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Inter-relationship between the physical parameters of Kinnow mandarin (*Citrus reticulata* L.) fruit via curve fitting and regression analysis

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Abstract
India is the world's fifth largest grower of citrus fruits. Kinnow mandarin agriculture accounts for over half of all citrus growing regions. In this study, physical properties of 140 different fruit samples were measured, including fruit diameter, width, height, and weight. The experimental data were fitted using curve fitting tool in the software, and the model were explained using correlation methods i.e. Pearson correlation (PC), Spearman's rho (SR), and Kendall's tau (KT). Fruit diameter found positively correlated with the fruit width (0.989), fruit height (0.908) and weight (0.957) of the fruit as per PC and SR method, whereas found to be in increasing order from fruit height (0.734) to weight (0.848) and finally to fruit width (0.913) with KT method. Regression equations formed with R^2 value of 0.9771, 0.9219 and 0.8247. The models formed will be useful in various post-harvest operations i.e. sorting, packaging and transportation of the fruit.

Keywords: Fruit diameter, fruit height, fruit weight, fruit width, kinnow mandarin

1. Introduction

Mandarin citrus fruits are India's leading citrus fruit, both relished and grown. Approximately half of the entire citrus producing regions are devoted to cultivation. Kinnow mandarin (Citrus reticulata Blanco), a hybrids cultivar of (King X Willow leaf), is produced mostly in northern India and is renowned for its golden-orange color, high juice content, pleasant perfume, and flavor. Citrus farming is a lucrative business that contributes significantly to the economies of nations such as the United States, China, Brazil, Mexico, Iran, Spain, India and Greece. India is the ranked as the fifth greatest producer of citrus, including mandarins, lemons, oranges, grapefruit, lime, tangerines, and other varieties. Citrus fruits occupy 10% of the total land area across fruit crops grown, and their output ranks third after mango and banana. In India, 4.75 million tonnes of oranges, comprising mandarin and kinnow, were produced on 0.43 million hectares of land (Mahawar *et al*. 2019) [6].

External characteristics such as skin colour, texture, and thickness, as well as morphological and biological characteristics of interior characteristics such as seediness, fresh juice and ascorbic Acid content, TSS, TA, and TSS: TA ratio, may all be used to determine the quality of citrus fruit. Cultural practises like as pruning, watering, fertilisation, and plant control measures all have an impact on fruit quality. Immature 'Kinnow' mandarin trees are known to yield fruit with a coarse skin and little juice concentration, and exporters are wary of accepting fruit from young plantations (Khalid *et al*. 2012 [5]; Ghanghas *et al*. 2022) [2]. Fruits differ significantly in diameter, mass, and juice content depending on altitude; fruits at higher elevations are often considerably smaller have a more acidic flavour. The length of fruit growth as well as the brightness of skin coloration in mandarins were affected by altitude. The level of development had a substantial impact on physiologic weight reduction and juice content, according to the researchers (Rokaya *et al.* 2016) [11]. In compared to those other subtropical and tropical fruits, citrus fruits have quite a greater post-harvest life. Citrus fruits must be stored properly for a lengthy amount of time in order to be used properly during surplus season. Kinnow is recognized for its qualitative features, notably its acidic flavour, both freshly and in packaged form. It really is produced into beverages by the industries and fruit merchants during its prime growth season in the winter (Rafiq *et al*. 2018) [9]. Lack of suitable marketing and poor post-harvest management practises are the most serious post-harvest issues with this fruit. Kinnow, unlike all the other citrus, has poor storage characteristics and cannot be carried in sacks.

Simultaneously and continuous output from several orchards frequently resulted in large truckloads, with excellent quality fruit going for fresh consumption and low-grade fruits being discarded. Early fruit drop and a lack of an on-processing plants in the producing catchments add to the already high levels of fruit waste. Farmers are particularly concerned about the predicted pre-harvest loss of 10–20 percent owing to deterioration and insect rearing grounds. Even as demand for and intake of kinnow rises, the amount of trash produced grows in full agreement, causing environmental problems (Mahawar *et al*. 2020) [7].

