# Technological development in the grading of fruits and vegetables

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**Abstract:** Grading is an ancient technique for selecting and separating high-quality, desirable products to increase the profit margin. Considering the importance of grader in food industry several types of graders, such as belt graders, weight graders, roller graders, image-based graders, and automated sensor-based graders, have been developed over time. However, the selection of grader and its efficiency mainly depends upon the grading mechanism and product to be graded. Grading operation consists of different mechanical operations and that can be improved with the use of artificial intelligence. Traditional graders having certain limitations such as less efficiency, high mechanical injury, higher instrumentation and maintenance cost. Whereas the modern grader with the artificial intelligence having less mechanical injury and more efficiency compared to traditional grading systems. Considering the importance of grader in food industry the present review summarized the different grader used in fruits and vegetables industry based on working principles, product suitability, and input/output capacity, and their limitation and advantages.

**Keywords**: grader, mechanical grader, weight grader, image-based grader, automated sensor-based grader, fruits and vegetables

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## 1 Introduction

Market/consumers' demand for superior and uniform quality of fruits and vegetables, which will decide the ultimate price of the commodity and the profit achieved by vendors/suppliers. Producing uniform food material every time with same quality is impossible, hence, the producers use different methods to segregate/separate the produce/food material based on the requirement for value addition. In 2021 –2022, India produced 107.24 million metric tons of fruits and 204.84 million metric tons of vegetables (APEDA, 2021–2022). At the same time, the value addition through the grading process was 8.39%, which was much lower compared to the USA (81%).

In post-harvest handling, conveying and grading are the two most critical activities to prevent mechanical damage to fruits and vegetables. Grading is one of the methods used to separate the quality/desirable produce for value addition. Different grading methods have been used for the value addition of fruits and vegetables based on size, shape, color and volume, i.e., screens,

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belt graders, weight graders, roller graders, image based graders, etc. Very few studies are reported on the types of graders used for fruits and vegetables, and no study compiled the different graders used for fruits and vegetable on a single platform. Hence, the objective of this review was to compile the published literature/comprehensive work done till date on the different types of graders used for fruits and vegetables apropos to working principle, advantages/disadvantages and recent improvements in line with commercial applications.

Grading refers to sorting of fruits and vegetables into various categories according to their size, shape, color and volume to fetch higher price in the market. It can be done manually as well as mechanically. Manual grading is based on visual observation where each person manually separates the best material based on his judgment of the physical attributes and quality. There is an absence of objectivity and exactness, which reduces the proficiency of the person involved in grading. Here, the product is picked up several times, which leads to the deterioration of fruit quality and fetch low market value (Gayathri et al., 2016). Manual grading is widely used for sorting fruits, vegetables, eggs and other food products in small enterprises. It has a lower initial investment but higher operating cost than mechanical grading (Narvankar et al., 2005). However, the grading of large quantities of fruits and vegetables in limited time, with high precision and reliability require mechanical grading (Zhang and Gu et al., 2018). It has high installation as well as maintenance cost but low (below 80%) sensitivity; hence skilled laborers are required to re-check the graded product. The mechanical grading can be either destructive (or contact) or non-destructive (or non-contact). The grading machine which works on the principle of the destructive method has a grading arm that comes in contact with the product and may cause injury to the product. A non-destructive grading method on the other hand uses machine vision/ spectroscopy detection/ electro-magnetic detection. It allows repeated measures on the same point over different time periods, and facilitate a qualitative analysis of the recorded data.

## 2 Materials and methods

### 2.1 Screening

Screening involves a perforated device called a screen or sieve through which the food material is passed, and the screen segregates the material into different grades based on the screen size. The performance of the screen can be increased by screens' oscillation with their slight parallel lifting. If the product size is larger than the screen opening size, then the product stays over the screen and moves towards the end of the screen. The products of size smaller than the screen holes pass through due to the gravitational force (Figure 1).

The effectiveness of grading by the screen is defined in terms of efficiency, which is calculated using Equation 1. If the screen functions correctly, all material 'o' would be in the overflow, while all the material 'u' would be in the underflow.

$$E=\frac{(m_f-m_u)(m_o-m_f)m_o(1-m_u)}{(m_o-m_u)^2(1-m_f)m_f} \tag{1}$$

where, $m_f$, $m_o$ and $m_u$ represent the mass fraction of material in feed (kg/kg), overflow (kg/kg) and underflow (kg/kg) respectively.

The screening devices are further classified as oscillating sieve graders, inclined screen graders and rotary screen graders (Table 1). The oscillating sieve grader have a rigid mesh screen which generally consists of square or ring-shaped openings (Balls, 1986). Considering the requirement, the shapes of the openings/holes may vary; thus, different product specific graders have been developed. Doriaswamy (2000) developed an oscillating sieve grader (600 kg $h^{-1}$) with two slotted sieves for peanut pods. The authors reported that the oscillating motion of sieves played a significant role in segregating the material into different grades. However, the sieves opening was blocked during operation and manual intervention was required to avoid blocking. Shyam et al. (1991) developed an oscillating riddle grader (2500 –3000 kg $h^{-1}$) for potatoes and reported an accuracy of 80%–90% with 2% damage due to the mechanical injury.

**Table 1 Different types of screen graders for fruits and vegetables**

| Subcategory | Suitable fruits & vegetables | Efficiency | References |
|---|---|---|---|
| Sieve | Groundnut | – | Doriaswatny, 2000 |
| Mechanical sieving | Potato | 80% –90% | Shyam et al. (1991) |
| | Gherkin | – | Mohan et al. (2010) |
| Inclined screen | Potato | – | Roy et al. (2005) |
| | Onion | 75% | Gayathri et al. (2016) |
| | Lemon, ber and aonla | 79%, 93.8% and 97.96% | Narvankar et al. (2005) |
| Rotary screen | Onion | 84.47% –93.46% | Gunathilake et al. (2016) |
| | Kagzi–lime | 95% | Pawar and Khodke (2016) |
| | Tomato | 80% | Preetha et al. (2016) |
| | Onion | 92.99% | Bisen et al. (2021) |
| | Date | 77.32% | Abdallah et al. (2019) |

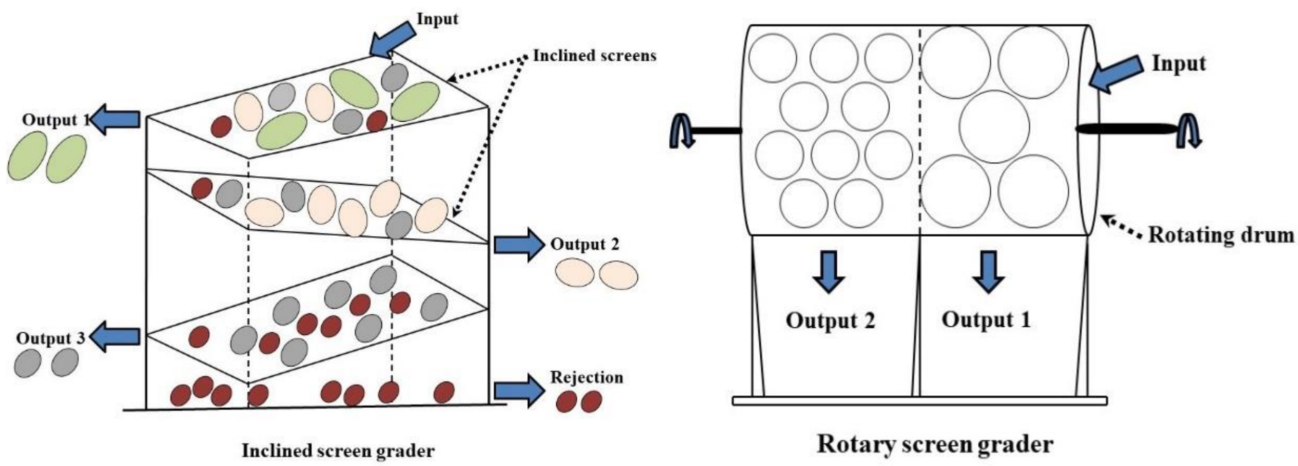



Figure 1 Schematic diagram of screen graders

The performance of oscillatory grading was improved by introducing inclined screen which comprises of a perforated sieve attached at an angle of 4 –15°. The inclined screen was made of rubber tubes, which eliminated trapping on the sieve's elements and increased the grading efficiency (Roy et al., 2005). The efficiency of the screen was dependent on the speed of oscillation, stroke length and inclination of the sieve. In addition, the feed rate was found as an essential factor affecting the efficiency. It was observed that the increase in the feed rate above a specific limit decreased the overall efficiency. Inclined oscillation sieve grader has been used for Gherkin fruits (750 kg fruits $h^{-1}$) (Mohan et al., 2010) and onions (1105 kg $h^{-1}$) (Gayathri et al., 2016).

