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Original Research Paper

Effect of maturity stages on the quality indices of wood apple (*Feronia limonia*) and modeling of its kinetics by applying machine learning approaches

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ABSTRACT

In the present investigation, an inexpensive and non-destructive method was tested for the appropriate maturity classification of wood apple (*Feronia limonia*). The investigation was conducted to establish the pronounced effect of maturity stages on the growth kinetics, physico-chemical properties, and other quality indices of wood apple. A systematic trend was observed for all the properties namely sphericity, bulk density (g/cm^3), true density (g/cm^3), pH, total soluble solids TSS (°Brix), titratable acidity (%) and TSS/TA ratio, *etc*. of the fruit. In contrast, regular changes were also observed in the color properties at various maturity stages of the wood apple. The maturity kinetics was formulated by applying recurrent neural network (RNN) in compliance with K means cluster algorithm. RNN modeling was applied by considering color property (redness value) as input and six maturity indices as the output of the formulated structure. The RNN architecture, 1-6-6 showed the best results for forecasting the wood apple maturity based on color features. Further, based on the results of the K means cluster algorithm, the maturity stages were classified into three main categories, illustrated in the form of a simplified color chart. Hence, this investigation can be useful for proper control and identification of wood apple maturity during the processing.

Keywords : Bio-chemical properties, K-means cluster algorithm, maturity stages, wood apple

INTRODUCTION

Fruits play a vital role in balancing diet. It is a widely recommended diet in daily intake of meals (Slavin and Lloyd, 2012). There is a sharp demand and increased interest in fruits, as their consumption appears to reduce certain chronic diseases. In terms of fruit production, India stands second in the world after China. The total area was reported to be 25.43 million hectares and total production was approximately 311.71 million tonnes in the year 2017 - 2018, which is one of the leading positions in the world (Anon., 2018). Despite the fact that India is among the leading position in the world in horticultural crop production, it seems inadequate. The reason behind this may be unscientific ways of processing perishable horticultural products. Therefore, it is high time that all the fruits and vegetables be processed in such a way that all parts including waste of them can be brought to maximum utilization.

Wood apple (*Feronia limonia*), a non-commercial and commonly found fruit is still under-utilized and has great potential in terms of health benefits but it lacks in-depth scientific knowledge. It belongs to *Rutaceae* family and is native to India (Mani and Mitra, 2020). The seedlings of the fruit are seen growing naturally in scattered and isolated at various agro- climatic zones (Yadav *et al*., 2018b). It is generally round in shape and turns brown to yellow when mature. The soft yellow pulp has net-like protective fiber with numerous small white seeds scattered. The average length, width, and thickness are 8.92 cm, 8.22 cm, and 7.95 cm respectively (Sonawane *et al*., 2020). The fruit has a heavy hard protective shell that comprises of 55.67% of the total weight of the fruit (Devi and Kulkarni, 2018) and an edible portion of 42.9 to 60.60% (Sharma *et al*., 2014). It contains properties that are of medicinal importance (Bobade *et al*., 2020), nutritionally rich (Yadav *et al*., 2018a), and rich in iron, protein, and minerals (Rao *et al*., 2011), and many more to count. The titratable acid and pectin content increases with maturity and thereafter decreases (Kumar and Deen, 2017). It can be processed into various food items, its pulp can also be dried effectively at 70°C and milled to powder for value addition (Goyary *et al*., 2021).

The palatability of fruit in terms of its quality is a closely linked factor that has an effect on the consumer perspective and can be correlated with fruit maturity and harvesting (Gupta *et al*., 2020**).** Ripening is the critical phase where fruits attain their desirable composition and makes fruit palatable. In the northeastern part of India, wood apples can be harvested from mid of November to the end of March. It has a longer period of duration of harvesting as compared to other fruits. The flesh has an appetizing flavor and tastes sour-sweet. The combination of excellent flavor, nutritive value, and medicinal characteristics possess great potential for processing into valuable products. There are various parameters and indices that are used to determine the harvesting of fruits. The degree of ripening of fruit can be determined by the colors charts that express color in terms of L*, a* and b* values in numerical forms along the axes (from white to black, green to red, and blue to yellow, respectively) that can be combined mathematically for calculating the color indexes (López and Gómez, 2004). A fruit ripening chart can be prepared for monitoring the ripening stages by using L*, a*, and b* and the RNN mechanism. Based on the color properties of the ripening stages, a color chart can be prepared using L*, a*, and b* and various other qualities by using RNN (Gupta *et al*., 2020). In present research work, an attempt was made to classify the maturity stages of wood apples using a clustering algorithm (CA) and mapping of color properties versus various physico-chemical properties by implementing a recurrent neural network (RNN). This study will ultimately provide a brief idea to the cultivators that the fruit has attained its maximum maturity level and its pulp has softened enough and is ready to be harvested.

