Scientia Horticulturae 287 (2021) 110220

Contents lists available at ScienceDirect

Scientia Horticulturae

journal homepage: www.elsevier.com/locate/scihorti

Genotypic selection approach made successful advancement in developing drought tolerance in perennial tree crop coconut

C.R.K. Samarasinghe [a], M.K. Meegahakumbura [a,*], D.P. Kumarathunge [b], H.D.M.A. C. Dissanayaka [a], P.R. Weerasinghe [a], L. Perera [a]

[a] Genetics and Plant Breeding Division Coconut Research Institute, Lunuwila, Sri Lanka
[b] Plant Physiology Division, Coconut Research Institute, Lunuwila, Sri Lanka

ARTICLE INFO

Keywords:
Coconut
Drought tolerance
Stable yield
Ambakelle special
Genotypic selection

ABSTRACT

Coconut (*Cocos nucifera* L.) is a major plantation crop in humid tropics that affects the socio-economic life of several developing countries. Being a rainfed crop, coconut is highly prone to drought and breeding for drought tolerance has become a high priority research. We have identified that selection within populations as the way forward to improve drought tolerance. The current study evaluates the comparative performance of Ambakelle special (AS), a progeny of a within population selection with unselected CRIC60 to identify stable higher yielding palms for future breeding programs. Six-year yield data (2014-2019) from 110 palms in each group were evaluated. Results revealed variety, year and interaction have significant impact on annual yield ($P<0.05$) however, variety x year showed a non-cross-over interaction. AS recorded significant higher mean annual yield (101 nuts/palm/year) compared to CRIC60 (90 nuts/palm/year). Due to low rainfall condition prevailed from July 2016; lower nut yields were recorded for both varieties in 2017 and 2018. However, AS maintained its superiority indicating a better adaptation than CRIC60 under low rainfall conditions. Regression coefficient (b_i) and mean annual yield were used in stability analysis and selected 45 palms as stable and higher yielding genotypes. Out of these 45 palms, thirty-three palms (73.3%) were from AS progeny further indicating the adaptability of AS to varying environmental conditions. Twenty palms (16 AS and 4 CRIC60) were further selected using variance of deviations from the regression (S^2_{di}) and mean kernel weight to be used in the future breeding programs for drought tolerance in coconut.

1. Introduction

Coconut is an important perennial plantation tree crop in many developing countries in the tropics with multifarious uses (Punchihewa and Aroncon, 1999). It plays a significant role in food security & livelihood of people and in the national economy of those countries (Gunasena and Gunathilaka, 2013). With the advent of health benefits of coconut and coconut-based products in the recent past (Prades et al., 2016; Sivapragasam, 2008), there is a very high demand for coconut globally. However, the supply of coconut is limited due to number of reasons (Moreno et al., 2020). Coconut is mainly a rainfed crop thus, occurrence of severe and frequent droughts is a significant contributing factor to reduced yield.

Coconut yield is a complex quantitative trait that varies with the variety, age, environmental factors and interaction between variety and environmental factors. Mature nuts are mainly considered as yield because solid endosperm (kernel) content in nuts is used for the production of a variety of food and is used to extract oil. Among the environmental factors, the climatic conditions, especially the rainfall and the air temperature that affect the viability of pollen and receptivity of female flower, are the major players (Ranasinghe et al., 2015) determining the yield because of its uncontrollable nature under open field conditions (Peiris et al., 2008; Perera, 2015).

One of the major challenges faced by the world in 21[st] century is supplying sufficient amounts of food for the ever-increasing population under the negative impact of global climate change (Lal et al., 2005). Even though several efforts have been made to mitigate the effects of climate change via improving the edaphic factors, development of drought tolerant crop cultivar/s by manipulating the genetic makeup of crops is appeared to be the most sustainable adaptation strategy in climate smart agriculture. As a result, development of drought/heat stress tolerant coconut cultivars has become a major objective of

* Corresponding author.
E-mail address: mkmeegahakumbura@gmail.com (M.K. Meegahakumbura).

https://doi.org/10.1016/j.scienta.2021.110220
Received 9 December 2020; Received in revised form 17 March 2021; Accepted 9 April 2021
Available online 21 May 2021

coconut breeding programmes in many coconut growing countries (Nair et al., 2016; Rajagopal et al., 2005). In Sri Lanka, several attempts were taken to develop drought tolerant coconut cultivars through inter and intra varietal hybridization. However, as was evident in our previous studies, these inter and intra varietal hybrids failed to develop cultivars withstanding drought and temperature stresses (Samarasinghe et al., 2018).