Further up-gradation of the screen grader was done by addition of rotary screen (0.071–0.613 m $s^{-1}$) with inclination (3 –16°) (Bisen et al., 2021; Gunathilake et al., 2016; Pawar and Khodke, 2016). The system is also known as trammel screen. Different graders have been developed for round and oval shaped fruits and vegetables, i.e., onion (Gunathilake et al., 2016; Bisen et al., 2021), kagzi-lime (Pawar and Khodke, 2016), tomato (Preetha et al., 2016), dates (Abdallah et al., 2019), lemon, ber and aonla (Narvankar et al., 2005). In this grader as the food material spirals down along the length of the rotating drum, the material with size smaller than the size of perforations passes through the drum while larger size material remains on the drum (Balls, 1986). The grading efficiency of the rotary screen grader was found to vary with the drum diameter, rotary speed of the drum, feed rate and perforated length (Narvankar et al., 2005; Preetha et al., 2016). Additionally, the physical properties of fruit and vegetables like bulk density, thickness, sphericity, and variety of fruit also affected the grading efficiency of the rotary screen grader (Bisen et al., 2021). The rotary screen grader with a segmented drum had an efficiency of 84.47% –90.14% for onion, 80% for tomato, and a maximum of 79%, 97.96% and 93.8% for lemon, ber and aonla, respectively. The rotary screen grader with concentric drums had the maximum grading efficiency of 95% in electrical operation mode and 86% in manual operation mode for Kagzi-lime. A rotary screen grader resulted in fruit damage to the extent of 4.14% for peach, 0.23% for potato and 3.5% for gherkin (Mohan et al., 2010) whereas Ebaid et al. (2012) reported no damage to apricots.

### 3.2 Belt grader

Belt graders are widely used in the fruits and vegetables industry to grade round shaped fruit and vegetables such as citrus and tomatoes. It can also segregate long thin crops such as leeks or spring onions. Belt graders may be V-type belt graders, lateral tilted belt graders, wire-type belt graders and expanding pitch graders (Table 2).

In V-type belt grader, several belts are arranged on pulleys. At the same time, the gap between the belts increases along the length of the belts (Figure 2). The belts are mostly operated at an equal linear speed (El-Sheikha et al., 2004; Mir et al., 2016) or at different linear speeds among the adjacent belts, allowing the products to orient itself with its axis parallel to the belt (Singh, 1980). The product gets dropped in a collection platform, where the width of the gap is adjusted just more than the grading dimension of the product. Grading efficiency of the V-type belt grader is affected by dimensions and mass of fruits, speed of the belt, slope of the belt and feed rate (El-Sheikha et al., 2004).

The efficiency of belt grader with equal belt speed varied from 90%–93% for segregating olives fruits into three size groups and from 85% –92% for walnuts (Mir et al., 2016). In other variant of V-type belt grader, the linear velocity of the belt at the feed side was higher than that at the discharge side (Goodman and Hamann, 1968; Brantley et al., 1975). The reported grading efficiency of this design was 95%–98% and 94% for sweet potato and cucumber (Goodman and Hamann, 1968; Brantley et al., 1975), respectively. In another study, Egyptian onions were carried along the edge of the flat belt possessing 3 –4 outlets of different sizes at different distances along the edge (Mostafa and Bahnasawy, 2009). The belt with 20° lateral inclination had an average grading efficiency of 94.33%, and the belt with 10° lateral and longitudinal inclination had the highest grading capacity of 1.72 tons $h^{-1}$. Wire-type belt grader possess successive spiral coils interwoven to create an open mesh. The mesh size is determined by the size and shape of the product. Grover and Pathak (1972) developed a wire-belt type grader for potatoes and reported a grading efficiency of 94%. The bruising of fruits and vegetables was a major problem with wire-belt type graders. Bruising of potatoes in the range of 1% –2% was reported (Grover and Pathak, 1972).

Expanding pitch type grader has a chain conveyor with stainless steel flaps. The distance between the flaps is increased along the length for movement of fruits. The grader is applied for grading spherical fruits (Mangaraj et al., 2005; Mangaraj and Pajnoo, 2019). The stepwise expanding pitch type grader has the provision to adjust the flap spacing in steps, in the range of 45–140 mm (Mangaraj et al., 2005). The reported grading efficiency for segregating sweet lemon and orange into four groups was 91.50% and 88.50%, respectively at the feed rate of 3.5 tons $h^{-1}$. The expanding pitch type grader with high capacity (5 tons $h^{-1}$) was used for grading citrus, apple, sweet lemon and orange into five grades, in the range of 30–145 mm equivalent diameter (Mangaraj and Pajnoo , 2019). The grading efficiency and energy consumption was 93%–

96% and 0.25 kW $ton^{-1}$ respectively. There was no skin cutting and bruising damage to fruits (Mangaraj et al., 2005; Mangaraj and Pajnoo, 2019).

**Table 2 Different types of belt graders for fruits and vegetable**

| Type | Subcategory | Suitable fruits & vegetables | Efficiency | References |
|---|---|---|---|---|
| | V type | Sweet potato & cucumber | 95%–98%<br>94% | Bisen et al. (2021) |
| | | Sweet potato | – | Abdallah et al. (2019) |
| | | Onion | 94.9% | Goodman and Hamann (1968) |
| Belt grader | | Olives | 93%, 91% and 90% | Brantley et al. (1975) |
| | Expanding pitch type | Walnuts | 85% –92% | Mir et al. (2016) |
| | | Potato | 87% | Singh (1980) |
| | | Sweet lemon & orange | 91.5% and 88.5% | Mangaraj et al. (2005) |
| | | Sweet lemon, orange & apple | 96%, 94% and 93% | Mangaraj and Pajnoo (2019) |

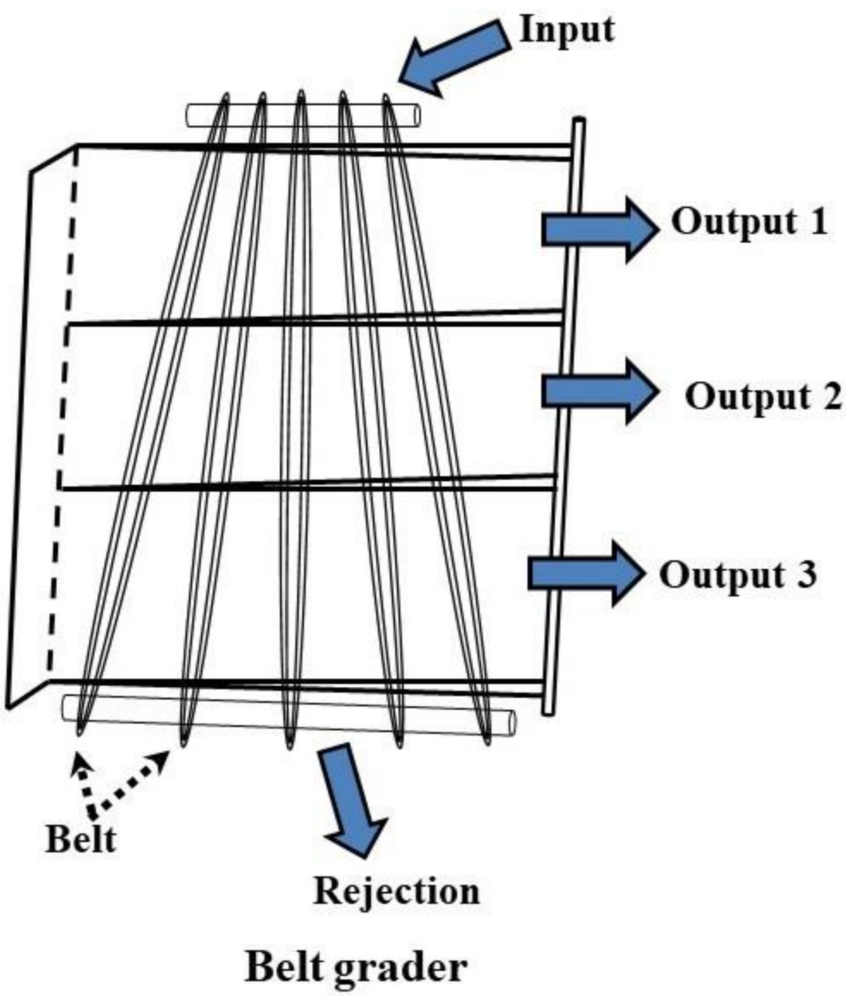



Figure 2 Schematic diagram of belt grader

**3.3 Weight grader**

Weight graders segregate the food material based on its' weight or density. Weight grader has high accuracy and negligible product damage with fast grading operation (Table 3). It consists of conveyor with moveable cups and a variable weight sensing device such as spring, electronic sensor (strain gauge based) and load cell. The spring tension based weight grader has a rotating hub to which several cups are attached. The cups are supported by springs, and the spring tension progressively decreases from the initial point to the final point of rotation. The individual fruit is fed to each cup through an automatic feed. As the cups carry the fruit, the automatic tipping mechanism discharges the fruit from the cup at a point where the weight of the fruit is higher (heavier) than the set spring tension. At the beginning of the travel, heavier fruits get discharged, whereas lighter ones move a greater distance and the lightest ones move till the last point of discharge. Whereas in a load cell-based grader, load cells are used to measure the weight of fruit and drops the fruit into a pre-determined chute.

Omre and Saxena (2003), and Gaikwad et al. (2014) developed a spring tension-based grader for multi-fruit (apples, peaches, pears, oranges, mosambi and pomegranates) and orange, respectively. In another study Badhe et al. (2011) developed a load cell-based mango grader to separate it into five different grades. It was observed that the grading efficiency of weight-based grader varied from 90%–96%, mainly depending on the capacity and speed of operation.