MATERIALS AND METHODS

In this research work, 100 healthy fruits were harvested thrice in a season first at the initial fruit development phase, second at its peak period of maturity, and third at the final ripe. Each harvested lot was taken for determining its various physico-chemical properties, and color properties. After that, the properties were mapped for maturity kinetics and its integrated simulation with physico-chemical properties.

Determination of physico-chemical properties

Weight, arithmetic mean diameter, and sphericity ratio

The fruit sample was randomly collected from different trees around Assam University Silchar campus. One hundred fruits were taken as a sample size for analysis. The weight (mass) of each fruit was measured with electronic weight balance (Scale-tec brand, capacity 1 kg and 0.1 mg precision). The arithmetic mean diameter (D_a) was measured using a vernier caliper (Kristeel Precision brand, 0 to 150 mm range and least count 0.01 mm) along the X, Y, and Z axes and calculated using the Equation 1. (Mohsenin, 1970; Bayram, 2005) and the sphericity ratio (φ) was calculated using Equation. 2 (Mansouri *et al*., 2017).

$$D_a = \frac{X \times Y \times Z}{3} \quad (1)$$

$$\emptyset = \frac{(X \times Y \times Z)^{\frac{1}{3}}}{X} \quad (2)$$

Bulk density (ρ_b)

The bulk density of wood apple was determined as per the standard procedure. A rectangular box container of 0.36 m × 0.28 m× 0.95 m volume was used. Firstly, the container was weighed empty to determine its mass, and then secondly it was filled with wood apple and weighed once again. The mass of the empty container was deducted and then the actual mass of the wood apple was divided by the volume of the container (Khalloufi *et al*., 2010). The bulk density was calculated by using Equation. 3.

$$\rho_b = \frac{\text{Weight of sample in container}}{\text{Volume of container}} \quad (3)$$

True density (ρ_t)

It is the density excluding the pores of the mass. The true density of wood apple was determined by the displacement method (Tscheuschner, 1987) and calculated by the Equation. 4.

$$\rho t = \frac{\text{Mass of the sample}}{\text{Volume of toluene displaced}} \quad (4)$$

pH

The pH of the wood apple pulp was measured with a pocket pH meter (PAL-pH). Prior to the test pH meter was calibrated against standard buffer solutions of known hydrogen ion activity. The pulp of wood apple was put at the sensor unit and the result was displayed on the display unit with two decimals. The method was followed according to Karastogianni *et al.* (2016).

TSS (°Brix)

Total soluble solids were measured using a pocket refractometer (LABART ERMA). The pulp sample of wood apple was put in the sample holder and the °Brix was recorded (AOAC, 2005; Jamil *et al.*, 2010).

Titratable acidity

The titratable acid was determined by titration method. The pulp of the wood apple was titrated with 0.1 N NaOH using phenolphthalein indicator (AOAC, 2005). The result was expressed in terms of percentage of malic acid equivalent (gram of malic acid equivalent per 100-gram fruit pulp weight) (Ranganna, 1986; Zhang *et al.*, 2005).

TSS/TA ratio

The ratio of total soluble solids to titratable acidity (TSS/TA) was calculated by dividing TSS by TA (Su *et al.*, 2013).

Color properties determination of wood apple

The color properties of the wood apple were determined by using Image J software. For the measurement of color properties, the image was captured by using an HD camera from six different angles of the fruit. L*, a*, b* values were considered for estimation of the color properties. The methodology for the image processing of wood apples is illustrated in Fig.1. The method of image analysis was followed according to Mohammadi *et al.*, (2015) with minor modifications such as increasing the megapixel of the camera lens and widening the capture angle.

Classification of maturity stages by using K-means cluster algorithm

For finding the clusters, N points were randomly selected from the "dataset" (database) for initializing the K-means algorithm. The appropriate operation for allocating and renovating the clusters was, to establish up to their convergence or to the point where they

