Discover Food

Research

Analysis of the effectiveness of natural treatments for preserving apricots and the YOLOv7 application for early damage detection

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Abstract
Maintaining the quality of apricot fruits during storage is not an easy task due to the changes in their physical and chemical properties, so it is necessary to use less expensive, easy to apply, environmentally friendly, and safer preservatives to maintain the nutritional value of apricot. The damage to some fruits during storage can be a source of infection, which leads to the damage of healthy fruits more quickly, which requires building an intelligent model to detect damaged fruits. The aim of the research is to study the effect of immersing apricots in lemon juice once and sugar-water solution again on the quality properties of apricots, including sweetness, color, hardness, and water content. On the other hand, the YOLOv7 algorithm was used to detect healthy fruits and damaged areas using a camera. The results showed that sweetness increased with increasing immersion time in sugar-water solution to reach 22.1 Brix, while it decreased with increasing immersion time in lemon juice to 19.12 Brix. Also, hardness increased with increasing immersion time in sugar-water solution to reach 3.7 kg/cm^2. The water content of apricots decreased with increasing immersion time in different immersion media from 77.14 g to 73.93 g. In addition, CIE-L*a*b levels increased with increasing immersion time in different immersion media. For the performance indicators of the YOLOv7 algorithm, precision of 84.5%, recall of 87%, F1 of 0.77, and mAP@0.5 of 77.2 were obtained, respectively. Therefore, this study is expected to reduce the workload in post-harvest fruit processing and help in the rapid identification and detection of damaged fruits based on smart detection algorithms, thus improving sorting efficiency and reducing both waste and economic losses, which enhances smart agriculture technologies.

Keywords YOLOv7 · Damaged fruits · Physicochemical properties · Lemon juice · Sugar-water solution

1 Introduction

Apricot (*Prunus armeniaca L.*) is a popular fruit among consumers due to its good taste and unique flavor. Nutritionally, apricot contains a range of beneficial compounds, including phenolics and carotenoids, especially vitamins A and C [1]. Notable phenolic compounds in apricots include catechin, epicatechin, chlorogenic acid, and nucleogenic acid [2]. These compounds exhibit antimicrobial, antimutagenic, anti-inflammatory, and antiallergic properties, contributing to the prevention of cancer and coronary heart disease [3]. The shelf life of apricots is limited due to postharvest factors, such

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as rotting, weight loss, and rapid ripening, which leads to tissue softening. Several techniques such as low-temperature storage, pre-cooling, and packaging under a moderate atmosphere have been studied to extend the post-harvest shelf life [4]. However, these methods are not sufficient to maintain the quality of apricots during storage. This is because apricots continue to ripen after harvesting due to the production of ethylene, and low temperatures slow this down but cannot stop it [5]. In addition, apricots are susceptible to fungal infection during storage, and without additional treatments the disease can spread rapidly even in controlled environments [6]. Fruit quality is the key factor in determining the value of fruits, which includes multiple aspects related to external appearance (size, shape, color, and smoothness of fruit surface, etc.) and internal quality (sugar content, acid content, sugar-acid ratio, pectin, total soluble solids, vitamin C, etc.) [7]. With the increasing health awareness of consumers, the demand for high-quality and healthy fruits is increasing. Therefore, there is an urgent need to explore innovative methods to extend the shelf life of fruits, including apricots. Proper storage processes are required to maintain the quality of fruits and extend their shelf life, where storage conditions such as temperature and humidity play a vital role. In addition, proper storage helps prevent foodborne diseases caused by bacteria and viruses, protecting the fruit from spoilage, and reducing financial losses. However, apricot fruits are exposed to pathogens after harvest, leading to significant losses. The use of fungicides has been restricted due to health concerns associated with chemical residues [8]. There are no registered post-harvest fungicides for apricots, calling for the search for effective alternatives to control pathogens and maintain fruit quality during storage and marketing. Various methods have been used to extend the shelf life of fruits. Environmentally friendly biopolymer coatings have been used to extend the shelf life of fruits, such as plums [9], and peaches [10]. Cold plasma treatments have also been applied to apple fruits [11], and salicylic acid treatments have been shown to be effective in reducing internal browning and preserving the quality of winter pineapple [12]. The use of plant essential oil compounds as coatings in foods has also been shown to inhibit microbial growth and nutrient loss; and increase the shelf life of foods [13]. Treating apricots with putrescine extends their shelf life and reduces mechanical damage [14]. Nanochitosan emulsion coatings mixed with pomegranate peel extract have also been used to improve apricot quality and reduce weight loss, helping to extend their shelf life [15]. Modified atmosphere packaging has also contributed to improving apricot quality and extending their shelf life by carefully controlling oxygen and carbon dioxide levels [16]. The incorporation of antimicrobial compounds into edible films and coatings presents a new approach to promoting microbial safety and the shelf stability of fruits. However, the methods already in place, such as treatment using putrescine, nanochitosan emulsion coatings with pomegranate peel extract, and modified atmosphere packaging, have some drawbacks. These include high cost, which limits their widespread application, limited access to the material used in some places, and stability and durability issues that may affect the performance of these coatings over time. Some environmental concerns regarding the use of nanomaterials and modified packaging have also emerged. Therefore, there is a need for lower-cost, easier-to-use, greener, and safer preservatives. Therefore, lemon juice or sugar-water solutions are important because of their unique properties. Citric acid is an antimicrobial and antibacterial substance present in lemon juice that protects the fruit from germs [17]. Excess moisture in the fruit is removed osmotically by the sugar-water solutions, which increases the hardness and quality of the fruit. The sweetness and flavor of the fruit can also be enhanced with sugar [18].

During storage, the quality of apricots will change and deteriorate over time due to moisture, heat, friction, or gasses such as ethylene [19, 20]. Some fruits that are damaged can be a source of infection, causing healthy fruits to deteriorate more quickly. Also, adjacent fruits may be affected by moisture loss or chemical changes caused by damaged fruits, and thus the deterioration of the fruits can affect the overall flavor of the stored products [21]. Therefore, damaged fruits must be carefully sorted from healthy ones. Manual sorting is labor-intensive and expensive, in addition to being inaccurate and slow [22]. Therefore, there is a need to adopt modern technologies that facilitate the sorting process with high efficiency.