**Table 3 Different types of weight graders for fruits and vegetable**

| Type | Subcategory | Suitable fruits & vegetables | Efficiency | References |
|---|---|---|---|---|
| Weight grader | Spring tension | Apples, peaches, pears, orange, mosambi and pomegranates | 96% | Omre and Saxena (2003) |
| | | Orange | 90% | Gaikwad et al. (2014) |
| | Load cell | Mango | 95.13% | Badhe et al. (2011) |

### 3.4 Roller grader

Roller graders are fast, accurate and cause less damage to the products. Different roller graders i.e., divergent roller graders, roller table graders, parallel roller graders and conventional roller graders (Table 4, Figure 3) are used for the grading of fruits and vegetables. The divergent roller grader has a pair of rollers inclined downwards with progressively increasing gaps between them. The products move down the roller and fall through the hole on the collection platform. The inclination angle of the rollers, speed and feed rate significantly affect the grading efficiency and percent damage (Dabhi and Patel, 2016; Shahir and Thirupathi, 2009). Different types of divergent roller have been developed for grading of onion (Dabhi and Patel, 2016), apple and pomegranate (Borkar et al., 2015) orange (Anonymous, 1989) and potatoes (Atwal and Gulati, 2001); and it was observed that the grading efficiency of the divergent roller grader was dependent on the angle of inclination and rotary speed of the rollers. The percent damage to fruits was inversely proportional to the feed rate (Gadakh and Gangarde, 1981; Hunter and Yaeger, 1970).

A roller table grader is used for inspecting the surface characteristics of fruits and vegetables while parallel roller grader is most suitable for vegetables with cylindrical or tapered profile due to less mechanical injury and higher separation efficiency than a screen type grader (Hutchison and McRae, 1980). Each layer of rollers is constructed as a module to grade different fruits by replacing the roller module. Studies are reported on the development of roller table and parallel grader for the grading of potatoes, lemons, orange and the other fruits and vegetables based on their sizes (Hunter and Yaeger, 1970; Malcolm and DeGarmo, 1953; Hutchison and McRae, 1980; Liu, 1989). Malcolm and De Garmo (1953) conducted experiments on roller table grader using artificial potatoes, lemons and oranges for efficient inspection and separation of defective ones. In another study, Hutchison and McRae (1980) developed the parallel roller grader for fruits and vegetables and reported a grading efficiency of 96.8% (capacity 12 ton $h^{-1}$). Further modification has been performed by Liu (1989) by adding three layered inclined rotating parallel roller graders to sort the Mei fruits into four different classes based on their size.

Conventional roller grader comprises of various arrangements for better accuracy, easy manufacturing, lesser mechanical injury, higher output capacity, higher grading efficiency and lower operating cost. Verma and Kalkat (1975) developed an expanding pitch type rubber spool sizer for potatoes, with an output capacity of the sizer being 2 –3 tons of potatoes $h^{-1}$. In another study, a prototype roller grader was developed in which the walnuts were graded based on the minimum diameter of their mean cross section (Rusalimov, 1986). The grader consisted of two inclined (12.2°) counter rotating rollers (diameter greater than or equal to 96 cm). The grading efficiency was 90.32% for the minimum nut diameter of the mean cross section in the range of 21.3–35.6 mm.

**Table 4 Different types of roller graders for fruits and vegetable**

| Subcategory | Suitable fruits & vegetables | Efficiency | References |
|---|---|---|---|
| Divergent roller | Onion | 79.95% | Dabhi and Patel (2016) |
| | Tomato, potato & onion | 84.3%, 86.7% and 82.4% | Shahir and Thirupathi (2009) |
| Roller table | Apple & pomegranate | 76.35% and 86.63% | Borkar et al. (2015) |
| | Groundnut | 71.2% | Gadakh and Gangarde (1981) |
| | Potato | 90% | Hunter and Yaeger (1970) |
| | Fruits & potatoes | – | Malcolm and DeGarmo (1953) |
| Parallel roller | Orange | 80% | Anonymous (1989) |
| | Potato | – | Atwal and Gulati (2001) |
| | Fruits & vegetables | 96.8% | Hutchison and McRae (1980) |
| | Mei fruits | – | Liu (1989) |
| Conventional roller | Potato | – | Verma and Kalkat (1975) |
| | Walnuts | 90.32% | Mangaraj and Pajnoo (2019) |

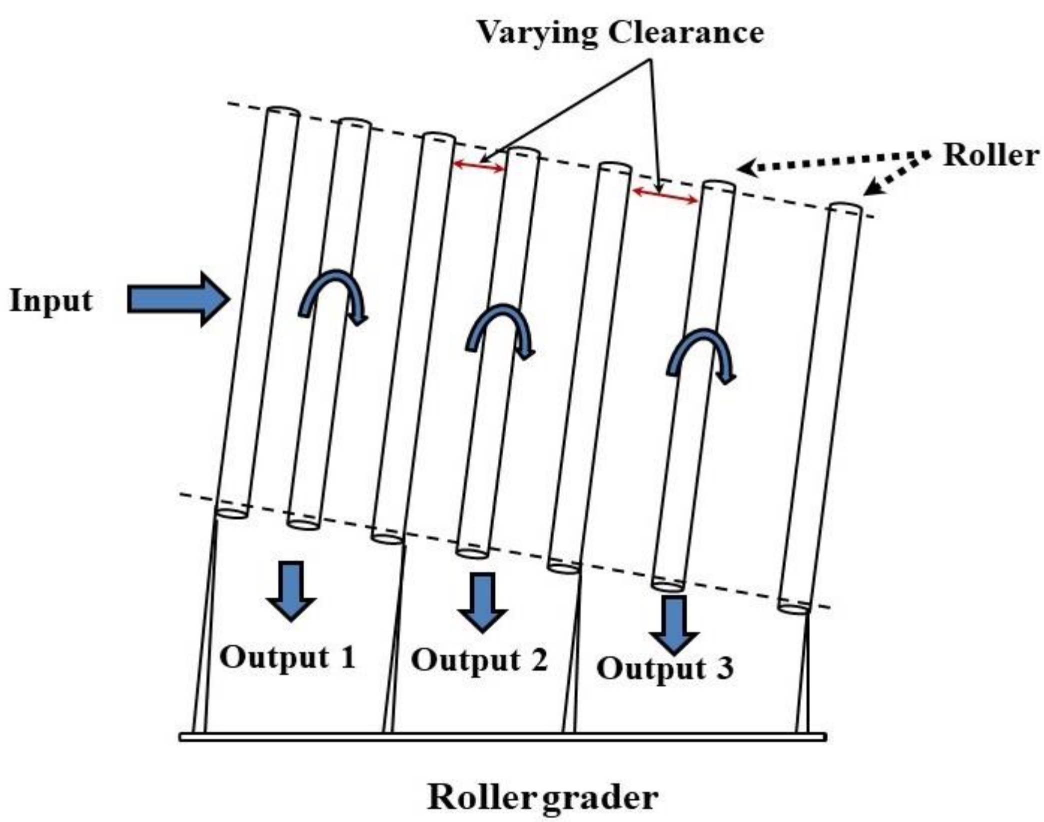



Figure 3 Schematic diagram of roller grader

### 3.5 Image based grader

The image-based technique is the most efficient method to segregate fruits and vegetables based on color and size. It also helps in defect recognition, sorting and determining the maturity level of fruits. Due to physical and biological inconsistency of fruits and vegetables, commercial exploration of the image–based grading methods is difficult, especially in context to the correct determination of surface area along with accurate detection of defects and stem/calyx, and development of a straight forward algorithm for sorting (Zhang and Dai et al., 2018). There are six types of image-based techniques used for grading fruits and vegetables, namely fuzzy logic technique, artificial neural network (ANN), support vector machine (SVM), RGB color model, HSI technique, K-Mean clustering, Infrared image, and deep learning based method (Table 5, Figure 4).

The fuzzy logic technique is widely used in process control, operations research, management and decision making. During the process, the fuzzifier transforms the input variables in numerical forms into linguistic variables. It uses approximate reasoning based on human interpretation to achieve the control logic. Mostly, the grading system had the RGB color sensor programmed to analyze the fruit ripening index and fuzzy logic to classify the fruit into unripe, ripe and overripe categories (Lorestani et al., 2005; May and Amaran, 2011; Alavi, 2012; Kavdir and Guyer, 2003; Othman et al., 2014). Whereas, ANN is a non-linear statistical data modeling tool which is considered as the best decision-making tool for any other technique applied in image analysis of biological items (Kavdir and Guyer, 2008). Image processing and ANN was used to monitor three diseases of grapes and two diseases of apples based on featured vectors of color, texture and morphology. The morphology of fruits is the best feature vector (grading accuracy: 90%) for classifying images and mapping them to their respective disease category (Jhuria et al., 2013). Similarly, back propagation neural network classifier was used for segregating date fruits (Al Ohali, 2011) digital image processing and ANN to sort apples**,** bananas**,** carrots**,** mangoes and oranges (Mustafa et al., 2011), linear discriminant analysis and multi-layer perceptron neural network method for grading star fruits (Abdullah et al., 2006), multilayer neural network for sorting of tomato (Arakeri, 2016), probabilistic neural network for sorting of apples (Ashok and Vinod, 2014), multi-layer perception neural network for surface defect inspection of apple (Unay and Gosselin, 2006), feed forward neural network classifier and SVM for grading of mango (Khoje and Bodhe, 2013), multi-layer perceptron neural network for grading of apples (Kavdır and Guyer, 2008).

SVM is used for classification and regression examination which investigates data and identifies patterns. Two sets of input data are used to obtain predicted results by SVM indicating a non-probabilistic binary linear classifier and utilized in multiclass issues by using one against all or one against one method (Kavdır and Guyer, 2008). For example, in support vector regression, multi attribute decision making system and fuzzy logic was adopted to segregate mango into four grades by analyzing maturity and quality features with an efficiency of 87% (Nandi et al., 2016). Similarly different SVM system were developed for color grading of apple (Suresha et al., 2012), defect based grading of apple (Unay and Gosselin, 2005), lemon & guava grading (Khoje et al., 2013) and online grading of pistachio nut (Nouri-Ahmadabadi et al., 2017). It was observed that the different fruits and vegetables were analyzed through various optical parameters and observed that SVM is the most suitable method with an accuracy of 96.59% (Bhargava et al., 2022; Zeeshan et al., 2020). In addition, the SVM classifier showed higher grading efficiency (96%) than the probabilistic neural network classifier.

