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Growth and Yield Performance of Cayenne Peppers in Ultisols

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ABSTRACT

Cayenne peppers (Capsicum annuum L.) are horticultural commodities with high economic value and increasing market demand, both for household consumption and large-scale processing industries. However, cayenne pepper productivity in Indonesia remains relatively low, partly due to the limited availability of fertile land. One potential solution to this problem is the utilization of marginal lands, including ultisols. Ultisols possess chemical characteristics that are less favorable for optimal plant growth, such as low pH, poor nutrient content, and high aluminum saturation. Therefore, this study aimed to obtain information on cayenne pepper genotypes that can adapt well and produce optimally on ultisols. The research was conducted at the Experimental Garden of the Faculty of Agriculture, University of Bengkulu, from May to October 2023, using a Randomized Complete Block Design (RCBD) with three replications. Observed parameters included plant height, first dichotomous height, stem diameter, number of dichotomous points, total leaf area, shoot dry weight, stomatal density, days to first harvest, number of fruits per plant, fruit length and diameter, fruit weight per plant, and percentage of marketable fruits. Data were analyzed using ANOVA at a 5% significance level and followed by Duncan's Multiple Range Test (DMRT) at the same level. The results indicated significant differences among genotypes in most growth and yield parameters. The genotypes 'Iggo' and 'Lajang' exhibited superior performance, with the highest dry biomass weight and the highest fruit weight per plant. These findings suggest that the 'Iggo' and 'Lajang' genotypes hold strong potential for cultivation on Ultisol soils to support sustainable national cayenne peppers production improvement.

Keywords: *crop productivity, environmental resilience, genotype testing, land use efficiency*

INTRODUCTION

Cayenne peppers (*Capsicum annuum* L.) is one of the high-value horticultural commodities in Indonesia. The demand for red chili continues to increase in line with population growth and the expansion of the food industry, which relies on chili as a primary raw material (Pusat Data dan Sistem Informasi Pertanian, 2023). In addition to being a culinary spice, red chili also has functional value in the health sector due to its bioactive compounds such as capsaicin, flavonoids, vitamin C, vitamin E, beta-carotene, and beta-cryptoxanthin, which act as antioxidants and anti-inflammatory agents, and have potential in preventing degenerative diseases and cancer (Rahardian, 2022).

Although national cayenne peppers production has shown an increasing trend, the imbalance between supply and demand remains a major issue. According to data from the Central Statistics Agency (BPS, 2022), cayenne peppers production in 2021 reached 1,360,571 tons, an increase of 9.94% compared to the previous year. However, cayenne peppers prices continued to rise, reaching IDR 48,909.00/kg in January 2022. This condition indicates that the increase in production has not yet fully met market demand. Furthermore, data from Kementerian Pertanian (2024) show an increase in cayenne peppers import volume from 48.5 thousand tons in 2022 to 60.1 thousand tons in 2023, confirming the persistent shortage in domestic supply.

In an effort to increase agricultural productivity, the availability of fertile land remains one of the limiting factors. Therefore, the utilization of suboptimal land, such as ultisols, has become a strategic alternative (BBSDLP, 2022). Ultisols are a type of soil characterized by low pH (<5.5), low base saturation (<50%), high aluminum content, and low nutrient availability, requiring specific management practices to be used productively (Murtilaksono & Anwar 2014). Globally, ultisols cover approximately 11 million km² or about 8.5% of the Earth's surface (Fiantis, 2017). In Indonesia, ultisols occupy around 45,794,000 hectares, or about 25% of the country's total land area (Prasetyo, 2006), making them one of the most extensive soil types with significant potential for development into productive agricultural land.

However, cultivating cayenne peppers on ultisols faces various agronomic challenges. Without appropriate treatments, the growth and yield of cayenne peppers on ultisols tend to be low (Budiyati *et al*., 2023). Physical factors such as compact soil structure, slow water infiltration, and low water retention capacity further worsen plant growth conditions (Septiaji *et al*., 2024). The selection of genotypes that can adapt to specific environments is crucial, considering that the performance of cayenne peppers genotypes is highly influenced by the agroecosystem in which they are grown. Some genotypes exhibit high productivity in one location but lack stability in others (Sayekti *et al*., 2021). Therefore, genotype evaluation based on morphological traits and yield, in accordance with the characteristics of ultisols, is necessary (Ratna *et al*., 2024).

