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MORPHOMETRIC AND YIELD CHARACTERISTICS OF SEMI-NATURAL *REUTEALIS TRISPERMA* (BLANCO) AIRY SHAW POPULATIONS IN GARUT, WEST JAVA, INDONESIA

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SUMMARY

Reutealis trisperma (Blanco) Airy Shaw is one of the vegetable oil producing tree plant species. Its seed kernel contains an average of 50% oil potentially utilized as biofuel. However, least research has been carried out on the morphometric traits of the tree species. Therefore, the present study aimed to characterize and evaluate the performance of eight populations of *R. trisperma* around Garut Regency, West Java, Indonesia. Tree samples of each population were determined using the purposive non-probability sampling method. Plant variables, including vegetative and generative component traits as well as seed yield, were observed, and all the data were analysed using correlation and multivariate analysis. The results showed no correlation among the populations based on vegetative and yield component traits. The seed kernel weight, which is an important variable also showed no correlation with any other traits. However, two populations of *R. trisperma*, namely Balong and Cigempol, were distinctively clustered apart from the other six populations. Interestingly, those two populations also showed a higher seed yield for four consecutive years.

Keywords: *R. trisperma*, *in situ* selection, morphometric characterization, multivariate analysis, biofuel.

Key findings: *R. trisperma* two populations namely Balong and Cigempol showed a distinct morphological characteristic as well as greater seed yield potential. These findings would enrich the valuable information for future breeding and conservation of this important vegetable oil-producing tree species.

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INTRODUCTION

Reutealis trisperma (Blanco) Airy Shaw is a monospecific member of the genus *Reutealis,* belonging to the subtribe Aleuritinae. The introduction of these deciduous tree species from the Philippines to Indonesia began in the 19^{th} century. It also has a close relationship with the genera *Aleurites* and *Vernicia*, while the genus *Reutealis* is characterized by oil-containing seeds (Heyne, 1987; Stuppy *et al*., 1999). However, the vegetable oil extracted from its seeds is classified as non-edible because it contains the toxic compound oleostearic acid (Lim *et al*., 2020).

In many cases, the economic value of *R. trisperma*'s oil is on its efficiency as a drying oil for wood finishing (Yoo and Youngblood, 2017), as well as a raw material for biodiesel based on the development of a renewable energy resources program (Pranowo *et al*., 2015). *R. trisperma*'s oil has a high opportunity for producing biofuel feedstock, supporting the national energy policy and accelerating the supply and utilization of biofuel. Several of its advantages include high seed oil content with characteristics that can serve various purposes in many industries. Compared to jatropha (*Jatropha curcas*), neem (*Azadirachta indica*), moringa (*Moringa oleifera*), castor beans (*Ricinus communis*) and candlenut (*Aleurites moluccana*), the kernel's oil content of *R. trisperma* is the highest (Martin *et al*., 2010). The esterification process was able to reduce the free fatty acid content of *R. trisperma*'s oil; hence, it could increase the quality of the final product (Prabaningrum *et al*., 2020). Biodiesel produced from *R. trisperma* has a unit cost of USD 0.69 L^{-1} and is highly competitive with diesel fuel (Riayatsyah *et al.*, 2017).

Despite its valuable oil content, the dense canopy of the *R. trisperma* tree also serves as a natural shade, specifically beneficial for rural communities as shade at funerals of their religious leaders. Moreover, this plant has the potential for phytoremediation, as it can tolerate degraded soils, such as gold mine tailings (Andriya *et al*., 2019). It also has a relatively robust growth and shows wide adaptability, growing well in lowlands up to 1,000 m above sea level. For soil conservation purposes, its strong and massive rooting system can function in holding the soil to prevent landslides (Herman *et al*., 2013).

Nowadays, several seminatural *R. trisperma* populations are dominant in the Garut District, West Java, Indonesia. However, limited information is available about the phenotypic and genotypic variability of intra- and inter-populations of *R. trisperma*. It is hypothesized that this tree species has a narrow genetic basis because of its recent introduction from the Philippines, as represented by a few parental trees (Izzah *et al*., 2021). Moreover, the highest rate of deforestation is another threat to the genetic variability of the tree species, especially for *R. trisperma* (Baucom *et al*., 2005; Subashini *et al*., 2015; Marir, 2024).

During the last decades, the selection initiatives of these tree species for high-yield populations commenced in Indonesia. However, the selection basis mainly relied on the yield of harvested fruits and seeds. The latest research aimed to analyze vegetative characters, fruit components, and seed production of *R. trisperma* plant populations. The acquired information would be significantly beneficial for future plant breeding initiatives, as well as in the conservation of plant genetic resources of *R. trisperma*.

MATERIALS AND METHODS

Plant material

Seminatural eight different populations of *R. trisperma* spread across the eight locations in Garut Regency, West Java, Indonesia (Figure 1) were chosen samples as genetic materials in the experiment. Each population has its distinct characteristics regarding size, age, elevation, planting pattern, and plant spacing (Table 1). Among the populations, Cigempol (7°01′27.5″ S 108°01′29.3″ E) and Balong (7°02′15.9″ S 107°58′50.6″ E) are the smallest populations, consisting of only six individual trees each. The Cileuweung (7°01′31.2″ S 108°00′34.7″ E) and Saapan (7°02′38.8″ S 108°00′16.2″ E)