With the advancement of computer vision and machine learning, these techniques are now widely used in agricultural production [23]. Current fruit detection methods rely on imaging technology, and traditional algorithms use color and shape to identify targets, which limits their effectiveness in complex scenes [24]. In contrast, deep learning algorithms, such as convolutional neural networks (CNN), have proven effective in extracting target features and overcoming the limitations of traditional methods. Various CNN algorithms, such as You Only Look Once (YOLO) and its variants, such as YOLO v3, YOLO v5, and Faster R-CNN, are widely used for fruit detection [25], with YOLOv7 being the most popular for their speed and accuracy in detecting small targets [26]. Recent research has reviewed the improvements of the YOLOv7 algorithm in apple fruit detection, where an improved model has been developed that enhances detection accuracy and effectively handles fruit defects [27]. Studies show that image enhancement techniques have been combined with YOLOv7, achieving an accuracy of up to 83.5% in distinguishing between fresh and spoiled apples [28]. A smaller version of the algorithm, YOLOv7-tiny, has also been presented with performance improvements using the α-IoU metric, addressing the limitations of traditional fruit detection models [29]. The reviews also discuss the effectiveness of YOLOv7 in processing large datasets, enhancing its potential for use in automated harvesting systems [30]. An improved YOLOv7-plum model was developed that achieved an average accuracy of 94.91% in detecting plum fruit, which is 2.03% higher than the original YOLOv7 [31]. Tomato diseases were identified and classified based on YOLOv7, achieving a mAP of 89.5% and an accuracy rate of 86.2% [32]. Weed detection in soybean fields was also achieved by improving the YOLOv7 model, which gave higher accuracy (0.9496) and recall (0.9125) compared to standard YOLOv7 models [33]. In another study, the YOLOv7-tiny model was used to detect defects and anomalies in tomato fruits in real time, the study achieved an accuracy of 90.6% [34]. Although YOLOv7 has been successfully used to detect damage in many fruit species, it has not been sufficiently investigated for apricots. There is an urgent need for research on developing a YOLOv7 model to improve the efficiency of automated classification and identification of defects or damages by analyzing apricot images. The article aims to study the effect of immersion of apricots in different solutions such as lemon juice, sugar-water on quality characteristics including sweetness, color, hardness, and water content, as well as to build an intelligent system for detecting damaged apricots after storage using a camera based on YOLOv7 algorithm. The two aims of the study are to maintain the quality of the fruits; the first aim is to study the effect of natural preservatives on preservation and the second is to use digital technologies to detect any damage quickly and accurately before it reaches the market and thus reduce the manual sorting process. The two aims are interconnected across different stages of the industrial and commercial fruit life cycle.

2 Materials and methods

2.1 Sample preparation

The experiment was conducted on ripe apricot samples (98 samples) of the Moniqui variety, collected from local markets in Baghdad, Iraq. The samples were carefully selected to ensure uniform ripeness. Initial measurements showed that the average sweetness was 22 Brix, the average hardness was 2.99 kg.f/cm^2, while the average color percentage was as follows: L 54.27, a 3.54, b 19.87, and the average water content was 72.54 g. Apricot fruits were treated by immersing them in lemon juice once, and in water-sugar solution again, for three different immersion times (5, 15, 25 min). The number of samples for each treatment was 14 samples. Lemon juice was diluted with water in a ratio of 1:4 to achieve a balance between antimicrobial benefits and strong taste and to reduce its antimicrobial activity [35]. This ratio reduces the acidity, preventing fruit spoilage due to high acidity. Water and sugar were mixed in a ratio of 1:2 to create a concentrated environment that facilitates osmosis, which helps remove excess moisture and improve hardness without excessive sweetness [36]. The volume of solutions used in the experiment was two liters for each solution. On the other hand, a group of apricot fruits were stored under the same storage conditions but without treatment to represent the control treatment. All samples (treated and untreated) were stored for a week at a temperature of 4 °C and 60% humidity.

2.2 Laboratory measurements

A CR1 color reader was used to measure the color variation of apricot fruits after storage with an accuracy of 0.1% and wavelengths of 400–700 nm. The device was calibrated before use by sending light to a white surface to distribute signals evenly and improve measurement accuracy by reducing signal loss and increasing stability. The working principle of this device is to send light at an angle of 10 degrees towards the surface of the apricot fruit, and then measure the amount of reflected light after it passes through 31 filters to measure the entire color spectrum. The measured spectral reflectance data is converted into three numbers representing CIE-L*a*b, which helps to accurately analyze color changes [37]. CIE-L*a*b This model is represented in three main dimensions: L* (lightness), a* (red-green), and b* (blue-yellow). The logic used is to convert CIE-X*Y*Z to CIE-L*a*b using the following equations:

$$L* = 116 \cdot f(Y/Yn) - 16 \quad (1)$$

$$a* = 500 \cdot \left[f(X/Xn) - f(Y/Yn)\right] \quad (2)$$

$$b* = 200 \cdot \left[f(Y/Yn) - f(Z/Zn)\right] \quad (3)$$

$$f = t^{1/3},\ t > (6/29)^3;\text{otherwise},\ f = 1/3(6/29)^2 t + (4/29),\ t(6/29)^3 \quad (4)$$

where, X, Y, Z are triadic stimulus values in XYZ space; X_n, Y_n, Z_n are triadic stimulus values for the reference white point; f is the conversion function.

The total color change was determined using the following equation [38]:

$$\Delta E = \sqrt{(L_0^* - L^*)^2 + (a_0^* - a^*)^2 + (b_0^* - b^*)^2} \quad (5)$$

where, L_0^*,a_0^*,b_0^* are initial color values; L^*,a^*, b^* are final color values.

In addition, a small Chinese mini fruit hardness meter, model GY-M30, with an accuracy of ± 2%, was used to measure the hardness of apricot fruits. The measurement range is 0.2 to 15 kg/cm^2, with a pressure head diameter of Φ11.1 mm. To measure fruit hardness, the fruit was placed on a wooden surface and held in the hand and the head of the device was pressed on the fruit to measure hardness. For sweetness and water content analysis, an Apocket SCiO molecular scanner (Consumer Physics Ltd., Illinois, USA) was used, with an accuracy of up to 78%. The device was also calibrated by sending light onto a white surface. This device contributes to measuring the chemical properties of fruits, which helps in evaluating their quality after storage [39].

2.3 Development of automated detection method

The YOLOv7 algorithm was used to detect apricots with damaged parts and classify them from healthy ones. The methodology consists of five main steps:

1. Apricot fruit treatment by immersion.
2. Measurement of physical and chemical properties.
3. Treatment evaluation: Study the effect of different treatments and immersion time on the quality characteristics of apricots.
4. Photography: Photographs of the fruits were taken under controlled conditions to ensure data accuracy.
5. YOLOv7 Algorithm Evaluation. To explain the YOLOv7 methodology in more detail, Fig. 1 shows the measurement methodology.

2.4 Capture images

Photographs of the samples were taken in a controlled environment inside a light chamber (Fig. 2). All the treated apricots were photographed by taking four photographs at different angles after manually rotating the sample, in addition to photos from the sides and from the top. An iPhone X camera with a resolution of 12 megapixels was used to capture the images. Camo Studio software installed on the computer was used for capturing and storing the images in JPG format.

The distance between the camera and the samples was 20 cm, which is a suitable distance to capture clear images of the apricot fruits. A good lighting system is essential to ensure uniform distribution of light, which helps to avoid glare or unwanted shadows. A strip of lamps with a brightness of 100 Lux was installed, and this brightness was measured using a digital Lux meter with an accuracy of ± 4%. The lighting was directed sideways and at an angle of 45° to the samples, as this angle helps to reduce reflections, thus contributing to the avoidance of unwanted glare [39, 40].