The coconuts are classified into three groups of varieties as tall (Typica), dwarf (Nana), and intermediate (Aurantiaca) based on its stature and breeding behaviour (Liyanage, 1958). Talls are the commercially cultivated group of varieties because of their high kernel quality. However, with the increasing demand for natural beverages, the dwarfs and intermediate groups are becoming popular. Contrasting to autogamous dwarfs, tall varieties are predominantly allogamous resulting highly heterozygous and heterogeneous populations (Liyanage, 1958; Perera et al., 2001). Therefore, within population selection strategy appeared as the best approach and the way forward in developing drought tolerant tall cultivars in coconut.

In Sri Lanka, the isolated seed garden in Ambakelle (ISG) was established in 1955 by planting selected talls to produce improved cultivar CRIC60. The selection was carried out for yield and good agronomic characters. Wickramaratne (1987), based on 16 years (1966-1982) of yield data at the ISG, selected 84 palms that gave a stable and moderately higher yield throughout the period of study including the years with adverse climatic condition using regression coefficient (Finlay and Wilkinson, 1963) method. From those 84 palms, 28 palms had been selected-out using fruit component data (weight of fruit, de-husked nut, kernel content) and phenotypic characters of the palms and had been named as Ambakelle Special (AS) (Wickramaratne, 1987). For further selection and comparison, a progeny of AS palms has been developed by paired crossing between these selected palms. This progeny has been planted in 1992 in the field No 11A of the same seed garden together with CRIC60 seedlings, an open pollinated progeny of unselected mother palms in the same seed garden (Everard et al., 1993). The present study was conducted to evaluate the comparative performance of AS progeny with CRIC60 palms under changing climatic conditions and to select stable higher yielding palms to utilize in future breeding program for the development of drought tolerant cultivar/s to changing climatic conditions.

2. Methodology

One hundred ten palms from each group (AS and CRIC60) at the experimental blocks in fields No 11A of ISG (center coordinates: 7° 41′27″ N, 79° 53′ 48″ E) in Ambakelle, Sri Lanka were used for the data collection. The field was planted at a density of 156 palms/ha and the standard management practices were applied throughout the study period. Coconut produces bunches of mature nuts throughout the year and generally harvests bimonthly. Bimonthly nut yield data (harvest-wise/pick-wise) were collected from January 2014 to December 2019. Daily rainfall and maximum temperature (day) (Tmax) were obtained from the meteorological station at ISG which is about 500m away from the experimental site. Two nuts from each palm at each harvest were used to collect kernel weight.

Yield and kernel weight data were analyzed by Analysis of Variance (ANOVA) procedure and mean separation was carried out using Tukey's mean separation method by using R v.3.3.2 (R Development Core Team, 2012) statistical software.

The regression coefficient (b_i) introduced by Finlay and Wilkinson was used to select stable yielding palms (annual yield) under varying climatic conditions during six-year period (used as environmental variation), The regression coefficient (b_i) is defined as the response of the genotype to the environmental index that is derived from the average performance of all genotypes in each environment (Finlay and Wilkinson, 1963). In this current selection, individual palms were considered as genotypes. If b_i does not significantly differ from 1, then the genotype is adapted to all environments. The $b_i > 1$ indicates genotypes with higher sensitivity to environmental change and greater specificity of adaptability to high yielding environments, whereas a $b_i < 1$ describes a measure of greater resistance to environmental change, thereby increasing the specificity of adaptability to low yielding environments (Finlay and Wilkinson, 1963).

The regression coefficient (b_i) was calculated using Eq. (1) (Finlay and Wilkinson, 1963; Fasahat et al., 2015)

$$b_i = 1 + \frac{\sum_i \left(X_{ij} - \overline{X}_{i.} - \overline{X}_{.j} + \overline{X}_{..}\right)\left(\overline{X}_{.j} - \overline{X}_{..}\right)}{\sum_i \left(\overline{X}_{.j} - \overline{X}_{..}\right)^2} \tag{1}$$

where X_{ij} is the performance of the i^{th} genotype in the j^{th} environment, $X_{i.}$ is the mean performance of the i^{th} genotype, and $X_{.j}$ is the mean performance of the j^{th} environment, $X_{..}$is the overall mean and E is the number of environments.

In addition to the regression coefficient, variance of deviations from the regression (S^2_{di}) introduces by Eberhat and Russell was used. It is one of the renowned parameters for the selection of stable genotypes. Genotypes with an $S^2_{di} = 0$ would be the most stable, while an $S2di_2 > 0$ would indicate lower stability across all environments. Hence, genotypes with lower values are identified as the most desirable (Eberhart and Russell, 1966).