Accordingly, this study aims to identify the best-performing cayenne peppers genotypes that are capable of adapting and producing optimally on ultisols.

MATERIALS AND METHODS

Study site and soil characteristics

The research was conducted from May to October 2024 at the experimental farm of the Faculty of Agriculture, University of Bengkulu, located in Beringin Raya, Bengkulu City, at an altitude of approximately 10 meters above sea level. The study was carried out using Ultisol soil. The soil at the experimental site has been classified as Ultisol, in accordance with previous studies conducted by Andriani & Bertham, (2016). The soil at the research location is characterized as acidic and low in nutrient content. A preliminary soil analysis was conducted prior to planting to determine parameters such as pH, total nitrogen (N), available phosphorus (P), exchangeable potassium (K), cation exchange capacity (CEC), organic matter (OM), and exchangeable aluminium (Al-dd). Soil samples were taken from a depth of 0–20 cm at six different points, then mixed and analysed at the Soil Science Laboratory, University of Bengkulu.

Experimental design

A Randomized Complete Block Design (RCBD) was used with a single treatment factor, consisting of 20 cayenne peppers genotypes. Each treatment was replicated three times, resulting in a total of 60 experimental units. Each unit consisted of a raised bed measuring 1 m × 4 m, planted with 20 plants arranged in two rows (10 plants per row) with uniform spacing.

Seedling preparation and planting

Eighty seeds of each genotype were germinated on moist tissue paper for three days until the radicles emerged. The germinated seeds were then transferred to seedling trays filled with a mixture of manure and topsoil at a 1:1 ratio (v/v). The seedlings were maintained for four weeks with daily watering and weekly pest control. After this period, healthy seedlings were transplanted to the raised beds. Planting holes were watered before transplanting, and the soil around the roots was slightly elevated to support plant stability.

Plant maintenance

Fertilization is done using Urea at a dose of 400 kg ha^{-1}, SP-36 at 400 kg ha^{-1}, and KCl at 150 kg ha^{-1} (Herison *et al*., 2021). Half of the Urea dose, along with the entire SP-36 and KCl, is applied during planting, 10 cm away from the planting hole. Additional fertilization is carried out weekly using NPK 16-16-16, Mutiara Grower, Karate Plus Boroni, Powersoil, and MKP. Foliar fertilization is done using Gandasil D, Growmore, Ecoenzyme, and MKP. Drip irrigation is used every morning and evening, provided there is no rain, for 10 minutes. Pest and disease control is implemented with carbofuran application during planting, followed by weekly spraying using insecticide (imidacloprid), fungicide (propineb, mancozeb), and acaricide (pyridaben) at concentrations of 1–2 mL L^{-1} or 1–2 g L^{-1} (Herison *et al*., 2021). Replanting is done one week after planting. Water shoots below the dichotomous branching are routinely pruned. Bamboo stakes, 100 cm in height, are installed 21 days after planting and are tied with plastic strings.

Data collection

Vegetative parameters observed included plant height, the height of the first dichotomous branching, total leaf area, number of dichotomous branching points, stem diameter, stomatal density, and plant dry weight. Plant height was measured at 10 weeks after planting (WAP), from the soil surface to the highest growth point, while the height of the first dichotomous branching was measured during the flowering stage. Total leaf area was measured on the fifth leaf from the apex using calibrated Image-J software. The number of dichotomous branches was counted at final harvest based on the number of formed branches. Stem diameter was measured using a caliper at the third internode from the soil surface. Stomatal density was observed from an impression of the leaf surface made using a clear nail polish layer and clear tape, then examined under a microscope at 400× magnification to count the number of stomata per mm². Plant dry weight was obtained by weighing the aboveground biomass after oven-drying at 75 °C until a constant weight was reached.

Generative and Yield Parameters observed included days to first harvest, number of fruits per plant, fruit diameter and length, fruit weight per plant, and percentage of marketable fruits. Days to first harvest were recorded from the day of planting to the date of the first harvest. The number of fruits per plant was obtained from the total number of fruits harvested from each plant during the production period. Fruit diameter and length were measured on 10 representative fruits per plant using a caliper and a ruler; diameter was measured at the widest part of the fruit, and length was measured from the base to the tip. Fruit weight per plant was calculated from the total fresh weight of all fruits harvested from each plant during the harvest period. The percentage of marketable fruits was determined based on the number of fruits meeting quality criteria—namely, those without defects, rot, holes, or signs of pest or disease infestation.