Fruits has a curved growth pattern that occurs at different stages of fruit development. After the formation of inflorescences, the fruits cell - cycle phase starts, accompanied by the cell expansion phase, that lasts until color-break. Its phase iii of citrus development is maturation, which begins with colour break and continues till it fruit is fully grown. Citrus fruit diameter and morphology indices are quality indicators obtained during the cell expansion period. Fruit volume influences fruit relative density, which is largely boosted throughout fruit stages of growth I and II, in adding to being utilised as a ripeness and quality indicator (Nawaz *et al*. 2020) [8]. Vegetable and fruits grading is a key part of effective marketing. To get a decent price, agricultural produce is usually separated into distinct grades and appealing shapes. Appearance, shape, and coloration are used to classify vegetables and fruit (Ramjan and Ansari, 2018) [10]. The inter-relation between the physical parameters of the fruit is more important than only measuring them. Correlation between the physical attributes i.e. Fruit diameter, fruit width, fruit height and fruit weight will provide the necessary size and shape features which can be used to calculate and interpolate the maturity of the fruit, mechanical damage predictions, to select right packaging practice for fruit transportation and many other aspects of food processing and post-harvest unit operations. The research was conducted to analye the inter-relationship between the physical propertied of the Kinnow mandarin fruit with the objective to measure the fruit physical properties and fitting of raw data to establish the modelling between the parameters using MATLAB and IBM SPSS software.

2. Material and Methodology

Freshly harvested kinnow mandarins were procured from fruit market in Hisar, Haryana, India (29° 9' 45.80 N", 75° 44' 18.57186 E"). According on a literature research and subsequent study of data sets, 140 samples of kinnow fruit from every ungraded and graded batch were obtained for examination of physical aspects. According to the Directorate of Marketing and Inspection (DMI), Government of India, the non - graded fruit lot was selected randomly, and three unique classes were formed based on the fruit diameter (Mahawar *et al*.2019) [6].

2.1 Determination of physical characteristics

Physical parameters of 140 healthy randomly selected fruits from every grade were studied, including axial dimensions and weight. An electronic balance (Metler Toledo make with the least count of 0.001 g) was used to determine the mass of every fruit (M). As indicated in Figure 1, the three axial dimensions of the kinnow fruit i.e. diameter, width and fruit height were measured using an electronic Vernier calliper (Mitutoyo, Japan, L.C of 0.01 mm) (Shahbazi and Rahmati, 2014) [13]. The weight of the kinnow was calculated through the use of an electronic weighing balance with a sensitivity of 0.001 g.

