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Mass modeling of kinnow mandarin based on some physical attributes

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Abstract

The correlation between the physical properties of fruits such as their dimensions, projected areas, volume, and mass may assist in predicting fruit quality along with the development of post-harvest machinery. Thus, the present study aims to predict the mass of kinnow mandarin (*Citrus reticulata* L.) fruit as a function of its axial dimensions, projected areas, and volume using linear and nonlinear mathematical models (quadratic, power, and s-curve). Further, the mass models were presented under three different classifications: dimension based, projected area based, and volume based. The effect of size grading was also evaluated and compared with the data of ungraded fruits. Results showed that mass modeling based on dimensions and volume of ungraded fruits was more appropriate compared to individual grades. The quadratic model based on geometric mean diameter (R^2 = 0.956) and ellipsoid volume (R^2 = 0.955) are recommended for predicting the mass of ungraded fruits with maximal accuracy.

Practical application

Mass based fruit grading is one of the important aspects of packaging as it not only reduces the wastage of handling and transportation resources by optimizing packaging formations but also enhances the marketability of commodity. Consumers generally prefer the fruits of uniform size, weight, and shape. Grading of horticultural produce is usually based on its appearance, size, and weight. The automatic fruit grading techniques generally use mass as a grading parameter due to its accuracy and effectiveness of the operation. The available kinnow grading systems primarily grade the fruits based on their dimensional attributes. Hence, the study was aimed at mass modeling of kinnow mandarin based on the selected engineering attributes such that results might be helpful to develop an accurate automatic grading system for grading based on the combined approach of size and mass. This study provides information about relationships between fruit mass and axial dimensions, projected areas, and volume, which are useful for the development of mass, and size based kinnow grading systems.

1 | INTRODUCTION

Kinnow comes in *"Mandarin"* group of citrus fruits, which is produced prominently in India and Pakistan. The fruit was initially developed at University of California Citrus Experiment Station in 1935 (Rashid, Khan, Fatima, Abbas, & Adnan, 2005) and was introduced in India during early 1940s (Singh, Gupta, & Chundawat, 1978). Kinnow is a hybrid of two citrus cultivars namely "King" (*Citrus nobilis*) and "Willow Leaf" mandarin (*Citrus deliciosa*) (Sharma, Kalra, Oberoi, & Bansal, 2007). In India, the production of orange group including mandarin and kinnow was about 4.75 million tonnes that has been obtained from an area of 0.43 million hectares (Anonymous, 2018).

Physical properties of agricultural products are essential for design of sorting and grading equipments, materials handling systems, and also for various processing and packaging machineries. Grading is one of the important unit operation which is generally performed on the basis of color, size, shape, appearance, mass, and textural attributes of an agricultural commodity. Grading operations help in obtaining the material having uniform geometrical attributes, which can minimize the expenses related to packaging, and transportation such that an optimum packaging configuration can be achieved (Sadrnia, Rajabipour, Jafary, Javadi, & Mostofi, 2007). Fruit size, being an imperative quality characteristic, has a major role in deciding consumer preference as the fruits with uniform profile (shape and weight) are preferred by the consumers (Khoshnam, Tabatabaeefar, Varnamkhasti, & Borghei, 2007; Rashidi & Gholami, 2008). However, grading becomes complicated when the fruits are similar in appearance but different in mass; thus, mass grading plays an important role in designing advanced machinery. In the past, various effective and accurate grading systems are developed based on recent advancement in automated sorting strategies; thus, eliminating human interference (Kleynen, Leemans, & Destain, 2003). Lorestani, Jaliliantabar, and Gholami (2012) also highlighted the importance of the grading by fruit mass as it was more economical than the grading based on fruit size. Grading based on the fruit mass can be accomplished by either direct weighing which is time-consuming or by applying appropriate models based on other fruit characteristics. Therefore, understanding the potential relationships between mass and physical properties of fruits may lead to a fast, accurate, economical sizing, and grading system (Seyedabadi, Khojastehpour, Sadrnia, & Saiedirad, 2011).

Numerous studies are reported in the literature for predicting fruit mass based on their physical properties. Tabatabaeefar, Vefagh-Nematolahee, and Rajabipour (2000) suggested 11 models for mass predication of orange fruits. Al-Maiman and Ahmad (2002) and Khoshnam et al. (2007) studied the physical properties of pomegranate and suggested optimal mass model(s) for envisaging fruit mass while employing dimensions, volume, and surface areas. Similarly, mass models for Iranian kiwi fruit based on the fruit dimensions, volumes, and projected areas were determined by Lorestani and Tabatabaeefar (2006). Khanali, Ghasemi Varnamkhasti, Tabatabaeefar, and Mobli (2007) predicted mass models for tangerine fruit, Naderi-Boldaji, Fattahi, Ghasemi-Varnamkhasti, Tabatabaeefar, and Jannatizadeh (2008) for apricot fruit and, Shahbazi and Rahmati (2014) for persimmon fruit. Apart from the model selection, sample size is also one of the important criterions in mass modeling study. For mass modeling, Khoshnam et al. (2007) in their study used 54–81 pomegranate fruits, and Vivek, Mishra, and Pradhan (2018) used around 70 *Sohiong* fruits and recommended the suitable models for the development of grading systems. As per the knowledge, no detailed study concerning mass modeling of kinnow fruit has been reported in the literature. Hence, this particular study was envisaged with the objective to determine appropriate mass model(s) for kinnow based on its physical attributes. The findings of this study may help in developing the grading systems based on the quality of kinnow fruit.

