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Research Article

Morphological Characteristics and Growth Behavior of Ridge Gourd [*Luffa acutangula* (L.) Roxb.] in Tropical Urban Ecosystem

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ABSTRACT

Ridge gourd (*Luffa acutangula*) is a climbing vegetable that produces edible fruits. Young fruits are harvested at a time when the seed coats have been established, but cotyledons have not yet formed. This study covered morphological characteristics, growth behavior, and cultivation practices suitable for increasing the production of the ridge gourd in urban ecosystems. Results of observation revealed the heart-shaped leaf of the ridge gourd was very uniform, and the leaf surface was flat so that their leaf area could be accurately estimated using leaf length and/or width ($R^2 > 0.97$). Yet, leaf thickness was not a reliable predictor for the leaf area ($R^2 < 0.34$). The length of petioles was not correlated with the leaf blade area. All single leaves, multiple tendrils, an inflorescence of male flowers and/or a single female flower, and a branch could be formed at each stem node. Water content in the leaf blade was lower than in the petiole. This phenomenon is related to water favor loss due to transpiration activity. Nevertheless, the total conserved water within the leaf blade was 6.26 times more than those within the petiole. The process of fruit enlargement followed the Sigmoid curve. The upper end of the curve started to flatten 10 days after the female flower bloomed. Moreover, at the age of 10 days, cotyledon has not yet formed, so it can be used as a guide to determine the harvest time of the gourd ridge fruit. Based on the leaf SPAD value, by the time the fruit began to enlarge, 4-5 leaves at the stem base were instigated to show symptoms of senescence. Ridge gourd fruit fresh weight can be best estimated using the length × diameter of the plants as a predictor.

Keywords: Climbing vegetable, Fruit age, Leaf shape, Sigmoid curve, Urban olericulture

Introduction

Ridge gourd (*Luffa acutangula*) is classified as a liana, a climbing plant. The average number of fruits/plants, fruit length, and fresh fruit weight were 10.7 fruits, 32.9 cm, and 229.7 g in an open-pollinated plot, respectively [1]. Kumar et al. [2] reported that the accumulative fruit yield of ridge gourd was 13.8 ± 0.1 kg/plant. However, yield may vary depending on fruit age at harvest.

In an urban farming system, the ridge gourd can be grown in 30-cm diameter pots and can be trained to grow upward on wooden or PVC vertical and horizontal support poles and nets at a height up to 2.0 meters. Natural light in the tropical climate should be enough for establishing a triple-layer cultivation system for increasing food security for urban communities with limited open space, i.e., using the concrete pool or moveable plastic or tarpaulin pool for fish culture plus a floating culture of leafy vegetables grown underneath the ridge gourd canopy.

Small freshwater fish such as catfish and tilapia can be cultivated using a shallow biofloc system [3]. Leafy vegetables such as some brassica species can be pot-grown on a lightweight floating raft constructed using recycled plastic bottles as floater and PVC pipe for the frame [4]. The floating raft also functioned as a cover on the water surface to prevent fishes from jumping out of the ponds.

Urban agriculture has become a popular activity in big cities all over the world [5-7], especially after experiencing the Covid-19 pandemic [8-10].

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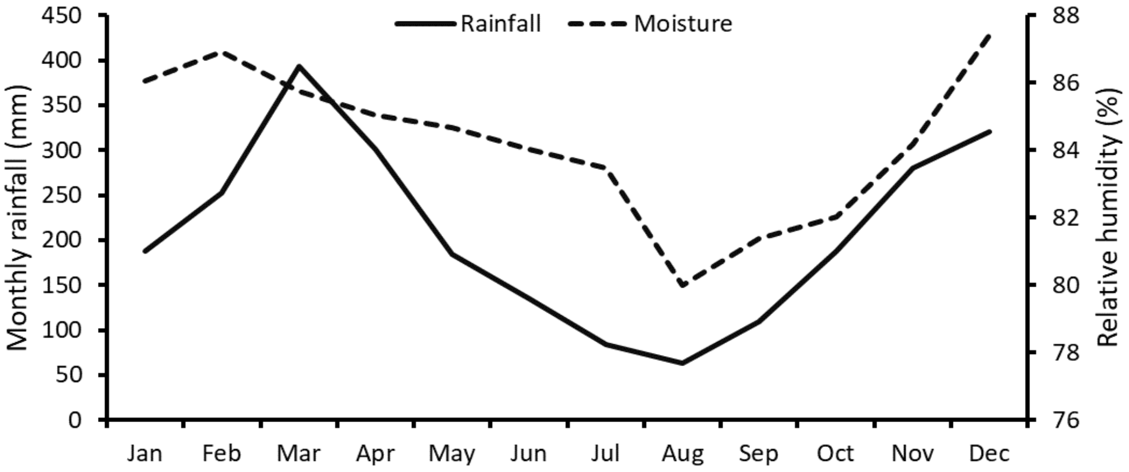