In RGB (red, green and blue) color model, captured images are converted into RGB format to generate a color for grading operation. Contrarily brightness, reflection and other factors reduce the efficiency. It is used for grading, sorting and segregation based on the color. The linear discriminant analysis (LDA) and stepwise discriminant analysis (SDA) was used to developed an image-based algorithm to categorize fruits by RGB color model (Manickavasagan et al., 2014). Different RGB based grading systems have been developed for dates fruits (Manickavasagan et al., 2014), potato (Hassankhani and Navid, 2012), citrus, papaya & banana fruits (Vidal et al., 2013; Pereira et al., 2018; Mendoza and Aguilera, 2004), apples (Sucipto et al., 2021), apple, orange and tomatoes (Narendra and Pinto, 2020). Similar to RGB, HSI model i.e., Hue (H), Saturation (S) and Intensity (I) is also used to represent the image. Here, spectroscopic systems integrate all the images in monochromatic image sets containing thousands of continuous wavelengths (Zhang and Dai et al., 2018). However, monochromatic image sets provide 3D image and spectral information for each wavelength/pixel in the full spectrum (Zhang and Gu et al., 2018). Different HSI based grading systems have been developed for oil palm (Abdullah et al., 2002), eggplants (Chong et al., 2008), Iranian saffron peach (Esehaghbeygi et al., 2010), and lemon (Khojastehnazh et al., 2010). Color grading is also combined with size and it was observed that the size grading showed higher efficiency compared to color grading (Esehaghbeygi et al., 2010; Khojastehnazh et al., 2010).

The clustering method categorized the objects into various data sets to facilitate each group's information perfectly and share consistent characteristics in clusters (subset) form. The computational task regarding splitting data sets into k subsets is regularly conferred to unsupervised learning. K-means is an emblematic clustering system commonly used to decide the regular groupings of pixels present in an image and simpler and faster operation. K-mean clustering and classification probabilities information was summarized by algorithm followed by development of different grading systems for apple (Leemans and Destain, 2004) and strawberry (Xu and Zhao, 2010). The quadratic discriminant analysis used in apple grading showed lower efficiency (73%) (Leemans and Destain, 2004) compared to multi attribute decision making used for strawberry (Leemans and Destain, 2004).

Infrared image-based sorter/grader used electromagnetic radiation (380–2500 nm) to irradiate the sample (Zhang and Gu et al., 2018; Aleixos et al., 2002). At the initial stage, electromagnetic waves penetrate the product, and then the incident radiation is either reflected, transmitted or absorbed; remaining light beams or changes in wavelength (via scattering or absorption) values are recorded (Zhang and Dai et al., 2018). Then, the data sets are analyzed to obtain the required output using multivariate statistical analysis (partial least squares discriminant analysis or least squares support vector machine) (Zhang and Dai et al., 2018; Menesatti et al., 2009). However, deviation in wavelength is associated with physical (size, shape, color, defect, surface, microstructure, etc.), chemical (C–H, O–H and N–H bonds) and textural properties of the product (Zhang and Gu et al., 2018; Lee et al., 2008). But individual calibration is essential for the smooth working of the infrared image technique, also known as the non-destructive method. Infrared image based graders are used for the grading of dates (Lee et al., 2008), citrus fruits (Aleixos et al., 2002), golden apples (Menesatti et al., 2009; Safren et al., 2007), and grapes (Xiao et al., 2019).

The machine learning models are time consuming and rely on hand craft feature extraction where the models are trained and tested for small data. Although the performance of the machine learning models is satisfactory, the biasedness comes due to the dependency on image based training and testing. These days, deep learning techniques are used to overcome the problem and extract the relevant features without manual intervention. These techniques have been used to classify and grade fruits. Different grading systems and approaches have been developed. Ismail and Malik (2022) applied a real time visual inspection system for grading fruits using computer vision and deep learning techniques. They observed that the grading efficiency was 96.7% for apples and 93.8% for bananas. In another study, Tian et al. (2019) used a cycle consistent adversarial network for augmentation and deep learning classifiers for detecting the lesion (95.57% using YOLOV3-dense) from the 700 apple images. They reported the suitability of the methodology for real time defect detection on apple surfaces. The use of deep learning has also been explored for the postharvest classification of Cavendish bananas (Ucat and Cruz, 2019). The model was trained using a self-designed Convolutional Neural Network (CNN) on four classes with a total of 1116 images and an average accuracy of 90% was reported for test data. Hu et al. (2020) reported 97.67% accuracy of the best predictive convolutional neural networks model trained by 3-D surface meshes to identify bruised apples. Similarly, Behera et al. (2021) proposed a deep learning based model with 100% accuracy for sorting papaya. Other application includes retail stores to speed up the checkout process of fruits and vegetable with and without plastic beg (Rojas-Aranda et al., 2020), separating clear and defected fruits in industrial and supermarket applications (Hossain et al., 2018), low cost sorting of apple in medium and large organizations (Yang et al., 2021), defected identification in apples (Fan et al., 2020) etc. As observed, the accuracy of the deep learning based system varied from 90%–100% and most of these models were trained and tested on small data sets. Hence, there is a need to enhance the reliability and performance/accuracy by proper testing and training using large data sets and online images.

### 3.6 Automated sensor based graders

Automated sensor based graders are gaining popularity due to their uniform grading process, high accuracy, less damage to the product, higher production rate and less manpower requirement. Researchers have developed numerous sensor-based graders to overcome this problem; some of these sensors include pressure, image, optical and RGB depth sensors (Table 6). For example, the pressure sensor is used to predict the maturity index, textural and firmness properties, whereas the image-based sensor calculates size, shape and color values of fruits and vegetables. Likewise, the RGB depth sensor calculates given product size, shape and volume. In the case of an optical sensor, reflected waves were examined through statistical analysis to get the required output. The pressure sensor based grading system has been developed for fresh corn ear (Wang et al., 2010), fiber optic spectroscopy based sensors for peach fruit (Matteoli et al., 2015), NIR sensor based grading method for mango (Nguyen et al., 2020), pressure as well as temperature sensor for guava, mango, papaya, tomato and peach (Aroca et al., 2013), image based sensor for kiwi fruits (Xu et al., 2013), weight sensors for kiwi fruits (Fu et al., 2016), optical sensor online sorting Khalal and Rotab (Pourdarbani et al., 2015), optical ring sensor for tomatoes and kiwi fruits (Moreda et al., 2007), optical sensor for mango (Izneid et al., 2014), photoelectrical sensors for strawberries (Xu and Zhao, 2010), RGB depth sensor for onion and apple (Wang and Li, 2014; Yamamoto et al., 2018), Si PIN photodiode grader for kiwifruit (Yang et al., 2020), mechanical thumb sensor for tomato and orange (Mizrach et al., 1992), color sensor for tomato (Rajkumar et al., 2021) etc.

**Table 5 Image-based graders for fruits and vegetables**

| Subcategory | Suitable fruits and vegetables | Efficiency | References |
|---|---|---|---|
| Fuzzy Logic Technique | Apple | 90.8% | Lorestani et al. (2005) |
| | Oil palm fruits | 86.67% | May and Amaran (2011) |
| | Mozafati dates | 86% | Alavi (2012) |
| | Apple | 89% | Kavdir and Guyer (2003) |
| | Mango | 85% | Othman et al. (2014) |
| ANN | Apple | 90% | Kavdır and Guyer (2008) |
| | Mango | – | Jhuria et al. (2013) |
| | Date | 80% | Al Ohali (2011) |
| | Apples, bananas, carrots, mangoes and oranges | 79%–90% | Mustafa et al. (2011) |
| | Starfruits | 95.3% (LDA) and 90.5% (MLP) | Abdullah et al. (2006) |
| | Tomato | 96.47% | Arakeri (2016) |
| | Apple | 86.52% (D) and 88.33% (ND) | Ashok and Vinod (2014) |
| | Apple | 89.9% (Q) and 83.7% (D) | Unay and Gosselin (2006) |
| | Mango | 97% | Khoje and Bodhe (2013) |
| Support vector machine | Mango | 87% | Nandi et al. (2016) |
| | Apple | 100% | Suresha et al. (2012) |
| | Apple | 90.3% | Unay and Gosselin (2005) |
| | Lemon and Guava | 96% | Khoje et al. (2013) |
| | Pistachio nut | 94.33% | Nouri-Ahmadabadi et al. (2017) |
| | Fruits and vegetables | 96.59% | Bhargava et al. (2022) |
| | Fruits | 87.06% | Zeeshan et al. (2020) |
| RGB Color model | Date | 72.5% | Manickavasagan et al. (2014) |
| | Potato | 96.82% | Hassankhani and Navid (2012) |
| | Citrus fruits | 92.5% | Vidal et al. (2013) |
| | Papaya | 78.1% | Pereira et al. (2018) |
| | Banana | 98% | Mendoza and Aguilera (2004) |
| | Apple | 98% | Sucipto et al. (2021) |
| | Apple, orange, and tomato | 83%, 93% and 83% | Narendra and Pinto (2020) |
| HSI Technique | Palm fruits | 92% | Abdullah et al. (2002) |
| | Eggplant | 78% | Chong et al. (2008) |
| | Iranian saffron peach | 90% | Esehaghbeygi et al. (2010) |
| | Lemon | 82.7% | Khojastehnazh et al. (2010) |
| K Mean clustering | Jonagold apples | 73% | Leemans and Destain (2004) |
| | Strawberry | 90% | Yang et al. (2020) |
| Infrared image | Citrus | 94% | Mizrach et al. (1992) |
| | Apple | 80.81% | Menesatti et al. (2009) |
| | Date | 87% | Lee et al (2008) |
| | Golden Delicious apple | 88.1% | Safren et al. (2007) |
| | Grape | 77% | Xiao et al. (2019) |
| Deep learning based method | Apple and banana | 96.7% and 93.8% | Ismail and Malik (2022) |
| | Apple | 91.7% | Tian et al. (2019) |
| | Banana | 90% | Ucat and Cruz (2019) |
| | Apple | 97.67% | Hu et al. (2020) |
| | Papaya | 100% | Behera et al. (2021) |
| | Fruits | 95% | Rojas-Aranda et al. (2020) |
| | Fruits | 96.75%–99.75% | Hossain et al. (2018) |
| | Apple | 99.70% | Yang et al. (2021) |
| | Apple | 92% | Fan et al. (2020) |

Note: Where, ANN –Artificial Neural Network; LDA –Linear discriminant analysis; MLP –Multilayer perceptron; D –defective; ND –non defective and Q –quality, respectively.

