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Cluster analysis of four lowland chili varieties (*Capsicum annum L.*) based on source-sink characters

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Abstract

Lowlands chili cultivation has lower productivity than highland areas in Indonesia. The increased assimilate translocation to fruit can support crop yield. Source-sink character is a method for yield evaluation. This study aimed to identify growth characteristics related to source-sink relationship and yield-limiting factors of lowland chili. This study used chili varieties adaptive to lowland conditions, namely Kencana, Lembang-1, Tanjung-2, and Ungara. The research was conducted using a randomized complete block design (RCBD) with three blocks as replications. The results based on cluster analysis and principal component analysis (PCA) of yield and yield components, showed that Kencana and Lembang-1 were classified as small-diameter chili fruit that had a similarity of 65.02%, while Tanjung-2 and Ungara as large-diameter chili fruit groups with a similarity of 51.82%. The small-diameter chili fruit group had low efficiency in fruit partition because the supply of assimilate to fruit was distrupted due to competition with leaf growth and number of fruits. The large-diameter chili fruit group had high efficiency in fruit partition by increasing root growth and fruit development but minimizing vegetative shoot growth. Thus, Tanjung-2 and Ungara had greater biomass efficiency to fruit partitioning than Kencana and Lembang-1. It was concluded that the source of assimilate was identified as yield limiting factor in lowland chili varieties

Keywords: Assimilate, lowlands, partition, sink, source

Introduction

An Increase in agricultural production is important to fill continuous demands of the increasing human population (Kleijbeuker & Lee, 2019). Chili (*Capsicum annum* L.) is one of the horticultural products needed for household and industrial consumption in Indonesia. Chili production in lowland areas is more massive than highlands in Indonesia. The area of chili cultivation in highlands is wider by 34.34% than lowland areas (Irjayanti et al., 2023). However, productivity of lowland chili (6.33 t ha^{-1}) has lower than highland (11.79 t ha^{-1}) (Irjayanti et al., 2023). The low productivity of chili in lowlands can be evaluated through plant potential with an approach source-sink. Leaf is source of assimilate through process of photosynthesis and root is source of water and minerals. Meanwhile, fruit is the main sink of chili plants. Evaluation of source-sink characters is one strategy to determine the source to support sink growth and factors that limit economic yield (Falchi et al., 2020).

Murchie et al. (2023) mentioned source is an organ that actively performs photosynthesis for plant growth such as leaves. The source capacity of leaves is related to photosynthetic capacity (Li et al., 2023). Wu et al. (2022) define leaf dry weight as a potential source. In rice, increased source capacity can be seen through an increase leaf area index, which encourages dry matter grain (Li et al., 2023). In maize, duration of leaf area can enhance dry matter accumulation during grain-filling stage, and it plays an important role in seed yield (Liu et al., 2022). While root is an organ of water source, soil nutrients, and absorbing assimilate. The root capacity can be seen through biomass, root length, and root volume (Djidonou et al., 2019). Root structure plays an important role in promoting plant growth and yield formation. In maize, an increase in root dry weight can increase uptake to maintain shoot growth (Zhang et al.,

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2023). Cao et al. (2019) reported that root length, root surface area, and root dry weight in soybeans are closely related to canopy biomass and crop yield.

In general, crop yield is affected by plant dry matter accumulation and efficiency translocation to economic organs. The dry matter allocation is influenced by sink strength such as sink capacity and sink activity (Ren et al., 2022). Increased sink capacity can promote assimilated demand for growth (Zhang et al., 2022). The harvest index is one of the parameters that can measure efficiency of dry matter partitioning (Cai et al., 2023). The harvest index can describe physiological efficiency in allocating assimilate into economic yield (Asefa, 2019). In peppers, high yields are influenced by amount of assimilate distributed in fruit set (Kleijbeuker & Lee, 2019). Strawberry is able to accumulate 40% - 50% biomass to fruit from plant dry weight (Forney & Breen, 1985). Li et al. (2023) suggest that strong source capacity and large sink size can increase yield of rice.

No research has been conducted on cluster analysis of four lowland chili varieties based on source-sink characters. According to Falchi et al. (2020), understanding the character of source – sink growth and effectiveness of partition are very important to identify yield-limiting factors. Lowland chili varieties including Kencana, Lembang-1, Tanjung-2, and Ungara are used in this research to determined efficiency partitioning chili yield based on cluster analysis and yield limiting factors can be identified.

Materials and Methods

This research was conducted at Sleman Farmer Garden, Yogyakarta, Indonesia (latitude: 7°41'16.18"S, longitude: 110°24'47.69"E). The experiment involved four lowland chili varieties, namely, Kencana, Lembang-1, Tanjung-2, and Ungara. The study was arranged with randomized complete block design (RCBD) with three blocks as replications.

The experimental procedure was used in this research, the chili seedbed was prepared using 1:1:1 of organic fertilizer, soil, and husk charcoal. The planting medium was placed into 50 g nursery plastic, each containing chili seed, which were arranged in germination tray (30 cm × 30 cm × 15 cm) under alternating light and dark conditions. After seven days, chili seedling with four fully opened were ready for transplanting. For transplanting, planting medium was prepared using mixture soil, husk, cow manure in 3:1:1 ratio, placed into 35 cm × 35 cm polybags. These polybags, filled with planting medium, were arranged with 35 cm × 20 cm spacing. Seedlings with four open leaves were transplanted into polybags at a depth of 5 cm until the base of stem was covered with soil. Each experimental unit consisted of 20 chili plant. Fertilization during vegetative phase at 2 weeks after transplanting (WAT), included applying 300 kg ha^{-1} of urea, 600 kg ha^{-1} of SP-36, and 300 kg ha^{-1} of KCl. During generative phase (6 WAT), P_2O_5 and $CaCO_3$ + B were applied at 3–5 g L^{-1} and 3 g L^{-1}, respectively. Weed control was managed manually in polybags. Pest control was performed using contact insecticide containing 135 g L^{-1} of pyridaben and 18 g L^{-1} of abamectin, applied every seven days. Yellow traps with 800 g L^{-1} of eugenol were used in field. Every 3-4 days, watering was done until field capacity in polybag. Harvesting was conducted gradually, strating the chili reached 80% ripe and continued until fruit were suitable for consumption.