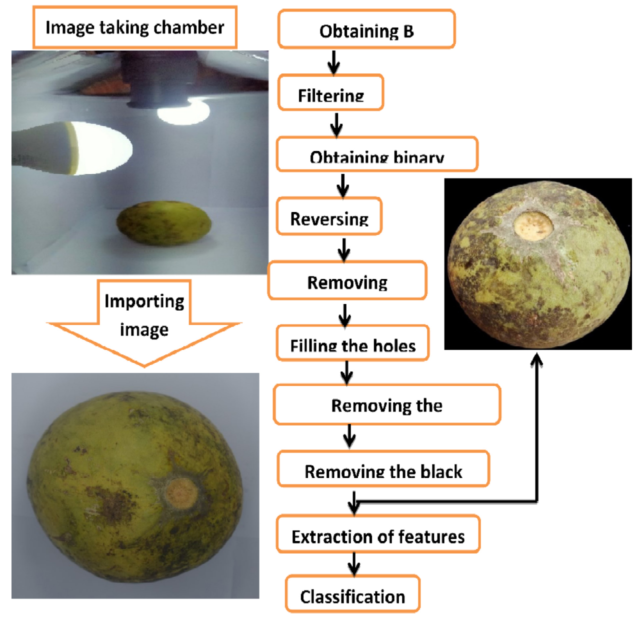

Fig. 1 : Classification of wood apple using color categorizing algorithm

reach a maximum limit of recurrence number. Alliterations were grouped within the same cluster to the nearest the centroid (assignment) point in each of the dataset points (Pacheco and Lopez, 2019).

Mapping of maturity kinetics and its integrated simulation with physico-chemical properties :

Recurrent neural network for the mapping of various properties

In the present study, a recurrent multilayer structure containing three layers input, hidden, and output of one each was used. The construction of RNN was done according to Cheroutre-Vialette and Lebert, (2002) with modification by improving the temperature in the input layer. There is no scientific or theoretical, set of principles/ rules for the decision of the unknown framework. The framework may be determined empirically and the best results showing arrangement be selected. The ideal neuron number of the unknown layer was recursively determined by developing a number of RNNs that differ with the size of the unknown layer (the tested neurons were three to nine). The statistical parameters namely mean square of error (MSE) and coefficient of determination were utilized as the measures for the choice of best RNN architecture. It was carried out by training and testing the data. From the unknown layer seven neurons were considered to be best framework. The testing was selected to be an activation function for each neuron. The RNN was trained recursively by using repetitive representative pairs of vector exemplar input/output. The weights of the neural connections were primarily selected at random and are adjusted by a non-linear optimization technique. In order to minimize the cost function equal to the mean square of the output error, the quasi-Newtonian formula (Shanno, 1970) was used. To adjust the weights the learning base was used, to allow over-learning during weight optimization the testing base was used and for the confirmation of the output, the validation base was used. Of the total experiments, a minimum of 60% of experiments comprises of the learning and testing bases and 40% in the validation base. MATLAB software and the Optimization Toolbox (Mathworks) were used for developing the recurrent network software. This software includes all the pre-requisite parameters such as pre-initialization of the information (data), the instruction of the recurrent network and the perception of the result.

RESULTS AND DISCUSSION

Effect of maturity stages on the physical properties of wood apple

The physical properties of wood apple were measured with standard procedures. All the literature that referred to the physical properties of wood apple was found to be not similar. A lot of variations were observed in shape and size, diameter, bulk, and true density. The data obtained by Sonawane *et al*. (2020) was different from the data obtained by Murakonda *et al*. (2021). The data of the physical properties like weight, diameter, sphericity, true and bulk density are shown in Table 1. At the early stage of fruit development, the weight was found to be 252.786 $\pm$ 17.431g. The arithmetic mean diameter was found to be 7.944$\pm$ 0.199 cm. The bulk and true densities were observed to be 0.447$\pm$ 0.018 and 1.029$\pm$ 0.158 g/cm^3 respectively. The wood apple grew up gradually and comparatively at a slow rate, unlike any other climacteric fruit. At the fully matured stage, the fruit became plumpy and changes occurred in all the physical properties. During that stage, weight increased up to 473.506$\pm$ 18.828 g, whereas arithmetic mean diameter was observed to be 9.505$\pm$ 0.212 cm. The changes were observed for the sphericity, bulk, and true densities of the wood apple also. During the ripening stage, no such changes were observed in case of physical properties excluding weight. Increased weight may be due to the development of high moisture content (77.02 g per 100 g of pulp according to Devi and Kulkarni, (2018)). During ripening stage, the weight was found to be 520.118$\pm$ 15.578 g, whereas arithmetic mean diameter was 9.621$\pm$ 0.223 cm. Sphericity, bulk and true densities were found to be 20.334$\pm$ 0.508,

Table 1 : Change of physical properties in wood apple during different stages of maturity