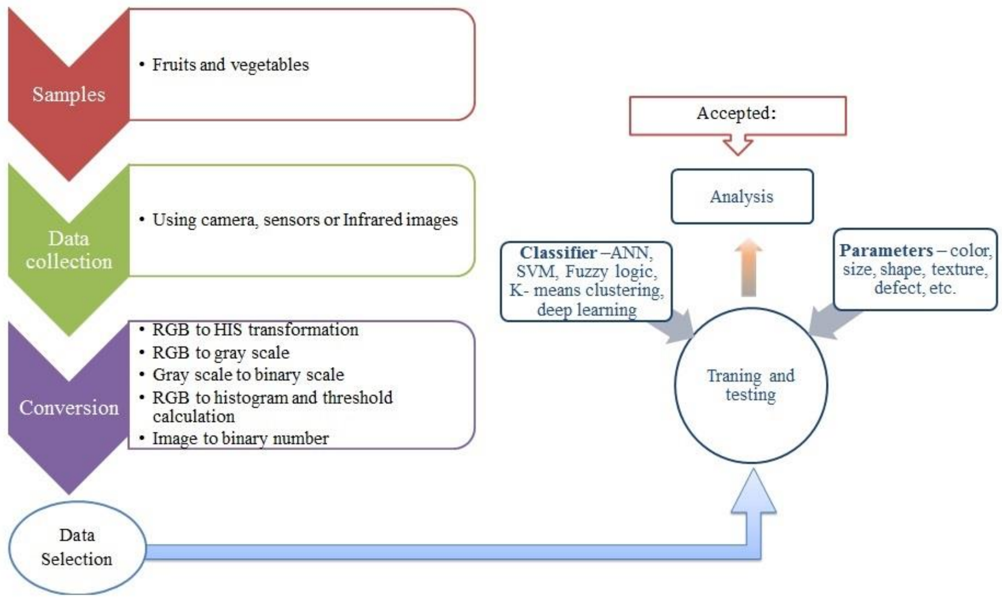


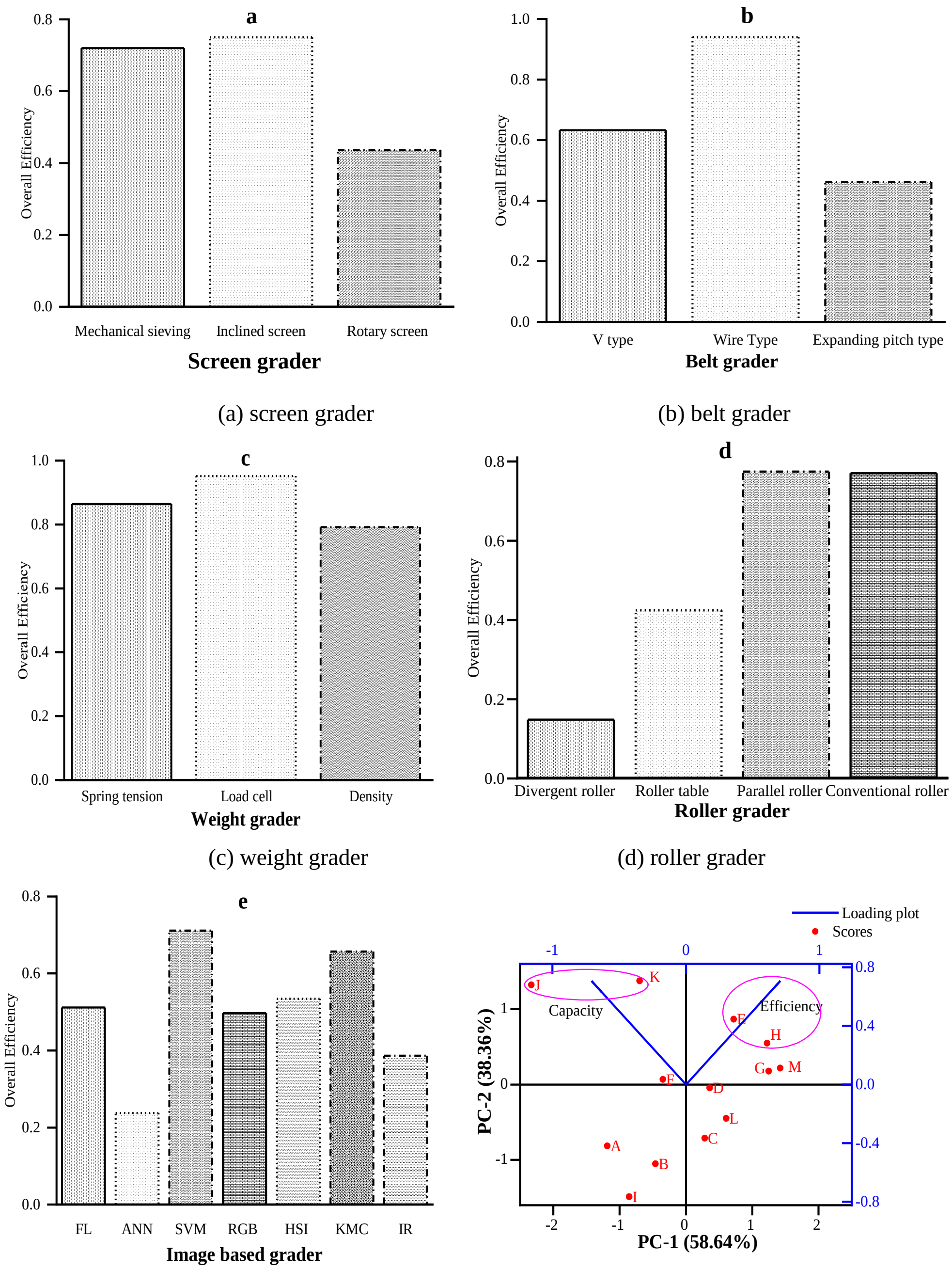

Figure 4 Working principle of image-based grader

**Table 6 Automated sensor based grader for fruits and vegetables**

| Types of sensors | Suitable fruits & vegetables | Efficiency | References |
|---|---|---|---|
| Photoelectrical sensors | Strawberry | 88.8%–95% | Xu and Zhao (2010) |
| Pressure sensor | Fresh corn ear | 96.67% | Wang et al. (2010) |
| Fiber optic spectroscopy based sensors | Peach | 80% | Matteoli et al. (2015) |
| NIR based sensor | Mango | 82.1% | Nguyen et al. (2020) |
| Pressure sensor and temperature sensor | Guava, mango, papaya, tomato and peach | 74%–90% | Aroca et al. (2013) |
| Image based sensor | Kiwi | 88.9%–94% | Xu et al. (2013) |
| Weight sensors | Kiwi | 98.3% | Fu et al. (2016) |
| Optical sensor | Date | 99.6%–97% | Pourdarbani et al. (2015) |
| Optical ring sensor | Tomatoes and kiwi | 87%–95%, | Moreda et al. (2007) |
| Optical sensor | Mango | 70%–100% | Izneid et al. (2014) |
| RGB depth sensor | Onion | 96.3% | Wang and Li (2014) |
| RGB depth sensor | Apple | 97.9%–98.6% | Yamamoto et al. (2018) |
| Si PIN photodiode | Kiwi | 74%–91.5% | Yang et al. (2020) |
| Mechanical thumb sensor | Tomato and orange | 95.7%–98.4% | Mizrach et al. (1992) |
| Color sensor | Tomato | 94.1%–94.6% | Rajkumar et al. (2021) |

## 4 Performance evaluation of grading process

The performance of any process can be determined by analyzing the efficiency, output capacity, cost of operation and time requirement. The mechanical grading process was more efficient than the manual grading process in terms of cost of operation, output capacity, and time (Gayathri et al., 2016; Mohan et al., 2010). Moreover, operator performance directly affects the efficiency and output capacity required to analyze the overall grading efficiency (OGE). Moreover, it represents a more liable value as compared to average grading efficiency (Figure 5). In screen graders, inclined screen graders showed higher OGE (0.75) than mechanical screen grader. Similarly, wire-type belt grader showed higher grading efficiency, but practically V-type belt grader exhibited higher OGE (0.63) value. The limited information on the weight grading process makes OGE calculation impossible, but load cell-based weight grader represents higher efficiency among them. Parallel roller graders showed a higher OGE value (0.77) than other roller graders. Various image graders have been developed with SVM based grader exhibiting a higher OGE (0.71) value. The relationship between grading efficiency and capacity has been investigated using principal component analysis (PCA). PCA offers a correlation between variables (i.e., positive or negative) by scores and loading plot (Figure 5f). A positive cluster was formed by score plot in the efficiency section, which indicated that SVM based grading, wire type belt grading, load cell based weight grading and spring tension based weight grading methods are highly efficient for grading operation. Besides that, roller table graders and parallel roller graders showed higher output capacity indicating that these roller graders are most suitable for industrial purposes. Similarly, mechanical screen graders, inclined screen graders, rotary screen graders, divergent roller graders and conventional roller graders are suitable for household/lab purposes or small-scale industries. The similarities, dissimilarities, advantages and disadvantages of different graders used for fruits and vegetables have been summarized in Table 6.