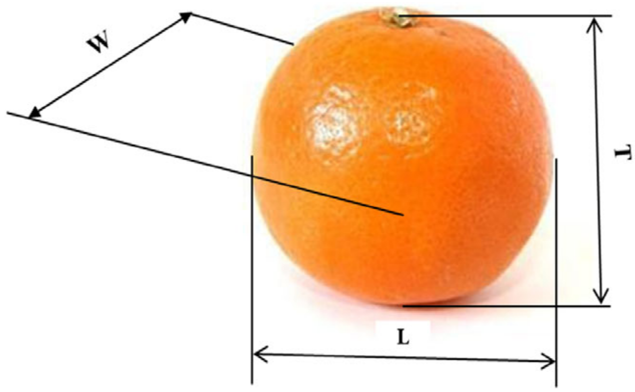

FIGURE 1 Pictorial view of kinnow fruit representing its three major dimensions: Length (l), width (w), and thickness (t)

2 | MATERIALS AND METHODS

2.1 | Material selection

Freshly harvested kinnow mandarins were procured from an orchard of Abohar, Punjab, India. Based on the literature review and preliminary analysis of selective sample sizes, 60 representative kinnow fruits from each graded and ungraded lots were taken for observation of its physical attributes. The randomly selected fruit lot was considered as ungraded fruits and based on the fruit diameter three different grades were obtained as suggested by Directorate of Marketing and Inspection (DMI), Government of India (Dhatt & Mahajan, 2007). The mass modeling was done on ungraded and graded fruit lots separately to evaluate the effect of grading on mass prediction from each standard grade and ungraded fruits, respectively.

2.2 | Determination of physical characteristics

Physical properties, viz., axial dimensions, weight, volume, and projected area of 60 sound randomly selected fruits from each grade were observed. Mass of each fruit (M) was measured by employing a digital balance (Metler Toledo; the least count ±0.001 g). The three axial dimensions namely length (L), width (W), and thickness (T) were recorded using a digital vernier caliper (Mitutoyo, Japan, ±0.01 mm) as shown in Figure 1. The volume of an individual fruit (V) was measured using water displacement method (Shahbazi & Rahmati, 2014). The geometric mean diameter (Dg), of the samples was determined using the formulae suggested by Mohsenin (1986) as shown in Equations (1–2).

$$Dg = (L \times W \times T)^{1/3} \tag{1}$$

$$Da = \frac{L + W + T}{3} \tag{2}$$

Projected area of an individual fruit serves as a good indicator of mass (Momin et al., 2017). The information on projected areas may result in designing of grading units as well as indicating the accurate

TABLE 1 Selected mathematical models along with their equation

Model	Equation
Linear	M = a + bX
Quadratic	$M = a + bX + cX^2$
S-curve	M = a + (b/X)
Power	$M = aX^b$

Note: Where, "M" is mass (g), "X" is the average value of the physical parameter considered for predicting its relationship with mass, and a, b, c, and d are curve-fitting constants.

modeling of heat and mass transfer analysis during the drying and cooling unit operations (Pathak, Pradhan, & Mishra, 2019). Fruit projected areas perpendicular to dimensions (PA_1, PA_2, and PA_3) were measured using graphical projections by projecting the shape on to an arbitrary plane. Thereafter, the criteria projected area (*CPA*) was calculated using Equation (3) (Mohsenin, 1986):

$$CPA = \frac{PA_1 + PA_2 + PA_3}{3} \qquad (3)$$

Where, PA_1 = projected area perpendicular to the length (mm^2), PA_2 = projected area perpendicular to the width (mm^2), and PA_3 = projected area perpendicular to the thickness (mm^2). Further, PA_1, PA_2, PA_3 are also called as first, second, and third projected areas, respectively.

2.3 | Mass modeling

Regression models including linear, quadratic, S-curve, and power models were utilized for mass predication of graded and ungraded kinnow fruits (Shahbazi & Rahmati, 2013; Shahbazi & Rahmati, 2014; Vivek et al., 2018) with their respective model equations as deliberated in Table 1. The physical properties of kinnow mandarin were measured and the data was fitted in the four models, the most suitable model was considered for mass prediction (Khodabakhshian Kargar & Emadi, 2016; Pathak et al., 2019). Mass modeling based on physical attributes, projected area, and volume were performed under three classifications of models as appended below:

1. Single variable regression of fruit mass based on linear dimensions including *L*, *W*, *T*, and *Dg*.
2. Multiple variable regression of fruit mass based on fruit projected areas (PA_1, PA_2, and PA_3) and *CPA*.
3. Single variable regression of fruit mass based on measured volume (*V*), volume of the fruit assumed as oblate spheroid shape (V_{osp}), and volume of the fruit assumed as ellipsoid shape (V_{ellip}).

2.4 | Based on LWT

In the first classification, mass modeling was accomplished using *L*, *W*, *T* using models listed in Table 1. In addition, another model obtained with

