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Productivity and fruit quality of ridge gourd plants regrown from seeds harvested from hybrid parents cultivated in tropical urban ecosystems

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Abstract The results showed that fruit morphology of ridge gourd was not significantly different in diameter, but significantly longer F2 fruits than F1 fruits. The size based on length x diameter was significantly correlated with the fresh weight of the fruit in F1 (R= 0.9159) and F2 (R= 0.8312). Fruit length and fruit diameter did not correlate with the fruit relative density. However, fruit length was strongly correlated with fruit volume (R = 0.8879) in F1 fruits. Amongst the two generations, there were no significant differences on the fresh weight and dry weight of the plants. They also did not exhibit differences in the length of main stem, average length of branches, number of main stem internode, number of branch internode, and the initiation time to bloom. In contrast, the number of branch, number of male flower, and number of fruit differed significantly between the two generations.

Keywords: Climbing vegetable, Hybrid seed, Replanting

Introduction

Ridge gourd (*Luffa acutangula*) is a climbing plant with edible fruits (Lakitan *et al.,* 2022). This plant is an economically important vegetable that is widely cultivated in China, India, and Southeast Asia (Pootakham *et al.,* 2021). It can be cultivated in urban ecosystems. The climbing vegetables is also known as liana. Conventionally, ridge gourd may produce a quantity of fruit 19.92 kg per plant with a weight of 1.95 kg per branch (Barik *et al.,* 2018).

Ridge gourd can produce optimum if planted with high quality seeds. To increase crop yields and quality, it is necessary to use hybrid seeds. Hybrid seeds are still widely used in plant cultivation activities even if they are costly for farmers. In many crops, an F1 hybrid contains the entire mix of both parent's genetic materials (Marie *et al.,* 2020). The cost of hybrid seeds is much more

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expensive. Utilization of second-generation hybrid seeds is an alternative in cultivation.

The increase in population, frequent occurrence of extreme weather events, limited amount of arable land, inadequate use of urban space, and other factors are threatening food security as urbanization spreads throughout the world (Xie *et al.,* 2022). Urban farming is one of the new trends that is slowly emerging and has the potential to be a solution to the developing food insecurity issues (Ivascu *et al.,* 2021). It can also optimize the efficiency of narrow land. Overall, urban farming has the potential to improve food supply, public health, the local economy, social integration, welfare, and environmental sustainability (Tapia *et al.,* 2021).

In urban ecosystems, ridge gourds can grow in pots. To grow vertically and improve light absorption, climbing plants required external support (Gianoli, 2015). Polyvinyl chloride (PVC) can be used to create plant support frames (Blanco *et al.,* 2021). It can be built above a concrete pool filled with freshwater fish to utilize the limited space available in urban environments. This fruit vegetable has a long harvest period so ridge gourd can be harvested on a regular basis to fulfill household food demands.

This study was designed to evaluate the productivity and fruit quality of ridge gourd plants regrown from seeds harvested from hybrid parents cultivated in tropical urban areas.

Materials and methods

Research sites

The research was carried out in Jakabaring (104°46'44" E, 3°01'35' S), Palembang, South Sumatra. The research location was within a research facility, recognized as a tropical urban climate with high rainfall and relative humidity (Figure 1).

Research setup

The research was conducted in two stages, the first stage was carried out at 26 March until 16 May 2022, and the second stage was carried out at 6 July until 21 September 2022. The first research used Anggun Tavi cultivar which was claimed to be a commercially obtained phenotype 1 (F1). Furthermore, the seed produced by the F1 was replanted as phenotype 2 (F2) as well as the second stage of the research.