The formula used to calculate variance of deviations from the regression (S^2_{di}) (Eberhart and Russell, 1966; Fasahat et al., 2015) is as follows (Eq. 2).

$$s^2_{di} = \frac{1}{E-2}\left[\sum_i \left(X_{ij} - \overline{X}_{i.} - \overline{X}_{.j} + \overline{X}_{..}\right)^2 - (b_i - 1)^2 \sum_i \left(\overline{X}_{j.} + \overline{X}_{..}\right)^2\right] \tag{2}$$

STABILITYSOFT online software developed by Pour-Aboughadareh et al. (2019) was used to calculate above b_i and $S^2_{di.}$

3. Results

The ANOVA (Table 1) showed that variety, year and variety x year interaction components of the ANOVA were significant ($P < 0.05$) for the trait annual yield (nuts/palm/year). AS showed a significantly ($P < 0.05$) higher yield (101 nuts/palm/year) compared to CRIC60 (90 nuts/palm/year). When mean annual yield was compared separately at each year (Fig. 1), mean annual yield of AS and CRIC60 were not significantly ($P < 0.05$) different in 2014 and 2015. However, from 2015 onwards AS showed a significantly ($P < 0.05$) higher mean annual yield compared to that of CRIC60 (Fig. 2).

The bimonthly (harvest-wise) nut yield (nuts/palm/harvest (pick)), was also varied significantly ($P < 0.05$) with the variety, harvest within year and interaction of variety x harvest within year (Table 2). AS showed significantly ($P < 0.05$) higher mean nut yield (16 nuts) compared to CRIC60 (14 nuts). Fig. 3 shows the harvest-wise mean yield variation of two cultivars during six-year period from January 2014. During most of the harvests, AS progeny was found to be superior to CRIC60.

Regression coefficient (b_i) values calculated for individual palms

Table 1
ANOVA table for yield (nuts/palm/pick) for two different coconut cultivar in ISG from 2014 to 2019.

Source of variance	DF	Sum of Square	Mean Square	F Value	Pr (>F)
Variety	1	39502.15	39502.15	30.15	0.0000
Year	5	573762.26	114752.45	87.59	0.0000
Variety x Year	5	15084.13	3016.82	2.30	0.0427
Error	1308	1713608.24	1310.10		
Total	1319	2341956.78			

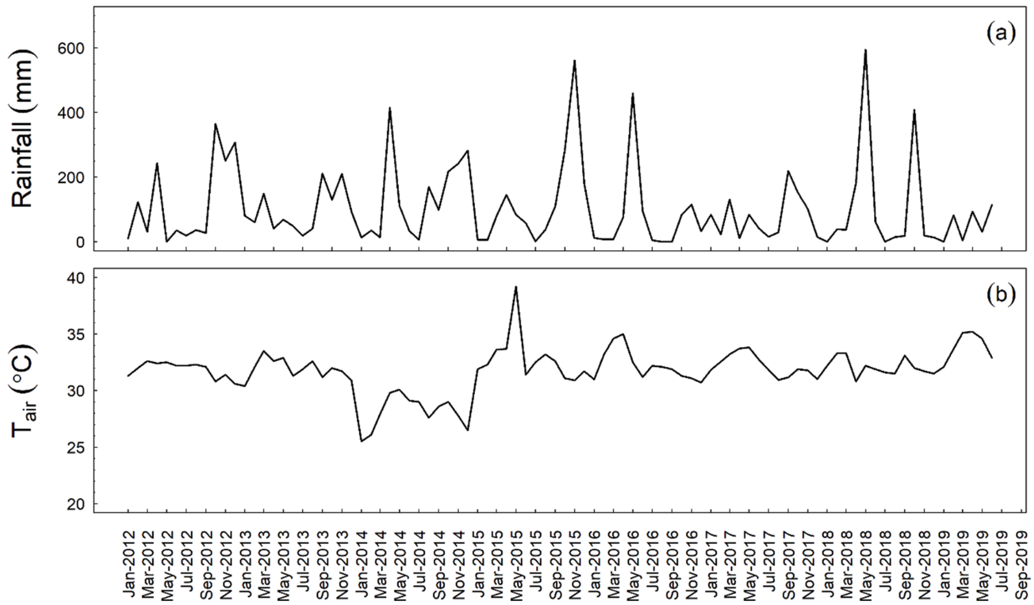

Fig. 1. (a) Monthly total rainfall and (b) Mean monthly air temperature in ISG Ambakelle from January-2012 to June-2019.