Figure 1. Averaged monthly rainfall and relative humidity from 2017 to 2021 at the research location in South Sumatera tropical lowland

Growers could benefit from its early harvest and longer harvesting period. Ridge gourd does not produce fruits at the same time. The fruit production is distributed throughout the two-month harvesting period. The timely spread of fruit harvest is beneficial to subsistence agriculture since the fruit becomes available over a longer period for the urban community without needing to store them. Fruiting behavior had not been exclusively studied in the ridge gourd plant.

Harfiani *et al*. [11] stated that the leaf of ridge gourd contained many beneficial phytochemicals for human health, including alkaloids, glycosides, saponins, carbohydrates, amino acids, lipids, steroids, terpenoids, and triterpenoids. Therefore, ridge gourd provides additional benefits in its edible young leaves besides the fruits. Actually, peels of many fruits, including ridge gourds, exhibited antioxidant activity and contained total phenolic [12].

Bhutia *et al.* [13] reported that genetic improvement of ridge gourd was possible since diverse genotypes had been identified. Similarly, Harshitha *et al.* [14] observed a wide variation of phenotypic and genotypic traits in ridge gourd, exhibiting high heritability. However, the ridge gourd was vulnerable to insect attacks [15]. This issue should not be a serious problem in small-scale urban farming since it could be handled manually.

This research covered aspects related to morphological characteristics, growth, and fruiting behavior of ridge gourd cultivated in the urban agroecosystem.

Material and Methods

Materials used, growing condition, and research protocols

Anggun Tavi F1 cultivar was used in this study. The research was conducted during the transition from the late rainy season to the early dry season of 2022 at the tropical lowland in South Sumatera, Indonesia. The monthly fluctuation of rainfall and relative humidity is presented in Figure 1. Slight fluctuation of sunlight intensity and maximum air temperature did not significantly affect the growth and yield of most cultivated crops. Low air temperature has never been a serious agricultural issue in the tropical lowland area.

Each pot was filled with mixed growing substrate consisting of topsoil, chicken manure, fine sand, and wood biochar at a ratio of 6:2:1:1 (v/v/v/v). Before seed planting, the growing substrate was treated with a bio-sterilant solution at a concentration of 2 g/l. The sterilant was a consortium of *Streptomyces* sp., *Geobacillus* sp., and *Trichoderma* sp. Each pot was applied with 200 ml of the solution. Then, the treated substrate rested for a week.

Two seeds were directly planted in each pot, measuring 30 cm in both diameter and height. Two weeks after planting, the more vigorous seedling continued to be nurtured while the other seedlings were excised. Additional seedlings were prepared for leaf and fruit morphology study and treated with similar procedures to those used for the growth and yield analysis studies. The NPK fertilization at the rate of 5 g per plant was applied at the early vegetative phase, early flowering stage, and mid-fruiting period. Insect pest control was carried out using transparent bottle traps in which sticky paper and pheromones containing methyl eugenol as the active ingredient were placed on the research site.

The ridge gourd as a climbing plant was trained to grow upward on the constructed frame using a 1-inch diameter PVC pipe as the skeleton. The frame was 4 m (length) × 2 m (width) × 2 m (height). Each frame was supported with 8 poles, i.e., 4 poles on each side of the frame. A net with a density of 30 cm × 30 cm was knitted from a 0.5 mm nylon fishing line. The nets were installed on both sides of the long section and the top of the frame (Figure 2).

Pots for the ridge gourd were placed in a single row along the outer side of the concrete pool. Each of the main stems was trained to vertically grow straight up following the installed nylon net all the way to the horizontal flatform of the frame. Branches developed at a vertical net were trained to grow horizontally but were let to grow freely after reaching the horizontal flatform.

Fruits were allowed to freely hang on the side and top of the frame so that the fruits could grow straight due to the gravity effect. Consumers prefer straight fruit therefore the straight one has a higher economic value. As a vegetable, the fruit of the ridge gourd is harvested early before the cotyledons had been developed.

