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ORIGINAL ARTICLE

Growth, maturation and ripening of underutilized *Carissa congesta* fruit

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Abstract – Introduction. *Carissa congesta* (syn. *C. carandas* L.) belongs to the family Apocynaceae. It is a sprawling semi-vine shrub native to India, Nepal, Sri Lanka, Malaysia, Thailand, Myanmar and China. However, it is categorized as an underutilized tropical fruit. One of the important prerequisites for the establishment of a fruit is to understand its growth and nutritional value changes as the fruit develops. Thus, this study was undertaken to study *C. congesta* fruit growth patterns and its compositional changes during maturation and ripening. **Materials and methods.** A total of 300 flowers at the full bloom stage were tagged randomly. The longitudinal and equatorial diameters of 34 fruits were measured every two weeks using a digital calliper until fruit had ripened. Compositional changes such as peel color, firmness, soluble solid concentration, titratable acidity, pH and vitamin C content of fruit were assessed from week 8 after flower full bloom until fruit had ripened. **Results and discussion.** The growth of *C. congesta* fruit exhibited a single sigmoidal curve, as measured by longitudinal and equatorial diameters. The peel color changed from pink to light red, and finally to dark purple, corresponding with the chromaticity values. The firmness of fruit decreased, while the soluble solid concentration increased as fruit matured and ripened. The increase in pH was paralleled by a decrease in the titratable acidity and content of vitamin C. **Conclusion.** Maturation and ripening affected the fruit nutritional composition of *C. congesta*. This fruit contains high vitamin C and it is worth exploring its potential as a new fruit crop for fresh consumption and processing.

Keywords: Malaysia / *Carissa congesta* / morphological traits / fruit quality / nutritional value

Résumé – Croissance, maturation et mûrissement des fruits sous-utilisés de *Carissa congesta*. Introduction. *Carissa congesta* (syn. *C. carandas* L.) appartient à la famille des Apocynaceae. C'est une liane arbustive tentaculaire courante en Inde, au Népal, Sri Lanka, en Malaisie, Thaïlande, au Myanmar et en Chine. Malgré cette vaste aire d'origine, elle est classée dans les espèces fruitières tropicales sous-utilisées. L'une des conditions préalables pour l'implantation d'une nouvelle espèce fruitière est de comprendre la croissance et les changements de valeur nutritionnelle des fruits au cours de leur développement. Aussi, cette étude a été entreprise pour étudier le type de croissance des fruits de *C. congesta* et l'évolution de leur composition en phase de maturation et de mûrissement. **Matériel et méthodes.** Un total de 300 fleurs au stade pleine floraison ont été marquées au hasard. Les diamètres longitudinal et équatorial de 34 fruits ont été mesurés toutes les deux semaines au pied à coulisse numérique jusqu'au mûrissement complet du fruit. Les critères qualitatifs tels que la couleur de la peau, la fermeté, la concentration en matières solubles, l'acidité, le pH et la teneur en vitamine C des fruits ont été mesurés à partir de la 8e semaine après floraison jusqu'au stade de fruit mûr. **Résultats et discussion.** La croissance des fruits de *C. congesta* présente une courbe sigmoïde simple telle que mesurée par les diamètres longitudinal et équatorial. La couleur de la peau du fruit a évolué du rose au rouge clair tournant finalement au violet foncé en correspondance avec les valeurs chromatiques. La fermeté des fruits a diminué alors que la concentration en matières solubles a augmenté jusqu'à pleine maturité. L'augmentation du pH est allée de pair avec une diminution de l'acidité titrable et de la concentration en vitamine C. **Conclusion.** La maturation et le mûrissement des fruits de *C. congesta* jouent sur la qualité nutritionnelle. Ce fruit est riche en vitamine C et ses qualités nutritionnelles en font une nouveauté potentielle tant pour la consommation en frais que pour la transformation.