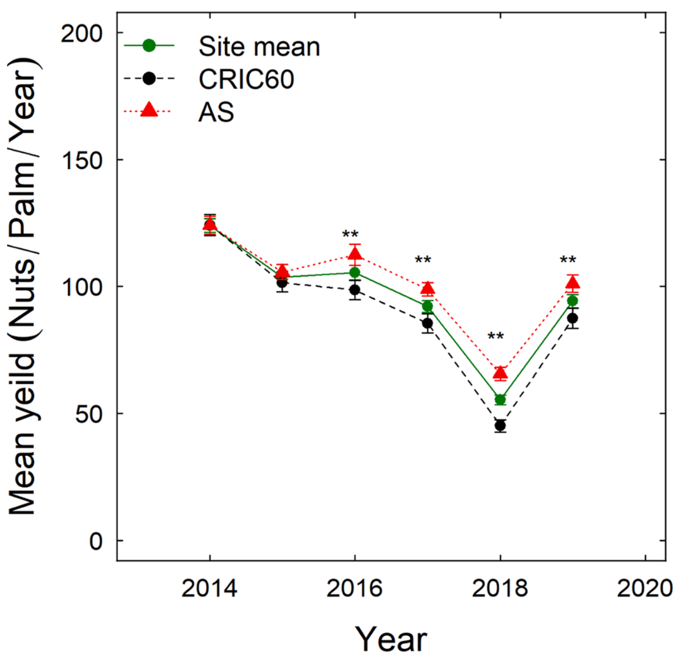

Fig. 2. Yearly mean nut yield (nuts/pam/year) of two different varieties and site mean yield of from 2014 to 2019. Error bars depict ±1SE. ** depicts significantly different mean nut yields between CRIC60 and AS ($\alpha = 0.05$).

Table 2
ANOVA table for yield (nuts/palm/harvest within year) two different coconut varieties in ISG from 2014 to 2019.

Source of variance	DF	Sum of Square	Mean Square	F Value	Pr (>F)
Variety	1	7057.27	7070.75	53.12	0.0001
Harvest (year)	55	215481.92	3890.15	29.23	0.0001
Variety x harvest (year)	37	16413.05	443.59	3.33	0.0001
Error	8950	1191299.90	133.11		
Total	9040	1430252.14			

varied from -0.54 to 2.707. Palms with a lower b_i value were considered as stable yielding palms. However, some of the palms with lower b_i value did not provide a higher nut yield. To select stable yielding palms with higher mean performance, Finlay and Wilkinson (1963) used a figure similar to Fig. 4 (a) (genotype regression coefficient against genotype mean performance) and categorized the genotypes based on their adaptability to the environment (Finlay and Wilkinson, 1963; Fasahat et al., 2015). The genotypes with higher mean performance and lover b_i values were considered as well adapted to all environments. A similar plot was obtained for the current study by plotting the regression coefficient (b_i) against the mean performance of each palm in the two variety groups of the study. Forty-five palms were observed within the region of above average stability ($b_i < 1$) and higher genotype mean performance (mean yield > 95.8 nuts/palm/year) (Fig. 4(b)), Out of these 45, 33 palms (73.3%) belonged to AS variety indicating the adaptability of AS to varying environmental conditions compared to CRIC60. The variation of deviation from the regression ($S^2_{d_i}$) values were also obtained for each palm and it ranged from 19.59 to 2304.9.

Best performing palms were selected in three stages. First, the above 45 palms that showed lower b_i value with mean yield over site mean yield (95.8 nuts/palm/year) were selected. The $S^2_{d_i}$ values were used in the second selection and the palms with higher values (11 palms) were rejected. Finally, the nut quality parameter kernel weight was included in the selection criteria. The, palms that produced a mean kernel yield lower than 250g/nut (14 palms) were rejected. Finally, 20 palms (Sixteen AS and four CRIC60) were selected (Table 3) as high yielding well adapted genotypes.

4. Discussion

Identification and selection of best crop varieties for target environments is one of the main goals of plant breeding studies (Ahmadi et al., 2016; Vaezi et al., 2017). However, due to the unpredictability of climatic conditions during the era of climate change, selection of best varieties for each environmental condition is not practical. Therefore, under such changing conditions, identification of varieties giving a stable yield across different environmental conditions is more advantageous. Gomaa et al. (2018) has described stable genotypes as the genotypes showing high mean yield with low fluctuations under diverse environments.