TABLE 2 Measured physical properties of different grades of kinnow mandarin

Property	Grade 1			Grade 2			Grade 3			F value
	Average	Maximum	Minimum	Average	Maximum	Minimum	Average	Maximum	Minimum	
L	78.19 ± 2.91^{c}	86.01	74.42	73.49 ± 2.33^{b}	79.36	68.90	68.12 ± 2.61^{a}	73.96	61.03	69.98^{S}
W	77.43 ± 2.89^{c}	83.99	74.28	71.84 ± 1.83^{b}	76.63	68.80	66.23 ± 2.31^{a}	69.21	60.24	122.06^{S}
T	63.41 ± 2.23^{c}	68.67	59.92	60.08 ± 3.68^{b}	71.93	53.18	56.88 ± 2.04^{a}	59.36	50.92	27.55^{S}
Dg	72.67 ± 2.30^{c}	78.61	69.74	68.18 ± 2.20^{b}	73.78	65.34	63.54 ± 2.06^{a}	66.40	57.58	84.59^{S}
PA_1	5,644 ± 37^{c}	6,150	5,260	4,726 ± 3.02^{b}	4,940	4,210	4,172 ± 1.04^{a}	4,350	4,090	53.69^{S}
PA_2	4,348 ± 25^{b}	4,730	3,970	4,114 ± 2.39^{b}	4,470	3,860	3,490 ± 2.04^{a}	3,820	3,310	22.01^{S}
PA_3	4,370 ± 16^{b}	4,620	4,120	4,092 ± 1.14^{b}	4,260	3,980	3,584 ± 2.58^{a}	4,010	3,320	18.01^{S}
CPA	4,787 ± 17^{c}	5,010	4,547	4,311 ± 1.59^{b}	4,483	4,060	3,749 ± 1.16^{a}	3,906	3,623	63.91^{S}
V (cm^3)	227.55 ± 19.68^{c}	292.00	200.00	177.85 ± 15.62^{b}	218	153	147.25 ± 13.33^{a}	168	109	120.11^{S}
Vosp (cm^3)	246.23 ± 26.83^{c}	311.09	218.68	198.98 ± 16.16^{b}	243.96	210.25	156.91 ± 15.58^{a}	180.19	153.27	100.32^{S}
Velli (cm^3)	201.49 ± 19.89^{c}	254.35	177.53	166.39 ± 16.62^{b}	210.25	146.04	134.68 ± 12.52^{a}	120.56	99.94	78.29^{S}
Weight (g)	198.97 ± 16.93^{c}	242.93	179.02	161.04 ± 11.39^{b}	185.21	143.77	135.03 ± 12.34^{a}	156.97	97.90	109.19^{S}

Note: Values are mean ± SE of 60 replications; average values in the same row followed by same superscript letter are not differed significantly at $p \le .05$; ^{S}Significant.
L, W, T, Dg are in mm; PA_1, PA_2, PA_3, CPA are in mm^2; Vm, Vosp, Velli are in cm^3, respectively.

TABLE 3 Models and constants for mass prediction of Grade 1 of kinnow mandarin

Model	Constants							
	a	b	c	d	Relation	R^2	χ^2	RMSE
Dimension based models								
a + bL	−215.5	5.30	-	-	215.5 + 5.30 L	0.788	71.23	7.78
a + bL + cL^2	739.24	−18.58	0.15	-	739.24−18.58 L+ 0.15L^2	0.796	72.92	7.64
a + (b/L)	629.9	−33,654.3	-	-	629.9−(33,654.3/L)	0.779	74.20	7.94
aL^b	0.26	2.04	-	-	0.26L$^{2.04}$	0.790	70.17	7.72
a + bW	−207.17	5.25	-	-	−207.17 + 5.25 W	0.762	79.84	8.24
a + bW + cW^2	3,191.28	−81.06	0.55	-	3,191.28−81.06 W + 0.55 W^2	0.826	72.92	7.64
a + (b/W)	615.6	−32,173.5	-	-	615.6- (32,173.5/W)	0.746	85.42	8.52
aW^b	0.029	2.03	-	-	0.03W$^{2.03}$	0.771	77.20	8.10
a + bT	−199.41	6.28	-	-	−199.41 + 6.28 T	0.648	118.56	10.03
a + bT + cT^2	12,619.65	−81.73	0.69	-	12,619.65−81.73 T +0.69T^2	0.702	106.21	9.22
a + (b/T)	600.2	−25,411.2	-	-	600.2- (25,411.2/T)	0.630	124.22	10.28
aT^b	0.046	2.014	-	-	0.05T$^{2.01}$	0.654	115.98	9.93
a + bDg	−318.27	7.12	-	-	−318.27 + 7.12Dg	0.931	23.02	4.42
a + bDg + cDg^2	118.08	−4.66	0.08	-	118.08−4.66Dg + 0.08Dg^2	0.931	24.15	4.40
a + (b/dg)	736.1	−38,997.4	-	-	736.1- (38,997.4/dg)	0.927	24.19	4.53
aDg^b	0.004	2.53	-	-	0.004Dg$^{2.53}$	0.933	22.74	4.39
Projected area based models								
a + bCPA	−232.05	0.093	-	-	−232.05 + 0.09CPA	0.872	99.35	6.30
a + bCPA + cCPA^2	4,489.43	−1.88	0.0001	-	4,489.43−1.88CPA + 0.0001CPA^2	0.931	106.53	4.61
a + (b/CPA)	655.55	−2,116,394.62	-	-	655.55- (2.1 × 10^6/CPA)	0.859	108.54	6.58
aCPA^b	0.0001	2.11	-	-	0.0001CPA$^{2.11}$	0.878	94.67	6.15
aPA$_1$ + bPA$_2$ + cPA$_3$ + d	6.26	−1.59	−6.18	198.87	6.26PA$_1$-1.59PA$_2$-6.18PA$_3$ + 198.87	0.966	15.65	3.23
Volume based models								
a + bV	28.65	0.75	-	-	28.65 + 0.75 V	0.757	81.23	8.34
a + bV + cV^2	−184.97	2.52	0.0001	-	−184.97 + 2.52 V + 0.0001 V^2	0.774	80.68	8.03
a + (b/V)	391.24	−43,460.88	-	-	391.24 − (43,460.88/V)	0.769	77.81	8.13
aV^b	1.88	0.86	-	-	1.88V$^{0.86}$	0.758	81.19	8.31
a + bVosp	55.97	0.58	-	-	55.97 + 0.58Vosp	0.846	51.56	6.62
a + bVosp + cVosp^2	205.3	−0.56	0.002	-	205.3−0.56Vosp + 0.002Vosp^2	0.856	51.74	6.43
a + (b/Vosp)	358.27	−38,818.04	-	-	358.27- (38,818.04/Vosp)	0.819	60.47	7.17
aVosp^b	3.52	0.73	-	-	3.52Vosp$^{0.73}$	0.843	52.40	6.67

(Continues)

three variables for predicting kinnow mass was utilized as shown in Equation (4).

$$M = aL + bW + cT + d \tag{4}$$

Where, *a*, *b*, *c*, and *d* are the regression constants.