Figure 2. The cultivation system of the gourd ridge plant by using the climbing frame (A and B). Plants at the age of 2 weeks (C), during flowering (D), fruits at time of the first harvest (E and F), and variations in the size of the harvested fruits.

It is not easy to recognize visually the perfect time to harvest. Fruit size and skin color cannot be used as a clue for the perfect time to harvest in the ridge gourd. Among other objectives, this challenge will be solved in this research.

Data collection

The scope of this research was morphology, growth, and yield of ridge gourd. Data collected included leaf midrib length (LM), blade length (LB), blade width (WL), leaf thickness (LT), leaf area (LA), leaf fresh weight (LFW), leaf water content (LWC), leaf volume (LV), petiole water content (PWC), petiole volume (PV), fruit length (FL), fruit diameter (FD), SPAD value, relative fruit density (RFD), the ratio of leaf midrib/width (LM/WL), the ratio of leaf length/width (LB/WL), and the ratio of fruit length/diameter (FL/FD).

LWC was calculated based on leaf fresh and dry weight; LV was calculated based on leaf area and thickness; PWC was calculated based on petiole fresh and dry weight; PV was calculated based on the area of petiole cross-section × petiole length, and RFD was calculated based on fruit fresh weight/fruit volume.

Leaves of large size on *L. acutangula* plants are formed on the main stems. The area of these leaves can be more than 400 cm2 in size. The leaves of this plant are amphistomatic. That is, the upper and lower surfaces have stomata. Its wide leaves give the advantage of capturing sunlight. The disadvantage of this plant is that its epidermal tissue does not have a protective system from insect attacks [15].

LA was measured directly using the Easy Leaf Area automated digital image analysis application developed by Easlon and Bloom [16]. SPAD value was measured using the chlorophyll meter (Konica Minolta, SPAD-502 Plus) to monitor leaf color changes as an indicator during the leaf senescence process. Fruit length and fruit diameter were monitored every other day until 10 days after flowering. Leaf SPAD values were monitored every other day until 18 days for lower (the 1st to 5th leaf), middle (the 6th to 20th leaf), and upper (the 21st to the terminal leaf) sections of the main stem during the early fruiting period, i.e., started as the first female flower blooming.

Data analysis

Ratios and relationships between two traits were calculated based on the linear regression model. Values of the ratio were determined based on the calculated slope (β) and the strength of the relationships was determined based on the coefficient of determination (R^2). Non-destructive estimation of LA was developed using LB, WL, LB × WL, or LT as predictors based on a zero-intercept linear or polynomial order-2 regression model.

The fruit enlargement trend pattern was established based on the length and diameter of the fruit and matched with the Sigmoid curve using the polynomial order-3 regression model.

Results and Discussion

The leaf of the ridge gourd has a symmetric heart shape. The largest fully developed leaf recorded in this study had a midrib length of 17.8 cm, blade length of 24.5 cm, and a blade width of 25.2

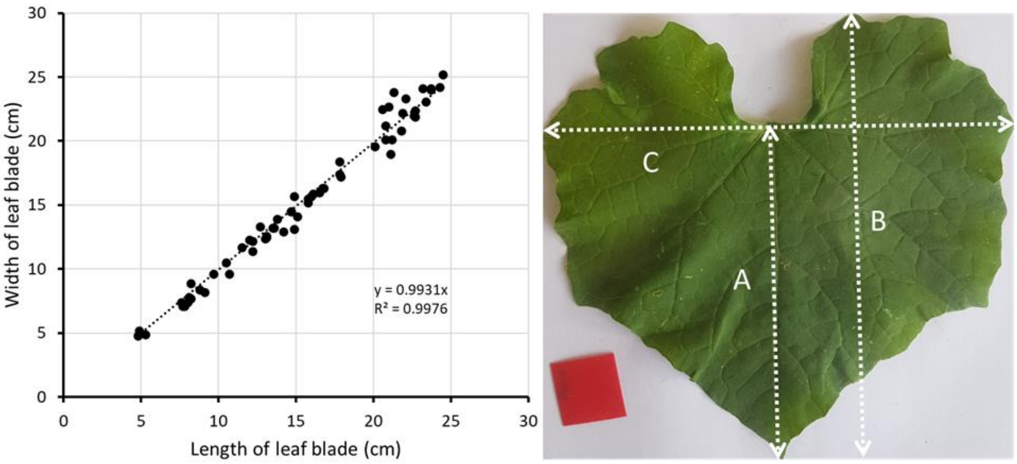

Figure 3. Morphology of the *Luffa acutangula* leaf and its measurements based on the length of midrib (A), length of leaf blade (B), and width of leaf blade (C).

cm. The length and width of the blade were almost similar in all healthy leaves (Figure 3).