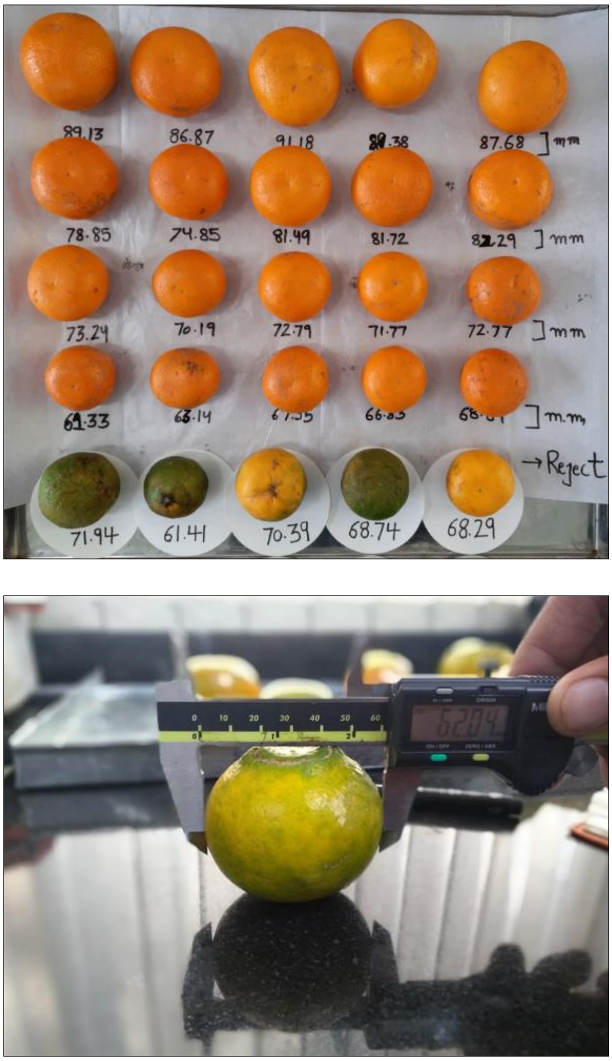


Fig 1: Kinnow mandarin fruit samples and dimension measurement via Vernier calliper

2.2 Model development and curve fitting

In all experimental cases, the results which were obtained from experiments were fitted to Linear, Quadratic models. Curve fitting parameter i.e. fruit width, fruit weight and fruit height have its relationship with fruit weight. For regression equations in general, the nearer R^2 is to 1.00, the better the fit. MATLAB 2019a (Trail version) software was used to analyze the data and determine regression models between the physical characteristics.

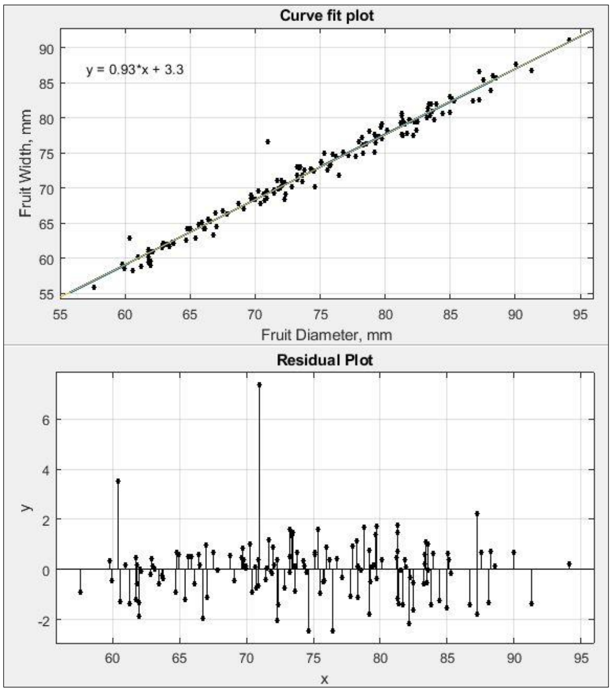
2.3 Correlation between the parameters

Experimental samples data was statistically analysed and parameters were correlated using bivariate analysis i.e. Pearson correlation, Kendall's tau and Spearman's rho method. The data on different parameters were analysed by using analysis of variance (ANOVA) by using SPSS software. Valid conclusions were drawn only on significant differences between the treatment mean at 0.05 level of probability.