2.5 | Based on Projected area

In the second classification, mass modeling was accomplished using projected areas PA_1, PA_2, PA_3, and *CPA* applying models listed in Table 1. Additionally, another model utilizing PA_1, PA_2, PA_3 was used for predicting kinnow mass as presented in Equation (5).

$$M = aPA_1 + bPA_2 + cPA_3 + d \tag{5}$$

Where, *a*, *b*, *c*, *d* are the regression constants.

2.6 | Based on volume

In the third classification, mass modeling was done using the volume based fruit mass. First, actual volume (*V*) was estimated, and then the kinnow fruit shape was assumed as a regular geometric shape, that is, oblate spheroid (V_{osp}) and ellipsoid (V_{ellip}), and their volume was further calculated using Equations (6 and 7) Khoshnam et al. (2007):

$$V_{osp} = \frac{4\pi}{3}\left(\frac{L}{2}\right)\left(\frac{W}{2}\right)\left(\frac{W}{2}\right) \tag{6}$$

$$V_{ellip} = \frac{4\pi}{3}\left(\frac{L}{2}\right)\left(\frac{W}{2}\right)\left(\frac{T}{2}\right) \tag{7}$$

2.7 | Statistical analysis and model validation

Coefficient of determination (R^2), χ^2, and root-mean-square error (RMSE) was selected as the criterion to evaluate suitability of the regression models. The models with higher R^2; lower χ^2 and RMSE values were selected as appropriate models (Soltani, Alimardani, & Omid, 2011). Data analysis and predicting the adequacy of model was performed using statistical packages such as “Statistica” (Version 6.0) and SPSS (Version 16.0). The selected mass models were validated by taking fresh kinnow fruits (50 nos.) randomly.

3 | RESULTS AND DISCUSSION

3.1 | Physical properties of kinnow mandarin

The relevant data of measured physical properties of graded and ungraded kinnow fruits along with the statistical significance is presented in Table 2. The physical properties of the samples varied in certain range such as 78.19–68.12 mm length, 77.43–66.23 mm width, 63.41–56.88 mm thickness, 72.67–63.54 mm geometric mean diameter,

TABLE 3 (Continued)

Model	Constants a	b	c	d	Relation	R^2	χ^2	RMSE
a + bVellip	33.36	0.82	-	-	33.36 + 0.82Vellip	0.931	22.76	4.39
$a + bV_{ellip} + cVellip^2$	18.17	0.96	0.0001	-	$18.17 + 0.96V_{ellip} + 0.0001V_{ellip}^2$	0.933	24.15	4.39
$a + (b/V_{ellip})$	384.39	−37,039.44	-	-	$384.39 - (37{,}039.44/V_{ellip})$	0.922	26.31	4.73
aV_{ellip}^{b}	2.30	0.84	-	-	$2.30V_{ellip}^{0.84}$	0.933	22.74	4.39
Based on LWT	43.09	3.67	−39.64	−303.62	43.09 L + 3.67 W-39.64 T−303.62	0.889	42.27	5.63

TABLE 4 Models and constants for mass prediction of Grade 2 of kinnow mandarin

Model	Constants							
	a	b	c	d	Relation	R^2	χ^2	RMSE
Dimension based models								
a + bL	−119.86	3.82	–	–	−119.86 + 3.82 L	0.613	56.15	6.91
$a + bL + cL^2$	1,488.24	−39.71	0.29	–	$1,488.24–39.71\ L+ 0.29L^2$	0.657	52.72	6.49
a + (b/L)	440.4	−20,515	–	–	440.4–(20,515/L)	0.596	58.72	7.06
aL^b	0.15	1.63	–	–	$0.15L^{1.63}$	0.615	55.87	6.89
a + bW	−170.46	4.61	–	–	−1,701.46 + 4.61 W	0.550	65.26	7.45
$a + bW + cW^2$	1,173.72	−32.58	0.26	–	$1,173.72–32.58\ W + 0.26\ W^2$	0.564	67.29	7.34
a + (b/W)	494	−23,906	–	–	494–(23,906/W)	0.543	66.34	7.51
aW^b	0.023	2.06	–	–	$0.02W^{2.06}$	0.553	64.78	7.42
a + bT	33.59	2.12	–	–	33.59 + 2.12 T	0.471	76.84	8.08
$a + bT + cT^2$	−154.19	8.14	−0.048	–	$−154.19 + 8.14\ T −0.05T^2$	0.482	79.89	7.99
a + (b/T)	298.40	−8,224.21	–	–	298.40- (8,224.21/T)	0.477	75.77	8.02
aT^b	6.22	0.79	–	–	$6.22T^{0.79}$	0.472	76.63	8.07
a + bDg	−148.49	4.54	–	–	−148.49 + 4.54Dg	0.771	33.12	5.31
$a + bDg + cDg^2$	−778.48	22.76	−0.13	–	$−778.48 + 22.76Dg-0.13Dg^2$	0.776	32.72	5.25
a + (b/dg)	480	−21,726.20	–	–	480- (217,263.2/dg)	0.774	34.54	5.27
aDg^b	0.035	1.89	–	–	$0.035Dg^{1.89}$	0.769	33.42	5.33
Projected area based models								
a + bCPA	−84.68	0.06	–	–	−84.68 + 0.06CPA	0.507	157.81	7.95
$a + bCPA + cCPA^2$	−1,274.45	0.62	0.0001	–	$−1,274.45 + 0.62CPA + 0.0001CPA^2$	0.52	307.43	7.84
a + (b/CPA)	400.53	−1,034,335	–	–	$400.53- (1 \times 10^6/CPA)$	0.60	156.21	7.90
$aCPA^b$	0.0001	1.53	–	–	$0.0001CPA^{1.53}$	0.51	158.26	7.96
$aPA_1 + bPA_2 + cPA_3 + d$	1.77	2.09	−5.08	197.61	$1.77PA_1 + 2.09PA_2-5.08PA_3 + 197.61$	0.827	27.43	4.28
Volume based models								
a + bV	53.38	0.61			53.38 + 0.61 V	0.677	45.16	6.19
$a + bV + cV^2$	60.34	0.53	0.00	-	60.34 + 0.53 V	0.677	47.98	6.20
a + (b/V)	271.33	−19,475.66			271.33- (19,475.66/V)	0.679	46.55	6.29
aV^b	4.94	0.67			$4.94V^{0.67}$	0.687	45.23	6.20
a + bVosp	50.41	0.56	–	–	50.41 + 0.56Vosp	0.621	54.91	6.83
$a + bVosp + cVosp^2$	124.42	−0.17	0.002	–	$124.42–0.17Vosp + 0.002Vosp^2$	0.624	57.75	6.79
a + (b/Vosp)	274.55	−22,450.56	–	–	274.55- (22,450.56/Vosp)	0.599	58.12	7.03