In coconut the entire developmental process from floral initiation to maturation takes over two years (Perera et al., 2010) and within that

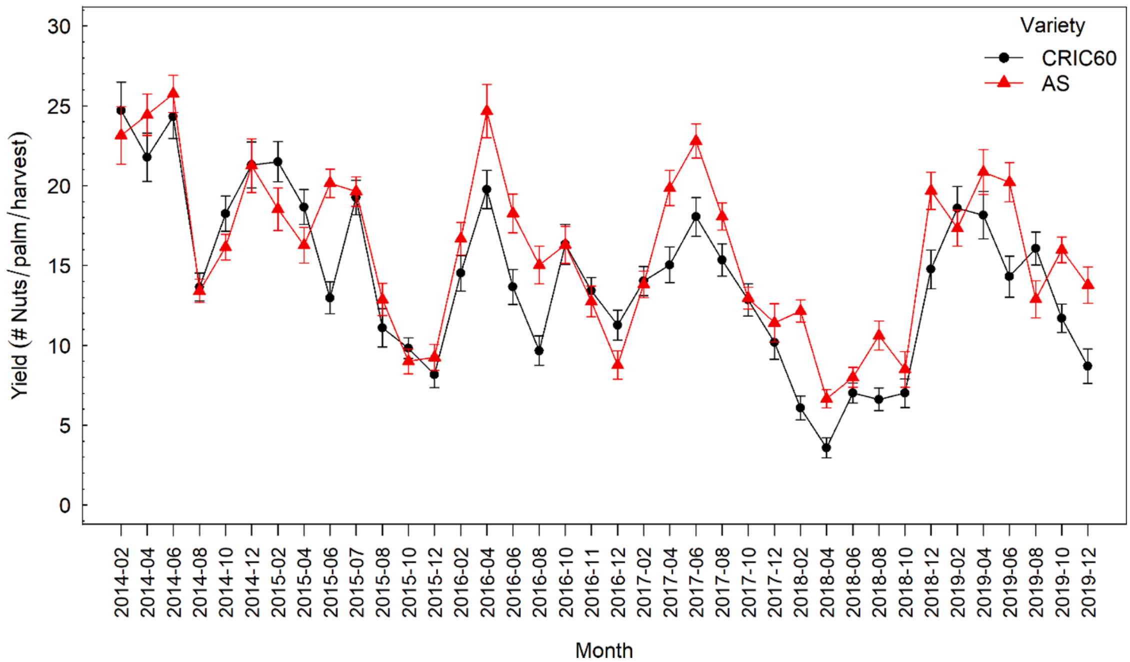

Fig. 3. Harvest wise mean yield of two cultivars during six-year period from January 2014 to June 2019. Error bars depict ±1SE.

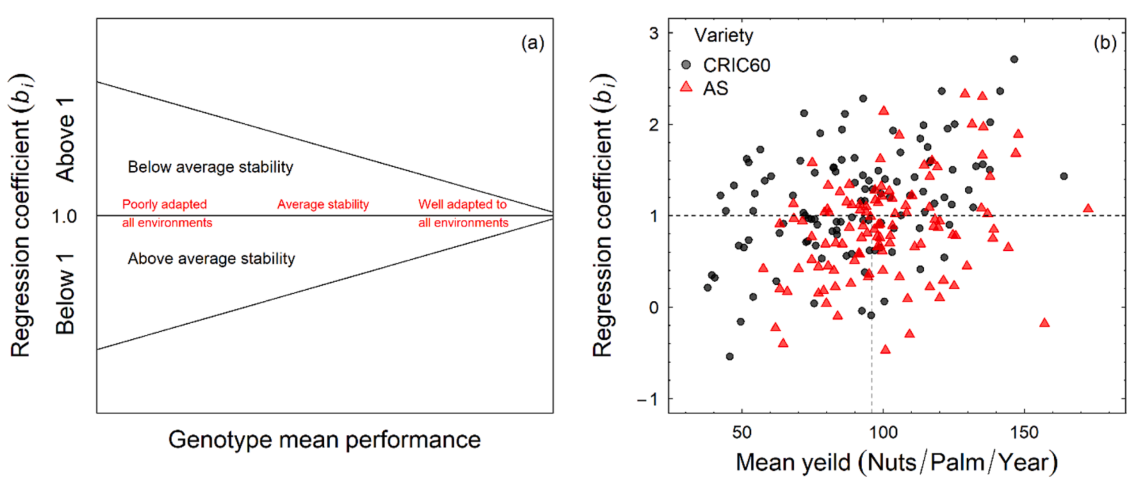

Fig. 4. Genotype regression coefficient against genotype mean performance (Finlay and Wilkinson, 1963) used for categorize genotypes based on adaptability to the environment (a). Regression coefficient (b_i) against mean performance for each palms in two variety groups (b).

period inflorescence opening to nut maturation takes 11 months. Environmental variation experienced by the palm throughout this entire development process could affect the final nut yield and nut quality of coconut. Samarasinghe et al. (2018) revealed that the moisture stress at the time of floral primordia initiation (nine to seven months prior to inflorescence opening) and the temperature stress at the time of nut setting (first three months after inflorescence opening) as the most critical factors affecting the coconut yield. In this study the significant interaction among variety x year and variety x harvest within year indicated the differential response of AS and CRIC60 to within year climatic variation. Low rainfall condition prevailed from July 2016 to August 2017 (Fig. 1) might be the reason for lower nut yields recorded in 2017 compared to previous years and for the further reduction occurred in 2018 for both AS and CRCI60 (Fig. 2).