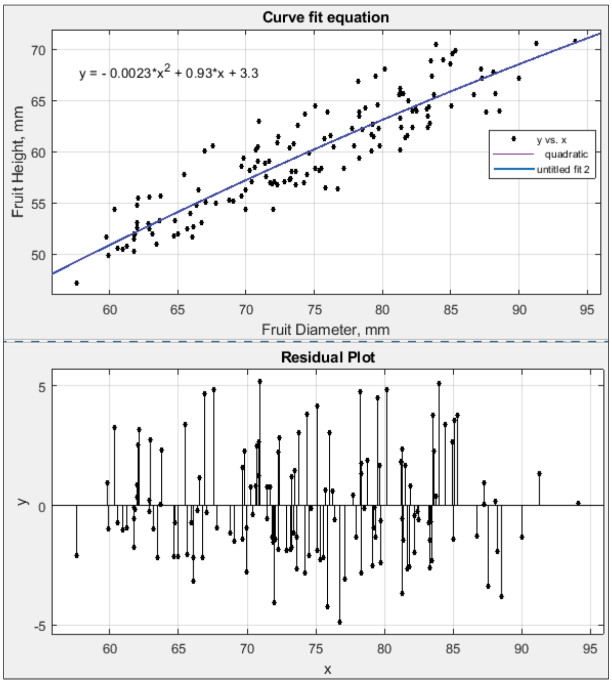
3. Results and Discussion

Curve fitting analysis of the measured data of 140 fruit samples i.e. Fruit diameter (mm) with fruit width (mm), fruit height (mm) and fruit weight (g) was studied and experimental data was fitted, a curve regression equation was set up. The equation established from the experiments of the two parameters was found y=0.93x+3.256 (Linear equation) for fruit diameter versus fruit width; $y=-0.0023x^2+0.93x+3.3$ (Quadratic equation) for fruit diameter versus fruit height; $y=0.0487x^2-2x+53$ (Quadratic equation) for fruit diameter versus fruit weight and the coefficient of determination value (R^2) of the fitting coefficients were 0.9773, 0.8247 and 0.9230, respectively. The varying range of the physical parameters are found as 57.58 to 94.13 mm for fruit diameter, 55.9 to 91.04 mm for fruit width, 47.23 to 70.73 mm for fruit height and 77.73 to 269.76 g for fruit weight.

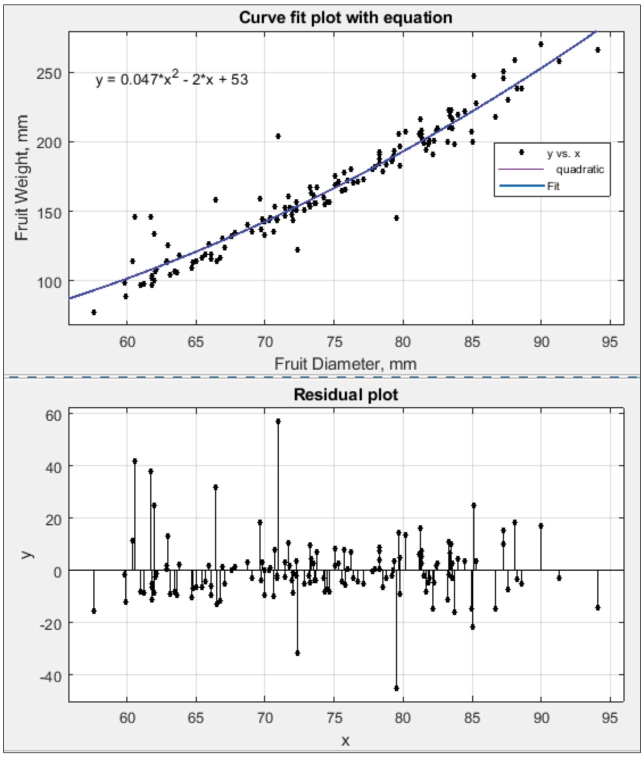
The parameters were determined approximately by having a relationship between the fruit diameter to the fruit width, height and weight. There was a clear relation between the fruit diameter and fruit width as well as the fruit weight with highest R^2 (0.9771) with width, R^2 value (0.9219) with fruit weight and R^2 value (0.8247) for fruit height. The linear model was the best fit for the fruit width parameter with the lower value of RMSE 1.178 and the quadratic models were fitted for the fruit weight (RMSE: 12.01) and fruit height (RMSE: 2.272) as presented in the Table 2, respectively. As shown in Fig. 2, the fruit height was not ideally predicted the fruit diameter, however the outcome was found satisfactory. This implies that the diameter of the fruit supposed to be well predict the fruit width and fruit weight whereas, it struggles a little to fit the experimental data of fruit height with the fruit diameter (Adelkhani *et al*. 2012 [1]; Sa'adah *et al*. 2022) [12].



(a)



(b)



(c)

Fig 2: Curve fit plot and residual plot for the inter-relation between the fruit physical parameters with fitted equation

Table 1 shows the results of correlation research findings among *Citrus reticulata* L. physical parameters. Correlation coefficients between different fruit features and fruit diameter would clearly provide an idea, which could be used to select favourable parameters for appropriate harvesting process. The extremely substantial positive association among acceptable parameters is beneficial since it may aid in the enhancement of both parameters at the same time. The negative correlation, on the contrary side, would prevent the phase will involve of both traits.

