Size, Shape, Colour, Manual sorting

1. Introduction

Grading is an important process in the fruits and vegetables industry as it ensures that the produce meets quality standards and consumer demands. Grading is typically based on a combination of factors, including size, shape, color, texture, and defects. The process is important in maintaining the quality of produce, reducing waste, and increasing efficiency in the supply chain.

Grading is a crucial step in the post-harvest handling of fruits and vegetables. It helps to maintain quality and reduce spoilage and waste during transportation and storage. Grading based on size, shape, color, texture, and defects can significantly impact the marketability and value of produce. For example, fruits and vegetables that are uniform in size and color are more attractive to consumers and have higher market value. (Kader 2005).

Traditionally, grading has been done by visual inspection and manual sorting. However, with advancements in technology, automated grading systems have become increasingly popular. These systems use computer vision and machine learning algorithms to sort produce based on predefined quality criteria. Automated grading systems offer several advantages over traditional methods, including increased efficiency, accuracy, and consistency. (Garcia-Segovia et al. 2017).

Non-destructive quality assessment techniques, such as spectroscopy and hyper spectral imaging, are also being used for grading fruits and vegetables. These techniques allow for the assessment of internal quality characteristics, such as sugar content and ripeness, without damaging the produce. Hyper spectral imaging has shown promising results in grading fruits and vegetables based on various quality attributes. (Dabbagh et al. 2016).

Grading of fruits and vegetables not only impacts the quality and marketability of produce but also has economic and environmental implications. Inefficient grading processes can result in increased waste and lower profitability for growers and retailers. Sustainable grading practices, such as the use of non-destructive quality assessment techniques and optimal packaging, can help reduce waste and improve the overall sustainability of the produce industry (Majeed et al. 2020).

2. Material and Methods

In the case of fruits and vegetables, size and shape are often important factors in determining their quality and market value. Therefore, sorting and grading machines that can accurately measure and sort produce based on these factors are commonly used. Some of the common types of sorters and graders used in the agricultural industry include.

2.1 Size Based Grading

Patil and Patil (2002) developed a sapota fruit grader using a divergent roller type machine. They studied the effect of roller speed and gap between the rollers on the machine's capacity and separation efficiency. The machine was tested with three different roller speeds and gaps between the rollers, achieving a maximum capacity of 1,800 kg/h and an overall sorting capacity of 1,727 kg/h for sapota fruits. The separation efficiency ranged from 54% to 87%, with an overall efficiency of 72%.

Ghuman and Kumar (2005) developed a low-cost rotary disc size grader for grading spherical fruits and vegetables. The manual grading process is costly and time-consuming, so a low-cost on-farm grader was designed and fabricated using rubber balls of different diameters in the laboratory. The optimal disc speed for proper separation of different grades was observed to be 60-70 r/min. Further testing of the grader for various fruits and vegetables is needed both in the laboratory and in the field.

Mangaraj et al. (2005) developed a stepwise expanding pitch fruit grader that uses the principle of changing flap spacing to grade fruits. The grader consists of a grading unit, elevator feeding unit, inspection platform, and power transmission system. The grading unit has two tracks of conveyor chains, stainless steel flaps, and fruit collection trays. The elevator feeding unit ensures constant and uniform feeding of fruits, while the inspection platform removes damaged or unwanted fruits. The grader can separate fruits into four grades by adjusting flap spacing between 45 to 140 mm, with an overall grading efficiency of 91.50% for sweet lemon and 88.50% for orange. The grader has a capacity of 3.5 t/h at a grading conveyor speed of 6 m/min.

Ashraf et al. (2007) developed and evaluated a fruit and vegetable grader, consisting of a take-in conveyor, grading unit, and take-away conveyor mounted on a main frame. Different speeds were tested for the take-in and take-away conveyors to optimize the feed rate and prevent mutual collusion of the graded produce. However, high grading speeds and take-in conveyor speeds resulted in increased damage index and grading errors. The study emphasized the importance of effective human supervision for ensuring smooth operation of the grader. The average grading charges were approximately Rs.4 per 100 kg of produce.

Ukey and Unde (2010) developed a sapota fruit grader to increase the output of fruit grading while saving time and labor. They designed and developed a sapota fruit grader based on the divergent roller type principle and experimented with different combinations of roller speed, roller inclination, and roller gap. The best combination of these parameters was 223 r min-1 for roller speed, 4.5º for roller inclination, and 38 to 64 mm for roller gap, resulting in a high efficiency of 89.5%. The developed sapota fruit grader had a capacity of 1,440 kg h-1 and costed Rs.11, 450/- (without electric motor).

Abdi, H et al., (2016) carried out a review on Automated Size-Based Grading of Fruits and Vegetables. The review paper identifies several size-based grading systems that have been developed for different types of fruits and vegetables, using a range of techniques. These systems include optical sorters, weight sorters, color sorters, shape sorters, and density sorters. Each system has its own advantages and limitations, depending on the specific requirements of the produce being graded.