The shape of ridge gourd leaves was uniform, and the shape did not change during the enlargement process. The ratio of midrib length to width of leaf blade (LM/WL) and the ratio of length to width of the leaf blades (LB/WL) were constant despite high variation in the length of the midrib (LM) and the length of leaf blade (LB), respectively (Figure 4). Average and standard deviation of the LM/WL ratio and the LB/WL ratio were 0.77 $\pm$ 0.047 and 1.03 $\pm$ 0.047, respectively.

The shape of *L. acutangula* leaf was consistent, from the time the young leaves begin to unfold until the mature leaves reach their maximum size. The LM/WL and LB/WL ratios did not change during the leaf enlargement process. This fact validated that the shape of *L. acutangula* leaves is constant. Manikandaselvi et al. [17] described that petiole of ridge gourd was 3-8 cm in length and somewhat twisted whereas the blade was light-green in color and angular at tip of the leaf. In our study, petiole could lengthen to more than 15 cm in dense leaf population conditions.

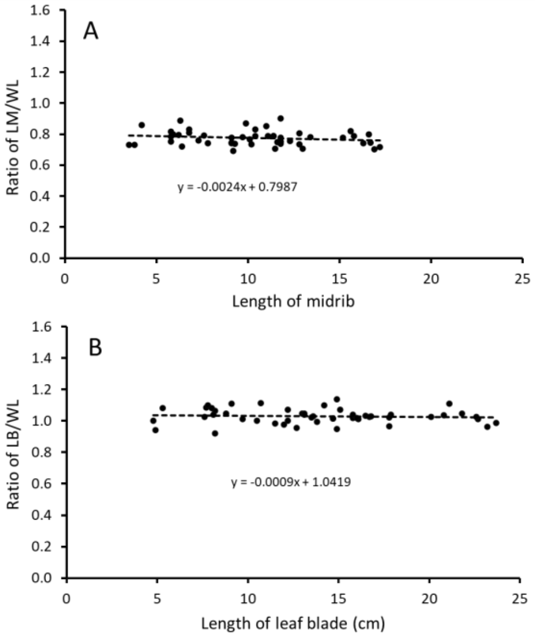

Figure 4. Ratio between length of midrib and width of leaf blade (LM/WL) (A), and between length and width of leaf blade (LB/WL) (B) are relatively constant within the full range of leaf size in *L. acutangula* plant.

Ma and Li [18] explained that under shade conditions, due to a high leaf density, many species exhibited shade avoidance responses by promoting the stem and petiole to elongate, so that the leaf blade could receive direct sunlight. It is clear that the lengthening of the petiole is stimulated more by light and not adjusting its size to the leaf blade area.

Branches, tendrils, and male flowers developed from the leaf axils on the main stem, but female flowers that will become fruit generally grew in the leaf axils on the primary branches. Manikandaselvi *et al*. [17] (2016) described that the male flower was yellow-colored and occurred in a small cluster, whereas the female flower was solitary, yellow-colored, and had a long pedicel. Fruits were cylindrical in shape, covered with 8-10 prominent longitudinal ribs on the outer skin surface, and obovate with a narrower end at the base.

The leaves of the *L. acutangula* plant are single, symmetric heart-shaped, and flat surfaces. Therefore, they can be accurately and non-destructively estimated using leaf morphological traits, i.e., leaf length and/or width as predictors. Some different models can be used to estimate their leaf area, including power, polynomial order-2, or zero-intercept linear regression [19-21]. The leaf thickness and weight-related traits had been reported to be less reliable for estimating leaf area [22, 23]. Estimating the total area of irregular compound leaves such as the konjac plant (*Amorphophallus muelleri*) was much more complicated [24, 25].

Petiole water content was 7.14 % higher than that in the leaf blade of the ridge gourd plant. Water content was consistently high regardless of the leaf size. Meanwhile, the volume of the blade was 6.26 times higher than the volume of the petiole of the same leaf (Figure 5). Lower water content in the leaf was associated with continuous water vapor loss through transpiration activity. A larger leaf blade is beneficial for capturing more sunlight required in photosynthesis to ensure plant growth.

Water content was found to be noticeable difference (more than 7%) between petiole and leaf blade. Lower leaf blade water content relates to continued water vapor loss through stomata during transpiration. However, the quantity of preserved water in the leaf blade was much larger than in the petiole of the same leaf. Water availability optimizes plant metabolism and enhances growth rates.