However, AS has given a significantly higher yield compared to CRIC60 indicating a better adaptation than CRIC60 under low rainfall conditions. Furthermore, out of the 20 palms selected based on the stability parameters, mean yield and mean kernel weight, 16 palms were from AS variety whereas only 4 belonged to CRIC60. These results suggest that AS variety respond and perform better under changing climatic conditions with a stable higher yield compared to widely grown CRIC60 cultivar.

For commercial coconut cultivation tall varieties are prominently used over dwarf varieties (Bourdeix et al., 1990), because of their kernel quality and ability to tolerate harsh environmental conditions. Therefore, this genotypic selection of tall coconuts can be used to further enhance the drought tolerant ability of coconut by developing the next generation progeny through paired crosses to enrich the genes responsible for the drought tolerance.

On the other hand, hybrid between tall and dwarf were also shown to be highly successful in terms of early flowering and nut yield (Liyanage et al., 1988; Perera et al., 2017; Meegahakumbura et al., 2019; Batugal and Bourdeix, 2005; Carpio et al., 2005; Batugal, 2005). Development of new drought tolerant hybrid coconut varieties showing stable and higher yield under changing climatic condition could be produced by crossing selected drought tolerant tall parent with dwarf parents. However, improvement of

Table 3
Selected 22 palms based on mean yield, regression coefficient (b_i), variation of deviation from the regression (S^2d_i) and mean kernel weight.

Palm No	Cultivar Type	Mean Annual Yield (nuts/year)	Regression Coefficient (b_i)	Variance of Deviations from the Regression (S^2d_i)	Mean Kernel Weight (g)
7104	AS	109.3±11.5	-0.301	391.96	341.33±14.70
6867	AS	157.2±12.0	-0.181	603.58	299.17±11.32
6895	AS	120.0±10.6	0.095	478.61	292.87±18.45
6865	AS	116.5±5.9	0.216	133.67	309.17±13.76
6937	AS	125.2±4.5	0.232	67.79	293.25±14.40
6691	AS	121.3±7.2	0.291	192.10	327.00±09.46
6869	AS	105.8±5.4	0.333	86.06	295.40±12.31
7107	AS	99.8±8.2	0.405	230.75	332.40±14.52
4931	CRIC60	113.2±8.6	0.414	254.38	288.00±16.31
7106	AS	129.7±6.4	0.447	100.14	255.37±18.67
7440	CRIC60	121.7±10.8	0.536	393.03	252.49±12.90
6853	AS	99.7±11.7	0.608	446.63	253.48±13.89
7357	CRIC60	97.0±11.2	0.625	393.18	298.00±20,92
4836	CRIC60	99.0±15.3	0.652	305.93	251.90±11.78
6685	AS	111.2±11.9	0.661	448.54	324.62±19.92
6938	AS	98.8±6.9	0.674	33.93	323.86±17.46
7031	AS	102.3±10.2	0.698	265.22	288.67±11.98
6816	AS	92.3±8.5	0.760	98.24	331.75±09.21
6827	AS	97.8±11.4	0.768	336.61	263.67±16.96
6683	AS	124.7±9.6	0.794	156.11	259.98±15.76

quantitative traits such as drought tolerance, yield or stable yield in a cross-pollinated crop cannot be achieved through simple selection. To gather favorable alleles responsible for those quantitative traits, genotypic recurrent selection techniques that combine several generations of selections followed by recombination are required. Therefore, the selected 20 palms of this study can be used as material to produce progenies for further selections and recombination.

This is a classic example of breeding coconut varieties for drought tolerance and other changing climatic conditions. As drought and adverse climatic conditions has become a major threat to coconut cultivation across the globe (Jayalath, 2020; Hegde et al., 2018; Chan and Elevitch, 2006), similar approaches could be used in other coconut growing countries as well to alleviate poverty in these developing countries.

Author statement

C. R. K. Samarasinghe: Data collection, Methodology, Data analysis, Writing- Original draft preparation; **M. K. Meegahakumbura**: Conceptualization, Methodology, Writing- Reviewing and Editing; **D.P. Kumarathunge**: Data analysis, Writing- Reviewing and Editing; **H. D. M. A. C. Dissanayaka**: Writing- Reviewing and Editing; **P.R. Weerasinghe**: Writing- Reviewing and Editing; **L. Perera:** Writing- Reviewing and Editing,

Declaration of Competing Interest

None.