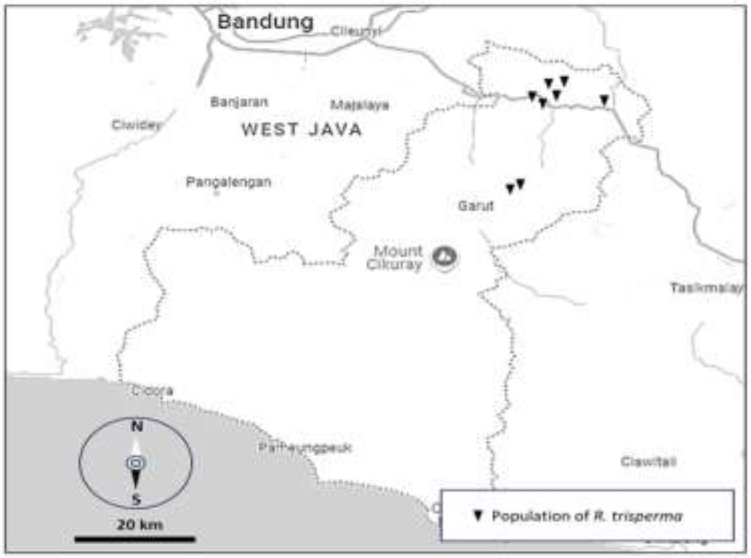

Figure 1. Geographical position of each population of *R. trisperma* in Garut Regency, West Java. Whole clustering of the eight populations of *R. trisperma* occurs in the sub-district of Balubur Limbangan, Garut, West Java, Indonesia.

Table 1. Populations of *R. trisperma* grown in Garut Regency.

Locations	Number of individuals	Elevation (m asl)	Planting pattern
Kondang	24	512	Monoculture
Cileuweung	49	505	Polyculture
Saapan	53	536	Monoculture
Wedasari	27	533	Monoculture
Bojongsari	20	705	Monoculture
Bojongkalapa	22	720	Monoculture
Cigempol	6	515	Monoculture
Balong	6	530	Monoculture

populations were the largest, comprising 49 and 53 individual trees, respectively. The remaining four populations, i.e., Bojongsari (7°10’31.2” S 107°57’44.8” E), Bojongkalapa (7°11’31.0” S 107°57’38.0” E), Kondang (7°00’11.0” S 108°00’31.2” E), and Wedasari (7°03’07.5” S 107°59’48.1” E), had 20, 22, 24, and 27 individual trees, respectively. Those eight *R. trisperma* populations can grow at an altitude of <1000 m above sea level, categorized as a low altitude (Ismail *et al*., 2019).

In each population, the planting pattern was generally monoculture, except for Cileuweung population, with irregular distribution and varied size of individual plants, indicating a seminatural sibling’s generation. According to local community information, each *R. trisperma* population comprised individual trees of different ages, ranging from 20 to 80 years. Therefore, one can assume the existence of overlapping generations, especially in a larger population. The morphometric characterization only proceeded to individual trees which have relatively the same biological age. *In situ* characterization of some morphometric traits ensued for each population of *R. trisperma*.

Morphometric traits characterization

Determining tree samples of each population used a purposive non-probability sampling method. Variables of observation, categorized

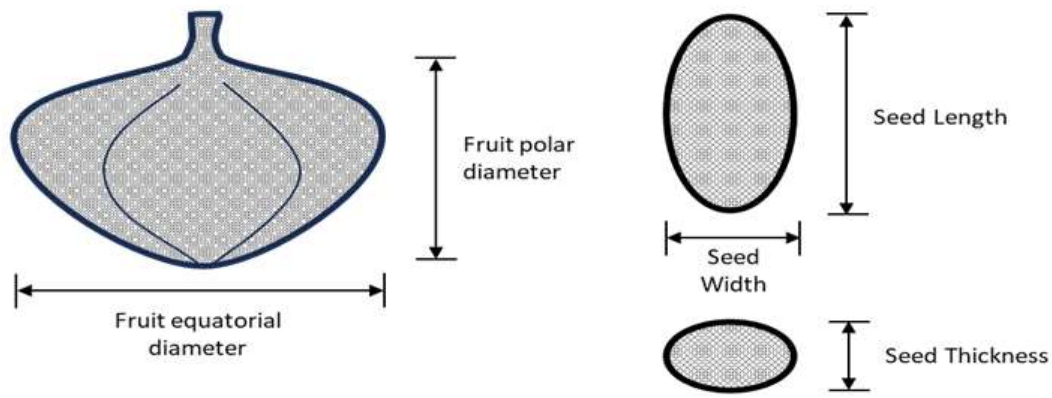

Figure 2. Schematic picture of fruit and seed morphometric measurements of *R. trisperma*.

into three groups, included vegetative traits, fruit component traits, and seed yield. The vegetative traits observed during the experiment comprised tree height (TH), trunk girth (TG), crown diameter (CD, as the average canopy width of East-West and North-South directions), leaf length (LL), leaf width (LW), and petiole length (LPL). The use of a laser distance meter help estimate the TH value (Sales *et al*., 2019). The ratio of leaf length to leaf width (LTW) was also calculated. Fruit component traits' measurement occurred. It included fruit weight (FWt), fruit polar diameter (FPD), fruit equatorial diameter (FED), fruit pedicel length (FPL), fruit skin (mesocarp) thickness (MT), seed weight (SWt), seed length (SL), seed width (SW), seed thickness (ST), kernel weight (KWt), seed shell weight (SSWt), and seed shell thickness (SST) (Figure 2) immediately after harvesting the sampled-mature fruits (wet based). According to Abduh *et al.* (2019), the moisture content of freshly harvested seeds was 21%. Seed morphometric variables depended on individual nut-in-shell instead of their cumulative in a single fruit. Calculating the ratios of FPD to FED (FPER) and KWt to SWt (kernel recovery = KR) also progressed.