Stages	Variables	Weight (g)	Arithmetic mean diameter (cm)	Sphericity	Bulk density (g/cm^3)	True density (g/cm^3)
Early Stage	Mean	252.786	7.994	15.781	0.447	1.029
	Min.	192.460	7.426	14.155	0.414	0.876
	Max.	288.240	8.613	17.731	0.481	1.422
	Var.	303.871	0.039	0.393	0.0003	0.025
	SD	17.431	0.199	0.627	0.018	0.158
Fully Matured Stage	Mean	473.506	9.505	19.974	0.880	1.932
	Min.	441.530	8.990	18.678	0.759	0.987
	Max.	546.970	10.110	21.681	0.988	2.506
	Var.	354.499	0.045	0.290	0.006	0.164
	SD	18.828	0.212	0.539	0.080	0.405
Ripe stage	Mean	520.118	9.621	20.334	0.943	2.230
	Min.	493.060	9.313	19.501	0.853	0.984
	Max.	568.260	10.503	22.307	1.121	2.984
	Var.	242.676	0.050	0.258	0.007	0.392
	SD	15.578	0.223	0.508	0.083	0.626

0.943± 0.083 and 2.230± 0.626 g/cm^3 respectively. The variation in the physical property data of the wood apple might be due to collection of the fruit samples from different climacteric zones, soil condition and variety.

Effect of maturity stages on the biochemical properties of wood apple

The changes in the biochemical properties of wood apples during different maturity stages are represented in Table 2. The wood apple pulp was slightly acidic in nature at the initial stage. As the fruit gradually matured, an increasing trend was observed in the pH values. At the early stage, it was found to be 3.55± 0.02, whereas during the matured stage it increased up to 4± 0.02. During the final ripened stage, the pH was found to be 5.24± 0.04 which was almost similar to any other such fruit. This result implies that there is more concentration of hydrogen ions at the initial stage and more hydroxyl ions at the ripened stage. Further, variation in the TSS in terms of °Brix values was also observed along with the changes in wood apple maturity. At the early stage of wood apple maturity, the TSS was found to be 15.8± 0.14° Brix. During the maturation period it was 16.90± 0.26° Brix followed by the ripening stage, the value was elevated to 18.22± 0.29° Brix. This sudden elevation in the °Brix value indicates that sugar content increased considerably during the ripening. Total acid concentration which generally measures the titratable acidity of any fruit was found at a high percentage during the initial stage and declination was observed during further stages. The ratio of TSS and TA also provides the characteristic flavor and texture of the fruit. Sometimes this ratio is also considered as the indicator for the harvesting period of the fruit. In case of wood apple, TSS/TA ratio followed a rising trend with the increase of maturity stages. At initial stage the ratio was found to be 3.80± 0.54 and further increased from 9.66± 0.26 to 14.07± 0.29 during matured to ripened stages. Hence, the bio-chemical properties of the wood apple changed with the advancement of maturity stages and ripening. From these properties it could be also observed that pH had positive impact on °Brix and negative impact on the titratable acidity, indicating formation of ethylene and ultimate ripening of the fruit. Hence, the ethylene helped wood apple to develop its sweetness and musky flavor with the advancement of maturity stages.

Color based mapping of maturity kinetics

Collection of color properties at various stages

The colour properties of the wood apple pulp and shell with respect to different maturity stages were evaluated based on the 'L*','a*','b*' values. Table 3 represents the color properties of the wood apple. With the advancement of maturity, increasing trend was observed in terms of all the color values. The L* value was found to be 59± 4.72, 61± 2.12 and 72± 1.92 at early, matured and ripened stages respectively, whereas a* followed the trend -15± 0.02, 0.52± 0.02 and 50.92 during these stages. Similarly, the b* value was found to be 39± 3.92, 41± 2.09 and 50± 1.09 at these three stages respectively. The changes in the colour values could be observed based on the pigment of the fruit. Fig. 2 demonstrates the classification of wood apple maturity based on changing colour properties. At early stage there might be more

Table 2 : Changes of bio-chemical properties of different stages of maturity in wood apple

Properties	Early stage	Matured stage	Ripened stage
pH	3.55+0.02	4.00+0.02	5.24+0.04
TSS (°Brix)	15.8+0.14	16.90+0.26	18.22+0.29
Titratable acidity (%)	4.16 +0.28	1.75 +0.01	1.29 +0.01
TSS/TA ratio	3.80+0.54	9.66+0.26	14.07+0.29

Table 3 : Color properties at various stages of wood apple

Colour properties	Early stage	Matured stage	Ripened stage
L* value	59+4.724	61+2.12	72+1.92
a* value	-15+0.002	0.52+0.02	5+0.92
b* value	39+3.92	41+2.09	50+1.09