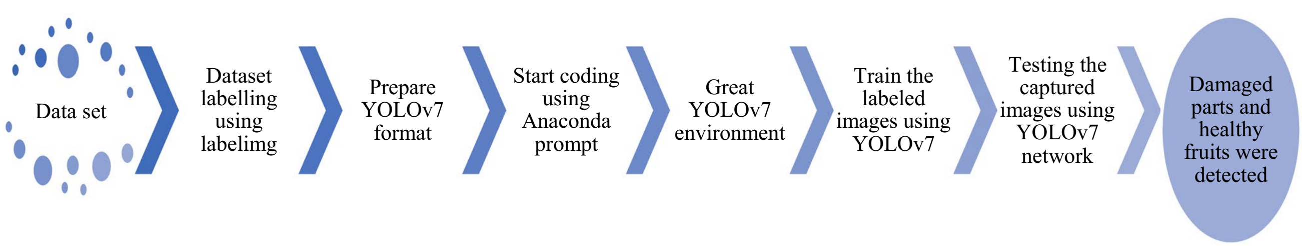


Fig. 1 The development process for the YOLOv7 detection algorithm

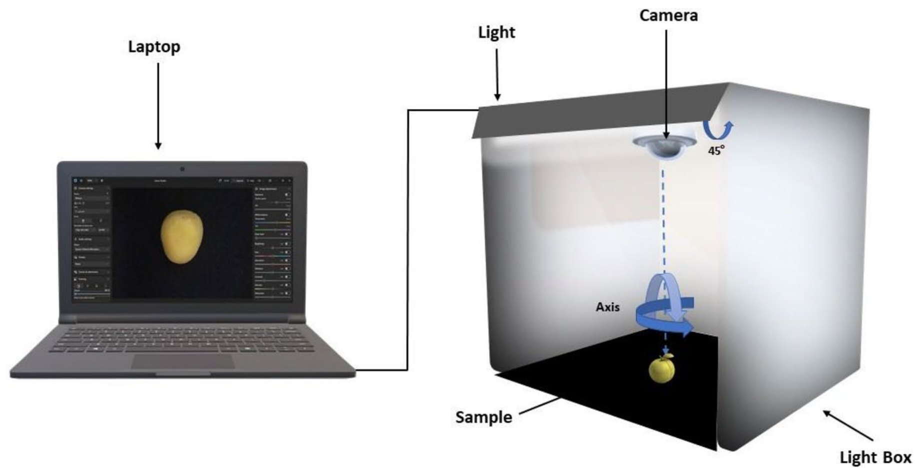


Fig. 2 Apricot fruit imaging system

2.5 YOLOv7 algorithm structure

YOLO is an advanced neural network-based target detection model that reformulates the target detection problem into a computational regression problem. The model directly processes the original image to produce the target location and class in real time. The YOLO process starts with an input image, divided into a grid of cells according to certain criteria. Each cell is responsible for predicting several boundary squares, with a confidence level for each square [41].

The YOLOv7 algorithm was built using Python programming language, Visual Studio version 1.92.1, and Anaconda Prompt were used as programming tools on a Lenovo laptop with 16 GB of storage and an Intel Core i7 processor at 2.3 GHz. The dataset used in this research included two types of apricots: healthy and damaged areas, and a total of 328 images were collected after using data augmentation techniques by rotating some images at different angles to increase their number for the purpose of increasing the classification accuracy. The image annotation software "Labelimg" was used to draw the outer rectangle of the healthy and damaged areas in all images of the training set to complete the manual labeling of the fruit. The images were labeled based on the smallest rectangle surrounding the healthy or damaged parts apricot to ensure that the rectangle contained as little background area as possible. After saving the image annotations, txt files were generated. The number of labels for healthy fruits was 122, while the number of labels for damaged areas was 347.

The images were divided into 80% for training, 10% for testing, and 10% for validation. During the preprocessing process, the image dimensions were adjusted to 640 × 640 pixels with three color channels, to preserve important information about the morphological characteristics of apricot fruits. To ensure the accuracy of the algorithm, the training, validation, and testing sets were randomly selected for use in all experiments. The activation function ReLU (Rectified Linear Unit) was used to enhance the performance of the model (Eq. 6), and the Gradient Descent algorithm was used to update the weights in the neural network (Eq. 7):

$$f(x) = \max(0, x) \tag{6}$$

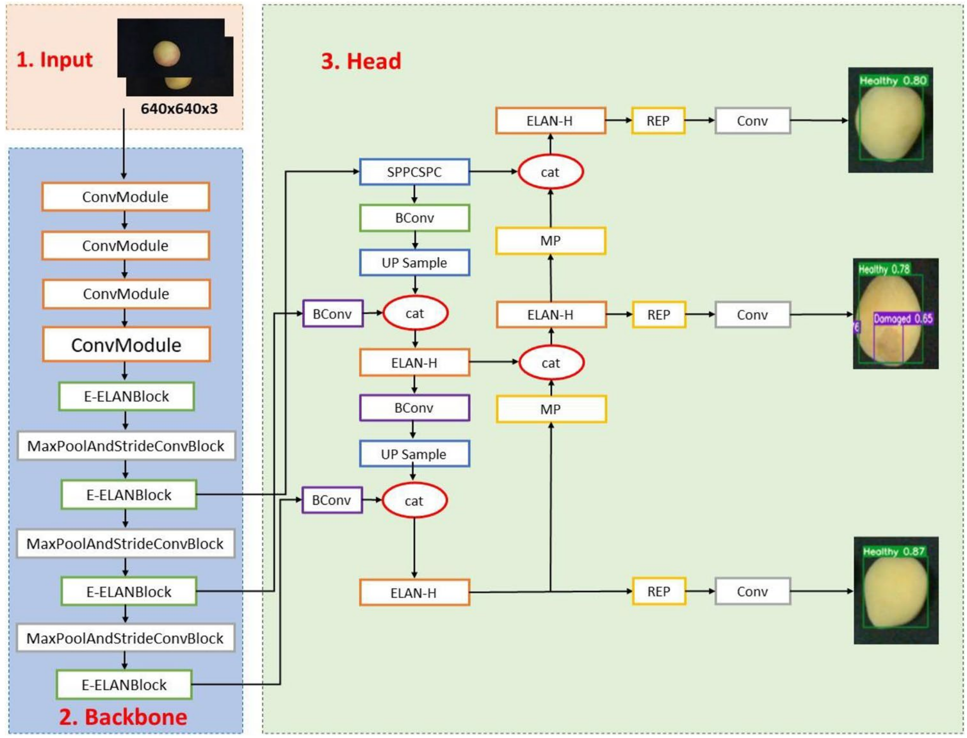
$$w = w - \eta \nabla L \tag{7}$$

Where, w is the weight; η is the learning rate; ∇L is the gradient of the loss function.

Figure 3 shows the structure of the YOLOv7 algorithm, where the final output of the neural network is the detection box of the given apricot fruit and the damaged part with the probability (confidence) that the object belongs to a given class.

The YOLOv7 model consists of three main modules: the input layer, the backbone network, and the vertex unit. The input layer preprocesses RGB images (640 × 640), while the backbone network extracts pixel features using the CSPDarknet53 architecture. The vertex unit is used to train the auxiliary vertex and match positive and negative samples to improve performance and speed up training. Use CSPDarknet53 because of its balance of speed, accuracy, and complexity that is suitable for real-time damage detection applications [42]. Unlike ResNet or EfficientNet which may not be optimal for applications that need real-time detection with YOLOv7 [43].