Root growth parameters evaluated were root diameter, total root lenght, root surface area, dan root volume. Root growth measurement was carried out at 5 WAT. The total root length (cm) (RL) and root surface area (cm^2) (RSA) were mesured using a meter video camera integrated with WinDWAS software. The root diameter (RD) was measured using a caliper. The root volume (cm^3) was obtained through Eq. (1).

$$RV\ (cm^3)\ \pi r^2 t = 3{,}14 \times (RD/2)^2 \times RL \qquad \text{Eq. 1}$$

Where RV = Root volume (cm^3); RD = root diameter (cm); RL = root length (cm)

Shoot growth parameters evaluated were leaf area, plant height, number of leaves, and leaf area index. Leaf area (cm^2) (LA) was measured using leaf area meter delta-T. Plant height (cm) was measured from stem base to the highest stem at 10 WAT. Increased plant height (PH) and leaf number (LN) were calculated through the difference in plant height at 10 WAT and 9 WAT. The leaf area index can be measured at 10 WAT using Eq. (2).

$$LAI\ (cm^2/cm^2) = LA/PD \qquad \text{Eq. 2}$$

Where LAI = Leaf area index (cm^2/cm^2); LA = leaf area (cm2); PD = planting distance (35 cm × 20 cm)

Dry weight was used to describe the accumulation of net assimilate that can be produced from source organ through process of photosynthesis translocated to sink. The plant part was divided into roots, and shoot consist of leaves, stems and fruits. Both were dried in oven with temperature of 80 °C for 24 h until a constant weight. Then, the root and shoot were weighed using analytical scales (ACS AD-300i, China) to determine root dry weight (DWR) and shoot dry weight (DWS) in grams (g) at 10 WAT. The root:shoot ratio was calculated by Eq. (3).

$$\text{Root: shoot ratio} = DWR/DWS \qquad \text{Eq. 3}$$

Where DWR = dry weight of root (g); DWS = dry weight of shoot (g)

The chili yield can be observed through fresh weight of fruit per-plant (FWF) and number of fruits (FN). The FWF was measured using analytical scales, and number of fruits was calculated during harvest until 16 WAT. The yield component can be observed through diameter of fruit (DF) and fruit thickness (FT) were measured using caliper. Fruit length (FL) was measured using ruler. The harvest index (HI) can be shown through Eq (4).

Harvest Index = DWF/DWP Eq. 4

Where HI = Harvest index; DWF = dry weight of fruit per plant (g); DWP = dry weight of plant (g).

All data were analyzed by RCBD ANOVA, followed by post hoc honestly significant differences at a 95% confidence level. The gouping based on sink character was analyzed through principal component analysis. Similarity value of four lowland chili varieties was analyzed using cluster analysis based on yield, yield component, root-shoot growth. Correlation analysis was used to determine relationships based on yield and root-shoot growth. OriginPro 2023, and SAS version 9 software programs (SAS Institute Inc. 2002) were used in the analyses.

Results and Discussion

The sink character can be observed through yield consumption and yield physiology of plants. The yield of consumption chili plants can be seen through fresh weight of fruit (FWF). Lowland chili varieties indicated significant differences for FWF ($P<0.05$). Kencana, Lembang-1, Tanjung-2, and Ungara had FWF 219.79 g, 268.17 g, 322.59 g, and 269.26 g, respectively (**Figure 2**A). Tanjung-2 had the highest FWF. FWF more related by fruit capacity, namely, fresh weight per fruit ($r = 0.79$) ($P<0.05$) (**Figure 3**A) compared to fruit quantity i.e. fruit number per-plant ($r = -0.43$) ($P>0.05$) (**Figure 3**A). An individual fruit capacity (**Figure 1**), FWF was related to fruit diameter (FD) ($r = 0.69$) ($P<0.05$) compared to the fruit length (FL) ($r = 0.56$) ($P>0.05$) and fruit number (FN) ($r = -0.43$) ($P>0.05$) (**Figure 3**A). Tanjung-2 and Ungara had a wider fruit diameter compared to Kencana and Lembang-1 (**Figure 2**E). The larger fruit diameter correlated with FT of ($r = 0.76$) ($P<0.05$) (**Figure 3**A). The large fruit diameter in Tanjung-2 and Ungara also had larger FT compared to Kencana and Lembang-1 which had a small fruit diameter (**Figure 2**F). According to to Marcelis & Heuvelink, (2007) fruit growth is influenced by sink ability to receive photoasimilate which depends on sink size and sink activity. Large sink capacity can encourage more assimilate partitions, which maximize sink development such as rice and maize (Smith et al., 2018). Sink growth was regulated by cell expansion with setting up strong pH gradient to attract resources. The sink expansion cells were controlled by an acidic growth mechanism whereby acidic environment in cell wall results in increased cell wall loosening. Cell wall acidification was regulated through H-ATPase which actively pumps protons out of cell into apoplast. The pH gradient resulting from cell wall acidification was regulated by proton pumps as driving force that carries carbon through active transport. This affects metabolism and turgor pressure through changes in solute and ion concentrations in cells, thereby increased sucrose absorption and solutes potential (Hageman & Van Volkenburgh, 2021).