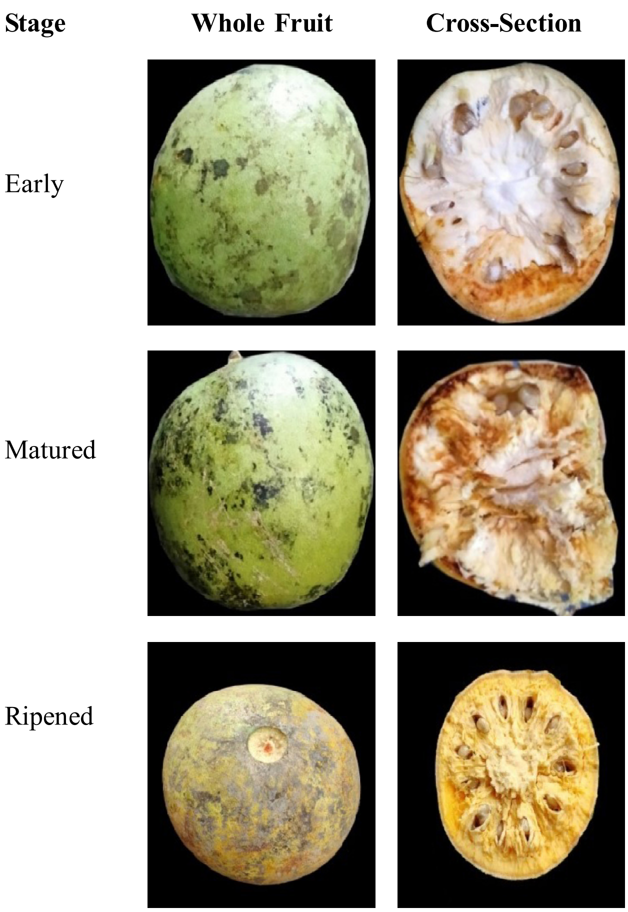

Fig. 2 : Pictorial representation for different stages of wood apple

deposition of chlorophyll pigments that reduced gradually with the advancement of maturity stages and resulted in the formation of carotenoids. During the matured stage, the carotenoids dominated chlorophyll pigments, bringing about the change of fruit colour to red-yellow.

Classification maturity kinetics by k-means cluster algorithm

For the classification of maturity stages of wood apple k- means cluster algorithm was used. Data of six physio-chemical properties namely bulk density (g/cm³), true density (g/cm³), pH, TSS (°Brix), titratable acidity (%) and TSS/TA ratio were considered along with the variation of redness value (a* value). From Fig. 3, classification of maturity stages based on k-means cluster algorithm can be observed. Three major stages *viz*., early stage, matured stage and fully ripened stage can be classified for recognizing ripening of wood apple. By considering these three stages, variation in other properties was discussed.

Application of RNN for the mapping of maturity kinetics

Fruit maturity properties determination based on color features is a challenging aspect to keep up the quality