Table 1: Correlation table among the physical parameters with different methods of bivariate analysis

		Fruit Diameter (mm)	**Fruit Width (mm)**	**Fruit Height (mm)**	**Weight (g)**
Pearson's Correlation	**Fruit Diameter (mm)**	1	0.989**	0.908**	0.957**
	Fruit Width (mm)		1	0.910**	0.961**
	Fruit Height (mm)			1	0.894**
	Weight (g)				1
		Fruit Diameter (mm)	**Fruit Width (mm)**	**Fruit Height (mm)**	**Weight (g)**
Kendall's tau_b	**Fruit Diameter (mm)**	1	0.913**	0.734**	0.848**
	Fruit Width (mm)		1	0.735**	0.860**
	Fruit Height (mm)			1	0.729**
	Weight (g)				1
		Fruit Diameter (mm)	**Fruit Width (mm)**	**Fruit Height (mm)**	**Weight (g)**
Spearman's rho	**Fruit Diameter (mm)**	1	0.987**	0.909**	0.956**
	Fruit Width (mm)		1	0.912**	0.965**
	Fruit Height (mm)			1	0.896**
	Weight (g)				1

** Correlation is significant at the 0.01 level (2-tailed).

Pearson correlation (PC) and Spearman's rho (SR) method gives almost the similar correlation values between the physical attributes, whereas Kendall's tau (KT) method predicts a significant variation in correlation among the parameters. Fruit diameter has a highly positive correlation with the fruit width (0.989), fruit height (0.908) and weight (0.957) of the fruit as per PC and SR method, whereas found to be in increasing order from fruit height (0.734) to weight (0.848) and finally to fruit width (0.913) with KT method.

Correlation among the other physical attributes was also found highly positive with PC and SR method i.e. fruit width with height (0.912) and weight (0.965) and was found in increasing order i.e. greater in fruit weight (0.860) comparative to the fruit height (0.735) in KT method. Lastly, the correlation between the fruit height and weight was found 0.894 for PC and SR, and 0.729 for KT bivariate analysis. It can be inferred from the abovesaid correlation table that fruit diameter is highly correlated with its width and weight comparatively to the fruit height due to the enormous lateral cell growth and the contribution of TSS and juice % in fruit weight. While, fruit height has a very little correlation with all other parameters which may be due to less contribution of longitudinal cell growth during the ripening cycle of the fruit (Kashyap *et al*. 2020 [4]; Gupta *et al*. 2021) [3].

Table 2: ANOVA table for the inter-relation between the physical parameters of Kinnow mandarin fruit

Fruit Diameter (mm) v/s Fruit Width (mm)					
	Sum of Squares	**DF**	**Mean Square**	**F value**	**P value**
Regression	8239.369	1.000	8239.369	5935.481	0.000
Residual	191.565	138.000	1.388		
Total	8430.934	139.000			
Fruit Diameter (mm) v/s Fruit Height (mm)					
	Sum of Squares	**DF**	**Mean Square**	**F value**	**P value**
Regression	3326.465	2.000	1663.233	322.337	0.000
Residual	706.910	137.000	5.160		
Total	4033.375	139.000			
Fruit Diameter (mm) v/s Fruit Weight(g)					
	Sum of Squares	**DF**	**Mean Square**	**F value**	**P value**
Regression	236750.538	2.000	118375.269	821.221	0.000
Residual	19747.930	137.000	144.145		
Total	256498.468	139.000			

5. Conclusion

The present research was conducted to determine and analyse the relation between the physical features (fruit diameter, fruit width, fruit height, and fruit weight) and was determined non-destructively using a Vernier calliper and a weighing balance. The curve fitting and prediction brought the higher correlations between fruit diameter and width, then fruit diameter with weight, followed by fruit height. Out of these factors, the information collected might be used to infer the post-harvest unit operation, such as sorting, packing, and transportation. The correlation among physical properties predicted by models might lead to material cost savings in mechanical packing and the development of Kinnow mandarin sorting machines. More feature studies, on the other hand, will be required for further exploration.

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