The yield physiology of plants can describe dry matter partitioning in plants. The efficiency of dry matter partitioning between source and sink can be seen through harvest index. The harvest index (HI) was measure of photosynthetic assimilate partitioning, which it describes physiological efficiency and ability of plants to convert dry matter into economic yield (Asefa, 2019). The harvest index (HI) of four lowland chili varieties indicated significant differences ($P<0.05$). HI was related to DF ($r = 0.68$) ($P<0.05$) (**Figure 3**A). Large-diameter chili fruit such as Tanjung-2 and Ungara had a larger HI compared to small-diameter chili fruit such as Kencana and Lembang-1 (**Figure 2**D). The efficiency of dry matter partitioning that occurs in large-diameter chili fruit occurs due to presence sink strength. The measurement sink strength can describe fruit growth rate efficient in attracting the assimilate produced through photosynthesis (Ji et al., 2020). The measurement of sink strength determined ratio of photosynthate distribution of plants. In tomatoes, fruit is the strongest sink so that assimilate distribution to fruit takes at high speed (Higashide, 2022). Increasing the speed of dry matter distribution causes conversion of total dry matter produced into economic yield (Asefa, 2019). Yang et al., (2022) reported that increase in economic yield on soybeans is due to an increase above-ground biomass and harvest index. Improvement of assimilate partitions in reproductive organs has an impact on increasing harvest index.

The group of dry matter partitioning efficiency to fruit consisted of large-diameter and small-diameter chili fruits can be shown through principal component analysis (PCA) (**Figure 3**B) and cluster analysis (**Figure 3**C). The results of principal component analysis reveal that two main components can explain the total diversity of 96.27% through yield and yield component characteristics. The proportion of first main component variant (PC1) was 86.13%, and that of second component variant (PC2) was 10.14% (**Figure 3**B). Based on positive eigenvalue in

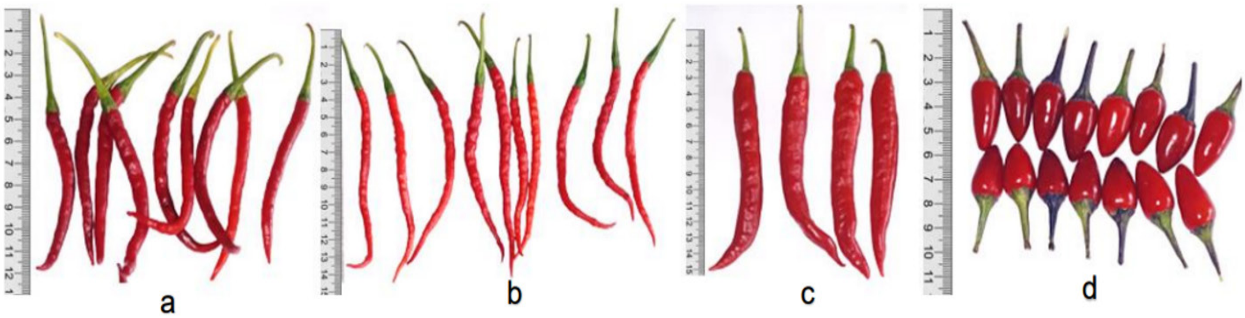

Figure 1. Chili fruit of Kencana (A), Lembang-1 (B), Tanjung-2 (C), Ungara (D)

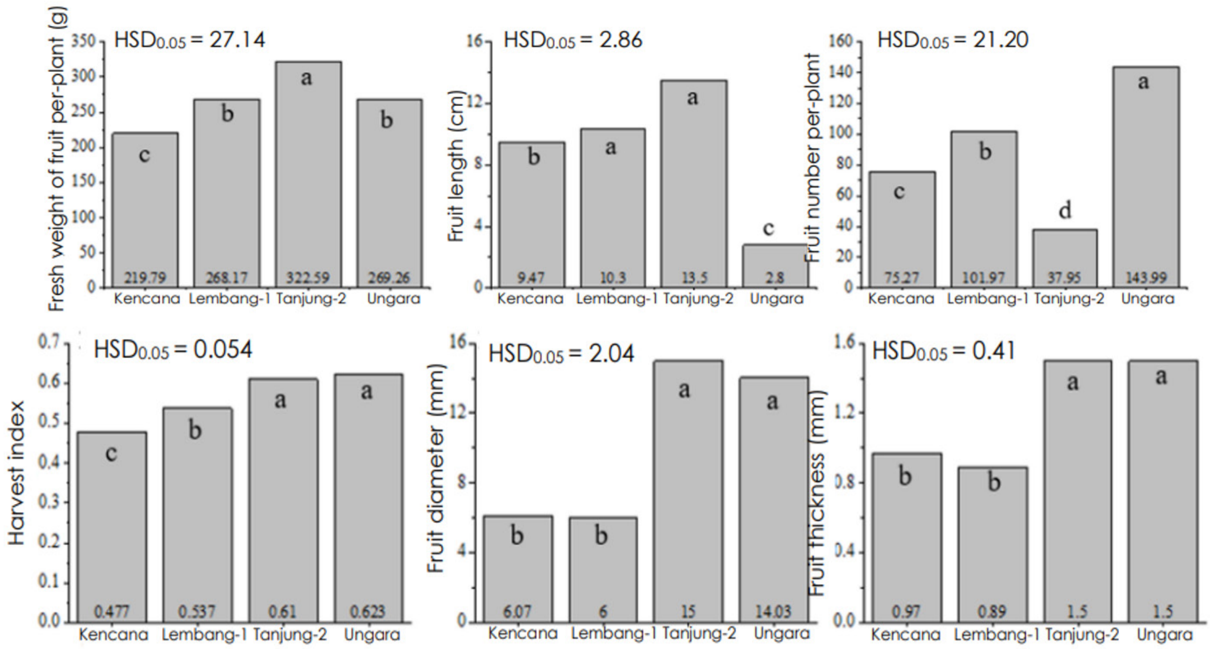

Figure 2. Fresh weight of fruit per-plant (A), fruit length (B), fruit number per-plant (C), harvest index (D), fruit diameter (E), and fruit thickness (F) at 16 WAT