(a) screen grader (b) belt grader

(c) weight grader (d) roller grader

(e) image based grader (f) principal component analysis plot

Figure 5 Grading efficiency of different type of graders used in food industry and correlation between grading efficiency and capacity

Note: Where, A –mechanical screen grader, B –inclined screen grader, C –rotary screen grader, D –v type belt grader, E –wire type belt grader, F –expanding pitch type belt grader, G –spring tension based weight grader, H –load cell based weight grader, I –divergent roller grader, J –roller table grader, K –parallel roller grader, L –conventional roller grader and M –support vector machine based grader.

**Table 6 Application, characteristics, advantages and disadvantages of different graders**

| Types | Similarities | Dissimilarities | Advantages | Disadvantages |
|---|---|---|---|---|
| Screen grader | Grading of fruits and vegetables based on<br>Size<br>Shape | Due to oscillatory/ vibratory motion, the grading process has occurred<br>Screens are made up of copper, plastic or stainless steel | More suitable for spherical or round shapes fruits and vegetables<br>Commercially, it is used to maintain the higher production rate | Increase in the feed rate above the critical limit decreased the overall grading efficiency<br>Blockage of the screen during operation<br>Higher vibration frequency increased mechanical injury |
| Belt grader | Grading of fruits and vegetables based on<br>Size<br>Shape | Grading operation is responsible for changing the space along the length of movement between belts<br>It is made from vinyl plastic, PE or other flexible plastic | It is widely used in the fruits and vegetable industry<br>Lesser mechanical injury and gentle handling during the segregation process | Optimum grading efficiency is dependent on velocity ratio and belt velocity for specific a product<br>This method is not suitable for long thin crops such as leeks or spring onions |
| Weight grader | | It segregates the fruits and vegetables based on weight<br>It is used in highly revenue generated products where quality and accuracy matter rather than price | More efficient and minimum product damage was observed<br>Lesser packaging and transportation costs will be required for graded products<br>It provides an optimum packaging configuration | Selected fruits were preferable for this grader due to higher equipment cost<br>Increase in grading speed offers higher mechanical injury |
| Roller grader | Grading of fruits and vegetables based on<br>Size<br>Shape | Roller graders with fixed space between the rolls are used for removing small fruit, twigs and leaves<br>Here, each roller rotates in a counter clockwise direction so that each product has an opportunity to register its minimum dimension with the space in the grader | It offers faster and higher grading efficiency and lesser mechanical injury<br>Lesser maintenance cost, simple working principle, easy operation as well as higher durability | This method is suitable for cylindrical or tapered shape products<br>However, optimum roller speed, slope and clearance between the roller decide the optimum grading efficiency |
| Image based grader | Grading of fruits and vegetables based on<br>Color<br>Size | In this method, capture images were analyzed by fuzzy logic, ANN, SVM or advanced statistical analysis for grading operation | It has the potential to mechanize manual grading procedures and reduces tedious analysis operations in a more precious way<br>More suitable for defect recognition, sorting as well as to determine the maturity level of fruits | It consumes more grading time<br>Higher instrumentation cost<br>This method is suitable for lab scale purposes |

The maximum grading efficiency of any mechanical/machine graders can be estimated using feeding rate, inclination angle and rpm for roller graders and weight graders to analyze the effect on actual capacity, segregation efficiency and overall grading efficiency. Performance of graders was calculated using Equations 2-4 in terms of actual capacity ($Q$), separation efficiency ($E_S$) and overall grading efficiency ($E$), respectively (Pawar and Khodke, 2016; Mangaraj and Pajnoo, 2019).

$$Q = \frac{Total\ weight\ of\ graded\ products(kg)}{Time\,(h)} \quad (2)$$

$$ES = \frac{N_t - N_u - N_o}{N_t} \times 100 \quad (3)$$

$$E = \frac{N_t - N_{tm}}{N_t} \times 100 \quad (4)$$

where, Q is the actual capacity (kg $h^{-1}$), ES is the separation efficiency of a particular grade (%), Nt is the total number of products, Nu is the total number of undersize products, No is the total number of oversize products, E is the overall grading efficiency and Ntm is the total number of the misclassified products.

## 5 Conclusion

Grading increases the marketing efficiency by encouraging the selling and buying of graded products without individual determination. It increases the product cost but cuts down the marketing, packing and transportation cost. During the process, products are separated from defective products, resulting in fairness between buyers and sellers while making them suitable for export. Until now, very limited automation technologies have been developed for grading operations to fulfill growing consumers' demands. However, some technologies exist at lab scale that requires extensive trials before entering the industrial sector.

Reducing blockage problems might be a good option for screen graders for inclined screen arrangement. But higher vibration frequency increases mechanical injury. Thus, some research is needed to make it more efficient. Additionally, the screens can be made using recyclable plastic and with focus on multipurpose uses. At present, screens are more suitable for spherical or round shapes fruits and vegetables. Further study should be focused on understanding the effect of different shapes and hole openings on efficiency, capacity, and suitability for grading.

Expanding pitch type belt grader offers lesser mechanical injury during operation, whereas v type belt grader exhibits higher efficiency. Mathematical relationship between suitable velocity ratio, belt velocity for particular products and OGE needs to be developed.

The weight based grading method is not popular due to higher instrumentation cost though it provides higher accuracy and minimum damage to the product. This method is only used in highly revenue-generated products where quality and accuracy matter rather than price. Upgradation with recent computer technology might reduce the overall cost of operation and provide a better quality product.

Roller graders are very popular due to their low maintenance cost, simple working principles, easy operation, higher durability, etc. However, some engineering problem still exists, i.e., optimum roller speed, slope and clearance due to non-uniformity of product shape. No perfect condition has been developed till now. For multipurpose uses, reconfiguration or reorientation is required which is not possible at the commercial level.

The image based grading required a high instrumentation cost compared to other techniques, and most of the image based grading methods have been developed only for lab scale purposes. However, ANN and SVM can be combined with multi-scale mathematical modeling techniques to improve commercial acceptability. Further, an investigation/study is required to capture an entire surface image and to understand the effect of different environmental conditions, maturity index, variety of fruits and vegetables on image segregation methods, and type of algorithm on grading efficiency. Finally, minimization of equipment cost, integration techniques and broader applicability for different fruits and vegetables is still a big challenge for the researchers.

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### Conflict of Interest

All the authors declared that they do not have any known conflict of interest.

## References

Abdullah, M. Z., L. C. Guan, A. M. Mohamed, and M. A. Noor. 2002. Color vision system for ripeness inspection of oil palm elaeis guineensis. *Journal of Food Processing and Preservation*, 26(3): 213–235.

Abdullah, M. Z., J. Mohamad-Saleh, A. S. Fathinul-Syahir, and B. M. N. Mohd-Azemi. 2006. Discrimination and classification of fresh-cut starfruits (*Averrhoa carambola* L.) using automated machine vision system. *Journal of Food Engineering*; 76(4): 506–523.

Abdallah, S. E., A. M. Deris, H. M. Sorour, and A. A. Tayoush. 2019. Manufacturing and testing the performance of prototype for grading of dates. *AMA, Agricultural Mechanization in Asia, Africa and Latin America*, 50(4): 49–60.

Anonymous. 1989. Development of orange size grader. *Quoted from Annual Research Report 1988–89 for Presentation to the Research Review Sub–committee of Agril. Process Engg*, Dr. PDKV. Akola, India: 63–67.

APEDA. 2021-2022. Horticultural Statistics at a Glance. National Horticulture Board, Ministry of Agriculture and Farmers Welfare. Government of India. Available at: https://apeda.gov.in/apedawebsite/six_head_product/FFV.htm. Accessed 12/01/2023.

Alavi, N. 2012. Date grading using rule-based fuzzy inference system. *Journal of Agricultural Technology*, 8(4): 1243–1254.

Aleixos, N., J. Blasco, F. Navarron, and E. Moltó. 2002. Multispectral inspection of citrus in real-time using machine vision and digital signal processors. *Computers and Electronics in Agriculture*: 33(2): 121–137.

Al Ohali, Y. 2011. Computer vision based date fruit grading system: Design and implementation. *Journal of King Saud University-Computer and Information Sciences*, 23(1): 29–36.

Arakeri, M. P. 2016. Computer vision based fruit grading system for quality evaluation of tomato in agriculture industry. *Procedia Computer Science*, 79(1): 426–433.

Aroca, R. V., R. B. Gomes, R. R. Dantas, A. G. Calbo, and L. M. Gonçalves. 2013. A wearable mobile sensor platform to assist fruit grading. *Sensors*, 13(5): 6109–6140.