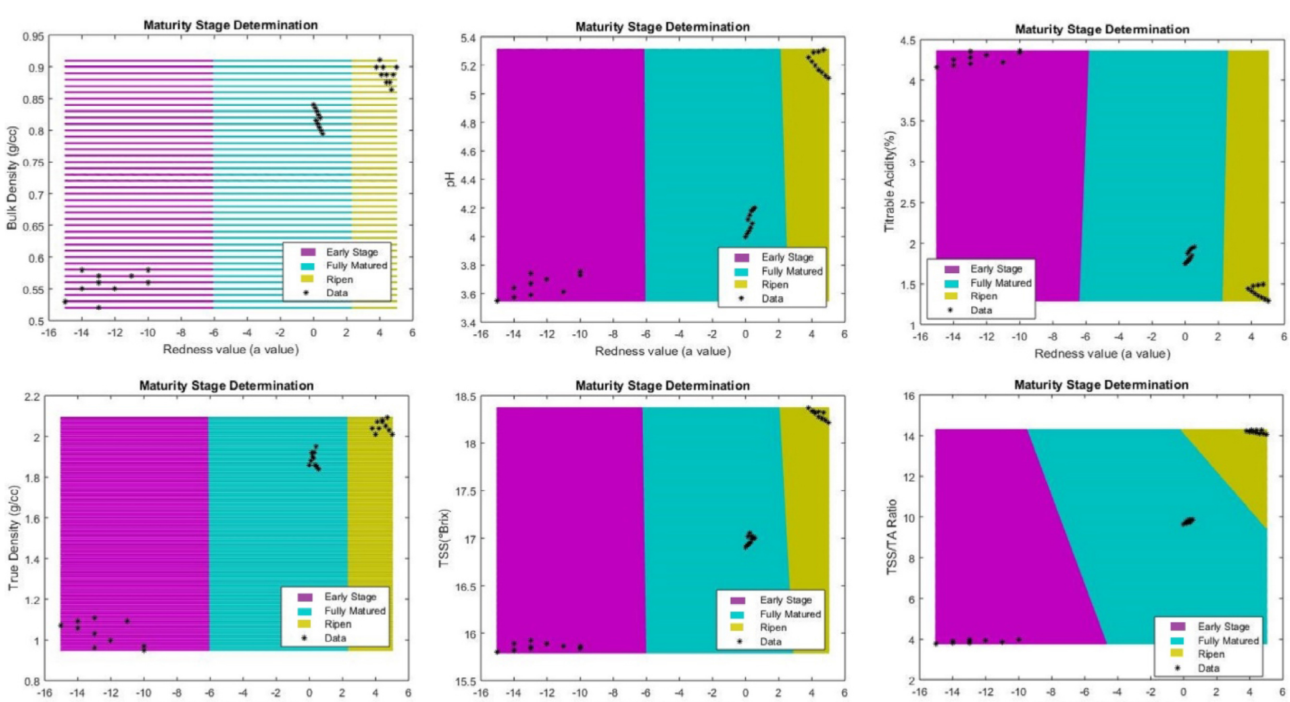

Fig. 3 : Classification of maturity stages by using k-means cluster algorithm

of the product during processing. To accomplish this particular task, a mathematical based relationship is made between the color features and maturity properties which are always highly reliable. Maturity kinetics of various fruits and vegetables based on colour parameters are reported by various researchers. ANN modeling can successfully draw a best relationship between colour properties and quality attributes of plucking time of fruit (Gupta *et al*., 2020). The evaluation of changes of colour of fruit throughout the maturity can be differentiated by color scales with the help of multi-dimensional regression based on Support Vector Regression (SVR) (Avila *et al*., 2015). In this study, RNN modeling was applied for the mapping of colour parameters and various maturity indices of wood apple.

Fig. 2 illustrates the sections for different stages of wood apple color properties. Fig. 4 shows different combination of RNN architectures with hidden layer neurons varying from 2 and 7. Selection of best RNN architecture on the basis MSE is illustrated in Fig. 5. The weight and bias values for the best RNN architecture is represented in Table 4. This can be used for further simulations of color-based quality indices and sensitivity analysis.

Color chart for wood apple

A color chart was developed for figuring out the distinctive maturity stages of wood apple. Fig. 6 illustrates the color chart of the wood apple. This chart will be beneficial to perceive different maturity stages of the fruit. pBy spotting the proper maturity levels, probable properties or quality of the fruit also can be predicted. This can be in the long run beneficial to govern required satisfactory of the product during processing. Hence, incorporation of the color chart as