Data analysis

The data were analyzed using Analysis of Variance (ANOVA) at a 5% significance level using the F-test. When significant differences were found, Duncan's Multiple Range Test (DMRT) at the 5% level was applied to compare the mean values among genotypes.

RESULTS AND DISCUSSION

The study was conducted in a location with an average temperature of 28.5 °C and humidity of 82%. The average rainfall was 162.6 mm, with a daily sunshine duration of 6.6 hours. The research site consisted of Ultisols soil with a pH of 4.13 and low nutrient content (N 0.37%, C 2.11%, P 4.31 ppm, K 0.31 me 100 g^{-1}, Al-dd 2.61 me 100 g^{-1}, and Cation Exchange Capacity (CEC) of 18.68 me 100 g^{-1}). The plant survival rate was 97.1%, with 85.9% growing normally, 9.49% experiencing leaf curling, 1.44% stunted growth, and 2.88% dying due to pest infestations. During the vegetative phase, plants were attacked by armyworms (*Spodoptera litura*), which defoliated the leaves, and thrips, which caused leaf curling. Thrips populations were higher in the dry season and decreased during rainfall. In the generative phase, fruit borers and fruit flies (*Bactrocera spp.*) caused fruit rot and premature drop. Fruit borers created holes in the chili walls, while fruit flies laid eggs at the base of the fruit, leading to rotting and fruit drop before harvest.

The data obtained from all observed variables were analyzed using Analysis of Variance (ANOVA) with a 5% F-test. The results of the variance analysis indicated that the significantly affected variables included plant height, total leaf area, first harvest age, number of fruits per plant, fruit diameter, fruit length, fruit weight per plant, and fruit weight per bed. However, no significant effects were observed for other variables. The quantitative traits analyzed exhibited different coefficients of variation (CV) within each genotype, ranging from 2.05% to 31.8%. According to Sari *et al*. (2014), the CV values are categorized as low (0% to <25%), moderately low (25% to <50%), fairly high (50% to <75%), and high (75% to 100%). Based on these criteria, the CV values obtained in this study fell within the low to moderately low categories. This indicates that the measurement accuracy was relatively high (Table 1).

The data marked with the symbol "T" represent transformed data. This transformation was performed to approximate a normal distribution, ensuring more valid regression analysis or ANOVA results. The method used was square root transformation (square root) (Tabel 1).

Table 1. ANOVA Results for growth and yield traits of Cayenne Peppers in Ultisols

Variables	F-value	CV (%)
Plant height	5.70^{*}	8.92
First dichotomous height	2.36^{*}	15.50
Total leaf area^{T}	16.2^{*}	31.80
Number of dichotomous points^{T}	2.27^{*}	22.30
Stem diameter	2.18^{*}	11.70
Stomatal density^{T}	1.55^{ns}	15.70
Plant dry weight^{T}	1.98^{*}	17.50
Days to harvest	399^{*}	2.05
Number of fruits per plant	8.55^{*}	27.60
Fruit diameter	42.7^{*}	10.30
Fruit length	19.4^{*}	11.60
Fruit weight per plant^{T}	5.62^{*}	18.60
Marketable fruit	2.71^{*}	25.30
F-table 5%	1.87	

Note: * indicates a statistically significant effect based on F-value ≥ F-table at the 0.05 significance level; ns = not significant; CV = coefficient of variation; T = data transformed using √x.