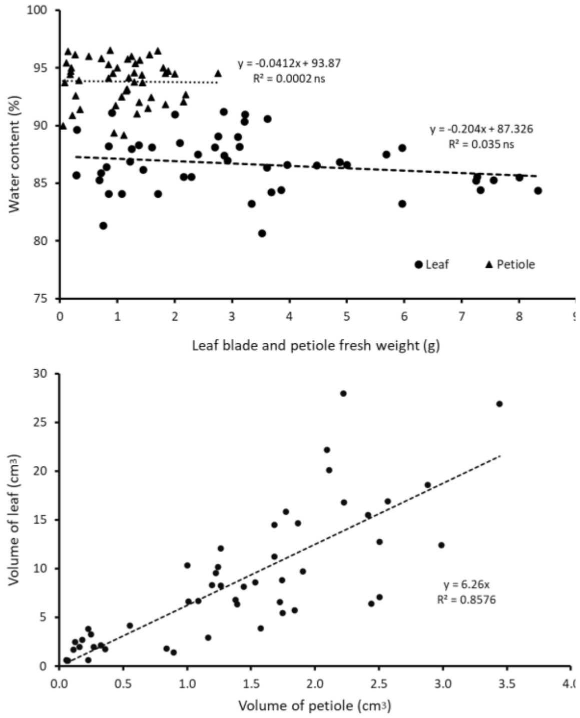

Figure 5. Water content and volume of leaf blade and petiole in *L. acutangula* plant

The shape regularity and flat surface make it easier to accurately estimate leaf area (LA) in ridge gourd plants. Some morphological traits successfully used as predictors in predicting LA were the length of the midrib, length of the leaf blade, and width of leaf blade; meanwhile, the thickness of the leaf failed to show a strong correlation with LA (Figure 6).

The findings could be used in non-destructively monitoring daily leaf expansion rate. The zero intercepts polynomial order-2 regression perfectly fit for estimating LA in ridge gourd plant.

Fruit growth in the ridge gourd plant is considerably fast. In this study, it took 10 days after a female flower bloomed for the fruit to reach an optimum size for harvesting. The fruit had reached 33.57 cm in length, 42.05 mm in diameter, and 214.29 g fresh weight on average at harvesting (Figure 7).

The growth of *L. acutangula* fruit was considerably fast. Under favorable agroclimatic conditions, the length of the fruit reached more than 30 cm and a diameter of more than 40 mm in just 10 days after the flower blooms. By the time they were harvested, the fruit's fresh weight had