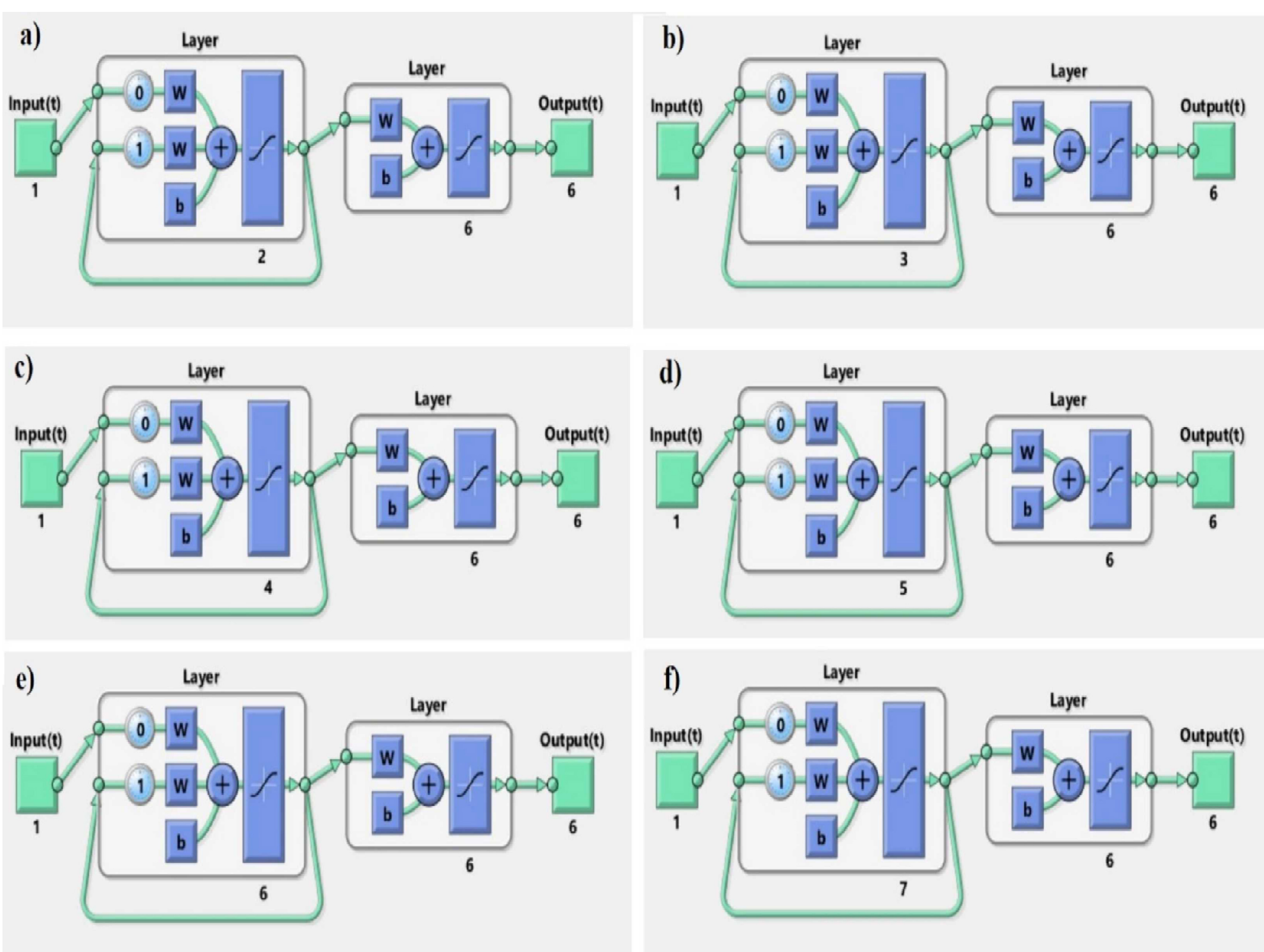

Fig. 4 : RNN modeling for the mapping of maturity kinetics total calculation time during run-time phase. The best network was selected based on the highest R^2 (0.99) and lowest MSE values.

Table 4 : Weight and bias values of best RNN architecture

IW{1,1}	-0.0378	LW{1,1}	-0.970	0.673	0.973	0.881	0.009	-0.389
	-1.453		0.383	-0.547	-0.873	-0.622	-0.336	0.709
	-1.367		-0.492	-0.208	-0.770	-0.883	0.847	0.411
	-1.343		-0.723	-0.191	-0.237	0.955	0.553	0.939
	0.757		0.241	0.190	0.867	0.794	-0.829	-0.601
	-0.914		0.587	0.643	-0.379	0.329	-1.066	0.278
LW{2,1}	-0.672	-1.041	-0.624	-0.977	0.302	1.208	B(1)	-1.847
	-0.60309	-1.078	-1.079	-0.963	-0.463	0.032		0.892
	0.93018	-0.14786	-1.318	-0.993	0.833	-0.428		0.919
	0.67438	-0.868	-0.969	-1.012	0.255	-0.502		0.455
	-0.1785	0.932	-0.184	1.5948	0.50812	-0.436		1.006
	-1.3929	-0.710	-1.414	-0.981	0.81681	0.498		-1.883
B(2)	1.582							
	0.838							
	-0.534							
	-0.089;							
	-1.457							
	-1.291							