Fig. 3 YOLOv7 network structure



2.6 YOLOv7 model evaluation indicators

In this paper, Precision, Recall, Mean Average Precision (mAP), and F1 score were used to evaluate the performance of the model accurately and objectively. Precision is the most common evaluation index, and it is the number of right targets divided by the number of detected targets. Precision ranges from 0 to 1. A higher value indicates fewer false positives. Precision is a very intuitive evaluation index, but sometimes high Precision does not represent all. Therefore, mAP, Recall, and F1 scores were introduced for comprehensive evaluation. Recall ranges from 0 to 1. A higher value indicates that more actual cases were correctly identified. mAP@0.5 ranges from 0 to 100%, with higher values indicating better detection accuracy across classes. Precision, Recall, mAP, and F1 scores were calculated as follows [44].

Precision:

$$P = TP/TP + FP \times 100\% \tag{8}$$

Recall:

$$R = TP/TP + FN \times 100\% \tag{9}$$

Average Precision:

$$A = \int_0^1 P(r)dr \tag{10}$$

Mean Average Precision:

$$mAP = \frac{1}{n}\sum_{t=1}^{n} API \tag{11}$$

F1 score:

$$F1 = 2x\frac{PxR}{P + R} \tag{12}$$

where TP (True Positive) represents the number of healthy apricots and damaged parts that were correctly detected; FP (False Positive) represents the number of fruits that were incorrectly detected; and FN (False Negative) represents the number of apricots that were not detected/missed. P is Precision and R(r) is Recall.

On the other hand, the loss function was used to evaluate the model's performance for object detection tasks [45]:

$$L_{bbox} = \frac{1}{N}\sum_{i=1}^{N} IOU(pred_i, true_i) \tag{13}$$

where, L_{bbox} is the bounding box loss; N is the number of bounding frames; $pred_i$ and $true_i$ are the predicted and true frames.

$$L_{cls} = -\frac{1}{N}\sum_{i=1}^{N} \left(\log y_i\left(yi^\wedge\right) + (1-1)\log\left(y_i - yi^\wedge\right)\right) \tag{14}$$

where, L_{cls} is the classification loss; yi is the true value; yi^ is the predicted value.

$$L_{obj} = -\frac{1}{N}\sum_{i=1}^{N} (\log o_i\left(oi^\wedge\right) + (1-1)\log(o_i - oi^\wedge)) \tag{15}$$

where, L_{obj} is the objectness loss; oi is the true value of the object's existence; oi^ is the expected value.

$$L = L_{bbox} + L_{cls} + L_{obj} \tag{16}$$

Where, L is the total loss function.

3 Results and discussion

In terms of sweetness study, the sweetness of apricot was investigated under different treatments with normal distribution. Table 1 shows the significant distribution measures of sweetness with different treatments.

Considering the (*W*) value for all the coefficients in Table 1 for the Shapiro–Wilk test, it was found that the data were consistent with the normal distribution. For the (*p*) values obtained at the level $p < 0.05$, the null hypothesis H0 should be accepted in favor of the alternative hypothesis H1, assuming that the distribution of the trait conforms to the normal distribution. This was the case for the control treatment, sugar-water solution, and time (5, 0 min). The null hypothesis H0 was rejected in favor of the alternative hypothesis H1, assuming that the distribution of the trait does not conform to the normal distribution. This was the case for the lemon juice treatment and time (15, 25 min). As for Levene's test and based on the (*P*) value, there is homogeneity in the variance between the different immersion times, unlike the immersion media, which has no homogeneity in the variance between its groups. From Table 1, the basic requirement

Table 1 Distribution coefficients of significance for apricot sweetness (Brix)

Treatment	N	Shapiro–Wilk Test		Levene's Test
		W	*P-value*	*P-value*
Control	14	0.89	0.11	0.00
Lemon juice	42	0.92	0.03	
Sugar-water solutions	42	0.96	0.14	
0 min	14	0.9	0.11	0.98
5 min	28	0.97	0.55	
15 min	28	0.85	0.001	
25 min	28	0.82	0.00	

Table 2 Summary of calculation results confirming the importance of differences between groups when studying sweetness (Brix)

Treatment	N	Mean Rank	*H*	*P-value*
Control	14	42.46	9.433	0.009
Lemon juice	42	41.73		
Sugar-water solutions	42	59.62		
0 min	14	42.46	2.47	0.48
5 min	28	45.75		
15 min	28	51.5		
25 min	28	54.77		

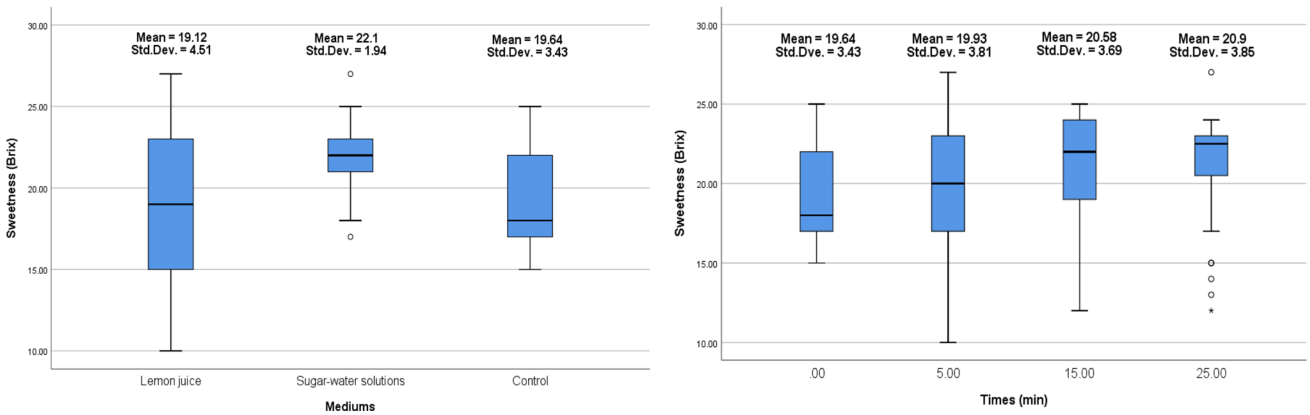


Fig. 4 Mean and standard deviation of sweetness values (Brix) at different treatments

for using parametric tests was not met. The nonparametric Kruskal–Wallis test was used to determine the significance of differences between groups (Table 2).

From the mean rank values in Table 2, sweetness increased with increasing immersion time, and sweetness increased when apricots were immersed in sugar-water solutions and decreased when immersed in lemon juice compared to the control. It is believed that this increase in sweetness is due to the osmotic leakage of sugar into the fruit cells [46], and the process of dissolving sugar increases the concentration of sweet molecules (glucose or sucrose) in the solution [47], and both reasons lead to an increase in sweetness over time. The *p-value* obtained at the level $p < 0.05$ for the different media is 0.009, which indicates a statistically significant difference between the different groups (Control, Lemon juice, and Sugar-water solutions), and therefore the alternative hypothesis H1 can be accepted. The *P*-value for immersion time is 0.48, indicating no statistically significant difference between the different immersion times, so we reject the alternative hypothesis H1 and accept the null hypothesis H0.