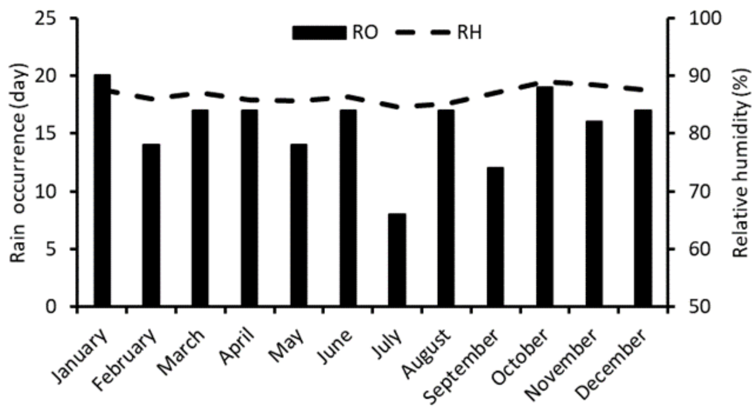

Figure 1. Monthly rain occurrence (RO) and average relative humidity (RH) during the research conducted (Source: Indonesian Meteorological, Climatological, and Geophysical Agency)

Each plant was planted in pot 30 cm in dimeter x 30 cm in height. The pot was filled with a mixtured substrate of soil, chicken manure, fine sand and rice-husk biochar (6:2:1:1). The substrate was added with bio-fungicide at concentration of 2 g/l (200 ml/pot), then the substrate was incubated for 1 week. The bio-fungicide contained living microorganisms consist of *Streptomyces* sp., *Geobacillus* sp., *and Trichoderma* sp.

The pots were arranged on both sides of a 4 x 2 m (length x width) experimental pond. A 4 x 2 x 2 (length x width x heigh) frame made of 1-inch diameter PVC pipes. Nylon fishing line with a thickness of 0.5 mm is woven with a distance of 25 cm x 25 cm vertically and horizontally on the sides and top to help the plant to climb. The vertical lines were intended for the main stem to elongate vertically, while the horizontal lines were provided for branches to horizontally grow. The above part of the nets was also reserved for fruit hanging.

Two seeds are planted directly into the growing medium in pots but only one good plant seedling is maintained until harvest. The selected plants were periodically fertilized, protected from pest attacks, and regularly watered. The NPK fertilizers were applied at a dosage of 5 g/plant at the early vegetative stage, early flowering stage, and mid-fruiting period. Meanwhile, fruit flies were controlled using trap bottles hung on climbing frames. The bait used was methyl eugenol attractant liquid at 800 g/l moistened on layered cotton.

Data collection

The length of main stem, leaf number, and SPAD value were measured on the F1 and F2 plants; meanwhile, the leaf expansion rate was calculated based on daily changes of the area of selected leaves. In our previous study, the leaf area (LA) of the ridge gourd plant could be non-destructively and accurately estimated using the leaf length and/or width as predictors (Lakitan *et al.,* 2022). The yield parameters measured were flowering time, fruit volume, fruit density, and fruit weight. Daily fruit enlargement rates were calculated based on fruit volumes.

The destructive observation was also carried out at 8 weeks after planting (WAP) for F1 plants and at 11 weeks after planting (WAP) for F2 to monitor the final stage of plant growth. The parameter was measured consist of stem length, stem fresh weight, stem dry weight, number of stem internode, number of branch, branch length, number of branch internode, branch fresh weight, branch dry weight, number of male flower, number of fruit, root length, root fresh weight, and root dry weight. The SPAD value was measured using a chlorophyll meter (SPAD-502 Plus, Konica-Minolta Optics, Inc., Osaka, Japan). The fruit and stem diameters were measured using digital vernier caliper with resolution 0.01 mm. Furthermore, all plant components are dried in an oven at 100°C for 24 hours to obtain dry weight data. Fruits are thinly sliced at a thickness of 2-3 mm before drying.

Data analysis

All data were analyzed by student t-test using R Studio software version 1.14.1717 for Windows (developed by RStudio team, PBC, Boston, MA) with $P < 0.05$ was referred as statistical significance. Furthermore, correlation analysis was carried out to determine the relationship between selected variables.