The observation results showed that the 'Perintis' genotype had the highest plant height (71.0 cm), but it was not significantly different from the 'Iggo', 'Caman', 'Romario' and 'Vitra OP' genotypes. However, it was significantly different from the 'Sempurna', 'Andalas', 'Landung', 'Bali 77', 'Kawat', 'Lajang', 'Laris', 'Labek', 'Horison', 'Aka', 'Tenggo', 'Ferosa' and 'Gelora' genotypes. The lowest plant height was observed in the 'Anies IPB' genotype (40.0 cm), which was significantly different from the other genotypes. The highest first dichotomous height was found in the 'Perintis' genotype (31.5 cm), with no significant difference from the 'Romario', 'Sempurna', 'Horison', 'Iggo', 'Andalas', 'Kawat', 'Bali 77', 'Lajang', 'Tenggo', 'Landung', 'Labek', 'Aka', and 'Vitra OP' genotypes. The lowest first dichotomous height was recorded in the 'Ferosa' genotype (17.7 cm). The highest total leaf area was observed in the 'Sempurna' genotype (503 cm^2), but it was not significantly different from the 'Horison', 'Anies IPB', 'Iggo', 'Andalas', 'Kawat', 'Gelora', 'Bali 77', 'Lajang', 'Perintis', 'Landung', 'Labek', 'Caman', 'Romario' and 'Vitra OP' genotypes. However, it was significantly different from the 'Ferosa', 'Laris', 'Aka' and 'Tenggo' genotypes (Table 2).

The highest number of dichotomous points was observed in the 'Tenggo' genotype (600 points), with no significant difference from the 'Sempurna', 'Romario', 'Iggo', 'Andalas', 'Kawat', 'Gelora', 'Ferosa', 'Bali 77', 'Lajang', 'Laris', 'Perintis', 'Labek', 'Caman', 'Aka' and 'Vitra OP' genotypes. The lowest number of dichotomous points was recorded in the 'Landung' genotype (162 points). The largest stem diameter was found in the 'Iggo' genotype (11.7 mm), with no significant difference from the 'Sempurna', 'Andalas', 'Kawat', 'Ferosa', 'Tenggo', 'Laris', 'Perintis', 'Landung', 'Caman', 'Romario' and 'Vitra OP' genotypes. The smallest stem diameter was observed in the 'Anies IPB' genotype (7.67 mm). The highest stomatal density was recorded in the 'Gelora' genotype (14.40 mm^2), with no significant difference from the other genotypes. The lowest stomatal density was observed in the 'Lajang' genotype (9.92 mm^2). The highest dry biomass weight was found in the 'Iggo' genotype (88.3 g), with no significant difference from the 'Sempurna', 'Kawat', 'Gelora', 'Ferosa', 'Tenggo', 'Laris', 'Perintis', 'Caman', 'Romario' and 'Vitra OP' genotypes. The lowest dry biomass weight was recorded in the 'Landung' genotype (35.0 g) (Table 2).

Table 2. The average vegetative growth of 19 cayenne peppers genotypes.

Genotypes	Plant height (cm)	First dichotomous height (cm)	Total leaf area (cm^2)	Number of dichotomous points	Stem diameter (mm)	Stomatal density (stomatal mm^{-2})	Dry biomass weight (g)
Sempurna	60.7 b-f	28 a-d	4317 a	503 a	10.0 abc	10.33 a	70.0 ab
Horison	55.0 d-g	27.7 a-e	1334 bc	165 bcd	8.00 cd	14.05 a	36.7 cd
Anies IPB	40.0 h	20 h	403 c	101 d	7.67 d	12.08 a	27.7 d
Iggo	69.0 ab	27.7 a-e	2230 ab	431 ab	11.7 a	12.68 a	88.3 a
Andalas	61.3 b-f	29.3 abc	2126 abc	409 abc	9.67 a-d	12.62 a	55.7 a-d
Kawat	57.0 c-g	24 d-h	2046 abc	369 abc	9.67 a-d	11.25 a	53.0 a-d
Gelora	49.3 g	20.7 gh	1690 bc	296 a-d	10.0 abc	14.40 a	57.0 a-d
Ferosa	51.7 fg	23 fgh	1341 bc	421 ab	10.7 ab	12.91 a	60.0 a-d
Bali 77	59.3 b-g	26.7 b-f	1189 bc	228 a-d	9.33 bcd	10.84 a	39.7 bcd
Lajang	59.0 c-g	25.3 c-f	1258 bc	274 a-d	9.33 bcd	9.92 a	41.3 bcd
Tenggo	53.3 efg	25 def	1288 bc	600 a	9.67 a-d	11.64 a	62.3 abc
Laris	57.3 c-g	23 fgh	1323 bc	405 abc	10.0 abc	11.91 a	66.0 abc
Perintis	71.0 a	31.7 a	2381 abc	459 ab	10.0 abc	12.54 a	69.3 abc
Landung	61.0 b-f	23.7 e-h	717 bc	162 cd	10.0 abc	9.55 a	35.0 bcd
Labek	56.3 c-g	25.7 c-f	2267 ab	454 ab	9.00 bcd	10.58 a	43.7 bcd
Caman	65.3 abc	26.7 b-f	1788 abc	400 abc	10.0 abc	11.72 a	47.0 a-d
Romario	63.7 a-d	30.3 ab	2696 ab	551 a	9.67 a-d	11.07 a	66.3 abc
Aka	53.7 d-g	24.3 d-g	1149 bc	374 abc	9.00 bcd	10.71 a	37.7 bcd
Vitra OP	62.3 a-e	24.7 d-g	1976 abc	441 ab	10.0 abc	10.30 a	57.3 a-d