Mots clés : Malaysie / *Carissa congesta* / caractères morphologiques / qualité du fruit / valeur nutritionnelle

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1 Introduction

Carissa congesta, formerly known as *C. carandas* L., belongs to the Apocynaceae family. It is native to India, Nepal, Sri Lanka, Malaysia, Thailand, Myanmar and China [1]. It is a sprawling semi-vine shrub, and produces fragrant tubular flowers that are white tinged with pink. The flowers are borne in terminal clusters of 2 to 12. The fruit is in clusters resembling grapes, with a color change from white to white-pinkish, pinkish-red, purplish-red and dark-purplish as maturation progresses [2]. The branches of the plant form dense masses set with simple or forked thorns in the leaf axils, which may be up to 5 cm long. Thus, it is a good fencing plant.

Fresh and ripe *C. congesta* fruit is used as dessert or for the preparation of fruit products such as jelly, squash and chutney in India [1]. The unripe fruits yield a milky white latex which can be used in preparing chewing gum and rubber. Since unripe fruit is sour, acid and astringent, it is often pickled. The dried fruits may become a substitute for raisins and are candied, just like cherries.

Both the leaf and fruit extracts of *C. congesta* contain alkaloid, glycosides, saponin, terpenoids, tannins and steroids, while the fruit extract has antimicrobial activity [4]. Begum *et al.* [5] found out that the leaf extract contains carandinol, betulinic acid, *β*-sitosterol-3-*o*-*β*-D-glucopyranoside, oleanolic acid, ursolic acid and 4-hydroxybenzoic acid. An *in vitro* study revealed that carandinol exhibited significant cytotoxicity to human cervical cancer (HeLa), prostate cancer (PC-3) and normal mouse fibroblast (3T3) cell lines. In addition, *C. congesta* fruit contains three major flavonoids, *i.e.* pelargonidin-3-*o*-glucoside, cyanidin-3-*o*-rhamnoside and cyanidin-3-*o*-glucoside, and the content varied with maturity stages [6] and showed strong antioxidant activities [7].

From the literature it is clear that *C. congesta* is a very useful plant. Unfortunately, this plant is categorized as an underutilized tropical fruit of Asia, especially Southeast Asia [8]. The fruit is appealing and nutritious. It has great potential to be established as a crop for fresh consumption and processed products. However, the information on its growth and compositional changes is limited. Both Ding and Syazwani [2] and Sulaiman and Loh [6] claimed the compositional content of *C. carandas* fruit changed at various stages; however, they did not include the diurnal pattern of growth in the changes. Knowledge of specific fruit compositional changes with growth and development is an important prerequisite for the establishment of a fruit crop and its postharvest practices. Understanding the relationship between fruit compositional changes and its diurnal pattern of growth will provide insight into harvest fruit at the proper stage of maturity. A proper stage of harvesting is favored in conserving fruit quality and nutrients. Therefore, this study was carried out to characterize the fruit growth diurnal patterns and its compositional changes during maturation and ripening to fill up this missing gap in the knowledge of *C. congesta* fruit.

2 Materials and methods

2.1 Plant materials

Fruit development was studied by using four 10-year-old *C. congesta* trees which grow 3-m apart at the University Agricultural Park, Universiti Putra Malaysia. The flowers of *C. congesta* are borne in terminal clusters of twigs. A total of 300 flowers, at a stage where the outer petals had just begun to gape and located at the periphery of crown, were randomly tagged from the four trees. In this study, the fruits were thinned so that only five fruits were allowed to develop in a cluster to minimize experimental error due to crop load. The longitudinal and equatorial diameter of thirty-four fruits were measured every 2 weeks (starting from flower blossom) using a digital calliper until fruit had ripened. Assessment of changes in fruit composition was done from week 8 after flower full bloom when the color of the fruit had turned from white to pink. Fifteen fruits with uniform size (4–5 g fruit^{-1}) were harvested every 2 weeks at 08:30 a.m. and transported to the laboratory within 30 min. The analysis stopped when the fruit senesced with shrinkage by week 16 after flower full bloom.

2.2 Peel color determination

The peel color of fruits was measured using a chroma meter (CR-300, Minolta Corp., Japan) with an 8-mm-diameter measuring head and calibrated with a standard white tile. Color was measured as lightness (L*), chroma (C*) and hue angle (h°). The L* coordinate measured lightness of colors (white-black and ranges from no reflection, L$*$ = 0, to perfect diffuse reflection, L$*$ = 100), and the C* measured the vividness of colors. The h° was actual color or perceived color used to classify the kind of color, which varies continuously from 0° to 360°. An h° of 0°/360° corresponds to red, while an h° of 90° corresponds to yellow, 180° corresponds to green and 270° corresponds to blue [9]. Three readings per fruit were recorded.