Results

Stem elongation, leaf count and enlargement

The elongated main stem and leaf count increased in the ridge gourd plants during the vegetative phase followed an exponential curve pattern until 28 days after planting (Figure 2). The process of the main stem elongation concurrently occurred with development of a new leaf on each new node. During the period of exponential growth, the length of each internode also increased significantly.

The ridge gourd leaf blade has a heart-like shape so that the leaf blade is longer than the midrib. Based on the order in which the leaves are formed along the main stem, the size of the midrib length, leaf blade length, and leaf blade width gradually increased but after that the leaf size became relatively constant. The leaf blade size was significantly smaller for leaves growing around the base of the main stem compared to those at the middle section of the main stem. Meanwhile, the leaves at the end section of the stem were still young and actively enlarging. Enlargement of leaf size in the ridge gourd plant took place actively during the first 7 days after the leaf blade unfolded and then slowed down afterward (Figure 3).

Ridge gourd response to NPK fertilizer

The response of ridge gourd to NPK fertilization at early vegetative and reproductive stages were different. The SPAD value of leaves after NPK application in the vegetative phase continued to increase up to 18 days; however, application at the reproductive phase showed that the leaf SPAD value increased immediately after NPK application; yet began to decline earlier, commencing on day 8 (Figure 4). This indicated that NPK uptake took place faster after ridge gourd plants enter the reproductive phase.

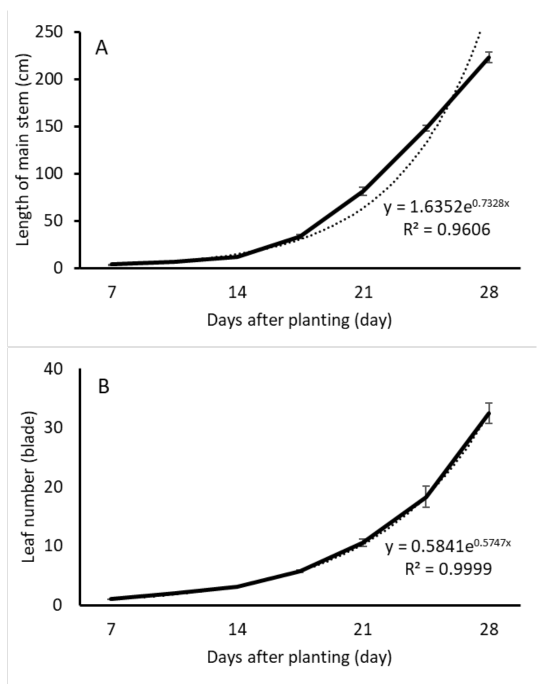

Figure 2. The elongation of main stem (A) and leaf count (B) during the early vegetative stage in the ridge gourd plant