Note: Means with different letters are significantly different at p≤0.05 and ranked by honestly significant difference

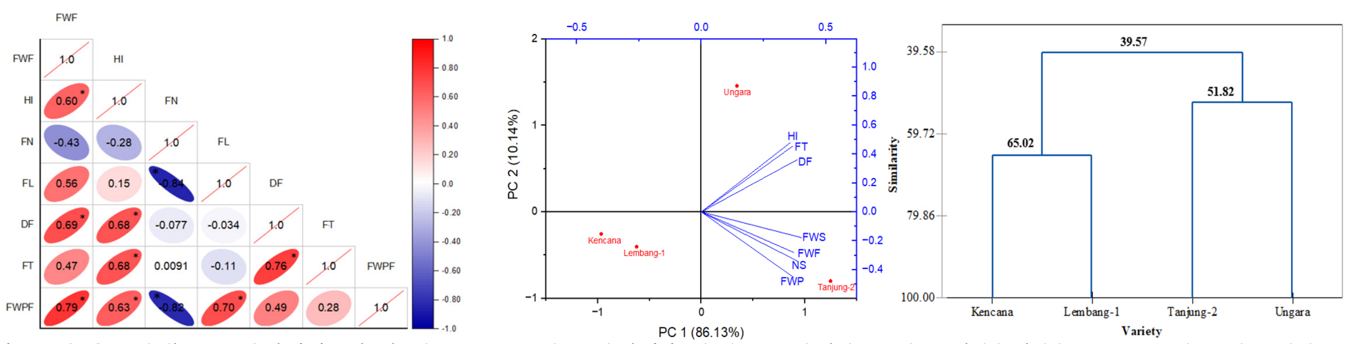

Figure 3. Correlation analysis (A), principal component analysis (B), cluster analysis based on yield, yield component, root and shoot growth (C).

Note: HI = harvest index, FT = fruit thickness, DF = fruit diameter, FWS = fresh weight seed per fruit, FWF = fresh weight of fruit per-plant, NS = seed number per-fruit, FWP = fresh weight of placenta, FWPF = individual fresh weight of fruit, FN = fruit number per-plant. *p<0.05

PC1 describes FWF (0.354), HI (0.393), number of seeds per fruit (NS) (0.391), DF (0.371), FT (0.355), fresh weight placenta (FWP) (0.379), and fresh weight seeds per fruit (FWPF) (0.399) (**Figure 3**B). Based on PC1, Tanjung-2 and Ungara were classified as large-diameter chili fruits, while Kencana and Lembang-1 were classified as small-diameter chili fruits. Based on cluster analysis (**Figure 3**C), 51.82% similarity was observed to Tanjung-2 and Ungara (large-diameter chili fruit), and Kencana and Lembang-1 (small-diameter chili fruit) were 65.02% similarity (**Figure 3**C).

Supporting factors in fruit growth and development can be seen through root and shoots as source of assimilate, water and nutrients. The root:shoot ratio is an indicator of relationship between growth through accumulation root and shoot biomass (Sheridan & Davis, 2021). Dry weight can describe number of net assimilate that can be produced from source through photosynthesis which is translocated to sink. The net assimilate obtained is balance of photosynthesis and respiration (Bláha, 2019). The root:shoot ratio in large-diameter chili fruit that had greater translocation efficiency to fruit in Tanjung-2 and Ungara (0.307 and 0.206, respectively) compared to Kencana and Lembang-1 (0.173 and 0.170, respectively) (**Figure 5**D). This indicates that the proportion of assimilate in large-diameter chili fruit was more translocated to the roots than small-diameter chili fruit. The root dry weight in large-diameter chili fruit showed greater results in Tanjung-2, and Ungara (11.68 g and 10.76 g, respectively) compared to small-diameter chili fruits, namely, Kencana and Lembang-1 (8.80 g and 9.98 g, respectively) (**Figure 5**B). The root growth in small-diameter chili fruit group was lower than large-diameter chili fruit group. It indicates that there was tendency to accumulate assimilate for large root growth in large-diameter chili fruit. Increased root growth can enhance uptake to maintain photosynthesis process (Bonifas & Lindquist, 2006). The shoot dry weight on small-diameter chili fruit was higher in Kencana and Lembang-1 (50.58 g and 58.68 g, respectively) compared to large-diameter chili fruit in Tanjung-2, and Ungara (38.06 g and 41.70 g, respectively) (**Figure 5**A).