Ashok, V., and D. S. Vinod. 2014. Automatic quality evaluation of fruits using probabilistic neural network approach. In *2014 International Conference on Contemporary Computing and Informatics (IC3I)*, 308–311. Mysore, India, 27–29 November 2014

Atwal, J. S., and S. Gulati. 2001. Design and development of a rubber rollers type of potato grader. *Journal of the Indian Potato Association*, 28(1): 70–71.

Badhe, V. T., P. Singh, and Y. C. Bhatt. 2011. Development and evaluation of mango grader. *Journal of Agricultural Engineering*, 48(2): 43–47.

Balls, R. C. 1986. *Horticultural Engineering Technology: Fixed Equipment and Buildings*. London: Macmillan.

Behera, S. K., A. K. Rath, and P. K. Sethy. 2021. Maturity status classification of papaya fruits based on machine learning and transfer learning approach. *Information Processing in Agriculture*, 8(2): 244–250.

Bhargava, A., A. Bansal, and V. Goyal. 2022. Machine learning–based detection and sorting of multiple vegetables and fruits. *Food Analytical Methods*, 15(1): 228–242.

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.

Borkar, P. A., I. L. Pardeshi, R. P. Murumkar, and M. R. Rajput. 2015. Development and testing of fruit grader suitable for rural entrepreneurship. *Journal of Food Research*, 3(3): 112–117.

Brantley, S. A., D. D. Hamann, and J. K. Whitfield. 1975. A multiple belt, adjustable vee size grader for sweet potatoes and cucumbers. *Transactions of the ASAE*, 18(2): 350–354.

Chong, V. K., N. Kondo, K. Ninomiya, T. Nishi, M. Monta, K. Namba, and Q. Zhang. 2008. Features extraction for eggplant fruit grading system using machine vision. *Applied Engineering in Agriculture*, 24(5): 675–684.

Dabhi, M. N., and N. C. Patel. 2016. Design and development of onion grader. *Journal of Agricultural Engineering*, 53(1): 27–32.

Doriaswatny, G. 2000. Groundnut machines-grader, decorticator, harvester and thresher. Training Cum Study Program on Farm Machinery. Department of Farm Machinery, College of Agricultural Engineering, Tamil Nadu Agricultural University, India.

Ebaid, M. T., M. M. Atallah, and K. S. Khalil. 2012. Development of a grading machine for apricot fruits. *Misr Journal of Agricultural Engineering*, 29(2): 511–530.

EI-Sheikha, M., H. E. Abdalla, and S. E. Mohamed. 2004. Development of belt grading machine for olive fruit. *Journal of Soil Sciences and Agricultural Engineering*, 29(11): 6355–6366.

Esehaghbeygi, A., M. Ardforoushan, S. A. H. Monajemi, and A. A. Masoumi. 2010. Digital image processing for quality ranking of saffron peach. *International Agrophysics*, 24(2): 115–120.

Fan, S., J. Li, Y. Zhang, X. Tian, Q. Wang, X. He, C. Zhang, and W. Huang. 2020. On line detection of defective apples using computer vision system combined with deep learning methods. *Journal of Food Engineering*, 286(1): 110102.

Fu, L., S. Sun, R. Li, and S. Wang. 2016. Classification of kiwifruit grades based on fruit shape using a single camera. *Sensors*, 16(7): 1012.

Gadakh, T. N., and D. P. Gangarde. 1981. *Testing Performance of Groundnut Grader*. MS thesis, Rahuri, India, MPKV.

Gaikwad, N. N., D. V. K. Samuel, M. K. Grewal, and M. Manjunatha. 2014. Development of orange grading machine on weight basis. *Journal of Agricultural Engineering*, 51(3): 1–8.

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

Goodman, H. C., and Hamann. 1968. Development and testing of v-belt type of sweet potato sizer. *Transaction of the ASAE*, ?(?): 3–6.

Grover, P. C., and B. S. Pathak. 1972. Development of a wire belt potato sizer. *Journal of Agriculture Engineering*, 9(4): 55–57.

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(1): 103–107.

Hassankhani, R., and H. Navid. 2012. Potato sorting based on size and color in machine vision system. *Journal of Agricultural Science*, 4(5): 235–244.

Hossain, M. S., M. Al-Hammadi, and G. Muhammad. 2018. Automatic fruit classification using deep learning for industrial applications. *IEEE Transactions on Industrial Informatics*, 15(2): 1027–1034.

Hu, Z., J. Tang, P. Zhang, and J. Jiang. 2020. Deep learning for the identification of bruised apples by fusing 3D deep features for apple grading systems. *Mechanical Systems and Signal Processing*, 145(1): 106922.

Hunter, J. H., and E. C. Yaeger. 1970. *Use of A Float Roll Table in Potato Grading Operations*. Bull: University of Maine, Orono.

Hutchison, P. S., and D. C. McRae. 1980. A Variable Grader for Fruit and Vegetables. Dept. Note S1N/293, Scot. Inst. Agric. Engng, Penicuik..

Ismail, N., and O. A. Malik. 2022. Real-time visual inspection system for grading fruits using computer vision and deep learning techniques. *Information Processing in Agriculture*, 9(1): 24–37.

Izneid, B. A., M. I. Fadhel, T. Al-Kharazi, M. Ali, and S. Miloud. 2014. Design and develop a nondestructive infrared spectroscopy instrument for assessment of mango (Mangifera indica) quality. *Journal of Food Science and Technology*, 51(11): 3244–3252.

Jhuria, M., A. Kumar, and R. Borse. 2013. Image processing for smart farming: Detection of disease and fruit grading. In *2013 IEEE Second International Conference oon Image Information Processing (ICIIP-2013)*, 521–526. Shimla, India, 09–11 November 2013 .

Kavdir, I., and D. E. Guyer. 2003. Apple grading using fuzzy logic. *Turkish Journal of Agriculture and Forestry*, 27(6): 375–382.

Kavdir, I., and D. E. Guyer. 2008. Evaluation of different pattern recognition techniques for apple sorting. *Biosystems Engineering*, 99(2): 211–219.

Khojastehnazhand, M., M. Omid, and A. Tabatabaeefar. 2010. Development of a lemon sorting system based on color and size. *African Journal of Plant Science*, 4(4): 122–127.

Khoje, S., and S. Bodhe. 2013. Comparative performance evaluation of size metrics and classifiers in computer vision based automatic mango grading. *International Journal of Computer Applications*, 61(9): 1–7.

Khoje, S. A., S. K. Bodhe, and A. Adsul. 2013. Automated skin defect identification system for fruit grading based on discrete curvelet transform. *International Journal of Engineering and Technology*, 5(4): 3251–3256.

Lee, D. J., R. Schoenberger, J. Archibald, and S. McCollum. 2008. Development of a machine vision system for automatic date grading using digital reflective near-infrared imaging. *Journal of Food Engineering*, 86(3): 388–398.

Leemans, V., and M. F. Destain. 2004. A real-time grading method of apples based on features extracted from defects. *Journal of Food Engineering*, 61(1): 83–89.

Liu, K. Y. 1989. *Mei Fruits Sizing Machine*. Taipei: National Taiwan University.

Lorestani, A. N., M. Omid, A. Tabatabaeefar, S. B. Shooraki, and A. M. Borghei. 2005. Apple grading using fuzzy logic. In *International Agricultural Engineering Conference, Bangkok, Thailand*, 6–9 December 2005.

Mangaraj, S., A. C. Varshney, B. S. Reddy, and K. K. Singh.

2005. Development of a stepwise expanding pitch fruit grader. *Journal of Agricultural Engineering*, 42(3): 74–79.

Mangaraj, S., and R. K. Pajnoo. 2019. Design and development of a high capacity multi fruit grader for commercial applications. *Agricultural Engineering Today*, 43(1): 11–19.

Malcolm, D. G., and E. P. DeGarmo. 1953. *Visual Inspection of Products for Surface Characteristics in Grading Operations* (No. 45). USA: US Department of Agriculture, Production and Marketing Administration.

Manickavasagan, A., N. K. Al-Mezeini, and H. N. Al-Shekaili. 2014. RGB color imaging technique for grading of dates. *Scientia Horticulturae*, 175(1): 87–94.

Matteoli, S., M. Diani, R. Massai, G. Corsini, and D. Remorini. 2015. A spectroscopy-based approach for automated nondestructive maturity grading of peach fruits. *IEEE Sensors Journal*, 15(10): 5455–5464.

May, Z., and M. H. Amaran. 2011. Automated oil palm fruit grading system using artificial intelligence. *International Journal of Video and Image Processing and Network Security*, 11(3): 30–35.

Mendoza, F., and J. M. Aguilera. 2004. Application of image analysis for classification of ripening bananas. *Journal of Food Science*, 69(9): 471–477.

Menesatti, P., A. Zanella, S. D'Andrea, C. Costa, G. Paglia, and F. Pallottino. 2009. Supervised multivariate analysis of hyper-spectral NIR images to evaluate the starch index of apples. *Food and Bioprocess Technology*, 2(3): 308–314.

Mir, G. M., U. Iqbal, and O. Nisar. 2016. Portable walnut grading machine best replacement for perforated cylindrical grader. *International Journal of Research and Innovation*, 3(8): 82–86.

Mizrach, A., D. Nahir, and B. Ronen. 1992. Mechanical thumb sensor for fruit and vegetable sorting. *Transactions of the ASAE*, 35(1): 247–250.

Mohan, H. C., M. C. Gowda, G. G. Reddy, and M. Mahesh. 2010. Development of power operated gherkin grader. *International Journal of Applied*, 5(4): 497–502.