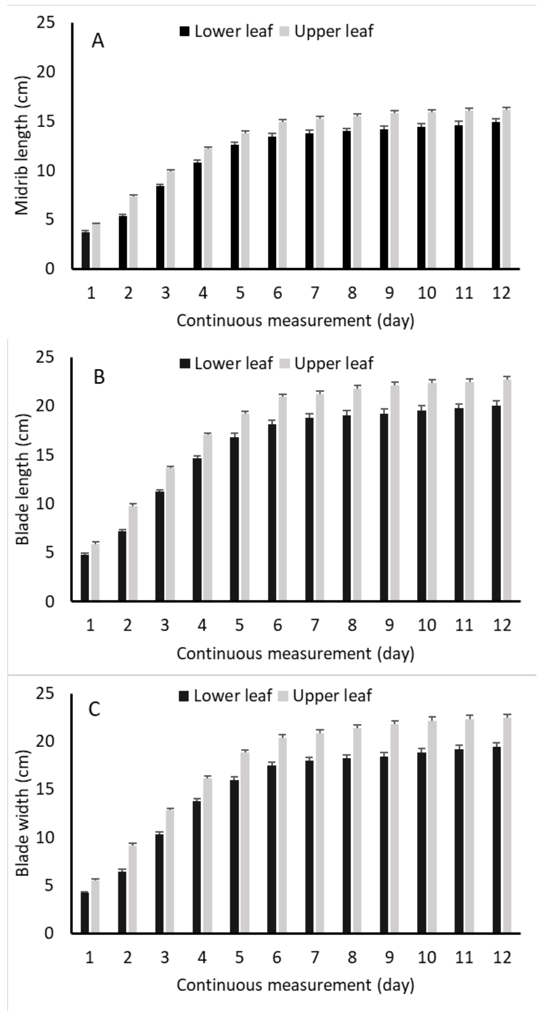

Figure 3. Increases in midrib length (A), blade length (B), and blade width (C) in the ridge gourd leaf during the first 12 days

Comparing fruit growth between F1 and F2

This study used commercial hybrid (F1) seeds. After the ridge gourd fruit was harvested, the seeds were collected for the next planting period (F2). The length and diameter of the fruits harvested were compared between F1 and F2 plants. The results showed that the fruit diameter did not differ significantly, but the fruit length of the F2 plant was significantly longer compared to the fruit of the F1 plant (Figure 5). The fruit elongation curve started to bend earlier than the fruit diameter curve. This early bending event could be an indication of slowing down the fruit lengthening process. Meanwhile, enlargement of fruit diameter is more likely caused by initiation and enlargement of seeds inside the fruit. As the fruit elongation process of the ridge gourd plants begins to slow down, it is the best time to harvest, because the fruit has reached its maximum size, but the seeds have not yet enlarged and hardened.

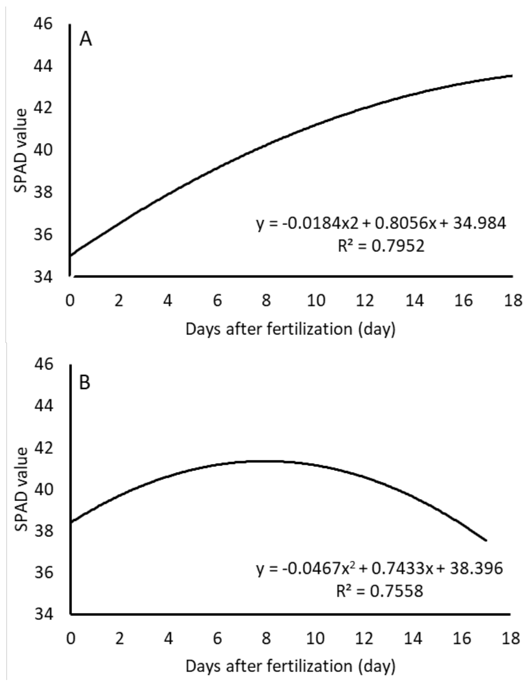

Figure 4. Leaf SPAD value in response to NPK fertilizer at vegetative phase (A) and reproductive phase (B)

Yield characteristic

The fresh weight of ridge gourd fruit depended on its length, diameter, and combination of length and diameter; but it was not affected by the ratio of length to diameter. However, the fruit size of F1 plants is more uniform compared to F2 plants, as indicated by the higher coefficient of determination (R2) in F1 plants (Figure 6).