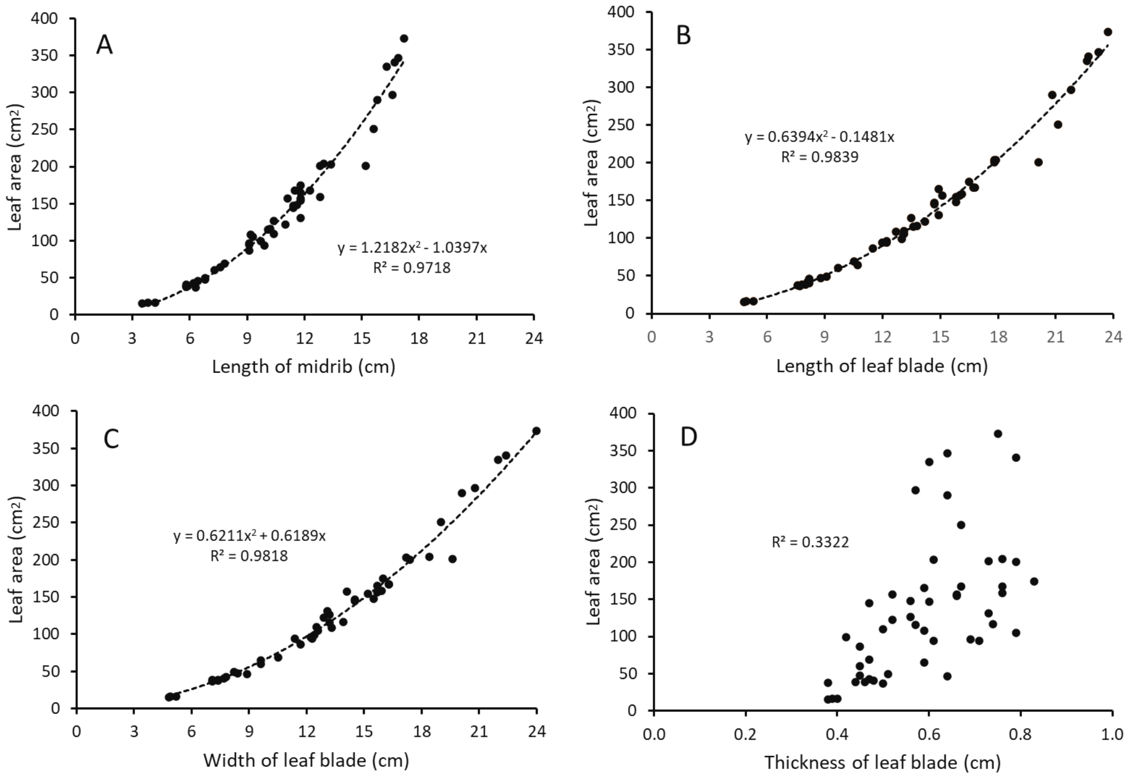

Figure 6. Estimation of leaf area in *Luffa acutangula* plant using length of midrib (A), length of leaf blade (B), width of leaf blade (C), and thickness of leaf blade (D) as predictors.

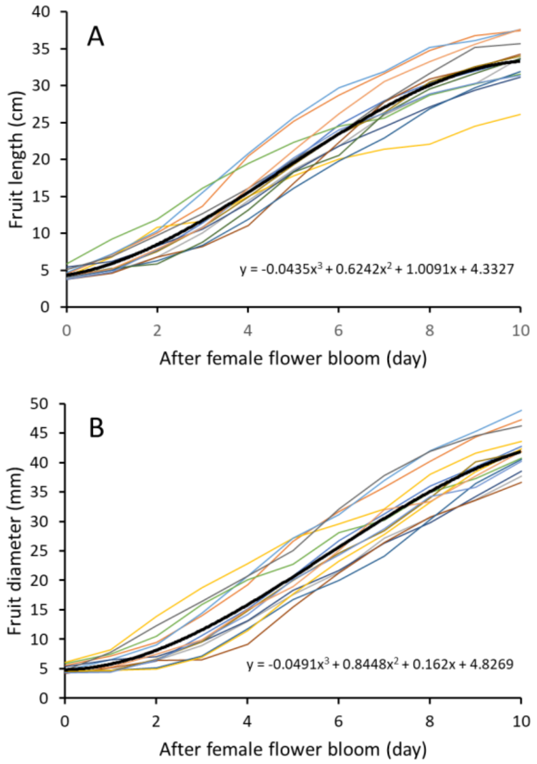

Figure 7. Increase in length (A) and diameter (B) of *L. acutangula* fruit at the first 10-days after female flower bloom.

reached more than 250 g. Large fruits were generally obtained at the beginning of the harvest, after which the size of the harvested fruits gradually became smaller.

Fruit lengthening and diameter expanding followed the S-curve. Early exponential growth switched to an asymptotic trend was observed at around 6 days after the flower bloom.

Fruit of ridge gourd plant as the vegetable is preferably harvested at the optimum size of 150-250 g FW. The seed coat had developed but the cotyledon development had not been initiated at the harvesting time.

Gardas et al. [26] stated that one of the important factors for reducing yield losses was to carry out the harvest at the right time. However, determining the right time for *L. acutangula* crop was not easy because this crop was harvested at a time when the fruit was young. There were no physical indications, including skin color change, aroma, softness, and waxy skin. Yet, the fruits have to be harvested at the optimum size for maximized marketable yield.

It was expected that after the plant had entered the reproductive growth phase and initiation of fruit development, demand for carbohydrates and other required substances, enzymes, and catalysators would increase for enhancing metabolic processes at the reproductive organ which may not be adequately supplied through photosynthetic activities. In this case, relocation of the photosynthates is clearly needed, commonly redistributed from the older leaves. Relocation of photosynthate can be indirectly monitored through declining in the SPAD value. This study observed a significant and continuous decline in SPAD value for 18 consecutive days in older leaves, i.e., the first to fifth leaves. The decline was much slower in the sixth to twentieth leaves; meanwhile, the SPAD value was slightly increased in the twenty-first and younger leaves (Figure 8).