2.3 Flesh firmness determination

Fruit firmness was measured using an Instron (Model 5543 load frame, Instron Corp., USA) with a 6-mm-diameter cylindrical probe at a speed of 20 mm min^{-1}. The Instron was used simultaneously with Instron Merlin software version M12-13664-EN. Two readings per fruit were recorded in newton (N) and the mean was calculated.

2.4 Soluble solid concentration (SSC) determination

SSC was obtained by using a refractometer (Model N1, Atago, Japan). The refractometer was calibrated with distilled water until the reading reached 0 before it was used. Twenty grams (4-6 fruits) of coarsely chopped fruit sample were weighed and put into a blender jug. A volume of 80 mL distilled water was added into the jug and homogenized for 1 min at high speed. The homogenized sample was filtered through cotton wool. About 1–2 drops of extract from the flesh were placed on the prism glass of the refractometer.

2.5 Titratable acidity (TA) determination

TA determination was carried out according to the titration method modified by Ranganna [10]. A volume of 30 mL of the remaining juice from SSC measurement was taken and two drops of 1% phenolphthalein were dropped as an indicator. Then, acidity was determined by titrating with 0.1 mol L^{-1} NaOH to pH 8.2 and expressed as % citric acid.

2.6 pH determination

The remaining juice from the SSC determination was used to measure the pH (Crison Micro GLP 21, Barcelona). The pH meter was calibrated with buffers at pH 4.0 and pH 7.0 before it was used.

2.7 Vitamin C determination

Five grams (1-2 fruits) of fruit with peel were homogenized with 45 mL of 2% metaphosphoric acid (HPO_3). The juice was filtered through cotton and 2% HPO_3 was added to make up 100 mL. The ascorbic acid content was measured using the direct colorimetric method [10]. One mL of extract was diluted with 2% HPO_3 up to 5 mL. The dilution was transferred into a conical flask and 10 mL of dye solution was added. The red color was measured at 518 nm wavelength using a spectrophotometer (S1200, Cambridge, England). The concentration of fruit ascorbic acid was noted from the standard curve.

2.8 Statistical analysis

For compositional change determination, the harvested fruit was arranged in a completely randomized design and repeated thrice. Data were analyzed using analysis of variance and correlation, while least significant difference (LSD) was used to separate the means when F-values showed significance at 5%. The data of the longitudinal and equatorial diameter were also non-linearly regressed versus the number of weeks after flower full bloom using a growth function:

$$Y = \alpha/(1 + \beta^{(-\delta x)})\ [11]$$

where Y is the fruit longitudinal or equatorial diameter; α, β and δ are regression constants; α is the asymptotic level of each parameter; $\alpha/(1+\beta)$ is the initial value of each parameter; and x is the number of weeks after flower full bloom. PROC NLIN (METHOD = DUD) software (SAS Institute Inc.) [12] was used in the model development.

3 Results and discussion

Carissa congesta fruit growth exhibited a single sigmoidal curve as measured by the longitudinal and equatorial diameter (*figure 1*). Both dimensions fitted the logistic model well, each with an estimated intercept and quadratic coefficient with a high regression coefficient (*table I*). The growth of the fruit

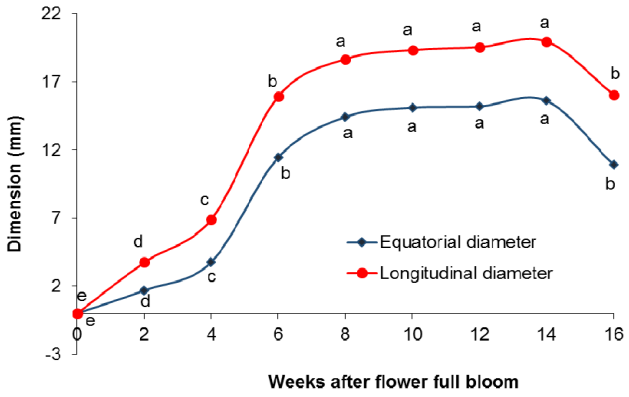

Figure 1. Changes in fruit size (equatorial and longitudinal diameters) of *Carissa congesta* from weeks 0 to 16 after flower full bloom. Means (n = 34) followed by different letters are significantly different ($P \leqslant 0.05$) within the same parameter.