(Continues)

TABLE 4 (Continued)

Model	Constants a	b	c	d	Relation	R^2	χ^2	RMSE
$aVosp^b$	4.08	0.69	–	–	$4.08Vosp^{0.69}$	0.619	55.23	6.85
$a + bV_{ellip}$	61.16	0.60	–	–	$61.16 + 0.60V_{ellip}$	0.766	33.89	5.67
$a + bV_{ellip} + cVellip^2$	−54.88	1.94	−0.004	–	$-54.88 + 1.94V_{ellip}\text{-}0.004{V_{ellip}}^2$	0.778	34.21	5.23
$a + (b/_{ellip})$	270.34	−18,029.11	–	–	$270.34\text{-}\ (18{,}029.11/V_{ellip})$	0.774	32.68	5.27
$aVellip^b$	6.44	0.63	–	–	$6.44{V_{ellip}}^{0.63}$	0.769	33.42	5.33
Based on LWT	1.06	2.58	1.41	−186.71	1.06 L + 2.58 W + 1.41 T-186.71	0.790	34.56	5.09

227.55–147.25 cm^3 measured volume, 198.97–135.03 g mass, 5,644–4,172 mm^2 first projected area, 4,348–3,490 mm^2 second projected area, 4,370–3,584 mm^2 third projected area, 4,787–3,749 mm^2 criteria projected area, 246.23–156.91 cm^3 oblate spheroid volume, and 201.29–134.68 cm^3 ellipsoid shape. The observed difference in the physical properties was because of the inherent difference in morphological features of fruits. The information of projected areas may found its applicability in design and development of grading machine utilizing machine vision technique. The selected geometrical attributes (L, W, T, Dg, CPA, Vm, Vosp, and Velli) of the observed fruits in all three grades were statistically significant (Table 2).

3.2 | Mass modeling

Mass modeling using dimensions, volume, and projected area are presented for graded and ungraded fruits in Tables 3–6. The model fitting for ungraded fruits was observed to be best, as corresponding higher magnitudes of R^2, lower χ^2, and RMSE values were obtained when compared with observations of individual grades (Tables 3–6).

3.3 | First category: Dimension based models

Among the first classified models, for Grade 1 fruits, the power model based on "*Dg*" (Equation 8) was found best with higher R^2, lower χ^2, and RMSE values that is, 0.993, 22.74, and 4.39, respectively (Table 3). For Grade 2 category, the quadratic model based on "*Dg*" (Equation 9) indicated R^2 of 0.776, χ^2 of 32.72, and RMSE of 5.25 (Table 4). Quadratic model based on "*L*" (Equation 10) of Grade 3 kinnow mandarin was most suitable as observed with maximum R^2 (0.886), χ^2 (20.61), and lower RMSE (4.06) as compared to other models for Grade 3 fruits (Table 5). For Grade 2 and Grade 3 fruits, the entire dimension based fitted models reported to have lower R^2 values as compared with Grade 1 fruits which might be an indication that the mass of smaller fruits was not uniform corresponding to its size. The prediction of ungraded fruits based on "*Dg*" (Equation 11) model was most appropriate with maximum R^2 (0.956), χ^2 (11.31), and lowest RMSE (3.25) values, respectively (Table 6). The selected models can be described by the following equations:

$$M = 0.004Dg^{2.53} \tag{8}$$

$$M = -778.48 + 22.76Dg - 0.13Dg^2 \tag{9}$$

$$M = -832.68 + 24.15L - 0.15L^2 \tag{10}$$

$$M = 104.08 - 4.91Dg + 0.09Dg^2 \tag{11}$$

Tabatabaeefar & Rajabipour (2005) recommended 11 models for mass prediction of apples based on physical characteristics. Lorestani and Tabatabaeefar (2006) recommended a linear model based on three fruit dimensions to approximate the mass of kiwi fruit. Khoshnam et al. (2007) recommended linear mass model with minor diameter