The fast fruit growth concurrently occurred with the enhancement of older leaves senescence,

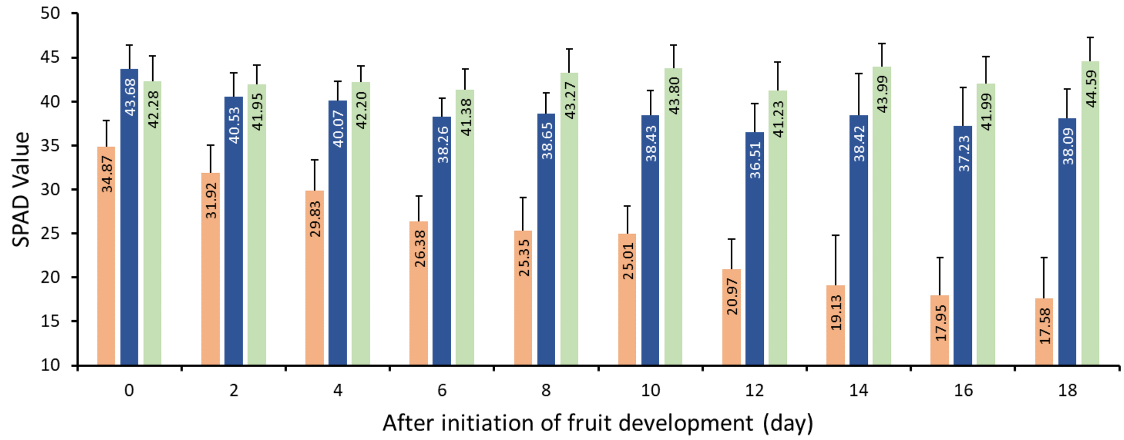

Figure 8. Average of leaf SPAD value at base (brown), middle (dark blue), and end-section (green) of the main stem during fruit development period in *L. acutangula* plant

as indicated by the decrease in SPAD value [27]. This phenomenon is also reported to occur in tomato plants [28]. Furthermore, Liu et al. [29] found that faster leaf aging after the plant began to bloom was mainly due to a decrease in the cytokinin content of the leaves. The last two findings justified that senescence of the older leaves in *L. acutangula* plants was associated with flowering and fruiting activities. Leaves at the mid-section of the main stem were only slightly affected while the younger leaves at the end section of the main stem had not yet been affected.

Fruit length was a better predictor for estimating fresh fruit weight and relative fruit density compared to fruit diameter. The length x diameter was more reliable ($R^2 = 0.8927$) in predicting fresh fruit weight, yet the ratio of length/diameter could not be used as a predictor ($R^2 = 0.0556$). As the length of fruit increased, i.e., as the fruit grew, relative fruit density also increased (Figure 9).

Non-destructive, continuous, and rapid monitoring of fruit growth could be done using the fruit length as proxy since there was a strong correlation between fruit length and fresh weight. Whereas, for increasing accuracy, the fruit length should be combined with fruit diameter for predictor. Hai & Thao [30] reported that yield components in *L. acutangula* plants were strongly corre-