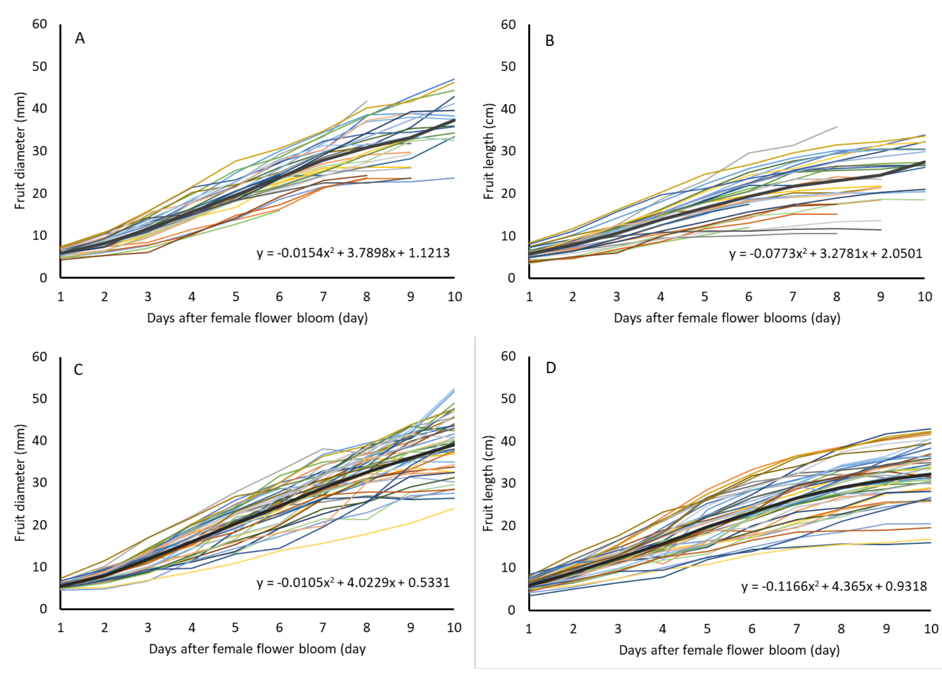

Figure 5. Comparison of the length (A, C) and diameter (B, D) of the ridge gourd fruit between F1 (A, B) and F2 (C, D) plants

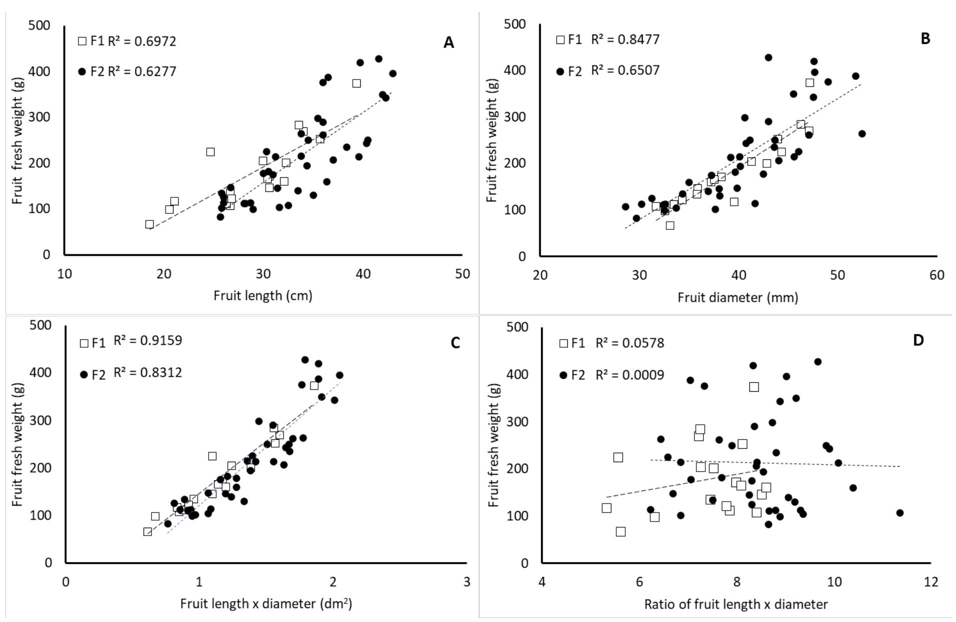

Figure 6. The fresh weight of ridge gourd fruit F1 and F2 is related to length (A), diameter (B), and combination of both (C), but not related to ratio of fruit length/diameter (D)

The length and diameter of the fruit are geometrically related to the volume of the fruit while fruit density is more related to the initiation and enlargement of cotyledons inside the seed coat. The fruit enlargement process takes place much earlier than the seed filling process. This phenomenon that caused length and diameter was closely related to the volume of the fruit, but not related to the fresh weight of the fruit (Figure 7). In this case, there was no significant difference between F1 and F2 plants, because the process of fruit enlargement and seed filling was similar.