Note: Numbers followed by the same letter within the same column are not significantly different based on DMRT at the 5% level

The latest first harvest was observed in the 'Caman' genotype (83.3 DAP), with no significant difference from the 'Gelora', 'Bali 77', 'Romario', 'Aka', 'Tenggo', 'Ferosa', 'Anies IPB', 'Kawat', 'Perintis', 'Landung', 'Labek' and 'Vitra OP' genotypes. Meanwhile, the earliest first harvest was recorded in the 'Laris' genotype (77.3 DAP), with no significant difference from the 'Sempurna', 'Andalas', 'Lajang', 'Horison' and 'Iggo' genotypes (Table 3). The highest number of fruits per plant was found in the 'Ferosa' genotype (789 fruits), which was significantly different from all other genotypes. The lowest number of fruits per plant was recorded in the 'Landung' genotype (174 fruits), with no significant difference from the 'Anies IPB', 'Horison', 'Gelora', 'Bali 77', 'Kawat', 'Labek', 'Caman', 'Aka' and 'Laris' genotypes (Table 3).

The largest fruit diameter was observed in the 'Landung' genotype (13.0 mm), which was significantly different from all other genotypes. The smallest fruit diameter was found in the 'Ferosa' genotype (5.33 mm), with no significant difference from the 'Andalas', 'Kawat', 'Perintis', 'Labek', 'Romario', 'Sempurna', 'Tenggo' and 'Aka' genotypes. The longest fruit was recorded in the 'Caman' genotype (18.0 cm), which was significantly different from all other genotypes. The shortest fruit was observed in the 'Romario' genotype (9.67 cm), with no significant difference from the 'Anies IPB', 'Kawat', 'Gelora', 'Ferosa', 'Bali 77', 'Horison', 'Tenggo', 'Andalas' and 'Laris' genotypes. The highest fruit weight per plant was found in the 'Iggo' genotype (315 g), with no significant difference from other genotypes. The lowest fruit weight per plant was recorded in the

Table 3. The average generative growth, yield components, and yield of 19 cayenne peppers genotypes

Genotypes	Days to harvest (DAP)	Number of fruits per plant	Fruit diameter (mm)	Fruit length (cm)	Fruit weight per plant (g)	Marketable fruit (%)
Sempurna	79.3 b-e	447 b-e	6.67 def	14.0 b	240 ab	91.1 ab
Horison	79.0 cde	192 f	11.7 b	10.7 def	203 ab	72.2 abc
Anies IPB	80.7 a-d	187 f	11.3 b	10.0 ef	158 b	78.2 abc
Iggo	78.7 de	473 bcd	8.00 cd	14.0 b	315 a	68.5 abc
Andalas	79.7 b-e	556 bc	5.67 ef	11.3 c-f	182 ab	96.3 a
Kawat	80.7 a-d	344 def	6.00 ef	10.3 ef	217 ab	60.4 bc
Gelora	83.0 a	248 f	10.7 b	10.0 ef	246 ab	88.0 ab
Ferosa	82.0 abc	789 a	5.33 f	10.0 ef	250 ab	95.1 ab
Bali 77	83.0 a	256 ef	11.3 b	10.0 ef	257 ab	82.8 ab
Lajang	79.3 b-e	460 bcd	7.00 de	13.3 bc	261 ab	81.9 ab
Tenggo	82.3 ab	451 b-e	6.67 def	10.7 def	177 ab	79.8 ab
Laris	77.3 e	367 c-f	8.67 c	11.7 b-f	260 ab	84.3 ab
Perintis	81.3 a-d	497 bcd	6.33 ef	12.3 b-e	172 ab	78.6 abc
Landung	81.3 a-d	174 f	13.0 a	13.0 bcd	217 ab	68.7 abc
Labek	81.3 a-d	336 def	6.33 ef	12.3 b-e	168 ab	68.5 abc
Caman	83.3 a	346 def	7.00 de	18.0 a	225 ab	23.9 de
Romario	83.0 a	572 b	5.67 ef	9.67 f	178 ab	44.2 cd
Aka	83.0 a	331 def	6.67 def	13.7 bc	200 ab	72.7 abc
Vitra OP	80.7 a-d	480 bcd	7.00 de	13.3 bc	237 ab	88.7 ab