The shoot is source of assimilate through leaves. Source organ is the main function in translocating assimilate to sink. Leaf growth in plant canopy can affect source capacity to produce photosyntate. Photosynthate is used for the division, enlargement, and elongation cells for plant growth. The stem growth is measured through growth of plant height. According to Torres-Bazurto et al. (2019) plant height is an important parameter related to plant vigor, while leaf number plays an important role in plant development. Small-diameter chili fruit was classified as efficient in assimilate translocation so it has higher shoot growth. In this research, leaf number growth in small diameter chili fruit more than large diameter chili fruit group (**Figure 6**A). The leaf number (LN) in Kencana and Lembang-1 at 10 WAT was followed by an increased leaf number for one week which was relatively increased. Kencana and Lembang-1 were an increased LN by 44.28% and 35.44%, respectively (**Figure 6**A). This is different from the small-diameter chili fruit which increase in LN for one week in Tanjung-2, and Ungara by 19.86% and 20.78%, respectively (**Figure 6**A). The increase LN is proportional to leaf area in plant canopy.

Leaf area is the main parameter of photosynthesis rate because of determines light interception. Leaf area will have an impact on dry matter accumulation in sink tissues (Weraduwage et al., 2015). The leaf area determines plant ability to absorb and convert light energy into economic yield (Assefa, 2021). Kencana and Lembang-1 had leaf area per plant canopy (LA) of 1046.19 cm^2 and 939.25 cm^2, respectively, or wider compared to Tanjung-2, and Ungara by 775.85 cm^2 and 832.40 cm^2, respectively (**Figure 6**C). Leaf growth is proportional to plant height growth. The stem growth is visible through growth of plant height. The small-diameter chili fruit group had a smaller plant height (PH) such as in Kencana and Lembang-1 by 82.00 cm and 67.83 cm, respectively, while in small diameter chili fruit group in Tanjung-2, and Ungara by 52.77 cm and 40.44 cm, respectively (**Figure 6**B). The increased plant height growth for one week in small-diameter chili fruit such as Kencana and Lembang-1 experienced a greater increased by 16.19% and 16.10%, respectively, while in large-diameter chili fruit in Tanjung-2, and Ungara only by 12.73% and 13.75%, respectively (**Figure 6**B).

Increased shoot growth on small-diameter chili fruit can be caused by larger leaf number, larger

Figure 4 Shoot of Kencana (A), Lembang-1 (B), Tanjung-2 (C), Ungara (D) at 10 WAT

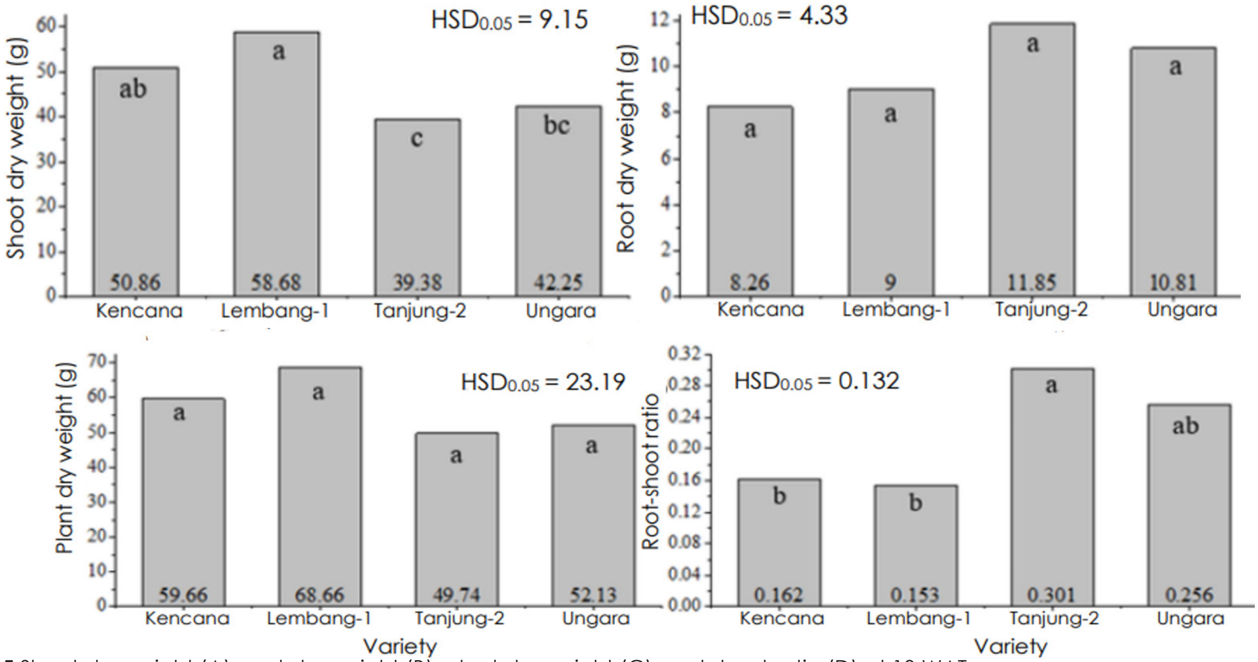

Figure 5 Shoot dry weight (A), root dry weight (B), plant dry weight (C), root:shoot ratio (D) at 10 WAT
Note: Means with different letters are significantly different at p≤0.05 and ranked by honestly significant difference