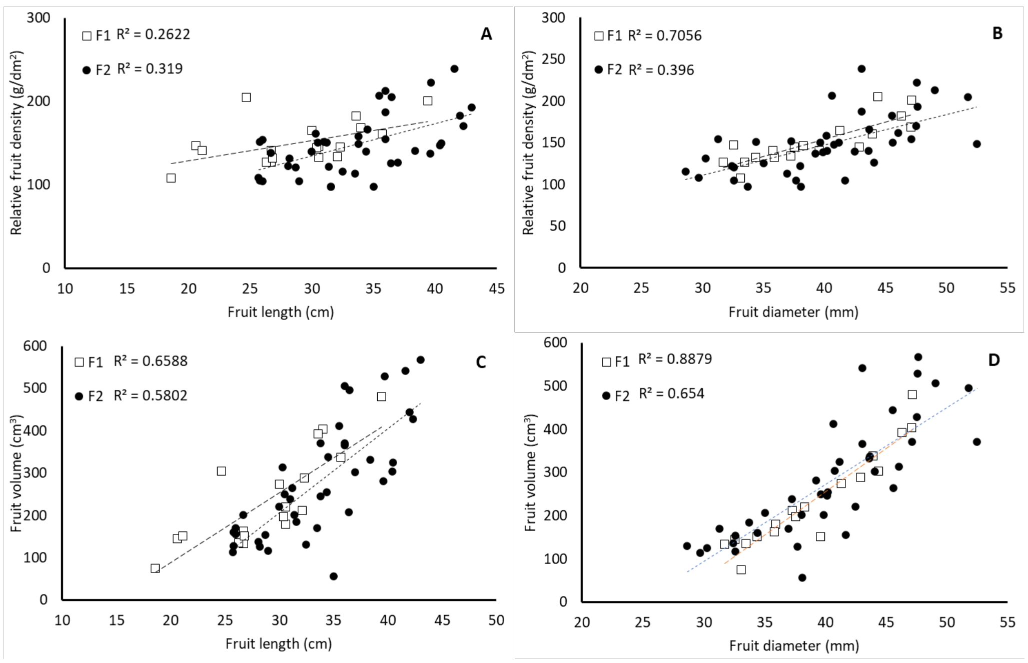

Figure 7. Fruit length (A, C) and diameter (B, D) affects fruit volume (C, D) but not fruit density (A, B) in both F1 and F2 plants

Among the main components of the plant, most of the fresh weight or dry weight accumulated on the main stem, only a small part was allocated for the growth of branches. More than half of the total biomass, both in wet and dry conditions, accumulates in the above-ground organs rather than in the roots. However, the growth trend of the main stem is more dominant in F1 plants than F2 (Figure 8), but at low confidence level ($p < 0.05$).