Yield observations

Fruit harvests were materialized in respective *R. trisperma* populations for four consecutive years. However, for technical reasons, the harvested fruits were bulked instead of grouped based on each sample tree. Harvested fruits then incurred peeling to separate seeds from the mesocarp. The seed yield description was the weight of fresh harvested seeds in each population.

Data analysis

All recorded data underwent Spearman correlation analysis. The 'rule of thumb' for interpreting Spearman correlation results was as follows: 0 to 0.20 – considered as negligible, 0.21 to 0.40 – weak, 0.41 to 0.60 – moderate, 0.61 to 0.80 – strong, and 0.81 to 1.00 – very strong (Prion and Haerling, 2014). Multivariate analysis also conducted to display and draw conclusions from morphometric data and identify the clustering pattern of the eight *R. trisperma* populations. Descriptive analysis helped compare seed yield data of the eight populations. All the analyses were performed using the Smartstat XL Ver 3.5.1.0 Professional Edition.

RESULTS AND DISCUSSION

Morphometric variations among the *R. trisperma* populations

R. trisperma is a deciduous tree species with a huge and dense plant canopy, extending up to 15 m. The TH can reach 15 m with the TG values ranging from 130 to 200 cm, and the CD can reach more than 15 m.

Table 2. Vegetative and generative morphological trait comparisons among eight populations of *R. trisperma* in Garut Regency, West Java.

Variables	Balong	Bojongkalapa	Bojongsari	Cigempol	Cileuweung	Kondang	Saapan	Wedasari
Plant Height	13,38 bc	**14,31 c**	**14,67 c**	12,59 abc	13,12 bc	11,53 ab	12,53 abc	9,96 a
Trunk Girth	157,70 abc	**197,25 c**	191,75 bc	164,00 abc	166,40 abc	148,25 ab	166,70 abc	130,56 a
Canopy Diameter	9,99 ab	**11,61 b**	8,77 ab	7,53 a	8,00 a	7,69 a	9,91 ab	10,61 ab
Leaf Length	13,67 ab	13,42 ab	**16,71 b**	16,27 ab	12,93 a	15,58 ab	15,55 ab	**16,33 b**
Leaf Width	13,18 abc	10,75 ab	**14,66 c**	14,36 abc	10,87 a	12,90 abc	13,17 abc	14,56 bc
Leaf Petiole Length	12,68 ab	10,48 a	13,81 ab	16,23 ab	12,58 a	14,31 ab	15,27 ab	**18,83 b**
Fruit Weight	**85,1 e**	35,96 abc	57,56 cde	74,26 de	51,30 bcde	35,96 ab	32,20 a	39,77 abcd
Fruit Polar Diameter	**60,30 d**	46,36 abcd	46,18 abc	52,12 cd	44,27 a	44,60 ab	46,44 bcd	46,21 abc
Fruit Equatorial Diameter	**60,20 c**	52,21 ab	54,33 bc	56,04 bc	54,36 bc	49,41 a	50,30 a	53,98 abc
Fruit Pedicel Length	12,37 b	13,14 bc	11,84 ab	13,32 bc	9,87 a	12,31 ab	**14,88 c**	11,50 ab
Mesocarp Thickness	1,37 a	3,61 bc	**4,49 c**	1,60 ab	3,63 bc	1,89 ab	2,71 ab	**4,60 c**
Seed Weight	**7,35 b**	5,94 a	**7,41 b**	**7,60 b**	6,70 ab	7,03 ab	6,00 a	6,13 a
Seed Length	25,30 a	28,48 bcd	28,51 cd	25,44 ab	27,60 abc	**28,94 d**	28,50 cd	28,33 bcd
Seed Width	24,79 a	**27,21 c**	**27,38 c**	24,62 a	25,30 ab	27,09 bc	27,10 bc	**27,32 c**
Seed Thickness	20,70 abc	21,33 bc	20,50 ab	19,30 a	20,10 a	20,23 ab	20,50 ab	**22,10 c**
Seed Shell Weight	3,08 bc	2,40 ab	**3,38 c**	**4,24 c**	2,90 abc	3,05 bc	2,14 a	2,40 ab
Seed Shell Thickness	1,32 ab	1,56 ab	**1,91 b**	1,58 ab	1,70 ab	1,19 a	1,50 ab	1,64 ab
Kernel Weight	4,27 a	3,54 a	4,04 a	3,36 a	3,80 a	3,98 a	3,94 a	3,64 a
Kernel Recovery	58,14 ab	59,15 ab	54,14 ab	44,14 a	56,36 ab	56,38 ab	**65,93 b**	59,18 ab

Notes: Different letters at the same line indicate a significant differences at a p-value < 0.05 of Kruskal-Wallis Test, followed by Dunn post-hoc test.

The vegetative and generative morphometric variation among *R. trisperma* populations are available in Table 2. The population of Bojongkalapa showed the highest TH and TG, significantly different from Kondang and Wedasari populations. The Bojongkalapa population also had a remarkably larger DC than the Cigempol, Cileuweung, and Kondang populations, but had a distinctly shorter LP than the Wedasari population. Difference in growth traits, such as TH and TG, could be a strong indication of the plant age variation among individuals, as well as among populations, as confirmed in avocado (Yangaza *et al*., 2024).