TABLE 5 Models and constants for mass prediction of grade 3 of KINNOW mandarin

Model	Constants a	b	c	d	Relation	R^2	χ^2	RMSE
Dimension based models								
a + bL	−164.17	4.39	–	–	−164.17 + 4.39 L	0.865	23.03	4.43
a + bL + cL^2	−832.68	24.15	−0.15	–	−832.68 + 24.15 L-0.15L^2	0.886	20.61	4.06
a + (b/L)	428.80	−19,979.80	–	–	428.80−(19,979.80/L)	0.879	20.46	4.17
aL^b	0.012	2.19	–	–	0.012L$^{2.19}$	0.852	25.23	4.63
a + bW	−147.41	4.26	–	–	−147.41 + 4.26 W	0.635	61.98	7.26
a + bW + cW^2	−178.52	5.23	−0.007	–	−178.52+ 5.23 W-0.007W^2	0.635	65.85	7.26
a + (b/W)	404.90	−17,852.10	–	–	404.90- (17,852.1/W)	0.634	62.25	7.27
aW^b	0.02	2.14	–	–	0.02W$^{2.14}$	0.635	62.08	7.26
a + bT	−116.60	4.42	–	–	−116.60 + 4.42 T	0.534	79.31	8.21
a + bT + cT^2	−1861.72	67.51	−0.57	–	−1861.72 + 67.51 T −0.57T^2	0.597	72.78	7.63
a + (b/T)	376.80	−13,732	–	–	376.80+ (−13,732/T)	0.551	76.44	8.06
aT^b	0.07	1.86	–	–	0.07T$^{1.86}$	0.526	80.68	8.28
a + bDg	−217.26	5.55	–	–	−217.26 + 5.55Dg	0.856	24.72	4.58
a + bDg + cDg^2	−429.09	12.34	−0.05	–	−429.09 + 12.34Dg-0.05Dg^2	0.856	26.15	4.57
a + (b/dg)	472	−21,391.10	–	–	472- (21,391.1/Dg)	0.856	24.55	4.57
aDg^b	0.002	2.69	–	–	0.002Dg$^{2.69}$	0.852	25.22	4.63
Projected area based models								
a + bCPA	172.89	−0.01	–	–	172.89−0.01CPA	0.135	17.32	2.64
a + bCPA + cCPA^2	−2,563.24	1.44	0.0001	–	−2,563.24 + 1.44CPA + 0.0001CPA^2	0.391	24.42	2.21
a + (b/CPA)	98.25	138,657.7	–	–	98.25+ (1.38 × 10^5/CPA)	0.129	17.45	2.64
aCPA^b	1,292.40	−0.27	–	–	1,292.40CPA$^{-0.27}$	0.132	17.40	2.64
aPA$_1$ + bPA$_2$ + cPA$_3$ + d	1.72	1.59	−4.58	200.66	1.72PA$_1$ + 1.59PA$_2$-4.58PA$_3$ + 200.66	0.618	63.91	6.53
Volume based models								
a + bV	23.11	0.76			23.11 + 0.76 V	0.672	55.56	6.87
a + bV + cV^2	−110.63	2.69	−0.007		−110.63 + 2.69 V-0.007V^2	0.697	54.78	6.62
a + (b/V)	234.30	−14,488.18			234.30- (14,488.18/V)	0.698	51.19	6.60
aV^b	2.35	0.81			2.35V$^{0.81}$	0.677	54.98	6.84
a + bVosp	25.13	0.70	–	–	25.13 + 0.70Vosp	0.782	37.23	5.63
a + bVosp + cVosp^2	−54.20	1.77	−0.004	–	−54.20 + 1.77 Vosp-0.004Vosp^2	0.786	38.21	5.53
a + (b/Vosp)	233.86	−15,346.29	–	–	233.86- (15,346.29/Vosp)	0.790	35.57	5.50
aVosp^b	2.34	0.80	–	–	2.34Vosp$^{0.80}$	0.783	36.91	5.60
a + bV$_{ellip}$	12.56	0.91	-	–	12.56 + 0.91V$_{ellip}$	0.850	25.34	4.64
a + bV$_{ellip}$ + cV$_{ellip}{}^2$	−36.65	1.69	−0.003	–	−36.65 + 1.69V$_{ellip}$-0.003V$_{ellip}{}^2$	0.854	26.43	4.59
a + (b/V$_{ellip}$)	241.93	−14,263.15	–		241.93- (14,263.15/V$_{ellip}$)	0.854	24.86	4.59
aV$_{ellip}{}^b$	1.65	0.89	–	–	1.65V$_{ellip}{}^{0.89}$	0.850	25.34	4.64
Based on LWT	3.26	0.88	0.93	−198.63	3.26 L + 0.88 W + 0.93 T-198.63	0.886	21.93	4.06

$M = 0.06c^2–4.11c + 143.56$, $R^2 = 0.91$ for pomegranate. Power model based on minor diameter of apricot was found best as reported by Naderi-Boldaji et al. (2008). Miraei Ashtiani, Baradaran Motie, Emadi, and Aghkhani (2014) suggested the application of a linear equation based on minor diameter for predicting the mass of lime ($M = 2.017c −43.868$, $R^2 = 0.97$). Based on model selection criteria, nonlinear quadratic model based on geometric mean diameter of ungraded fruits may be recommended for kinnow fruit mass prediction as compared to other models. The applicability of a model is a function of fruit properties thus; suitability of the models may vary from fruit to fruit.