Acknowledgement

The authors specially acknowledge Mr. Roshan Jayathilake and Mr. S.M.T.R Senarathna, Genetics and Plant Breeding Division of the Coconut Research Institute for their assistance in data collection. Authors also wish to thank the past and present staff members of the Genetics and Plant Breeding Division of the Coconut Research Institute who supported in planting and maintaining the research blocks at Ambakelle Seed Garden. We wish to acknowledge NRC research grant (18-084) for supporting this research project.

References

Ahmadi, J., Vaezi, B., Pour-Aboughadareh, A., 2016. Analysis of variability, heritability, and interrelationships among grain yield and related characters in barley advanced lines. Genetika 48, 73–85.
Batugal, P., Bourdeix, R., 2005. Conventional coconut breeding. Coconut Genet. Resour. 251–252.
Batugal, P., 2005. Performance of coconut hybrids in some countries of Asia, Africa and Latin America. Coconut Genet. Resour. 302–303.
Bourdeix, R., N'Cho, Y.P., Lesaint, J.P., Sangare, A., 1990. A coconut (*Cocos nucifera* L.) selection strategy I Rundown of achievements. Oleagineux 45, 359–371.
Carpio, C.B., Santos, G.A., Emmanuel, E.E., Novarianto, H., 2005. Research on coconut genetic resources in Southeast and East Asia. Coconut Genet. Resour. 533–534.
Chan, E., Elevitch, C.R., 2006. *Cocos nucifera* (coconut). Species Profiles Pac. Island Agroforest. 2, 1–27.
Everarad, J.M.D.T., Fernando, W.M.U., Peries, R.R.A., Fernando, W.B.S., Attanayake, R. B., 1993. In: Mahindapala, R., Liyanage, M.S. (Eds.), Progeny Trial for Testing of Putative Drought Tolerant Palms by the Performance of their Progeny at ISG. Report of the Coconut research Institute for 1992. Coconut research Institute, Lunuwila, Sri Lanka, pp. 64–66.
Eberhart, S.A., Russel, W.A., 1966. Stability parameters for comparing varieties. Crop Sci. 6, 36–40.
Fasahat, P., Rajabi, A., Mahmoudi, S.B., et al., 2015. An overview on the use of stability parameters in plant breeding. Biom. Biostat. Int. J. 2 (5), 149–159.
Finlay, K.W., Wilkinson, G.N., 1963. The analysis of adaptation in a plant-breeding programme. Aust. J. Agric. Res. 14 (6), 742–754.
Gomaa, M.R., EL-Badawy, M., El, M., El-Hosary, A.A.A., El-Areed, R.M., Amer, A., 2018. Stability anlysis for yield and its components in wheat. Egypt. J. Plant Breed 22 (7), 1535–1550.
Gunasena, H. P. M., Gunathilake, H. A. J., 2013. Present status of the coconut industry of Sri Lanka. in: Gunasena, H.P.M., Gunathilake, H.A.J., Fernando, L.C.P., Everard, J.M. T.D., Appuhamy, P.A.H.N. (Eds.), Weligama Coconut Leaf Wilt Disease: Six Years After. Coconut Research Institute, Lunuwila, Sri Lanka, pp. 1-12.
Hegde, V., Pilet, F., Omuru, E., 2018. Major threats to coconut genetic resources. Chapter 1. Introduction to the Global Coconut Strategy. In: Bourdeix, R., Prades, A. (Eds.), A Global Strategy for the Conservation and Use of Coconut Genetic Resources, 2018-2028. Bioversity International, Montpellier, pp. 19–22.
Jayalath, K.V.N.N., Punyawardena, B.V.R., Silva, P., Hemachandra, D., Weerahewa, J., 2020. Climate change and extreme events in WL1a agro-ecological zone of Sri Lanka: implications on coconut production. Trop. Agric. Res. 31 (4), 13–25.
Lal, R., 2005. Climate change, soil carbon dynamics and global food security. et al., (Eds.). In: Lal, R., Stewart, B., Uphoff, N. (Eds.), Climate Change and Global Food Security. CRC Press, Boca Raton (FL), pp. 113–143.
Liyanage, D.V., 1958. Varieties and forms of the coconut palm grown in Ceylon. Ceylon Coconut Quart. 9, 1–10.
Liyanage, D.V., Wickramaratne, M.R.T., Jayasekara, C., 1988. Coconut breeding in Sri Lanka: a review. Cocos 6, 1–26.
Meegahakumbura, M.K., Samarasinghe, C.R.K., Dissanayaka, H.D.M.A.C., Perera, S.A.C. N., Herath, H.M.N.B., Weerasinghe, P., Perera, L., 2019. Development of high yielding and early flowering new coconut cultivars with exotic pollen. In: Rodrigo, V.H.L., Wijesuriya, B.W., Edirisinghe, D.G., Nayanakantha, N.M.C. (Eds.), Proceedings of the Seventh Symposium on Plantation Crop Research- "Towards Achieving Sustainable Development Goals in the Plantation Sector. Sri Lanka. Rubber Research Institute of Sri Lanka, Dartonfield, Agalawatta, 12200, pp. 1–11.