Narayanan, R. et al (2019) developed of a size-based grading system for fruits and vegetables using machine vision and artificial neural networks. The size-based grading system achieved an accuracy of 96% for classifying fruits and vegetables into the three size categories. The system was also able to process products at a rate of 4 units per second, which is much faster than traditional manual methods.

Garg, N. et al (2020) a review of size-based grading systems for fruits and vegetables. In conclusion, the review paper highlights the importance of size-based grading in the agricultural industry, and provides an overview of the different techniques and systems that have been developed for this purpose. The paper also discusses the potential for further research and development in this area, including the use of advanced technologies such as artificial intelligence and robotics.

2.2 Screen Grader

Singh and Ilyas (2001) designed and developed a grader capable of grading both vegetables and fruits, specifically onion and potato. They observed that shaking the products helped in altering their orientation, thus increasing grading efficiency. The machine was able to grade 1500 to 1800 kg/hr of produce, with external mechanical damage (such as bruising, skinning, and cutting) remaining under 1%. Electrical energy consumption per tonne of potatoes was measured at 80 watts/hr, and the machine itself weighed 300 kg.

Doriaswatny, (2000) developed a sieve-type grader to grade groundnuts into three different sizes, which had an output capacity of 600 kg/h and was powered by a 1 hp 3-phase electric motor. However, during testing, there were issues with the pods getting stuck in the sieve holes, which required modifications to the shaking system. After reviewing the literature, Adler concluded that sieve-type graders commonly experienced issues with sieve hole blocking. To summarize, Doriaswatny developed a groundnut grader using a sieve-type system, but the design had issues with blockage of the sieve holes, which is a common problem for this type of grader.

Meerut (2002) developed a mobile potato screen grader that could be powered by a tractor PTO or a 5 hp electric motor. The grader was capable of grading potatoes into four different sizes in a single operation, with a capacity of 4-5 tonnes per hour. The available grading sizes ranged from IS to 7S mm and above.

According to their findings, the grader required 10 man/days of labor to handle 40 tonnes of potatoes per day. This mobile grader provides a convenient solution for potato grading in agricultural settings.

Narvankar and Singh (2005) researched a rotating screen grader suitable for grading fruits like lemon, ber, and aonla into four different grades. Using a second-order response surface design at 80 design points, they tested the grader's capacity and optimum grading performance based on rotating speed, screen diameter, exposure length, and input at four different levels. The grader's capacity varied for each fruit, ranging from 45 to 327.27 kg/h for lemon, 43.63 to 464.51 kg/h for aonla, and 46.75 to 436.36 kg/h for ber. The maximum grading efficiency was 79% for lemon, 93.8% for aonla, and 97.96% for ber.

Roy, Wohab, and Mustafa (2005) developed an inexpensive potato grader that featured three sieves at a 15° angle with the horizontal. The sieves were constructed from rubber impregnated al wires and could sort potatoes into four sizes, with a capacity of 2,030 kg/h. However, issues with trapping of potatoes in the sieves were observed, and a re-orientation mechanism was suggested to prevent this problem.

Pawar et al. (2015) conducted a study to evaluate the performance of a concentric screen grader. They graded the material at a constant speed of 16 revolutions and found that the maximum grading efficiency was 96% for onions and 62.3% for potatoes. The actual capacity for grading onions and potatoes was determined to be 1154 kg/hour and 952 kg/hour, respectively. The researchers concluded that the concentric screen grader was suitable for grading onions but may not be as effective for grading potatoes. Overall, the study provided valuable insight into the use and limitations of the concentric screen grader for grading fruits and vegetables.

Singh, A. et al (2021) developed of a low-cost screening grader for grading of fruits and vegetables. The grader is composed of a hopper, conveyor belt, screening unit, and discharge chute. The screening unit consists of a frame, mesh screen, and an eccentric mechanism for vibration. The grader was evaluated for grading of potatoes and tomatoes based on size. The results showed that the grader was able to grade the fruits and vegetables with an accuracy of 95%. The screening grader is easy to operate and maintain, and it can be used by small farmers and processors to improve the quality of their produce.

Kumar, R. et al (2022) developed a vision-based screening grader for grading of fruits and vegetables. The grader uses a camera and image processing algorithms to classify the produce based on size, shape, and color. The grader consists of a hopper, conveyor belt, imaging system, and discharge chute. The imaging system captures images of the produce as it passes by on the conveyor belt, and the image processing algorithms analyze the images to classify the produce into different grades based on predetermined criteria. The grader was evaluated for grading of apples and tomatoes, and the results showed that it was able to classify the produce with an accuracy of 98%.

2.3 Electronic color grading and reflectance grading

Ahmad et al. (2010) developed an automatic grading machine for citrus using image processing. The machine had a rotating fruit feeder, a belt conveyor, a color CCD camera, four openings for different grades, four collecting boxes, a logic control panel, and a computer with software. The machine was tested, and its performance was visually observed. Results showed that the machine could classify citrus based on size and skin color and could replace manual sorting.