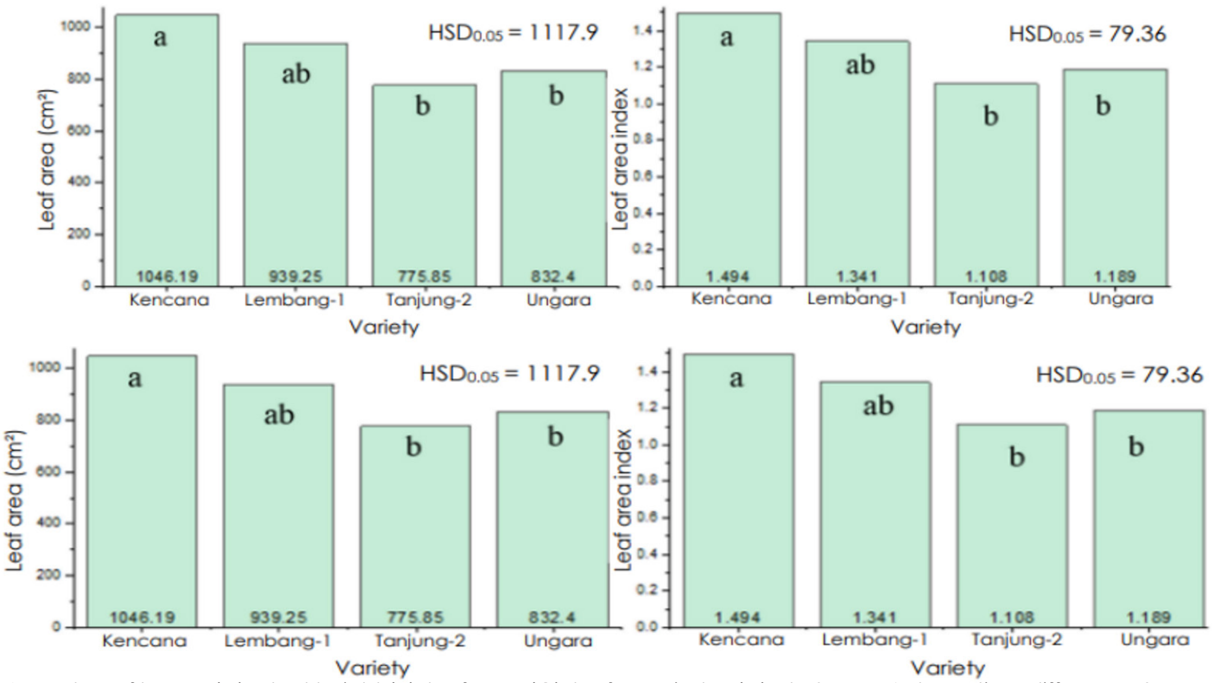

Figure 6 Number of leaves (A), plant height (B), leaf area (C), leaf area index (D) at 10 WAT. Δ shows time difference 9 WAT - 10 WAT
Note: Means with different letters are significantly different at p≤0.05 and ranked by honestly significant difference

leaf area, and taller plant height (**Figure 6**). Assimilate translocated in Kencana and Lembang-1 to vegetative organs for growth and to fruit development. The competition between vegetative organs and fruits during fruit growth and development makes source of assimilate as limiting factor. Assimilate photosynthates produced through photosynthesis are not optimally partitioned for fruit growth and development, but also used for vegetative shoot growth. Thus, leaf growth and taller plant height in the small-diameter chili fruit group caused assimilate partition to fruit less efficient and harvest index was lower. In fruit plants, there is strong competition between fruit and vegetative organs for growth during fruit development stage (Falchi et al., 2020). In large diameter chili fruit group where the assimilate partition competition for leaf growth and plant height was less so fruit development more optimal. Shoot growth conditions in large-diameter chili fruit were lower than small-diameter chili fruit so source acts yield-limiting factor. In peppers, growth and development change growth dynamics of vegetative organs by competing for assimilate because fruit is dominant sink (Erel et al., 2020). In large diameter chili fruit group, the assimilate partition competition for leaf growth and plant height is less so that fruit development becomes more optimal. Canopy growth in large-diameter chili fruit group, which are relatively low, can be source of photosynthate.

Roots act as source of water and nutrients from soil to support shoot growth (Sainju et al., 2017). Root growth is influenced by shoot as organ in supplying assimilate from photosynthesis (Yan et al., 2022). The root capacity can be seen through biomass and root length (Osorio et al., 2014). Cao et al. (2019) suggest that total root length, root surface area, and root dry weight are related to shoot biomass and yield. Small-diameter chili fruit group such as Kencana and Lembang-1 had smaller root diameter (RD) of 0.089 cm and 0.122 cm, respectively compared to large-diameter chili fruit group such as Tanjung-2 and Ungara by 0.115 cm and 0.175 cm, respectively (**Figure 7**A). Smaller root diameter had relatively greater hydraulic conductivity and optimized nutrient absorption (Lopez et al., 2023). However, root with large diameter is reported to grow more easily through compressed soils (Perkons *et al*., 2014). Large-diameter chili fruit have more biomass partitions to roots so that they can increase water and nutrient uptake in plants (Bonifas *et al*., 2005).

Root growth can be seen through root length (RL) in Kencana and Lembang-1 by 7832.54 cm and 391.11 cm, respetively, or smaller than Tanjung-2, and Ungara by 11989.53 cm and 14650.70 cm respectively (**Figure 7**B). Large-diameter chili fruit in Tanjung-2, and Ungara had root surface area (RSA) by 4268.85 cm^2 and 5959.35 cm^2, respectively, whereas small-diameter chili fruit group in Kencana and Lembang-1 only by 2784.14 cm^2 and 1683.46 cm^2, respectively (**Figure 7**C). The total root length is result of root cell elongation and enlargement in apical meristem tissue to form lateral roots growth (Tagliavini et al., 1993). Tajima (2021) also reported that higher root length densities can absorb more nutrients. A more root surface area can increase root contact with ions so that the nutrients absorbed are greater (Yan et al., 2022). The increase root diameter and root length can affect root volume produced in Tanjung-2 and Ungara by 225.31 cm^3 and 351.82 cm^3, respectively while Kencana and Lembang-1 had root volume of 49.01 cm^3 and 46.78 cm^3, respectively (**Figure 7**D). Reducing assimilate allocation for root growth may illustrate root and shoot competition in obtaining assimilate (Stoffella et al., 1992).