3.4 | Second category: Projected area base models

Among the models based on the projected area, linear model comprising projected areas (Equation 12) was the best fitted having higher R^2 of 0.966, RMSE of 3.23 and χ^2 of 15.65, for Grade 1 fruits. For Grade

TABLE 6 Models and constants for mass prediction of ungraded KINNOW mandarin

Model	Constants a	b	c	d	Relation	R^2	χ^2	RMSE
Dimension based models								
a + bL	−262.75	5.84	–	–	−262.75 + 5.84 L	0.926	31.65	5.48
a + bL + cL^2	61.22	−3.02	0.06	–	61.22–3.02 L + 0.06 L^2	0.920	35.89	5.79
a + (b/L)	585.51	−30,672.88	–	–	585.51 - (30,672.88/L)	0.897	38.81	6.07
aL^b	0.026	2.04	–	–	0.026L$^{2.04}$	0.874	70.41	8.18
a + bW	−231.98	5.53	–	–	−231.98 + 5.53 W	0.918	27.29	5.09
a + bW + cW^2	124.55	−4.39	0.07	–	124.55–4.39 W + 0.07 W^2	0.925	30.27	5.32
a + (b/W)	556.42	−27,972.92	–	–	556.42- (27,972.92/W)	0.897	35.82	5.83
aW^b	0.03	1.98	–	–	0.03W$^{1.98}$	0.895	45.63	6.58
a + bT	−232.42	6.61	–	–	−232.42 + 6.61 T	0.714	87.82	9.13
a + bT + cT^2	−799.55	25.29	−0.15	–	−799.55 + 25.29 T −0.15T^2	0.729	87.23	9.02
a + (b/T)	569.94	−24,251	–	–	569.94–(24,251/T)	0.733	86.95	9.08
aT^b	0.05	1.97	–	–	0.05T$^{1.97}$	0.684	134.34	11.30
a + bDg	−291.38	6.70	–	–	−291.38 + 6.70Dg	0.951	11.59	3.32
a + bDg + cDg^2	104.08	−4.91	0.09	–	104.08–4.91Dg + 0.09Dg^2	0.956	11.31	3.25
a + (b/dg)	616.06	−30,606.19	–	–	616.06- (30,606.19/Dg)	0.933	19.60	4.32
aDg^b	0.024	2.09	–	–	0.024Dg$^{2.09}$	0.897	52.06	7.03
Projected area based models								
a + bCPA	−363.17	0.07	–	–	−363.17 + 0.07CPA	0.264	1,000.48	28.29
a + bCPA + cCPA^2	4,414.67	−1.21	0.00	–	4,414.67–1.21CPA	0.292	1,057.35	27.84
a + (b/CPA)	721.69	−4,016,608	–	–	721.69- (4,016,608/CPA)	0.261	1,008.48	28.40
aCPA^b	0.08	0.87	–	–	0.08CPA$^{0.87}$	0.135	1,187.73	30.83
aPA$_1$ + bPA$_2$ + cPA$_3$ + d	4.68	0.67	0.79	−118.99	4.68PA$_1$ + 0.67PA$_2$ + 0.79PA$_3$-118.99	0.394	775.34	18.18
Volume based models								
a + bV	21.92	0.77	–	–	21.92 + 0.77 V	0.937	86.81	9.08
a + bV + cV^2	5.59	0.95	0.00	–	5.59 + 0.95 V	0.937	25.35	4.86
a + (b/V)	306	−24,970.90	–	–	306–(24,970.9/V)	0.895	43.56	6.43
aV^b	1.79	0.87	–	–	1.79V$^{0.87}$	0.937	25.03	4.87
a + bVosp	26.49	0.69	–	–	26.49 + 0.69Vosp	0.943	20.66	4.43
a + bVosp + cVosp^2	19.57	0.76	0.00	–	19.57 + 0.76 Vosp	0.943	21.72	4.50
a + (b/Vosp)	297.83	−25,542.09	–	–	297.83–(25,542.09/Vosp)	0.882	43.27	6.42
aVosp^b	1.91	0.84	–	–	1.91Vosp$^{0.84}$	0.943	21.11	4.48
a + bV$_{ellip}$	12.92	0.91	–	–	12.92 + 0.91V$_{ellip}$	0.955	11.21	3.26
a + bV$_{ellip}$ + cV$_{ellip}{}^2$	5.68	0.99	0.00	–	5.68 + 0.99V$_{ellip}$	0.955	11.32	3.25
a + (b/V$_{ellip}$)	311.69	−23,704.66	–	–	311.69–(23,704.66/V$_{ellip}$)	0.902	33.65	5.65
aV$_{ellip}{}^b$	1.47	0.92	–	–	1.47V$_{ellip}{}^{0.92}$	0.955	11.23	3.27
Based on LWT	1.96	2.83	1.65	−281.05	1.96 L + 2.83 W + 1.65 T-281.05	0.954	12.23	3.35

2 category, in comparison to other models, relatively higher R^2 (0.60) was observed in the S-curve model (Equation 13); however, due to such a low R^2 value it was not considered as best fit. For Grade 3 and ungraded fruits, models based on CPA were not found suitable owing to lower R^2 (≤ 0.39) values.

$$M = 6.26PA_1 - 1.59PA_2 - 6.18PA_3 + 198.87 \quad (12)$$

$$M = 400.53 - \left(1 \times 10^6 / CPA\right) \quad (13)$$

3.5 | Third category: Volume based models

In practice, the process of computing actual fruit volume is cumbersome and time-consuming. Therefore, the models based on oblate spheroid (V_{osp}) and ellipsoid (V_{ellip}) that needs sample dimensions are preferred for the design of sorting equipment (Miraei Ashtiani et al., 2014). The power model based on "V_{ellip}"(Equation 14) was found suitable with maximum R^2 of 0.933 and lower χ^2 and RMSE of 22.74, and 4.39 for Grade 1 fruits, respectively. Quadratic model based on V_{ellip}