The Bojongsari population had a significantly higher LL and LW values, whereas the Wedasari population had a higher LL and LP values than the Cileuweung population. Balong and Cigempol populations produced comparatively higher FPD, FED, and FWt than the other six populations. Interestingly, the seeds recovered from the fruits of both populations were heavier, but smaller (lower SWt, SL, SW, and ST values). In contrast, the Saapan, Wedasari, and Bojongkalapa populations gave comparatively lighter but larger seeds. Those results could be a strong indication of seed bulk density variation among *R. trisperma* populations. The seeds of *R. trisperma* have characteristics of hard seed shells covering soft white-colored kernels.

Eight *R. trisperma* populations in Garut, West Java, reached growth and development in seminatural conditions. However, a lack of clear information exists regarding the pedigree status, as well as the age of each individual plants, hence the genetic grouping of intra- and interpopulations remains unknown.

Correlation among vegetative and generative traits

A strong positive correlation (r = 0.63*) appears between the traits of TH and TG (Table 3). Past studies also reported that TG has a strong positive correlation with seed yield in other plant species, such as sunflower, tomato, and coffee (Atinafu and Mohammed, 2017; Singh *et al*., 2018; Oke *et al*., 2020). However, no correlation emerged between those two traits and CD. This result does not align with the previous findings on *Acacia auriculiformis* and *Vitellaria paradoxa,* which showed a high positive correlation among TH, TD, and CD

(Buba, 2013; Dey *et al*., 2021). Contrastingly, TH had a weak negative correlation with LL (*r* = -0.33*) and LW (*r* = -0.24*) and a moderate negative correlation with leaf LPL (*r* = -0.44*). Trunk girth has no correlation to LL and LW traits, but, it only shows a weak negative correlation to LPL. However, these results are contradictory to a previous report by Ma *et al*. (2022) on *Quercus pannosa*.

The LL shows an extremely positive correlation to LW (*r* = 0.84*) and a high positive correlation to LPL (*r* = 0.65*). High positive correlation is also evident between LW and LPL (*r* = 0.68*). Significant positive intercorrelations among LL, LW, and LPL also occurred in coffee plants (Adepoju *et al*., 2020). The majority of vegetative traits, i.e., TH, TG, LL, and LPL, have no correlation to any generative traits (Table 3). Only CD has a weak positive correlation to FPD (*r* = 0.25*), ST (*r* = 0.39*), SS (*r* = 0.37*), and SST (*r* = 0.24*). CD also has a moderate negative correlation to SW (*r* = -0.44*) and a weak negative correlation to SSWt (*r* = -0.34*). Meanwhile, LL has a weak positive correlation to SW (*r* = 0.31*). However, all vegetative traits have no correlation to the most economically important traits, i.e., KW and KR.

Among generative traits, FWt had a weak positive correlation to FPD (*r* = 0.38*), but a very strong positive correlation to FED (*r* = 0.90*). Therefore, one could infer that FWt is determined mainly by the equatorial growth instead of polar growth of the fruits. This pattern was also apparent in other fruit-bearing plants, such as tomatoes (Li *et al*., 2016). The FWt also had a strong positive correlation to SWt (*r* = 0.65*) and SSWt (*r* = 0.63*). However, it had a strong negative correlation with SL (*r* = -0.63*), as well as a moderate negative correlation with FPL (*r* = -0.41*) and SW (*r* = -0.59*).

The SWt has a weak negative correlation with SL (*r* = -0.28*) and SW (*r* = -0.38*) and a moderate negative correlation with ST (*r* = -0.49*). This phenomenon contradicts the previous research finding on rapeseed (Li *et al.*, 2015). Angiosperm seeds consist of three distinct sections, i.e., embryo, endosperm, and seed shell (Shamrov, 2022). The fusion of the embryo and the endosperm results in a seed kernel (Zakaria *et al*., 2019). Therefore, SWt is the sum of KWt and SSWt. The results showed that SWt has a high and moderate positive correlation to SSWt (*r* = 0.64*) and KWt (*r* = 0.42*), respectively. However, no correlation appeared between SWt and KR. As a consequence, the SWt is not a good predictor for KR. Moreover, no correlations existed between SL, SW, ST, and SS to KR. It is different from previously reported findings in macadamia, which evidently showed a larger-seed (nut-in shell) size means higher KR values (Richards *et al*., 2020).Conversely, KR in *R. trisperma* has an extremely negative (*r* = -0.83*), but high positive (*r* = 0.73*) correlations to SSWt and KWt, respectively.

Populations' clustering by multivariate analysis

The three different and widely used multivariate statistical analyses are principal component analysis (PCA), factor analysis (FA), and cluster analysis (CA). PCA and FA analyses help eliminate dataset's dimension (Wang, 2009; Santos *et al*., 2019), and both have different techniques (Elsayed, 2022). However, the CA groups observations into categories based on similarity among their attributes (Wang, 2015).