Noordam and Otten (2000) developed a high-speed machine vision system for grading and inspecting potatoes based on size, shape, and external defects. The system used a 3-CCD line-scan camera and mirrors to obtain a 360-degree view of the potato without the use of product holders. The system used 11 SHARC Digital Signal Processors to perform image processing and classification tasks, achieving a capacity of 50 potatoes per second. The color segmentation procedure used Linear Discriminant Analysis and a Mahalanobis distance classifier to classify pixels. A Fourier based shape classification technique was used to detect misshapen potatoes. The system was found to be robust and consistent in its classification of red and yellow skin-colored potatoes.

Khojastehnazhand et al. (2011) developed a lemon sorting system based on color and size using two CCD cameras, capture cards, lighting system, computer and mechanical parts. The system had two inspection stages, external fruit inspection based on color image processing and internal inspection based on special sensors for moisture, sugar, and acid contents. The developed algorithm extracted the fruit from the background and was implemented in a visual basic environment. The system was calibrated off-line with different grades of lemon samples.

Shi, P., et al (2020) color image segmentation and recognition based on improved deep convolutional neural networks for sorting fruits and vegetables. This study presents an improved deep convolutional neural network (CNN) approach for color image segmentation and recognition in sorting fruits and vegetables. The proposed method uses a ResNet-based encoder-decoder structure for segmentation and a multi-scale CNN architecture for recognition. Experimental results showed that the proposed method achieved high accuracy rates for color image segmentation and recognition of five different types of fruits and vegetables (apple, kiwi, tomato, cucumber, and pepper) with an overall accuracy of 97.72%. The results demonstrate the potential of deep learning-based approaches for color-based sorting of fruits and vegetables in the food industry.

Jha, S.K., et al (2021) studied that Vision-based intelligent sorting systems for fruits and vegetables. Vision-based sorting systems are becoming more popular in the food industry due to their accuracy, speed, and non-destructive nature. The authors note that these systems can be used to sort fruits and vegetables based on various characteristics such as color, shape, size, and defects. The paper also discusses the challenges faced by the industry in implementing these systems, such as cost, maintenance, and operator training. Overall, the review concludes that vision-based intelligent sorting systems have great potential to improve the quality and efficiency of fruit and vegetable sorting processes.

2.4 Miscellaneous grader

Gayathri et al. (2016) designed and tested an onion grading machine for Rose onions. They found that the angle of repose for these onions was 54.5° and the coefficient of static friction varied for different surfaces. The experiments involved three slopes, three feed gate opening lengths, and two swing directions. Statistical analysis showed that the optimal parameters were a 4° slope, lengthwise swing direction, and full feed gate opening. The machine had a grading capacity of 1105 kg/h with an overall grading efficiency of 75% and a required grading efficiency of 75%. The operational cost of the machine was six times less than that of manual grading.

Dabhi and Patel (2015) designed and developed an onion grader. They found that, increasing inclination of roller and speeds of rollers move the onion bulbs faster for grading, resulting in higher grading capacity, and maximum grading capacity of onion was found 751.38 kg.h-1. Grading efficiency of the machine varied between

70.02 to 91.69 per cent. The best combination of roller speed and roller inclination for grading onion bulbs at high efficiency was found to be S6I2 (S6 = 15 rpm and I2 = 8o) which gave 82.98 % grading efficiency with a machine capacity of 601.38 kg.h-1.

Singh et al. (2004) studied on optimization of fed trough angle and separating trough angle for best grading efficiency of zero energy multi fruit grader and they observed that the grading efficiency for lower separating angle is low and increase with increase in separating trough angle up to a certain limit after that again it decreases because rolling resistance exceeds the coefficient of friction.

Singh (2002) has designed and fabricated a slit-size type mango grader at Central Institute for Subtropical Horticulture, Lucknow. It was observed that about 5 quintals of Dashehari mango fruits could be graded per hour in the machine, whereas two labourers grade only 1 to 1.5 q manually. About 7 to 10 per cent overlapping in grades was observed. Bruising and rotting was observed in 5 per cent fruits after seven days of ripening period. Efforts were made to increase the efficiency upto one tonne per hour by way of providing automatic bucket type mango feeding system

Atwal and Gulati (2001) designed and developed a rubber rollers type of potato grader. They found that six categories of grades, viz. less than 10gm 10-25g, 50-75g, 75-100g and more than 100g can be obtained with this grader with almost negligible bruising. More than 6000 kg of potatoes can be graded in an hour when the speed of conveyor belt was 14 m/min and roller revolve at 83 rpm. Twelve persons were engaged for feeding and moving the gunny bags filled with graded tubers.

3. Conclusion

There are various methods of grading fruits and vegetables, and each method has its advantages and limitations. Manual grading is the traditional and most widely used method, but it is time-consuming, labour-intensive, and prone to errors. Mechanical grading, on the other hand, is faster, more consistent, and accurate but requires significant capital investment. Machine vision-based grading has gained popularity due to its high accuracy, speed, and automation, but it is limited by the need for high-quality images, the complexity of algorithms, and the requirement for constant calibration. Near-infrared (NIR) spectroscopy-based grading is a promising method for rapid, non-destructive, and objective grading, but it requires extensive calibration, and the cost of the equipment is high.

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