Table I. Logistic models fitted for different dependent variables against growing time (x, in weeks from full bloom) of *Carissa congesta* fruit according to the mean square.

Dependent variable, Y	Logistic model	R^2
Length (cm)	$Y = 18.94/(1 + 42.49e^{-0.86x})$	0.97
Diameter (cm)	$Y = 14.33/(1 + 232.29e^{-1.13x})$	0.96

longitudinal and equatorial diameters of *C. congesta* was slow initially and then became faster by week 4 after flower full bloom (*figure 1*). The rapid increase in the fruit longitudinal and equatorial diameter was sustained for 2 weeks and started to fall at 6 weeks after flower full bloom. From week 8 until week 14 after flower full bloom, there was no difference in the longitudinal and equatorial diameter. By week 16, the fruit entered the senescence stage and shrunk, with decreasing longitudinal and equatorial diameter.

Comparing the two dimensions, *C. congesta* fruit showed a longer longitudinal diameter than its equatorial diameter throughout its growth and development (*figure 1*). As a result, the shape of fruit remained oval, starting from fruit set until the senescence stage. Unlike red-fleshed pitaya (*Hylocereus polyrhizus*) fruit, the growth of the length was rapid at the initial stage of growth [13]. When fruit reached 20 days after pollination, the growth of the diameter exceeded its length, and this led to the rounded shape of pitaya fruit at the end of ripening.

Although the size of *C. congesta* fruit is small, the growing period was rather long (14 weeks after flower full bloom, before senescence) as compared with large fruit such as *Musa* AAB Rastali banana (12 weeks after the first emergence of the first hand) [14], arazá *Eugenia stipitata Mc Vaugh* (8.5 weeks after full bloom) [15] and red-fleshed pitaya (5 weeks after pollination) [13]. This indicated that *C. congesta* is a slow-growing fruit and it takes a long period of time to accumulate its biomass. Although the growth period of *C. congesta* is long, it was noted that the plant flowers abundantly and continuously all year round. Thus, there is no problem in ensuring continuous supply of the fruit. This characteristic is of interest for the

Table II. Correlation coefficients (r) between peel color (L*, C* and h° values), firmness (Firm), soluble solid concentration (SSC), pH, titratable acidity (TA) and ascorbic acid (AA) of *Carissa congesta* during maturation and ripening (n = 15).

	L*	C*	h°	Firm	SSC	pH	TA	AA
L*	–							
C*	0.61*	–						
h°	−0.64*	−0.89**	–					
Firm	0.56*	0.70*	−0.71*	–				
SSC	−0.79**	−0.88**	0.74*	−0.82**	–			
pH	−0.70*	−0.84**	0.62*	−0.49	0.85**	–		
TA	0.79**	0.66*	v0.62*	0.20	−0.61*	−0.81**	–	
AA	0.36	0.80**	−0.88**	0.63*	−0.61*	−0.46	0.37	–

*,** Significant difference at $P \leqslant 0.05$ or $P \leqslant 0.001$, respectively.

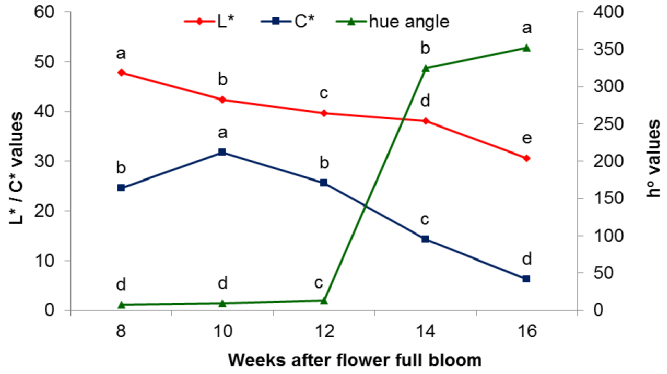

Figure 2. Changes in peel color (L*, C* and h° values) of *Carissa congesta* from weeks 8 to 16 after flower full bloom. Means (n = 9) followed by different letters are significantly different ($P \leqslant 0.05$) within the same parameter.