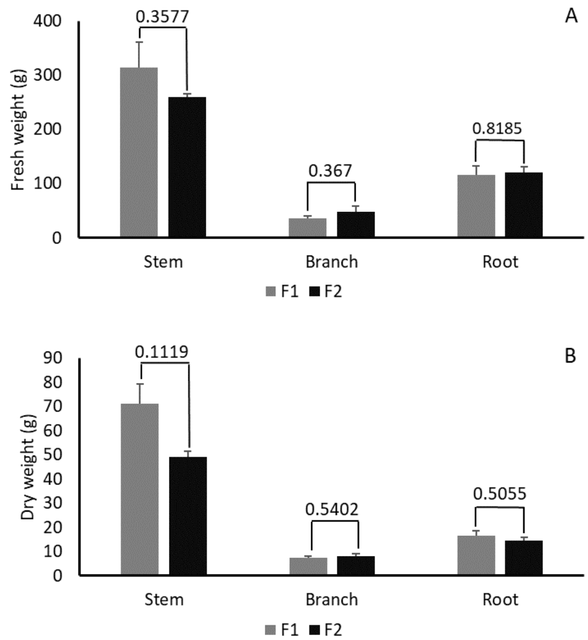

Figure 8. Fresh weight (A) and dry weight (B) comparison between main stem, branches, and roots in F1 and F2 ridge gourd plants

The variability of morphological traits was high within the respective groups of F1 plants and F2 plants, causing the difference in mean values between these two groups to be statistically indifferent. In this case, noticeable differences were only detected in the variables of the number of male flowers, the number of fruits, and the number of branches. Collectively, F1 plants outnumbered F2 plants for all three variables (Table 1).

Table 1. Plant characteristics based on phenotype

Observed variables	F1			F2			P-value	
Length of main stem (cm)	500.63	±	38.17	475.38	±	21.19	0.6022	
Branch length (cm)	143.28	±	13.37	162.06	±	10.00	0.3283	
Root (length)	84.04	±	6.68	64.04	±	2.75	0.7970	
Flowering time (day)	26.67	±	0.88	24.67	±	0.67	0.1500	
Number of male flower	80.33	±	6.68	51.89	±	6.72	0.0399	**
Number of fruit	14.00	±	1.30	6.28	±	0.56	0.0155	**
Number of branch	9.00	±	0.50	6.39	±	0.29	0.0174	**
Number of main stem internode	38.75	±	2.67	37.28	±	0.64	0.6409	
Number of branch internode	12.46	±	0.76	13.43	±	0.73	0.4089	

Means of F1 and F2 were compared by Student's t-test ($p < 0.05$)

Discussion

Growth pattern of climbing plant

The stem and leaf play important roles in the structure and function of climbing plants. The stem organ is involved in elongating the plant along its path, while the leaf contributes to increasing the total leaf area. Nevertheless, there were occasions when the growth of both organs ceased. Therefore, it was crucial to monitor the growth of climbing plants, particularly focusing on the stem and leaf organs. Earlier studies on different types of climbing plants had highlighted the significance of closely observing the progress of stem and leaf structures. A number of the mentioned research studies involved the examination of plant species like bottle gourd (Sithole and Modi, 2015) and cucumber (Kehinde-Fadare *et al.,* 2022).

The growth of the stem and leaf in ridge gourd displays a distinct characteristic. Based on the study, the stem length and leaf number consistently increased. The stem of ridge gourd exhibits twining growth. Sperotto *et al.* (2020) reported that several climbing plants have classified in the twining stem growth. Fiorello *et al.* (2020) stated that the stem of the twining climbing plant followed the twisting movements. In order to facilitate this movement, the elongation of the stem was always accompanied by the emergence of other structures, such as tendrils (Burris *et al.,* 2018). The elongation stem of the climbing plant was strongly influenced by environmental factors (Lehnebach *et al.,* 2022). The leaf growth of ridge gourd increased as the plant ages. Mitha *et al.* (2023) reported that appropriate cultivation techniques contributed to an increase in leaf numbers.

Monitoring individual leaf growth is crucial, particularly for determining the optimal function of this important organ. Lakitan *et al.* (2023) observed that leaves experienced a period of stagnation after fully expanding. In the case of ridge gourd, the leaf expansion was slowing down after the 6 days of exponential growth. The enlargement patterns of the lower and upper leaves exhibited similarities, although there was a noticeable variability in size. The increased size of the middle leaves is a result of the distribution of nutrients from the lower leaves to the developing cells. According to Jiang *et al.* (2021), each plant species showed different characteristics between the upper and lower leaf surfaces due to the uneven distribution of absorbed materials by the plants.