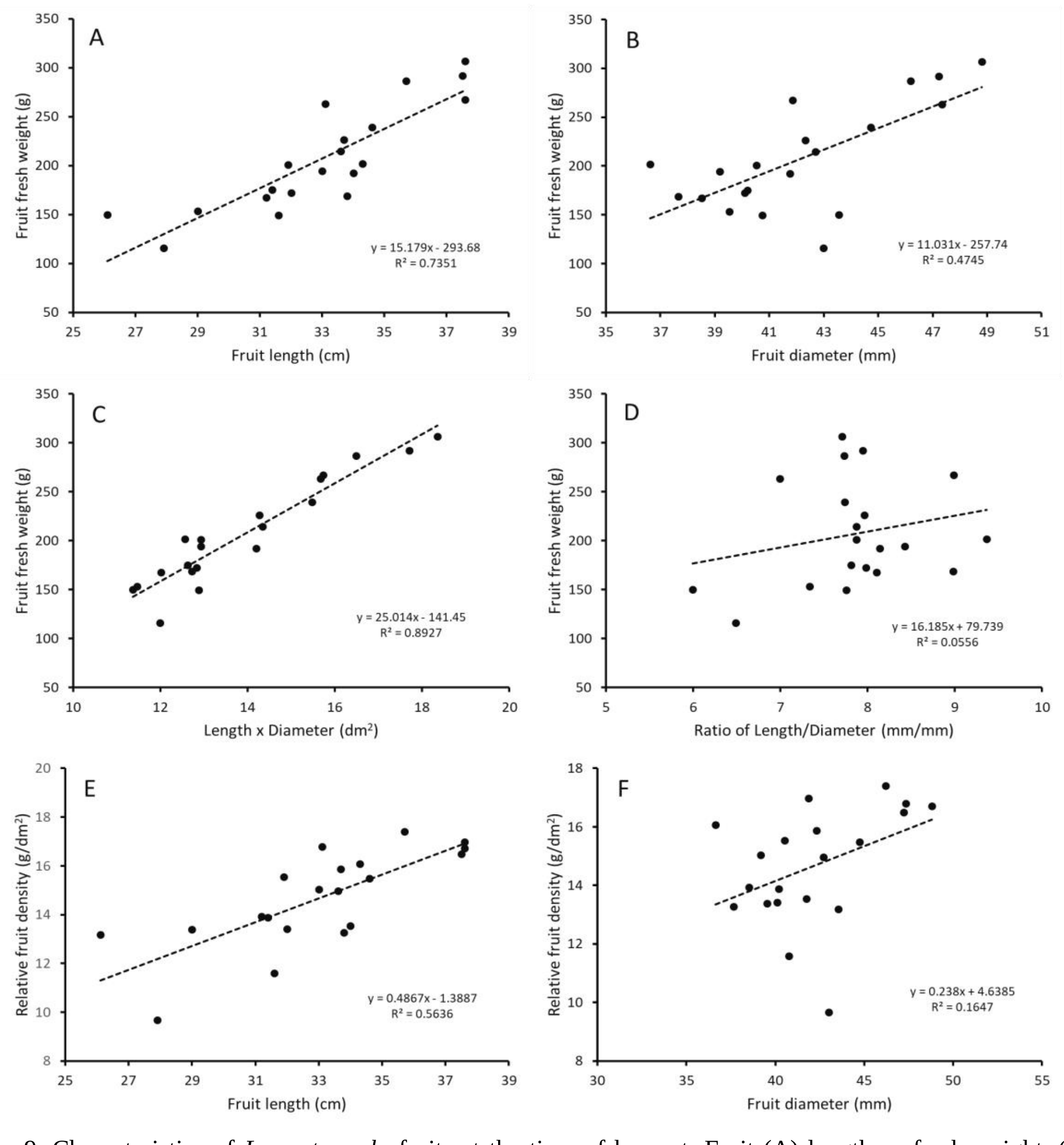

Figure 9. Characteristics of *L. acutangula* fruits at the time of harvest. Fruit (A) length vs fresh weight, (B) diameter vs fresh weight, (C) length x diameter vs fresh weight, (D) ratio of length/diameter vs fresh weight, (E) length vs relative fruit density, and (F) diameter vs relative fruit density.

lated with the number of fruits per plant, fresh fruit weight, fruit diameter, and fruit length. Poornima et al. [31] believed that the pranic treated plants had effectively increased leaf chlorophyll content, overall growth, and yield.

Harvesting should be done at the optimum age of each fruit, 10 days after the flowers bloom to obtain optimal fruit size and density. The fruit firmness could also be directly measured based on sensing mechanical, sonic, vibrational, and optical properties of the fruits [32]. The dense fruit was also harder to punch. Information on either fruit density or fruit firmness was needed in the post-harvest handlings. Mohebbi et al. [33] found that calcium dip treatment significantly increased fruit calcium content. Calcium inhibited cell-wall modifying enzymes and improved cell-to-cell adhesion. Therefore, calcium application increases the quality and storability of fruits.

Conclusion

The *Luffa acutangula* plant produced a single and uniform heart-shaped leaf blade from a newly unfolded young leaf to a fully expanded mature leaf. The blade was consistently flat. With these morphological characteristics, the leaf area (LA) of the *Luffa acutangula* plant could be non-destructively and accurately estimated using the leaf length and/or width as predictors. The ability to estimate LA non-destructively opened the opportunity to monitor leaf expansion rate on the same existing leaves periodically. The fruit of *Luffa acutangula* was consumed as a cooked vegetable. The desirable young fruit was ready to be harvested 10 days after the female flower blooms. The size and fresh weight of the young fruit at harvest reached more than 30 cm in length, 40 mm in diameter, and 250 g in fresh weight. About 4-5 old leaves at base of the main stem started to senescence at early flowering stage as indicated by a steady decline in the leaf SPAD value. Amongst fruit morphological traits, fruit length exhibited the strongest correlation with fresh fruit weight.

Based on the results of this study, it is recommended to urban communities to cultivate ridge gourd plants using a vertical frame because the growth of this plant is fast with available yields in a period of up to 2 months, and still open opportunities to cultivate floating vegetables and fishes by making concrete pools under the shade of the ridge gourd canopy.

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