Figure 4 shows that the highest mean sweetness was obtained when apricots were immersed in a sugar-water solution, which was 22.1 Brix, while the lowest mean sweetness was 19.12 Brix when immersed in lemon juice compared to the control (without treatment) which was 19.64 Brix. In terms of immersion time, an immersion time of 25 min gave the highest mean sweetness, which was 20.9 Brix, followed by 15 min, which was 20.85 Brix, while an immersion time of 5 min gave the lowest mean sweetness, which was 19.93 Brix, compared to the control (without immersion) which was 19.64 Brix. The treatment with sugar-water solution at 25 min gave the best combination in terms of mean apricot sweetness.

Immersion of fruits in lemon juice or sugar-water solution, which are highly tonic solutions, leads to the process of osmotic dehydration. The water content of the fruit decreases due to the osmotic gradient that pushes water out of the fruit cells [48]. Table 3 shows the significant distribution measures of water content (g water per g apricot) with different treatments.

The results of the Shapiro–Wilk test, as shown in Table 3, showed that all the coefficients were homogeneous with the normal distribution, as the (*W*) value for all coefficients indicated this. When analyzing the (*p*) values obtained, it was found that at a significance level of $p < 0.05$, the null hypothesis H0 should be accepted in favor of the alternative hypothesis H1, which means that the distribution of the trait conforms to the normal distribution. However, the immersion time of 25 min was excluded from this result. As for the Levene test, the results extracted from the (*P*) value showed

Table 3 Distribution coefficients of significance for apricot water content (g water per g apricot)

Treatment	N	Shapiro–Wilk Test		Levene's Test
		W	P-value	P-value
Control	7	0.98	0.96	0.29
Lemon juice	21	0.93	0.16	
Sugar-water solutions	21	0.92	0.08	
0 min	7	0.98	0.96	0.36
5 min	14	0.94	0.47	
15 min	14	0.95	0.52	
25 min	14	0.86	0.03	

that there was homogeneity of variance between the different immersion media and time. Table 4 shows the results of the nonparametric Kruskal–Wallis test to determine the significance of differences between groups.

Analyzing the data in Table 4, it is evident that the water content of apricots decreases with increasing immersion time. It was also observed that the water content of apricots decreased when immersed in lemon juice, sugar, and water solutions compared to the control group. Overall, the results indicate that longer immersion times lead to increased water loss and shrinkage in the fruits [46]. Low water content protects the fruits from damage by reducing water activity and slowing down biological processes, which enhances the shelf life of the product and increases its storage period [49]. Evaluating the statistical values, the calculated $p < 0.05$ for different media was 0.27, while it was 0.52 for different immersion times, indicating that there was no statistically significant difference between the different groups. Accordingly, the null hypothesis H0 can be accepted, and the alternative hypothesis H1 can be rejected.

Figure 5 shows that the average water content of apricots reached its lowest value, recording 74.48 g water per g apricot when immersed in a sugar-water solution. This was followed by immersion in lemon juice, which showed an average water content of 75.9 g water per g apricot, compared to the control sample, which reached 77.14 g water per g apricot. On the other hand, it was observed that the water content decreased with increasing immersion time, recording values of 76.56, 75.22, and 73.93 g water per g apricot, respectively. All these values were lower than the

Table 4 Summary of calculation results confirming the importance of differences between groups when studying water content (g water per g apricot)

Treatment	N	Mean Rank	*H*	*P-value*
Control	7	30.36	2.65	0.27
Lemon juice	21	26.79		
Sugar-water solutions	21	21.43		
0 min	7	30.36	2.28	0.52
5 min	14	26.82		
15 min	14	24.36		
25 min	14	21.14		

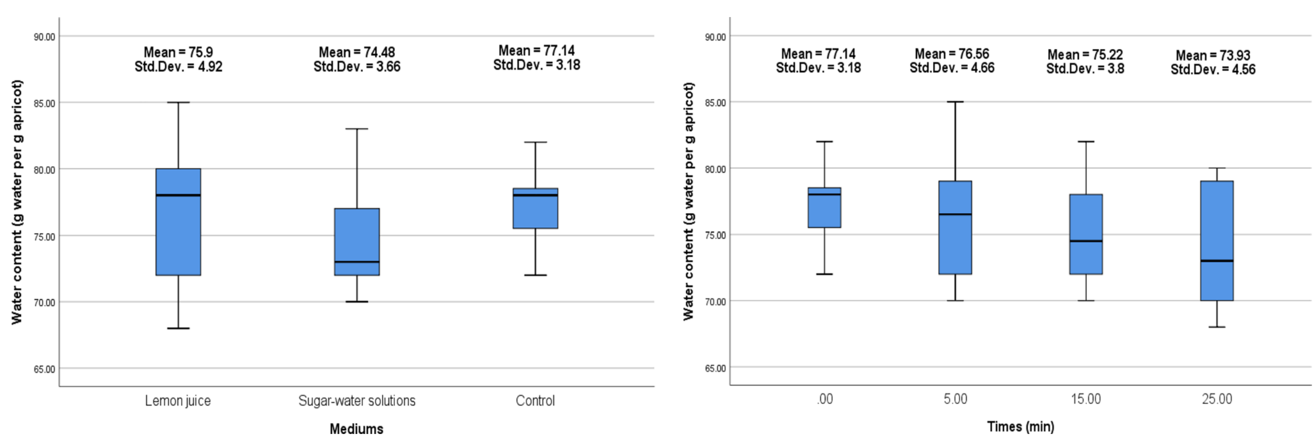


Fig. 5 Mean and standard deviation of water content values (g water per g apricot) in different treatments

Table 5 Significance distribution coefficients for apricot fruit hardness (kg.f/cm^2)

Treatment	N	Shapiro–Wilk Test		Levene's Test
		W	P-value	P-value
Control	14	0.82	0.008	0.99
Lemon juice	42	0.97	0.23	
Sugar-water solutions	42	0.98	0.96	
0 min	14	0.82	0.008	0.047
5 min	28	0.98	0.86	
15 min	28	0.95	0.19	
25 min	28	0.98	0.75	

Table 6 Summary of calculation results confirming the importance of differences between groups when studying hardness (kg.f/cm^2)

Treatment	N	Mean Rank	*H*	*P-value*
Control	14	33.18	6.18	0.04
Lemon juice	42	49.45		
Sugar-water solutions	42	54.99		
0 min	14	33.18	24.31	0.00
5 min	28	35.23		
15 min	28	53.18		
25 min	28	68.25		

control sample value, which reached 77.14 g water per g apricot, indicating the effect of immersion time on reducing the water content in apricots.

When fruit is immersed in a hypertonic solution, water moves out of the fruit cells due to the osmotic gradient, resulting in dehydration and shrinkage. This process can make the fruit firmer or harder due to loss of water content [50]. Table 5 shows the important distribution parameters of apricot fruit hardness (kg.f/cm^2) with different treatments.

Shapiro–Wilk test was performed for all parameters in Table 5, and the results showed that the data followed a normal distribution. For the *p-values* obtained at a significance level of $p < 0.05$, the null hypothesis H0 was accepted in favor of the alternative hypothesis H1, indicating that the distribution of the trait followed a normal distribution. This situation was valid for all parameters except the control group (no treatment). As for Levene's test, the resulting values showed homogeneity of variance between different immersion media, while homogeneity of variance between immersion times groups was not shown. Table 6 shows the results of the nonparametric Kruskal–Wallis test to determine the significance of differences between groups.