Note: Numbers followed by the same letter within the same column are not significantly different based on DMRT at the 5% level

'Anies IPB' genotype (158 g). The highest percentage of marketable fruit was observed in the 'Andalas' genotype (96.3%), with no significant difference from the 'Ferosa', 'Sempurna', 'Gelora', 'Bali 77', 'Lajang', 'Tenggo', 'Laris', 'Vitra OP', 'Horison', 'Anies IPB', 'Iggo', 'Perintis', 'Landung', 'Labek' and 'Aka' genotypes. The lowest percentage of marketable fruit was found in the 'Caman' genotype (23.9%), with no significant difference from the 'Romario' genotype (Table 3).

Factors affecting the growth and yield of cayenne peppers plants include internal and external factors such as environmental conditions. Environmental factors significantly influencing plant growth include temperature, air humidity, sunlight exposure, water availability, and soil conditions (Widyastuti, 2023). During the study, the cayenne peppers plants experienced a mortality rate of 2.88%, which is still considered low in chili cultivation. This indicates a relatively high success rate in cultivation. The environmental factors contributing to this mortality were high temperatures and low rainfall (Appendix 4). These conditions can cause plant stress, particularly during the early growth phase, potentially inhibiting root development and reducing plant resilience to environmental stress. The optimal air temperature for cayenne peppers growth and development ranges between 25-27 °C, while the optimal humidity for growth is 70%-80% (Kalsum, 2024). Additionally, the optimal rainfall for cayenne peppers plant growth ranges from 600 to 1200 mm per year or 50 to 100 mm per month (Directorate General of Horticulture, 2024). Drought caused by suboptimal rainfall during the study affected both vegetative and generative plant growth. This aligns with the findings of Airlangga *et al*. (2023) who stated that drought stress in cayenne peppers plants leads to significant changes in various growth aspects, including flowering time, number of branches, plant height, stem diameter, stomatal count, root length, and fruit quantity.

Another factor is the condition of the research site, which consists of ultisols soil with a highly acidic pH of 4.13, low nutrient content, and high aluminum (Al) concentration. Ideal soil for chili cultivation should be loose, fertile, rich in organic matter, and have a pH between 6 and 7 (Purba, 2024). In the research area, the level of aluminum toxicity was classified as high. Excessive Al content and extremely high soil acidity prevented the plants from growing optimally. As a result, many plants experienced stunted or inhibited growth. This finding aligns with research conducted by Purnomo *et al.* (2008), which stated that Al-induced stress can interfere with plant growth and development, particularly in terms of root length, plant height, the number of harvested fruits, fruit length, fruit weight, and total yield weight.

The primary variables in selecting the best cayenne peppers genotype are plant dry biomass weight and fruit weight per plant, while other variables serve only as supporting factors. This is consistent with the findings of Lestari *et al.* (2015) which stated that fruit weight per plant is the main characteristic for selecting cayenne peppers genotypes. The results of the study, which involved 13 observation variables, showed that the highest average values for plant dry biomass weight and fruit weight per plant were obtained from the 19 cayenne peppers genotypes tested. These average values were derived from a comparison of the 19 selected cayenne peppers genotypes grown on ultisols soil. Based on the analysis, two genotypes were selected: 'Iggo' and 'Lajang'. These two genotypes had the highest and second-highest values for plant dry biomass weight and fruit weight per plant compared to the other genotypes.

CONCLUSION

Among the 19 genotypes tested in Ultisols, two genotypes, 'Iggo' and 'Lajang', were found to have the highest shoot dry weight and fruit weight per plant compared to the other genotypes.

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