In the presented research, following the Kaiser-Guttman Criterion (KGC) rule of thumb of eigenvalue >1 (Auerswald and Moshagen, 2019), both PCA and FA were able to reduce 21 variables into six principal components (PCs). These factors contributed ~86% of the cumulative variance (Figure). However, the variable reduction did not proceed in PC1 and PC2 because their cumulative contribution was merely 44%, which was far less than 80%. The first PC appeared strongly correlated with most yield-related traits, except the ratio of leaf length to leaf width. The main contributor to the second PC comprised only the vegetative traits (Table 4). Factors 1 and 2 had links to more than half of the yield traits (Table 5). Despite the difference between the PCA and FA, both

Table 3. Spearman correlation indices among the vegetative and yield traits of *Reutealis trisperma.*

Variables	TH	TG	CD	LL	LW	LPL	LTW	FWt	FPD	FED	PER	FPL	MT	SWt	SL	SW	ST	SS	SSWt	SST	KWt	KR
Tree height (TH)	1,00																					
Trunk girth (TG)	0,63 *	1,00																				
Crown diameter (CD)	0,21	0,21	1,00																			
Leaf length (LL)	-0,33 *	-0,15	0,05	1,00																		
Leaf width (LW)	-0,24 *	-0,09	0,07	0,84 *	1,00																	
Leaf petiole length (LPL)	-0,44 *	-0,26 *	-0,07	0,65 *	0,68 *	1,00																
LL/LW (LTW)	-0,03	-0,01	-0,16	0,13	-0,38 *	-0,13	1,00															
Fruit weight (FWt)	0,22	0,03	-0,16	-0,05	0,19	-0,05	-0,39 *	1,00														
Fruit polar diameter (FPD)	0,19	-0,03	0,25 *	-0,02	0,14	-0,02	-0,28 *	0,38 *	1,00													
Fruit equatorial diameter (FED)	0,22	-0,02	-0,04	-0,12	0,09	-0,08	-0,36 *	0,90 *	0,43 *	1,00												
FPD/FED (PER)	0,08	-0,06	0,17	-0,04	0,09	-0,02	-0,22	0,10	0,80 *	0,07	1,00											
Fruit pedicel length (FPL)	0,14	0,22	0,18	0,05	0,05	0,04	0,08	-0,41 *	0,44 *	-0,38 *	0,64 *	1,00										
Mesocarp thickness (MT)	-0,03	0,08	0,19	0,14	0,05	0,09	0,13	-0,14	-0,40 *	-0,11	-0,73 *	-0,38 *	1,00									
Seed weight (SWt)	0,07	0,04	-0,44 *	0,10	0,16	0,03	-0,05	0,65 *	0,16	0,48 *	0,14	-0,19	-0,30 *	1,00								
Seed length (SL)	-0,08	0,07	-0,11	0,19	-0,03	0,11	0,36 *	-0,63 *	-0,41 *	-0,67 *	-0,30 *	0,12	0,32 *	-0,28 *	1,00							
Seed width (SW)	-0,14	0,03	0,16	0,31 *	0,21	0,17	0,14	-0,59 *	-0,22	-0,58 *	-0,22	0,20	0,44 *	-0,38 *	0,62 *	1,00						
Seed thickness (ST)	-0,14	-0,19	0,39 *	0,02	0,04	0,13	-0,09	-0,18	0,15	-0,09	-0,01	-0,02	0,35 *	-0,49 *	0,16	0,40 *	1,00					
Seed sphericity (SS)	-0,03	-0,19	0,37 *	0,00	0,21	0,07	-0,39 *	0,40 *	0,64 *	0,47 *	0,43 *	0,09	-0,12	0,01	-0,65 *	-0,05	0,51 *	1,00				
Seed shell weight (SSWt)	0,09	0,09	-0,34 *	0,12	0,22	-0,01	-0,16	0,60 *	0,05	0,40 *	0,02	-0,26 *	-0,20	0,64 *	-0,33 *	-0,31 *	-0,42 *	0,03	1,00			
Seed shell thickness (SST)	0,11	0,14	0,24 *	0,14	0,07	-0,07	0,10	0,12	-0,08	0,05	-0,31 *	-0,24 *	0,50 *	-0,11	-0,08	-0,03	0,03	-0,03	0,15	1,00		
Kernel weight (KWt)	0,01	-0,07	-0,08	-0,05	-0,08	0,00	0,11	0,08	0,12	0,13	0,16	0,03	-0,14	0,42 *	0,04	-0,08	-0,14	-0,03	-0,34 *	-0,28 *	1,00	
Kernel recovery (KR)	0,03	-0,04	0,15	-0,12	-0,20	-0,01	0,18	-0,39 *	0,03	-0,22	0,08	0,26 *	0,03	-0,22	0,24	0,16	0,14	-0,09	-0,83 *	-0,25 *	0,73 *	1,00

Notes: • highly and • very highly correlated.

clearly grouped the two populations of *R. trisperma,* i.e., Balong and Cigempol, which were separate from the other six populations (Figure).

Based on the dendrogram generated from the Agglomerative Hierarchical Clustering method, the eight populations of *R. trisperma* belonged to two main clusters. The first cluster comprised two populations, i.e., Cigempol and Balong, whereas the second cluster comprised six populations of *R. trisperma* (Figure 5). Therefore, it can be inferred that the two populations (Cigempol and Balong) of *R. trisperma* have the most distinctive morphological characteristics. However, each population consisted of individuals with high similarities. Morphological variation was substantially lower for intrapopulation variation than the interpopulation variation of *R. trisperma*. Hypothetically, the development of each population of *R. trisperma* came from a single mother tree. This hypothesis gained support from the local people's information regarding the origin of *R. trisperma* trees in the surrounding area.