By analyzing the data in Table 6, it is clear that the apricot hardness increases with increasing immersion time. It was also observed that the apricot hardness increases when immersed in lemon juice and sugar-water solution compared to the control group. By evaluating the statistical values, the $p < 0.05$ calculated for different media was 0.04, while it was 0.00 for different immersion times, indicating that there is a statistically significant difference between the different groups. Therefore, the null hypothesis H0 can be rejected, and the alternative hypothesis H1 can be accepted.

Figure 6 shows that the highest mean hardness was obtained when apricots were immersed in a sugar-water solution, which was 3.7 kg.f/cm^2, followed by a mean hardness of 3.52 kg.f/cm^2 when immersed in lemon juice compared to the control group (no treatment) which was 2.77 kg.f/cm^2. In terms of immersion time, an immersion time of 25 min gave the highest mean hardness, which was 4.18 kg.f/cm^2, followed by 15 min, which was 3.67 kg.f/cm^2, while an immersion time of 5 min gave a hardness of 3 kg.f/cm^2, compared to the control group (no treatment) which was 2.77 kg.f/cm^2. Treatment with sugar-water solution at 25 min gave the best combination in terms of mean hardness. Based on the results, the immersion process will contribute to facilitating the process of transporting and storing fruits with high efficiency, thus preserving their appearance and texture, which meets the consumer's requirements.

It is clear from the above results that when the water content of the fruits decreases, their hardness increases, and in return, their sweetness increases [9]. Except for immersion in lemon juice, where the sweetness decreases.

The immersion of apricot fruits in different immersion media and immersion times affects their color. Figure 7 shows the relationship between CIE-L*a*b levels and different coefficients.

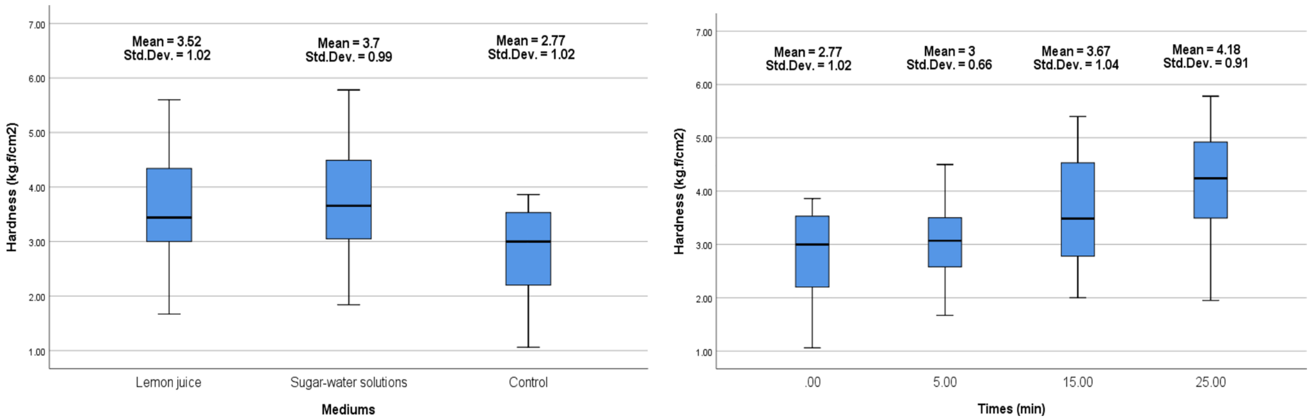
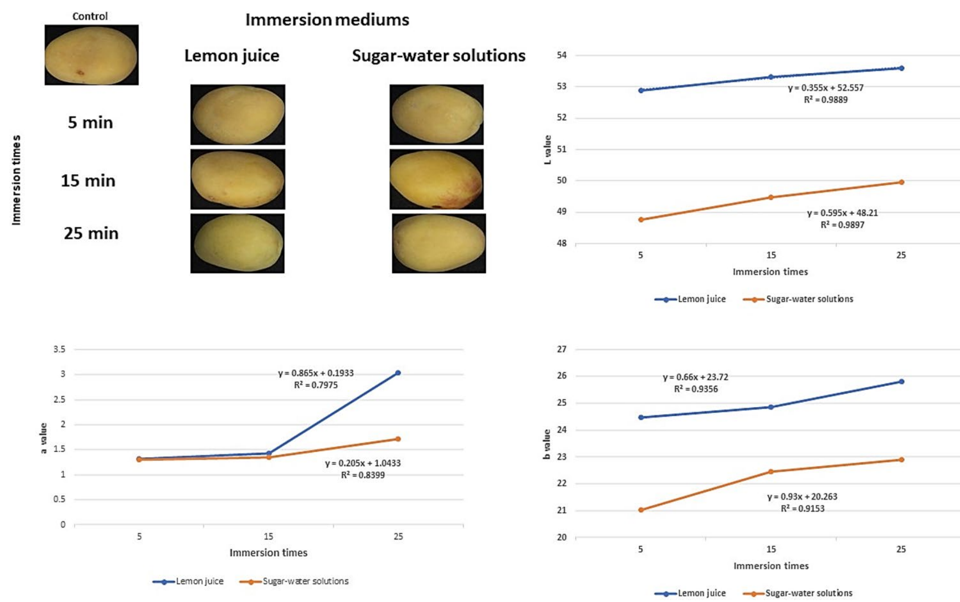


Fig. 6 Mean and standard deviation of hardness (kg.f/cm^2) in different treatments

Fig. 7 The relationship between CIE-L*a*b levels and different coefficients



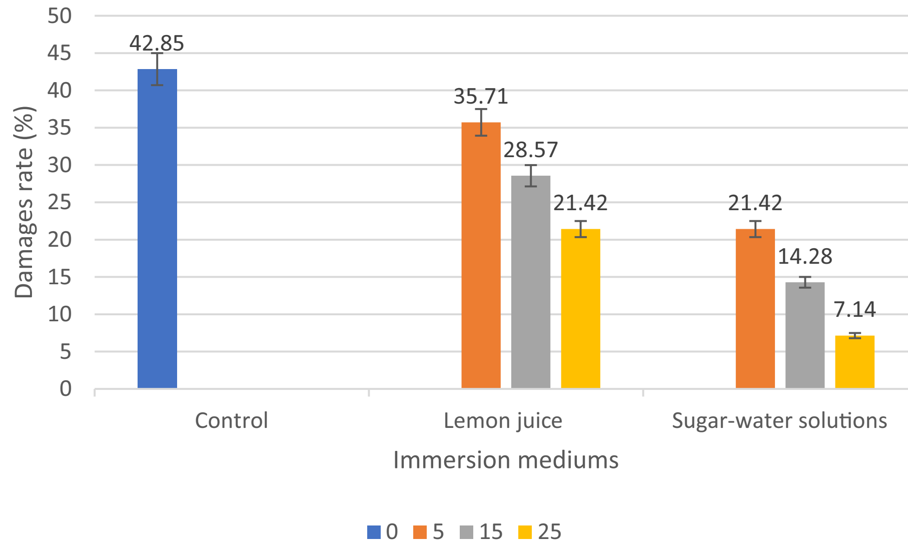
It is clear from Fig. 7 that CIE-L*a*b values increased when apricots were immersed in lemon juice and sugar-water solution compared to the control (47.97, 0.73, 20.95). Also, CIE-L*a*b levels increased with increasing immersion time. Immersion in sugar-water solution or lemon juice can reduce the browning of the fruits, maintaining their original color and increasing CIE-L*a*b values. This is because the solution prevents oxidation reactions that lead to browning [51]. On the other hand, lemon juice contains citric and ascorbic acid, which act as antioxidants. The first works to change the pH of the environment [52], and the second prevents the oxidation of phenols into millions [53]. It is clear from the results above that there is a direct relationship between the levels of CIE-L*a*b, which represent the amount of reflected light, and the red and yellow colors, respectively, with the immersion time.