The Group root and shoot growth in large and small-diameter chili fruits can be shown through principal component analysis. Based on principal component analysis shows that two main components can explain the total diversity of 95.39% (**Figure 8**). The loading plot on the first main component variant (PC1) is 74.41%, the second main component variant (PC2) is 20.98% (**Figure 8**). Based on PC1, the loading values that showed positive direction were harvest index (0.221), total root length (0.276), root surface area (0.267), root dry weight (0.299), and root:shoot ratio (0.305), while variable that can be explained by loading plot negative direction were

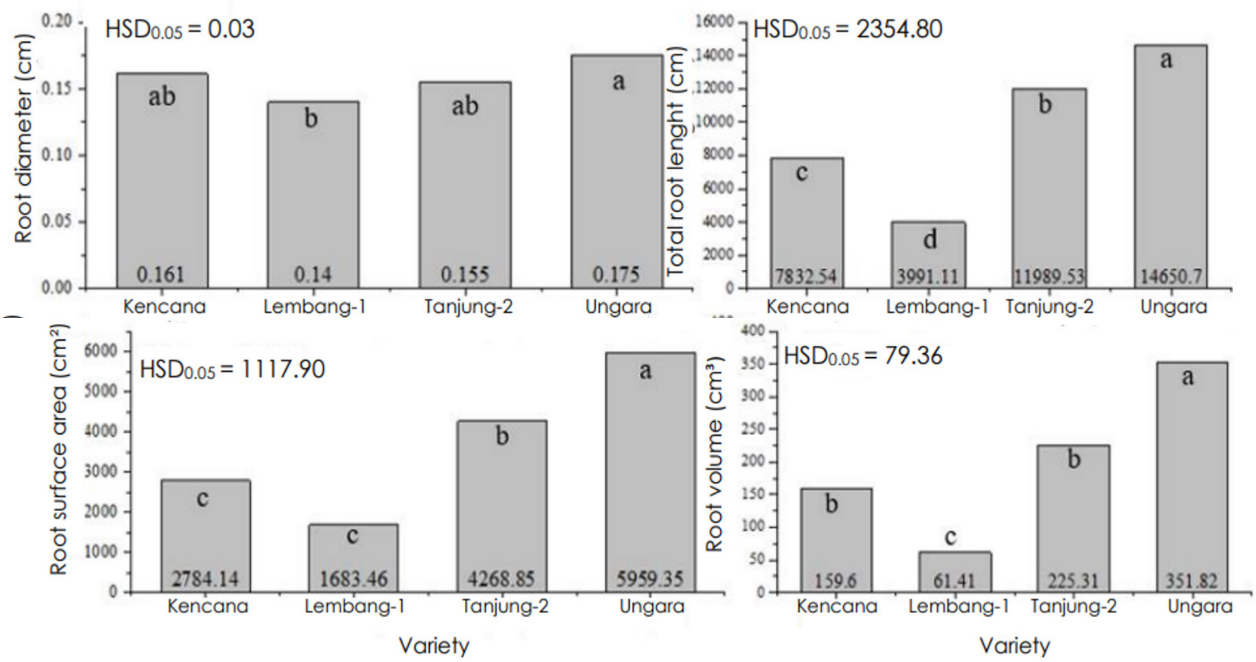

Figure 7 Root diameter (A), total root length (B), root surface area (C), root volume (D) at 5 WAT
Note: Means with different letters are significantly different at p≤0.05 and ranked by honestly significant difference

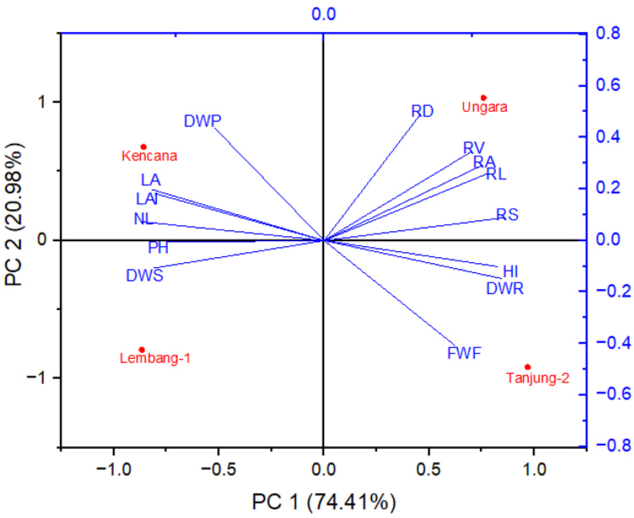

Figure 8 Analysis of principal component
Note: FWF = fresh weight fruit, HI = harvest index, RL = root length, RA = root area, RD = root diameter, RV = root volume, LA = leaf area, LAI = leaf area index, PH = plant height, NL = number of leaves, DWR = dry weight root, DWS = dry weight shoot, R/S =

leaf area (-0.291), leaf area index (-0.286), plant height (-0.263), and leaf number (-0.307) (**Figure 8**). Based on score plot, it appears that large-diameter chili fruit group such as Ungara and Tanjung-2 were in positive loading plot (PC1). Thus, Ungara and Tanjung-2 had higher harvest index, total root length, root surface area, root dry weight and root:shoot ratio compared to Kencana and Lembang-1. In small-diameter chili fruit group, the dominating characters were leaf area, leaf area index, plant height, and leaf number. This can be seen from score plots of Kencana and Lembang-1 in negative loading plots on PC1. Fruit growth depends on import of assimilate from leaves as source organ. Large fruit depend on faster assimilate translocation, and longer assimilate import periods. The faster translocation of assimilate can be influenced by greater phloem tissue and higher phloem transport speed.