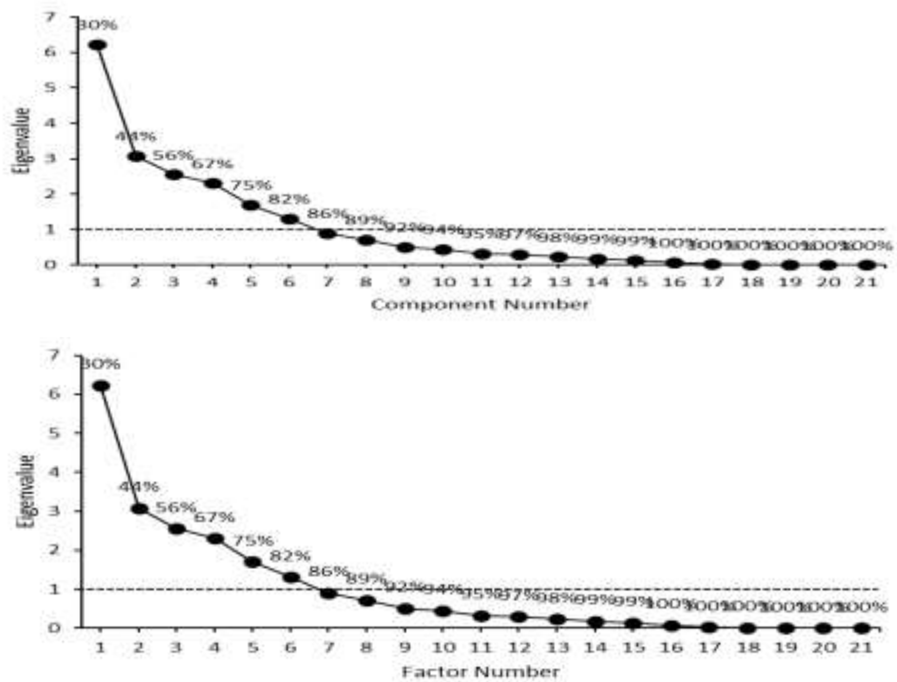

Figure 3. Scree plot of principal component analysis (PCA) (left) and factor analysis (right) show identical Eigenvalues and cumulative variance.

Table 4. Sorted component loadings and communalities.

Variables	PC1	PC2	PC3	PC4	PC5	PC6	Communality
Fruit Weight (FWt)	0.949	-0.026	0.099	0.223	-0.011	0.032	0.962
Seed Length (SL)	-0.921	-0.022	0.055	-0.060	0.102	-0.067	0.870
Fruit Polar Diameter (FPD)	0.917	0.072	-0.267	-0.080	0.043	0.086	0.933
Fruit Equatorial Diameter (FED)	0.846	0.039	-0.100	0.389	-0.135	0.091	0.905
Seed Width (SW)	-0.747	0.277	-0.139	-0.142	0.171	0.206	0.745
FPD to FED Ratio (PER)	0.678	0.080	-0.331	-0.505	0.198	0.062	0.874
Pericarp Thickness (PT)	-0.632	0.090	0.090	0.535	-0.166	0.396	0.887
Seed Sphericity (SS)	0.586	0.390	-0.490	0.115	-0.128	0.322	0.868
Seed Weight (SWt)	0.581	-0.010	0.579	0.020	0.011	-0.182	0.706
Seed Shell Weight (SSWt)	0.559	0.036	0.548	0.161	0.118	0.004	0.654
LL to LW Ratio (LTW)	-0.499	-0.283	0.220	-0.085	-0.056	-0.181	0.421
Tree Height (TH)	0.178	-0.615	0.019	0.166	0.498	0.298	0.775
Leaf Length (LL)	-0.121	0.743	0.469	-0.052	0.276	0.017	0.867
Leaf Width (LW)	0.136	0.855	0.313	0.004	0.286	0.128	0.945
Leaf Petiole Length (LPL)	-0.084	0.801	0.293	-0.138	-0.001	-0.001	0.753
Seed Thickness (ST)	-0.281	0.397	-0.638	0.246	-0.204	0.253	0.810
Outturn (OT)	-0.261	0.216	-0.592	0.433	0.418	-0.349	0.950
Fruit Pedicel Length (FPL)	-0.024	0.041	-0.236	-0.752	0.439	0.256	0.882
Seed Shell Thickness (SST)	-0.167	-0.026	0.288	0.573	0.073	0.408	0.612
Trunk Girth (TG)	-0.048	-0.423	0.122	0.154	0.695	0.287	0.785
Kernel Weight (KWt)	0.114	0.232	-0.283	0.518	0.483	-0.553	0.954

Table 5. Sorted factor loadings and communalities.

Variables	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6	Communa-lity
Seed Sphericity (SS)	0.875	0.273	0.100	-0.059	-0.123	0.023	0.868
Fruit Polar Diameter (FPD)	0.867	-0.222	-0.062	-0.357	0.033	0.017	0.933
Fruit Equatorial Diameter (FED)	0.864	-0.329	-0.124	0.153	-0.032	0.100	0.905
Seed Length (SL)	-0.825	0.397	0.084	0.144	0.036	0.050	0.870
Fruit Weight (FWt)	0.800	-0.559	-0.059	-0.007	0.066	0.030	0.962
LL to LW Ratio (LTW)	-0.619	-0.037	-0.160	0.080	-0.015	-0.069	0.421
Seed Weight (SWt)	0.222	-0.790	0.159	-0.012	-0.008	-0.084	0.706
Seed Thickness (ST)	0.228	0.790	0.050	0.223	-0.236	0.162	0.810
Seed Shell Weight (SSWt)	0.306	-0.680	0.233	0.121	0.154	-0.065	0.654
Seed Width (SW)	-0.486	0.631	0.321	0.035	0.078	-0.016	0.745
Leaf Width (LW)	0.206	-0.054	0.945	0.019	-0.028	0.081	0.945
Leaf Length (LL)	-0.130	-0.103	0.912	0.052	-0.040	0.050	0.867
Leaf Petiole Length (LPL)	-0.025	0.023	0.809	-0.003	-0.310	-0.034	0.753
Pericarp Thickness (PT)	-0.270	0.418	0.101	0.787	0.067	-0.072	0.887
Fruit Pedicel Length (FPL)	-0.052	0.322	0.196	-0.745	0.352	-0.242	0.882
FPD to FED Ratio (PER)	0.579	-0.045	0.022	-0.722	0.088	-0.077	0.874
Seed Shell Thickness (SST)	0.009	0.008	0.126	0.694	0.335	-0.049	0.612
Trunk Girth (TG)	-0.113	-0.071	-0.063	0.048	0.867	0.094	0.785
Tree Height (TH)	0.092	-0.147	-0.339	0.032	0.793	0.004	0.775
Kernel Weight (KWt)	0.128	-0.069	0.092	0.027	0.049	0.960	0.954
Outturn (OT)	-0.025	0.431	-0.001	0.035	0.057	0.871	0.950