In order to study the effect of different treatments on apricot fruit damage, Fig. 8 shows the percentage of damage for each treatment.

From Fig. 8, it is clear that the least damage rate when immersed in sugar and water solution followed by immersed in lemon juice compared to the control. It also appears that the damage decreased with increasing immersion time in different immersion media. Hard fruits with low water content generally have less damage due to their low water activity, which limits the growth of spoilage microorganisms [54].

After processing the apricots, the original dataset and the YOLOv7 network were used to design a model to identify healthy apricots and those with damaged areas. The effectiveness of the developed model is highlighted by the graphs, which show multiple metrics to evaluate the performance of the training and validation sets. Three separate types of loss are documented in Fig. 9: box loss, objectivity loss, and classification loss. Box loss assesses the accuracy of the algorithm

Fig. 8 The percentage of damage for each treatment



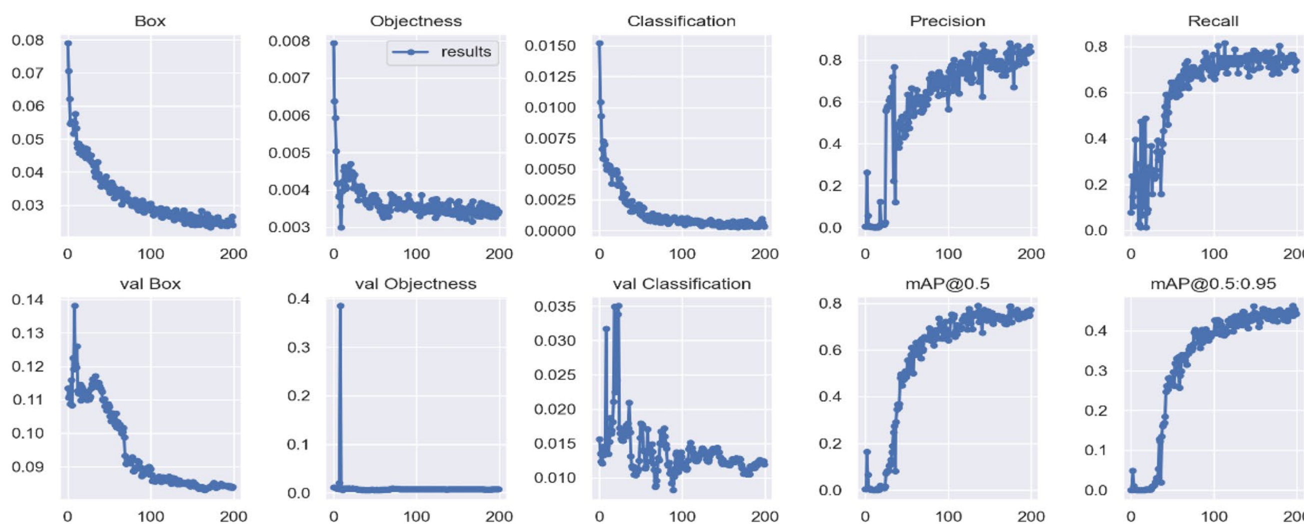


Fig. 9 Visual analysis of model evaluation indicators (Precision, recall, and mAP@0.5 for the proposed YOLOv7) during training

in locating the center of the object and estimating its bounding box, while objectivity assesses the probability of the object being in a specific region, with high objectivity indicating the probability of the object being within the visible region of the image. Classification loss indicates the accuracy of the algorithm in identifying the appropriate class for the object.

Precision and recall cannot be considered as the only determinants of model performance because they may mislead us about the model performance [55]. Therefore, we use additional curves to evaluate the model performance as shown in Fig. 10. The precision and recall curve are shown in Fig. 10a, Fig. b shows the graph of precision (P) versus confidence (C), and Fig. 10c shows the F1 score of 0.77 with confidence of 0.407, which calls for balancing P and R based on the apricot fruit image dataset. Figure 10d shows the graph of recall (R) versus confidence (C).

Based on these values, it can be said that the model shows good performance. The F1 Score value of 0.77, along with good precision and recall values, indicates that the model achieves a good balance between precision and recall. In addition, the mAP@0.5 value of 77% indicates good performance in identifying objects at the specified confidence threshold. To achieve a better level of clarity, we have attached a confusion matrix for the positive and negative results (Fig. 11). The prediction accuracy for healthy and damaged fruits is 89% and 68% respectively, which means that the model has classified the fruits well.

After the model training process was completed, the performance indicators were measured to test and validate the trained YOLOv7 model (Table 7).

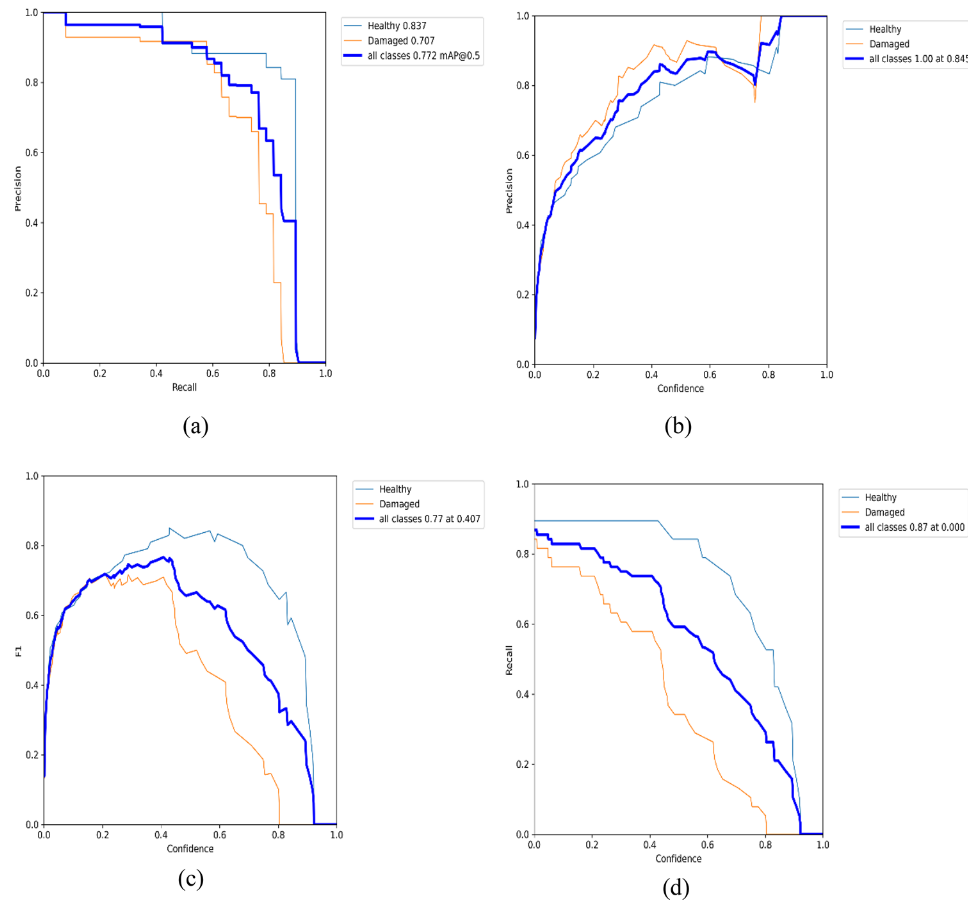


Fig. 10 Operation results curve; **a** precision-recall curve, **b** precision-confidence curve, **c** F1-confidence curve, and **d** recall-confidence curve