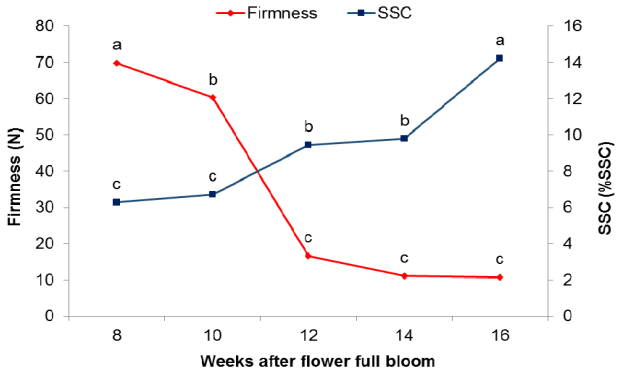

Figure 3. Changes in firmness and soluble solid concentration (SSC) of *Carissa congesta* from weeks 8 to 16 after flower full bloom. Means (n = 9) followed by different letters are significantly different ($P \leqslant 0.05$) within the same parameter.

fruit industry, as it ensures the supply of fruit throughout the year.

The exponential growth phase of *C. congesta* was shorter (6 weeks) than its arrested growth phase (8 weeks) before senescence took place (*figure 1*). Cells may undergo intensive division, enlargement and differentiation during the exponential growth phase, as found in *Musa* AAB Rastali banana [14]. Since the exponential growth phase of *C. congesta* is short, this could probably be the limiting factor to the fruit size. When fruit enters the arrested growth phase with no apparent changes in fruit size, major developmental changes occur internally and this leads to the palatability of fruit.

As the fruit matured, the L* and C* values of *C. congesta* fruit peel decreased significantly, while the h° values increased (*figure 2*). *Carissa congesta* fruit showed drastic changes in peel color as it developed. At the initial stage of fruit development, young *C. congesta* fruit was white in color, and gradually the sun-exposed sides turned pink with fruit growth (unpublished data). When *C. congesta* fruit attained its maximum size without a significant increase in its longitudinal and equatorial diameter at week 8 after flower full bloom, the whole fruit was pink. Eventually, the color of the fruit changed from pink to light red, and finally to dark purple, with shrinkage by week 16 after flower full bloom.

At week 8, the firmness of the fruit was 70 N (*figure 2*). As the fruit matured, the firmness decreased significantly by 76% from weeks 8 to 12, and thereafter no significant differences were found (*figure 3*). In contrast, the SSC of fruit increased as the fruit matured, with the highest value recorded at week 16. The Pearson's correlation coefficients indicated that firmness correlated negatively with SSC (r = −0.82) (*table II*), indicating reduction of firmness contributing to increasing SSC. A decline in firmness is most likely due to conversion of starch into sugars as ripening occurred.

The pH of *C. congesta* fruit increased while TA decreased as the weeks after flower full bloom progressed (*figure 4*). This was proven by the negative correlation (r = −0.81) between pH and TA (*table II*). The pH measures the free hydrogen ion activity, while TA is the amount of weakly bound hydrogen ions that can be released from the organic acids in *C. congesta*. The rise in pH and decrease in TA indicates that citric acid concentrations in the fruit declined with maturity. This finding is in agreement with changes in citric acid in *C. congesta*, as reported by Sulaiman and Loh [6]. It is well known that organic acids contribute to the sourness of a fruit. With the decrease in citric acid in matured and ripened *C. congesta* fruit, the sourness was reduced. Moreover, Pearson's correlation coefficient indicated that TA correlated negatively