Moreno, M.L., Kuwornu, J.K., Szabo, S., 2020. Overview and constraints of the coconut supply chain in the Philippines. Int. J. Fruit Sci. 1–18.

Nair, R.V., Jerard, B.A., Thomas, R.J., 2016. Coconut breeding in India. In: Al-Khayri, J., Jain, S., Johnson, D. (Eds.), Advances in Plant Breeding Strategies: Agronomic, Abiotic and Biotic Stress Traits. Springer, pp. 257–279.

Peiris, T., Thattil, R., Mahindapala, R., 2008. An analysis of the effect of climate and weather on coconut (*Cocos nucifera*). Exp. Agric. 31 (4), 451–460.

Perera, S.A.C.N., 2015. Coconut. In: Gupta, S.K (Ed.), Breeding Oilseed Crops for Sustainable Production. Acadamic press, Elsevier, pp. 201–216.

Perera, P.I.P., Hocher, V., Weerakoon, L.K., Vakandawala, D.M.D., Fernando, S.C., Verdeil, J.L., 2010. Early inflorescence and floral development in *Cocos nucifera* L. (Arecaceae). S. Afr. J. Bot. 76, 482–492.

Perera, L., Russell, J.R., Provan, J., Powel, W., 2001. Levels and distribution of genetic diversity of coconut (*Cocos nucifera* L., var.Typica form typica) from Sri Lanka assessed by microsatellite markers. Euphytica 122, 381–389.

Perera, L., Samarasinghe, C.R.K., Kumarathunge, D.P., Dissanayaka, H.D.M.A.C., Meegahakumbura, M.K., 2017. Cultivar by environment interaction of coconut under different water and heat regimes at their early stage of growth. Pak. J. Bot. 49 (2), 475–478.

Pour-Aboughadareh, A., Yousefian, M., Moradkhani, H., Poczai, P., Siddique, K., 2019. STABILITYSOFT: a new online program to calculate parametric and non-parametric stability statistics for crop traits. Appl. Plant Sci. 7 (1), e01211. https://doi.org/10.1002/aps3.1211.

Prades, A., Salum, U.N., Pioch, D., 2016. New era for the coconut sector. What prospects for research? OCL 23 (6), D607. https://www.ocljournal.org/articles/ocl/pdf/2016/06/ocl160048s.pdf.

Punchihewa, P.G., Arancon, R.N., 1999. Coconut: Post-harvest Operations. FAO. http://www.fao.org/fileadmin/user_upload/inpho/docs/Post_Harvest_Compendium_-Coconut.pdf.

Rajagopal, V., Bai, K.K., Kumar, N., 2005. Breeding for drought tolerance in coconut: status and potentials. In: Batugal, P., Rao, R., Oliver, J (Eds.), Coconut Genetic Resources. IPGRI-APO, Serdang, Selangor DE, Malaysia, pp. 282–301.

Ranasinghe, C.S., Silva, L.R.S., Premasiri, R.D.N., 2015. Major determinants of fruit set and yield fluctuation in coconut *(Cocos nucifera L.)*. J. Natl. Sci. Found. Sri Lanka 43 (3), 253–264.

R Development Core Team, 2012. R: a Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria.

Samarasinghe, C.R.K., Meegahakumbura, M.K, Dissanayaka, H.D.M.A.C., Kumarathunge, D.P, Perera, L., 2018. Variation in yield and yield components of different coconut cultivars in response to within year rainfall and temperature variation. Scientia Horticulturae 238, 51–57.

Sivapragasam, A., 2008. Coconut in Malaysia-Current developments and potential for re-vitalization http://www.iipm.com.my/ipicex2014/docs/oral/Session%202B%20Sivapragasam.pdf.

Vaezi, B., Pour-Aboughadareh., Mohammadi, R., Armion, M., Mehraban, A., Hossein-Pour, T., Dorii., M., 2017. GGE Biplot and AMMI analysis of barley yield performance in Iran. Cereal Res. Commun. 45 (3), 500–511.

Wickramaratne, M.R.T., 1987. Breeding coconut for adaptation to drought. COCOS 6, 16–23.