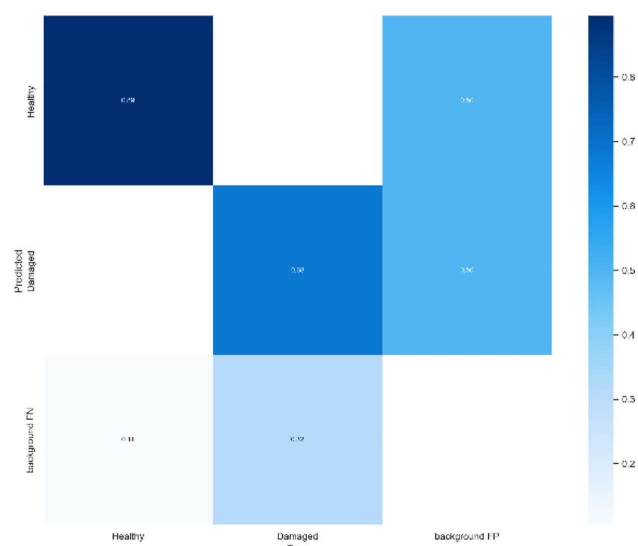


Fig. 11 Confusion matrix

Table 7 Performance evaluation index for testing and validating the trained YOLOn7 model

	F1	Precision	Recall	mAP@0.5
Test	0.80	92%	90%	81%
Validation	0.79	89%	83%	75%

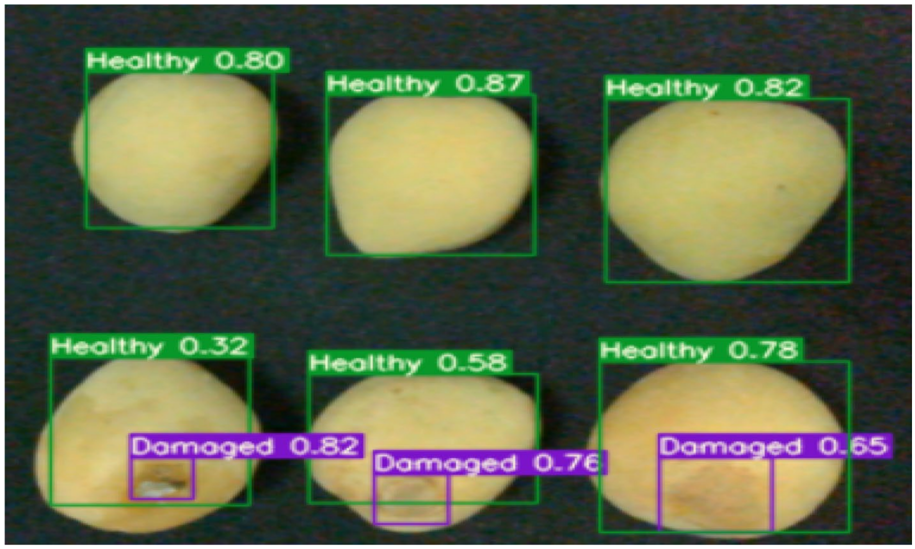


Fig. 12 Visualization results for identifying healthy apricots and fruits with damaged areas

The visualization results of identifying healthy apricot fruits and fruits with damaged areas are shown in Fig. 12. This figure shows that the proposed algorithm accurately detects and identifies healthy fruits and damaged areas by constructing an optimal boundary box. By identifying fruits with damaged parts, farmers can use more effective measures to sort out damaged fruits.

4 Conclusions

Maintaining the quality and nutritional value of fruits during storage is a major challenge, as the internal and external quality of fruits often deteriorates. To increase the shelf life and ensure the quality of apricot fruits, various techniques are required. The results showed that the sweetness increased with increasing immersion time in the sugar-water solution, while it decreased with increasing immersion time in lemon juice. Also, the water content of apricots decreased with increasing immersion time in different immersion media. In addition, the hardness and CIE-L*a*b levels increased with increasing immersion time in different immersion media. Thus, immersion in different media helped to maintain the internal and external quality of apricot fruits. From another aspect of research, the system for detecting and identifying damaged fruits could have great potential for the economies of the world countries. The YOLOv7 model was used to detect healthy apricot fruits and fruits with damaged areas, with a precision of 84.5%. Based on the results, it can be said that the model shows good performance. This study will contribute to sustainable agriculture by reducing post-harvest losses and improving food security. During the experiment, we encountered problems such as determining the correct parameters for spoilage and how lighting affects image quality, in addition to the small sample size. There were also problems related to the change in apricot appearance after dipping and the time required to train the model. To expand the scope of the research, multispectral techniques can be used to investigate the effect of different storage conditions on apricot quality and improve the performance of the automatic detection system. Soft learning or deep machine learning techniques can be used to improve the performance of YOLOv7 and create a system that can be expanded to other types of fruits. The proposed algorithm can also be implemented in a mobile application to help farmers find spoiled fruits at any time, outdoors or mixed. We also recommend applying alternative preservation methods such as essential oils or biopolymer coatings.

Statement of compliance with guidelines This research, which involved the collection and study of apricot samples, was conducted according to all relevant guidelines and legislation at institutional, national, and international levels. In particular, the principles set out by the International Plant Protection Convention (IPPC) in force were adhered to ensure ethical and responsible handling of plant materials. All necessary permits were obtained before the collection of plant samples, and our research protocols were reviewed and approved by the relevant scientific committee.

Author contributions Mustafa A. J. Al-Sammarraie, Zeki Gokalp, and Samsuzana Abd Aziz contributed to the conceptualization. Mustafa A. J. Al-Sammarraie contributed to the methodology, software, formal analysis, and investigation. Mustafa A. J. Al-Sammarraie, Zeki Gokalp, and Samsuzana Abd Aziz contributed to the data curation and analysis. Mustafa A. J. Al-Sammarraie, Zeki Gokalp, and Samsuzana Abd Aziz contributed to the writing, review, and editing.

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Data availability Data availability The data that supports the findings of this study is available from the corresponding author upon reasonable request.

Declarations

Ethics approval and consent to participate Ethical approval was not required for this research.

Informed consent Not applicable.

Competing interests The authors declare no competing interests.

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