SPAD value on growth stages

SPAD value can reflect the concentration of nutrients contained in the leaf. The determination of nitrogen status using the SPAD value approach has been confirmed in several cultivated crops (Yang *et al.,* 2022). Furthermore, the determination of SPAD value in response to fertilization had also been reported in other climbing plants, such as grapevine and blueberry (Raffa *et al.,* 2022; Lafond, 2023).

The SPAD value of ridge gourd leaf generally increased immediately after fertilizer application. Lakitan *et al.* (2021) reported that SPAD value had gradually increased after the fertilizer application. This condition suggests that the plant had absorbed the applied fertilizer. Then, followed by the accumulation of nitrogen in the treated leaf (Zhang *et al.,* 2020).

During the vegetative phase, nitrogen uptake is primarily accumulated in the leaves, resulting in high leaf SPAD values. Muda *et al.* (2022) reported that plants in the vegetative phase continued to show an increase in SPAD values after the application of fertilizer. Conversely, there was a decrease in the SPAD response upon entering the reproductive phase. Kandel (2020) stated that the nitrogen accumulation in the leaves decreased during this phase, leading to a decrease in the SPAD value. Wang *et al.* (2018) also found a similar trend, where the SPAD value of plants decreased after entering the reproductive phase. This consistent pattern had been observed in other studies conducted on long beans and luffa as well (Wang *et al.,* 2021). This phenomenon was believed to be a result of leaf senescence, which hinders nitrogen accumulation in the leaf.

Difference growth among F1 and F2

There were differences in growth characteristics between F1 and F2 plants, although statistically not always significant. In fruit growth, F2 plants exhibited longer fruits, although with a non-significant difference in diameter compared to the fruits produced by F1 plants. A similar phenomenon had been observed in tomatoes, where F1 produces smaller fruits compared to the F2 plant (Rodríguez *et al.,* 2006). However, in chili fruit, the F2 generation produced fruits that were not longer than those produced by F1 (Srivastava *et al.,* 2019).

The fruit undergoes rapid growth initially, followed by a gradual slowdown starting at 7 days after anthesis. The development of fruit was influenced by the growth of fruit cells, leading to changes in the shape and structure of the fruit (Wang *et al.,* 2022). Yang *et al.* (2022) reported that several factors, including genetics and the environment, were found to be associated with fruit development. As a vegetable fruit, ridge gourd should be harvested at the appropriate stage of maturity for cooking purposes. Therefore, it is important to consider the level of fruit maturity. The ideal time to harvest the ridge gourd fruit was around 10 days after anthesis. At this stage, the fruit reached optimal size and did not contain fully formed seed.

The growth of vegetative and generative organs in both F1 and F2 plants was different, especially in terms of the number of branches, number of male flowers, and number of fruits. Meanwhile, the stem length in F1 was confirmed to be longer compared to F2 plants, although not significantly. Guo-shen *et al.* (2016) reported that F1 watermelons have longer main stems compared to subsequent generations.

The growth performance of F1 and F2 plants can be interpreted through the fresh and dry weight of each plant organ. Although both parameters were not significant, there was a tendency for F1 to be higher than F2. This was due to the fact that F1 demonstrated higher vigor compared to its parent plants, whereas a decrease was observed in subsequent generations (F2) (Bhargav *et al.,* 2022). The growth superiority of F1 compared to F2 had also been evidenced in other plant species, including *Lens culinaris* (Tan *et al.,* 2022).

Based on research, differences in hybrid F1 generation and F2 generation showed results that did not differ significantly on fruit diameter, distribution of fresh weight and dry weight of plants in sink organ, length of main stem, branch length, number of main stem internode, number of branch internode and flowering time. However, vegetative growth and sexual organs such as the number of branches, the number of male flowers, and the number of fruits significantly different in different generations.

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