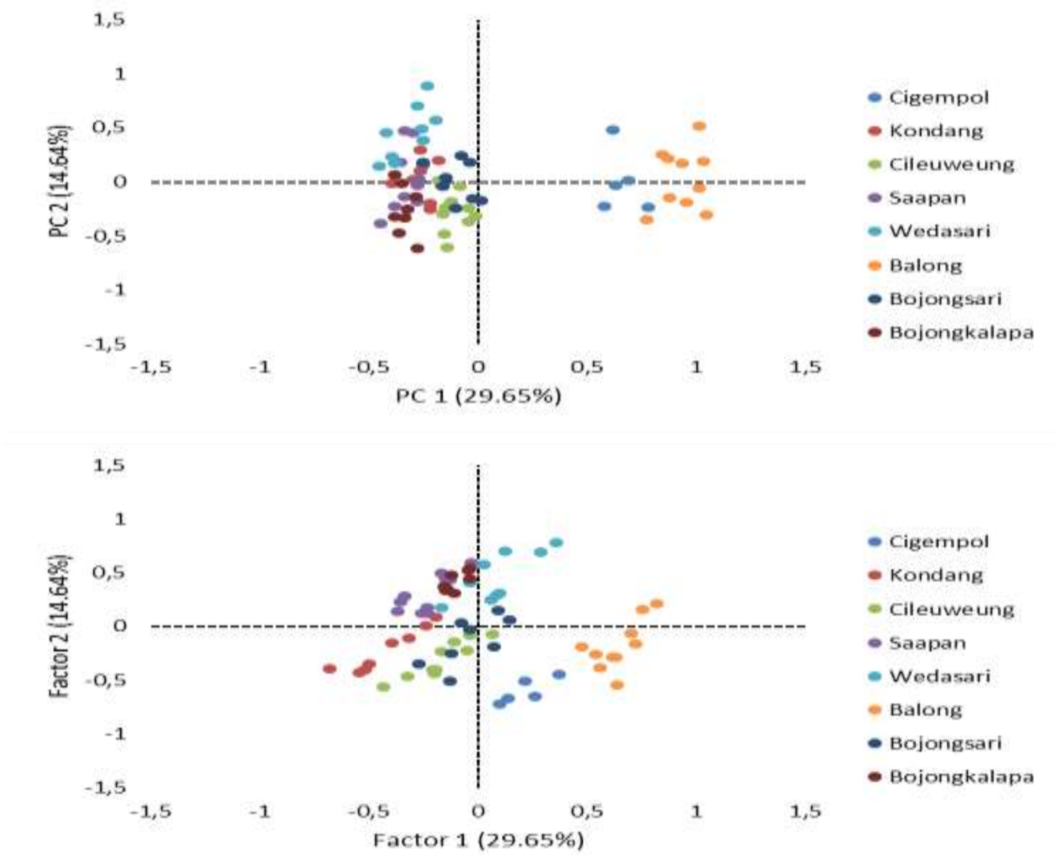

Figure 4. Principal component and factor analysis of 21 morphometric variables of *R. trisperma* revealed a clear separation of Cigempol and Balong populations.