Moreda, G. P., J. Ortiz-Cañavate, F. J. García-Ramos, and M. Ruiz-Altisent. 2007. Effect of orientation on the fruit on-line size determination performed by an optical ring sensor. *Journal of Food Engineering*, 81(2): 388–398.

Mostafa, H. H., and A. H. Bahnasawy. 2009. Development of affordable machine for sizing Egyptian onion. *Agricultural Engineering International: CIGR Journal*, 11.

Mustafa, N. B. A., K. Arumugam, S. K. Ahmed, and Z. A. M. Sharrif. 2011. Classification of fruits using probabilistic neural networks-improvement using color features. In *TENCON 2011-2011 IEEE Region 10 Conference*, Bali, Indonesia, 21–24 November 2011.

Nandi, C. S., B. Tudu, and C. Koley. 2016. A machine vision technique for grading of harvested mangoes based on maturity and quality. *IEEE Sensors Journal*, 16(16): 6387–6396.

Narendra, V. G., and A. J. Pinto. 2021. Defects detection in fruits and vegetables using image processing and soft computing techniques. In *Proceedings of 6th International Conference on Harmony Search, Soft Computing and Applications: ICHSA 2020, Istanbul*, 325–337. Singapore: Springer.

Narvankar, D. S., S. K. Jha, and A. Singh. 2005. Development of rotating screen grader for selected orchard crops. *Journal of Agricultural Engineering*, 42(4): 60–64.

Nguyen, C. N., Q. T. Phan, N. T. Tran, M. Fukuzawa, P. L. Nguyen, and C. N. Nguyen. 2020. Precise sweetness grading of mangoes (*Mangifera indica* L.) based on random forest technique with low-cost multispectral sensors. *IEEE Access*, 8(1): 212371–212382.

Nouri-Ahmadabadi, H., M. Omid, S. S. Mohtasebi, and M. S. Firouz. 2017. Design, development and evaluation of an online grading system for peeled pistachios equipped with machine vision technology and support vector machine. *Information Processing in Agriculture*, 4(4): 333–341.

Omre, P. K., and R. P. Saxena. 2003. Design and development of multi–fruit grader. *AMA, Agricultural Mechanization in Asia, Africa and Latin America*, 34(3): 39–42.

Othman, M., M. N. A. Bakar, K. A. Ahmad, and T. R. Razak. 2014. Fuzzy ripening mango index using RGB colour sensor model. *Researchers World*, 5(2): 1–9.

Pawar, S. G., and S. U. Khodke. 2016. Design and development of grader for Kagzi-lime. *International Journal of Agricultural Engineering*, 9(1): 12–18.

Pereira, L. F. S., S. Barbon Jr, N. A. Valous, and D. F. Barbin. 2018. Predicting the ripening of papaya fruit with digital imaging and random forests. *Computers and Electronics in Agriculture*, 145(1): 76–82.

Pourdarbani, R., H. R. Ghassemzadeh, H. Seyedarabi, F. Z. Nahandi, and M. M. Vahed. 2015. Study on an automatic sorting system for date fruits. *Journal of the Saudi Society of Agricultural Sciences*, 14(1): 83–90.

Preetha, P., R. Pandiselvam, J. Deepa, and N. Varadharaju. 2016. Development and performance evaluation of rotary drum grader for tomato. *International Journal of Agriculture, Environment and Biotechnology*, 9(1): 137–144.

Rajkumar, P., K. Abinaya, J. Deepa, R. Pandiselvam, C. I. Rani, and S. Parveen. 2022. Development of a farmer‐friendly portable color sorter cum grader for tomatoes. *Journal of Food Process Engineering*, 45(6): e13894.

Rojas-Aranda, J. L., J. I. Nunez-Varela, J. C. Cuevas-Tello, and G. Rangel-Ramirez. 2020. Fruit classification for retail stores using deep learning. In *12th Mexican Conference, MCPR 2020*, 3-13. Morelia, Mexico, 24–27 June.

Roy, K. C., M. A. Wohab, and A. D. M. G. Mustafa. 2005. Design and development of a low-cost potato grader. *Agricultural Mechanization in Asia Africa and Latin America*, 36(2): 28–31.

Rusalimov, Z. H. 1986. Grading walnuts according to the minimum diameter of their mean cross-section. *Selskostopanska Tehnika*, 23(6): 21–29.

Safren, O., V. Alchanatis, V. Ostrovsky, and O. Levi. 2007. Detection of green apples in hyperspectral images of apple-tree foliage using machine vision. *Transactions of the ASABE*, 50(6): 2303–2313.

Shahir, S., and V. Thirupathi. 2009. Performance evaluation of a divergent roller grader for selected vegetables. *Ama, Agricultural Mechanization in Asia, Africa & Latin America*, 40(4): 60–62.

Shyam, M., R. Singh, and V. Singh. 1991. Development of oscillating sieves seed potato size grader. *Journal of the Indian Potato Association*, 18(1–2): 61–67.

Singh, B. 1980. Development and performance of differential belt speed expanding pitch type potato grader. *Journal of Agricultural Engineering*, 17(2): 69.

Sucipto, A., A. K. Zyen, B. B. Wahono, T. Tamrin, H. Mulyo, and R. R. Ali. 2021. Linear discriminant analysis for apples fruit variety based on color feature extraction. In *2021 International Seminar on Application for Technology of Information and Communication (iSemantic)*, 184–189. Semarangin, Indonesia, 18–19 September 2021 .

Suresha, M., N. A. Shilpa, and B. Soumya. 2012. Apples grading based on SVM classifier. *International Journal of Computer Applications*, 975(1):27–30.

Tian, Y., G. Yang, Z. Wang, E. Li, and Z. Liang. 2019. Detection of apple lesions in orchards based on deep learning methods of cyclegan and yolov3-dense. *Journal of Sensors*, 8(1): 1–13.

Ucat, R. C., and J. C. D. Cruz. 2019. Postharvest grading classification of cavendish banana using deep learning and tensorflow. In 2019 *International symposium on multimedia and communication technology (ISMAC)*, 1–6. Quezon City, Philippines, 19–21 August 2019.

Unay, D., and B. Gosselin. 2005. Artificial neural network-based segmentation and apple grading by machine vision. In *IEEE International Conference on Image Processing* 2005, II-630. Genova, Italy, 14 September 2005.

Unay, D., and B. Gosselin. 2006. Automatic defect segmentation of 'Jonagold' apples on multi-spectral images: A comparative study. *Postharvest Biology and Technology*, 42(3): 271–279.

Verma, S. R., and H. S. Kalkat. 1975. Design and development of an expanding pitch rubber spool potato sizer. *Journal of Agricultural Engineering*, 12(2): 35–40.

Vidal, A., P. Talens, J. M. Prats-Montalbán, S. Cubero, F. Albert, and J. Blasco. 2013. In-line estimation of the standard colour index of citrus fruits using a computer vision system developed for a mobile platform. *Food and Bioprocess Technology*, 6(12): 3412–3419.

Wang, H., Y. Sun, G. Zhang, T. Zhang, Y. Li, and X. Xu. 2010. Grading method of fresh corn ear maturity based on pressure and image. *Transactions of the Chinese Society of Agricultural Engineering*, 26(7): 369–373.

Wang, W., and C. Li. 2014. Size estimation of sweet onions using consumer-grade RGB-depth sensor. *Journal of Food Engineering*, 142(1): 153–162.

Xiao, H., L. Feng, D. Song, K. Tu, J. Peng, and L. Pan. 2019. Grading and sorting of grape berries using visible-near infrared spectroscopy on the basis of multiple inner quality parameters. *Sensors*, 19(11): 2600.

Xu, M., and C. Zhao. 2010. Automated strawberry grading system based on image processing. *Computers and Electronics in Agriculture*, 71(sup1): S32–S39.

Xu, L., Z. You, S. Wu, H. Zhao, and L. Wu. 2013. Development and experiment on automatic grading equipment for kiwi. *INMATEH-Agricultural Engineering*, 41(3): 55–64.

Yamamoto, S., M. Karkee, Y. Kobayashi, N. Nakayama, S. Tsubota, L. N. T. Thanh, and T. Konya. 2018. 3D reconstruction of apple fruits using consumer-grade RGB-depth sensor. *Engineering in Agriculture, Environment and Food*, 11(4): 159–168.

Yang, B., W. Guo, X. Huang, R. Du, and Z. Liu. 2020. A portable, low-cost and sensor-based detector on sweetness and firmness grades of kiwifruit. *Computers and Electronics in Agriculture*, 179(1): 105831.

Yang, M., P. Kumar, J. Bhola, and M. Shabaz. 2021. Development of image recognition software based on artificial intelligence algorithm for the efficient sorting of apple fruit. *International Journal of System Assurance*

*Engineering and Management*, 13(1): 322–330.

Zhang, B., B. Gu, G. Tian, J. Zhou, J. Huang, and Y. Xiong. 2018a. Challenges and solutions of optical-based nondestructive quality inspection for robotic fruit and vegetable grading systems: A technical review. *Trends in Food Science and Technology*, 81(1): 213–231.

Zhang, B., D. Dai, J. Huang, J. Zhou, Q. Gui, and F. Dai. 2018b. Influence of physical and biological variability and solution methods in fruit and vegetable quality nondestructive inspection by using imaging and near-infrared spectroscopy techniques: A review. *Critical Reviews in Food Science and Nutrition*, 58(12): 2099–2118.

Zeeshan, M., A. Prabhu, C. Arun, and N. S. Rani. 2020. Fruit classification system using multiclass support vector machine classifier. In *2020 International Conference on Electronics and Sustainable Communication Systems (ICESC)*, 289–294. Coimbatore, India, 02–04 July 2020.