(Equation 15) was suitable with R^2 of 0.778, χ^2 of 34.21 and RMSE of 5.23 with respect to Grade 2 fruits. S-curve model based on V_{ellip} (Equation 16) achieved the best fit as R^2 of 0.854 with χ^2 of 26.43 and RMSE of 4.59 were obtained for the fruits belong to Grade 3 category. The R^2 value of 0.955, χ^2 of 11.21 and RMSE value of 3.26 represented the linear model based on V_{ellip} (Equation 17) best for the ungraded fruits. The selected mass models based on "Dg" and "V_{ellip}" of ungraded kinnow fruits are shown in Figure 2.

$$M = 2.30Velli^{0.84} \tag{14}$$

$$M = -54.88 + 1.94Velli - 0.004Vellip^2 \tag{15}$$

$$M = 241.93 - (14263.15/Vellip) \tag{16}$$

$$M = 12.92 + 0.91Vellip \tag{17}$$

Khoshnam et al. (2007) reported the linear model equation with high R^2 for mass modeling of pomegranate based on the actual volume. Naderi-Boldaji et al. (2008) suggested a power regression equation for mass prediction of apricot as a function of V_{ellip}. Ashtiani, Motie, Emadi, and Aghkhani (2015) reported the prolate spheroid volume model for prediction of the mass of the lime as M = 1.002Vpsp −1.094 with R^2 = 0.99. Based on model selection criteria, linear model based on ellipsoid volume ungraded fruits may be recommended for kinnow fruit mass prediction as compared to other models.

The predicted values of mass observed by the quadratic model based on geometric mean diameter and linear model based on ellipsoid volume are in line (~5% variation) with the actual experimental findings of kinnow mandarins than the other established models. Furthermore, the results also revealed that mass modeling based on dimensions and volume of ungraded samples were more appropriate compared to models of individual grades.

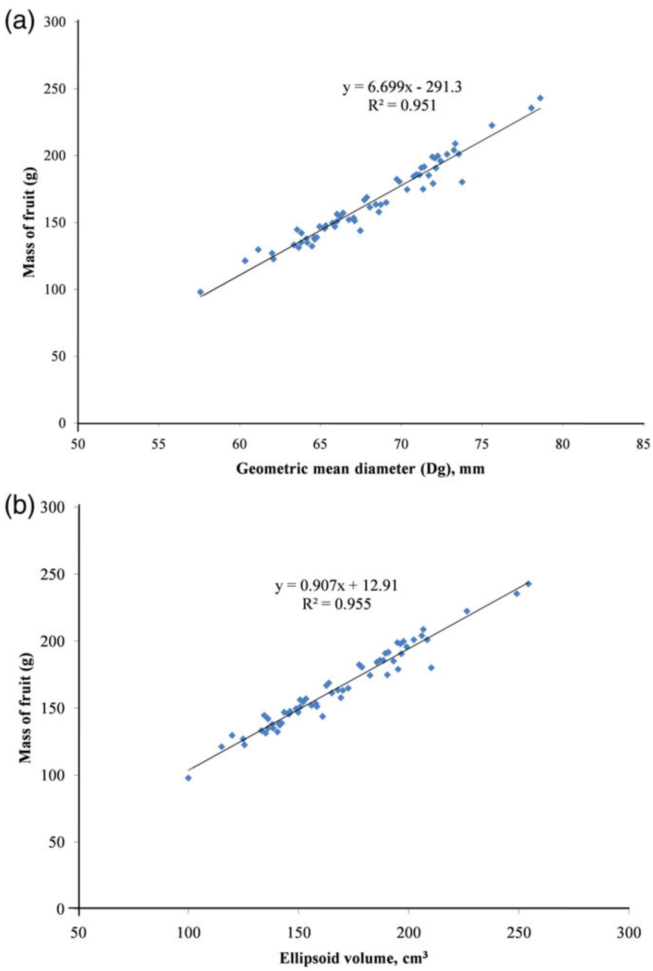

FIGURE 2 Kinnow mass model based on: (a) geometric mean diameter (d_g), (b) ellipsoid volume (V_{ellip}) of ungraded fruits

4 | CONCLUSIONS

1. This study encompassed determination of physical properties of kinnow mandarin as a function of their grades and then establishing their corelation with fruit mass. All considered properties were statistically significant at 5% probability level.
2. Grading based on the fruit size showed a non-significant effect on mass prediction of fruits, as the corresponding statistical parameters (R^2, RMSE, and χ^2) suggested good fit for ungraded fruits for all the models.
3. The recommended model equation for ungraded fruits based on geometric mean diameter in non-linear form is 104.08–4.91Dg + $0.09Dg^2$ with R^2 0.956.
4. The linear model equation is recommended for ungraded fruits based on ellipsoid volume: 12.92 + $0.91V_{ellip}$ having R^2 0.955.

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NOMENCLATURE

a, b, c, d	regression coefficients
CPA	criteria projected area (mm^2)
Dg	geometric mean diameter
L	length (mm)
M	mass (g)
PA_1	first projected area (mm^2)
PA_2	second projected area (mm^2)
PA_3	third projected area (mm^2)
R^2	coefficient of determination
RMSE	root-mean-square error
T	thickness (mm)
V	volume (cm^3)
V_{ellip}	volume of ellipsoid (cm^3)

Vosp volume of oblate spheroid (cm^3)
W width (mm)
χ^2 chi square

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