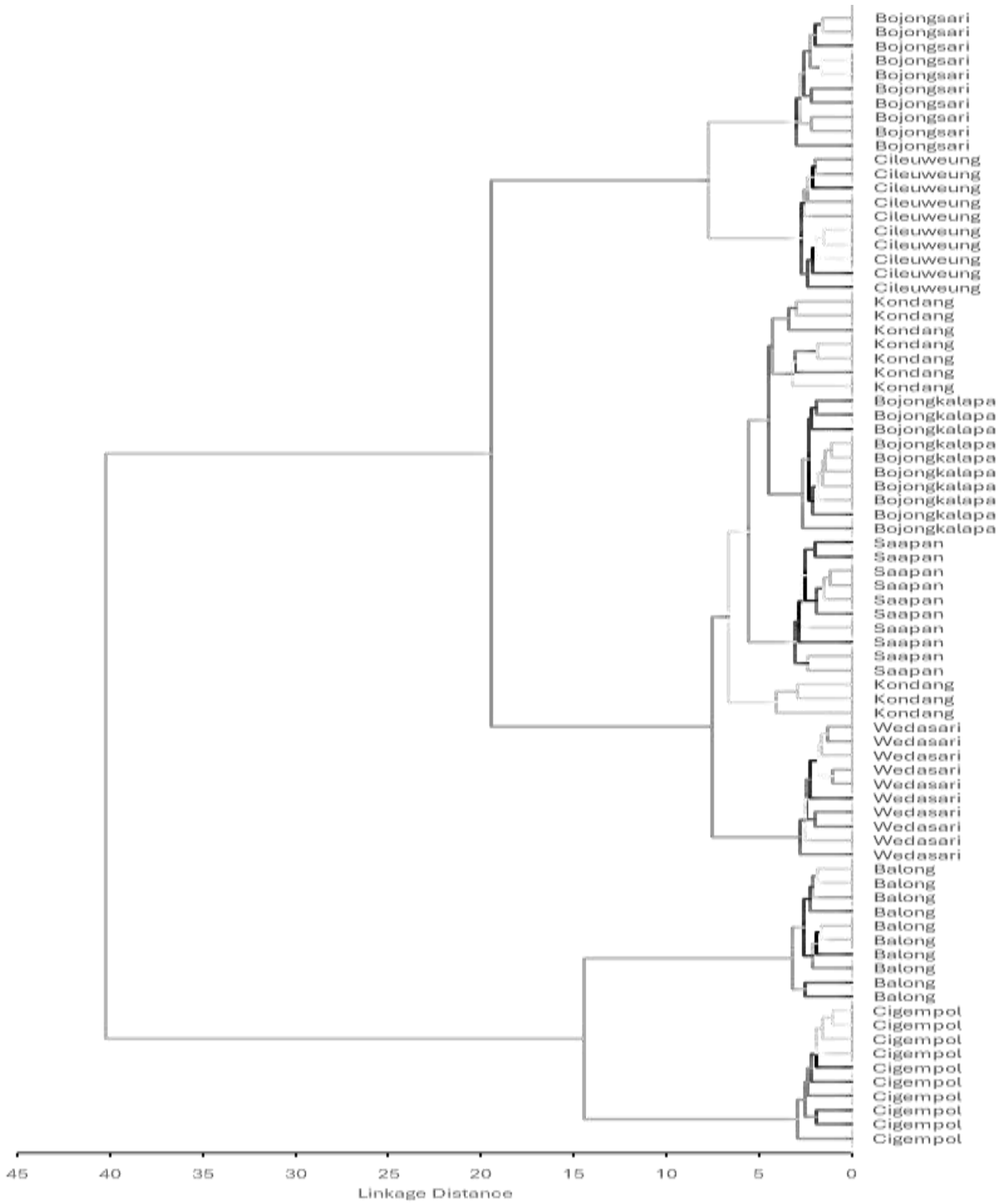

Figure 5. Agglomerative clustering analysis of 21 morphometric variables of *R. trisperma* revealed a distinct grouped of Cigempol and Balong populations.

R. trisperma seed yield

Each individual tree of the eight populations showed quite stable yields, on the average, of four years' production, ranging from 93.81 to 157.17 kg per plant. The Cigempol and Balong populations revealed higher average seed yields than the other six populations (Figure 6). Therefore, those two populations of *R. trisperma* could be a selection of candidate genotypes for seed source. The higher yield of both populations might have a strong correlation with the size and weight of their fruits (Table 2). Unfortunately, this study could not perform the correlation analysis because individual data for harvested seeds were not available.

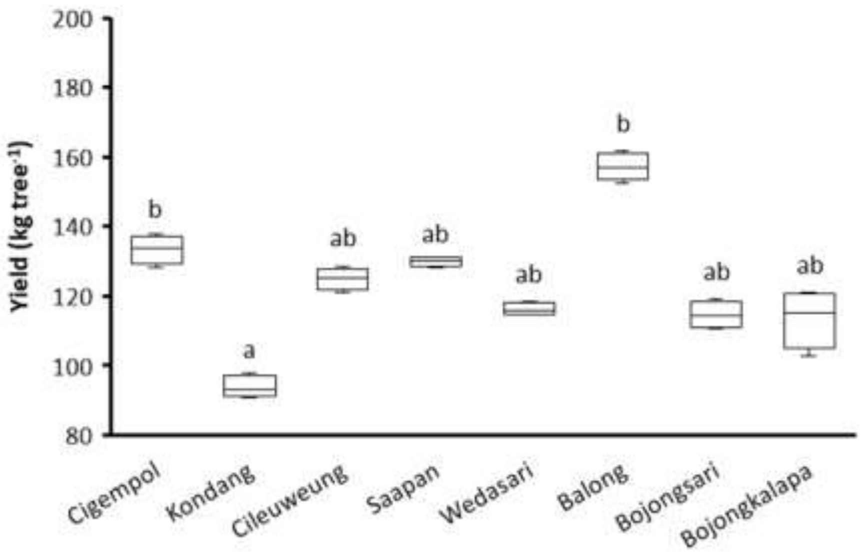

Figure 6. Yield variation among eight populations of *R. trisperma* for four consecutive years of harvest. Different letters above the boxplots show a significant difference at a p-value < 0.05, according to Kruskal Wallis with Dunn post-hoc test.

CONCLUSIONS

Based on the analysis of morphometric characters, a significant variation in both vegetative and generative morphological traits existed among *R. trisperma* populations. Bojongkalapa and Bojongsari populations have the largest tree size, whereas Bojongsari and Wedasari populations show the largest leaf size. However, Balong and Cigempol produced the largest fruit weight and size. On the other hand, no correlations were evident among the vegetative and yield-related traits. Seed kernel weight (KWt), which is an important parameter, revealed no correlation with other traits. Fruit equatorial diameter (FED) had a strong correlation to fruit weight (FWt), suggesting that FED is an influential characteristic in determining the yield of *R. trisperma*. Among all the populations, two populations of *R. trisperma*, namely, Balong and Cigempol, distinctively clustered apart from the other six populations. These two populations also displayed the highest seed yield for four consecutive years of the study.

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