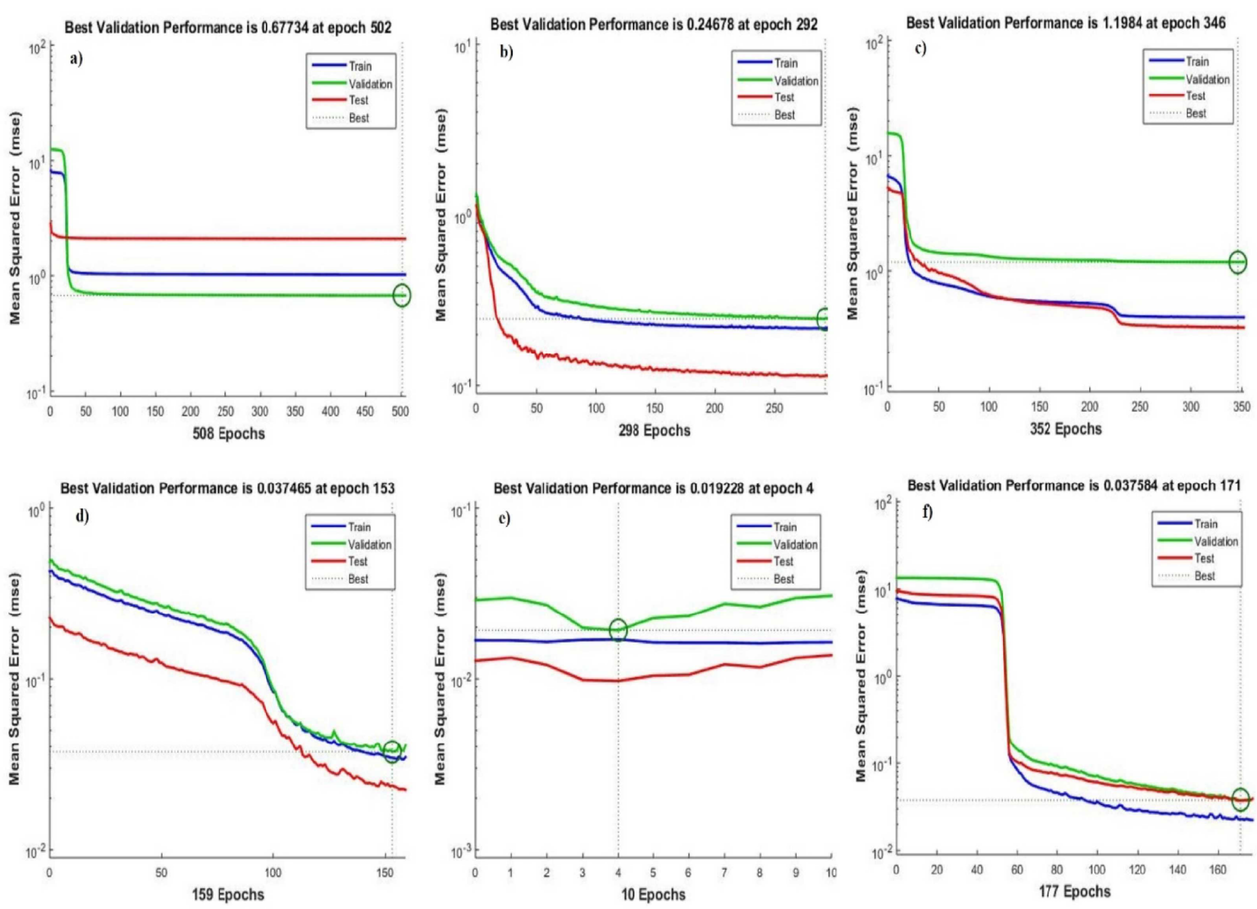

Fig. 5 : Selection of best architecture for RNN model

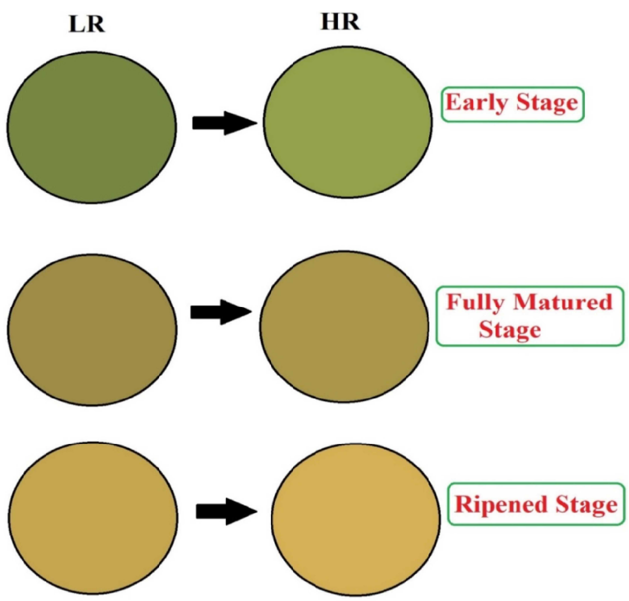

Fig. 6 : Color chart for identifying maturity stages of wood apple

reference handout, will exceptionally help farmers as an outcome of this unique investigation.

CONCLUSION

In this study, the effect of maturity stages on colour, physical and bio-chemical properties of the wood apple were investigated. An attempt was made to differentiate the changes in the properties with respect to three different stages of the wood apple *viz.* early, matured and ripe. A systematic trend was observed for all the properties namely sphericity, bulk density (g/cm^3), true density (g/cm^3), pH, TSS (°Brix), titratable acidity (%) and TSS/TA ratio, *etc.* of the fruit. In contrast, regular changes were also observed in the color properties at various maturity of the wood apple. The maturity kinetics was formulated by applying recurrent neural network (RNN) in compliance with K means cluster algorithm. RNN modeling was applied by considering color property (redness value) as input and six maturity indices as the output of the formulated structure. The RNN architecture, 1-6-6 showed the best results for forecasting the wood apple maturity based on color features. Further, based on the results of the K means cluster algorithm, the maturity stages were classified into three main categories. A color chart was also developed for figuring out distinctive maturity stages of wood apple. This chart can be utilized as a reference handout by the farmers for the maturity detection of the wood apple.

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