The large-diameter chili fruit such as Ungara and Tanjung-2 had greater biomass partition efficiency compared to small-diameter chili fruit group such as Kencana and Lembang-1. The large-diameter chili fruit show that there was relationship between FWF and HI (r = 0.42*) (**Figure 9**A). Increasing fresh weight of fruit can enhance harvest index and fruit partitioning efficiency. In general, crop yield is determined not only by dry matter but also assimilate allocation which is affected by translocation efficiency. According to Ren et al. (2022) sink activity affects sink translocation and assimilation. Higher sink activity results in large carbohydrate assimilation storage in sink organ. The fresh weight of fruit was positively related to plant root characteristics such as root length (r = 0.54*), and root surface area (r = 0.62*) (**Figure 9**A). The relationship between fresh weight of fruit and leaf growth showed negative trend in leaf number (r = -0.63*) (**Figure 9**A). This showed that fresh weight of fruit in large-diameter chili fruit was influenced by root compared to shoot development. Meanwhile, an increase root:shoot ratio was associated with an increase in harvest index (r = 0.70*) (**Figure 9**A). This showed that root growth contribution was more dominant than shoot growth to harvest index. This condition was shown in root biomass (r = 0.78*) and root length (r = 0.45*) against harvest index (**Figure 9**A).

In small-diameter chili fruit in Kencana and Lembang-1 which had smaller biomass partition efficiency showed that there was no relationship between fresh weight of fruit and harvest index. This showed that assimilate allocation for chili growth was not linearly of fruit number and harvest index. The fresh weight of fruit

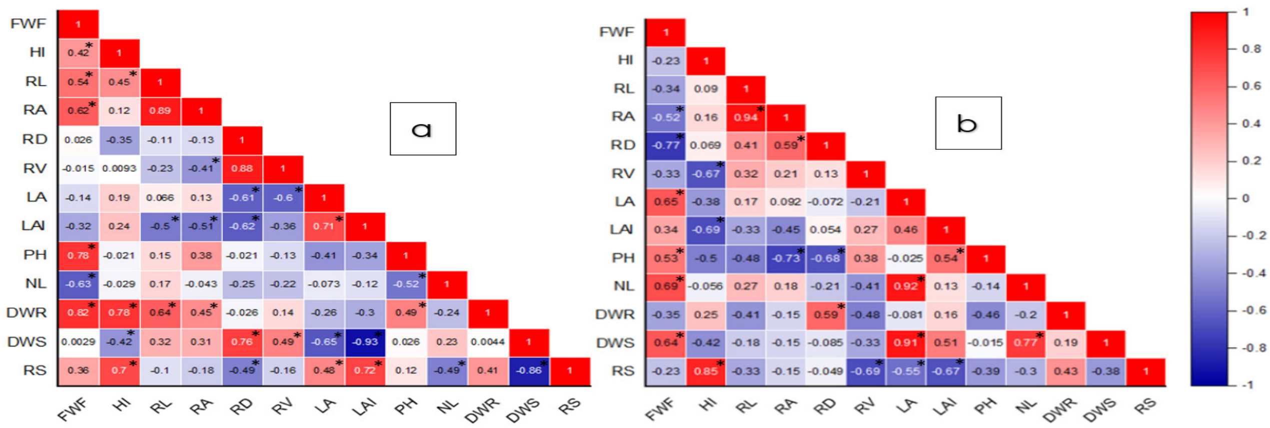

Figure 9 Source and sink relationship in large-diameter chili fruit (Tanjung-2 dan Ungara) (A) and small-diameter chili (Kencana dan Lembang-1) (B).
Note: FWF = fresh weight of fruit per-plant, HI = harvest index, RL = total root length, RA = root surface area, RD = root diameter, RV = root volume, LA = leaf area, LAI = leaf area index, PH = plant height, NL = number of leaves, DWR = dry weight of root, DWS = dry weight of shoot, RS = root:shoot ratio. *p<0.05

in Kencana and Lembang-1 was positively correlated with leaf number (r=0.69*), leaf area (r=0.65*), shoot dry weight (r=0.65*) and plant height (r=0.53*) (**Figure 9**B). Kencana and Lembang-1 had massive shoot growth can be seen from leaf growth during one week (**Figure 6**). The competition between vegetative and fruit organ during fruit growth and development makes source a limiting factor. Assimilate photosynthate produced through photosynthesis process were not optimally partitioned for fruit growth and development, and it was used for shoot growth. The increase fresh weight of fruit was influenced by leaf growth and root growth such as root surface area (r=-0.52*), and root diameter (r=-0.77*) (**Figure 9**B).

Conclusion

Lowland chilies were classified into two groups, namely, large-diameter chili fruit and small-diameter chili fruit groups, based on efficiency assimilate partitioning to fruit, as observed through sink characteristics. The large-diameter chili fruit group included Tanjung-2 and Ungara, and small-diameter chili fruit group included Kencana and Lembang-1. The large-diameter chili fruit group plants were more efficient in translocating to fruit compared to small-diameter chili fruit. In small-diameter chili fruit, source capacity was a limiting factor because of assimilated competition for shoot growth. The assimilate capacity of the source from large-diameter chili fruit was more efficiently partitioned to fruit than vegetative sink so that higher harvest index. The lower leaf growth in large-diameter chili fruit group made the source of assimilate as limiting yield factor.

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