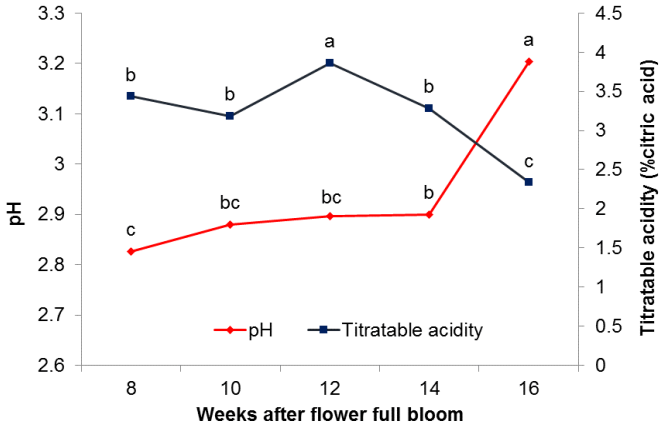

Figure 4. Changes in pH and titratable acidity of *Carissa congesta* from weeks 8 to 16 after flower full bloom. Means (n = 9) followed by different letters are significantly different ($P \leqslant 0.05$) within the same parameter.

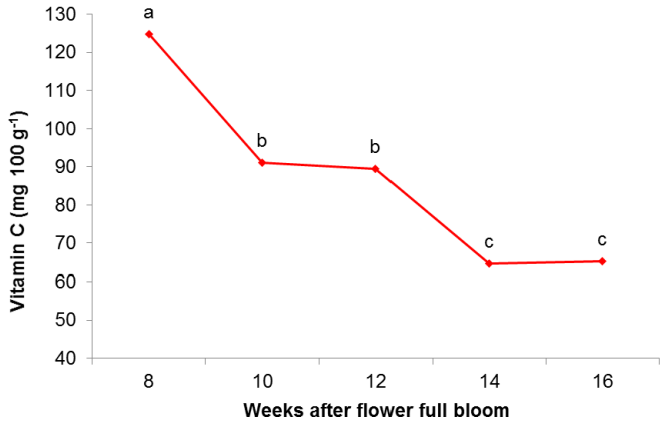

Figure 5. Changes in vitamin C of *Carissa congesta* from weeks 8 to 16 after flower full bloom. Means (n = 9) followed by different letters are significantly different ($P \leqslant 0.05$).

with SSC (r = −0.61) (*table II*), indicating *C. congesta* fruit becomes palatable as growth progresses.

The vitamin C of *C. congesta* decreased from 123 to 65 mg 100 g^{-1} within 8 weeks of maturation and ripening (*figure 5*). Even though a 48% decrease in vitamin C occurred, *C. congesta* fruit retained high vitamin C by week 14 after flower full bloom as compared with other tropical fruits such as 'Kampuchea' guava (40 mg 100 g^{-1}) [16], 'B10' carambola (20 mg 100 g^{-1}) [17], 'Eksotika' papaya (76 mg 100 g^{-1}) [18], 'Harumanis' mango (10 mg 100 g^{-1}) [19], 'Glamour' rockmelon (23 mg 100 g^{-1}) [20] and watermelon (6 mg 100 g^{-1}) [21]. This indicates that *C. congesta* fruit is a good source of vitamin C. Vitamin C is one of the most important antioxidants in fruits and vegetables. It is a powerful hydrosoluble antioxidant that protects the body against oxidative stress by trapping hydroxyl and superoxide radicals [22]. It is suggested that a regular daily intake of 250–500 mg vitamin C reduces oxidative damage [23].

Peel color is one of the aspects that determine both the developmental and optimal harvest stage of a fruit. For *C. congesta*, the changes in peel color, especially chroma and hue values, correlated well with organoleptic quality (*table II*). From the present findings, it is clear that the optimum harvesting stage for *C. congesta* fruit is week 12 after full flower bloom. Fruit harvested at this stage has softened, with reasonable sensorial quality. This implies that a fruit that has turned from pink to red is suitable for fresh consumption.

4 Conclusion

This is the first report on *Carissa congesta* (syn. *C. carandas* L.) fruit growth and its compositional changes in correspondence to its diurnal development. The quality of fruit is affected by maturation and ripening. *Carissa congesta* fruit is an underutilized fruit without much attention from growers and consumers. The fresh fruit may not be palatable until it is fully ripe with minimal gummy latex and acidity. Unfortunately, at this stage the vitamin C has decreased as maturation advances. However, the vitamin C content in ripe fruit is still higher than in many other tropical fruits. A comprehensive study, especially the secondary metabolites of fruit, is recommended to explore its potential as an alternative source for nutrition and well-being.

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