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Yield Performance of Promising Cocoa Clones (*Theobroma cacao* L.) in Dry Climatic Conditions

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Abstract

El Nino impacts resulted from global climate change need to be effectively anticipated to maintain the profitability of the cocoa plantation business which is generally lower due to the long dry season. Cocoa production technology packages suitable for dry land are currently demanded to maintain the sustainability and the empowerment of cocoa production at marginal drylands. The principal component of the technology packages is drought-tolerant superior planting material. This research aimed to obtain information on clones those produce stable in diverse environmental conditions and produce well in dry conditions. The research method was applied by observing 22 promising cocoa clones planted in the Kaliwining Experimental Station in the period of 2013 to 2017 observation, each of which was planted in three blocks. The observed variables included estimated production, resistance to VSD, helopeltis, and pod rot. Based on the multivariate analysis, KW 617 had a stable production performance during period of observation while ICCRI 07 and the promising clones of KW 562 and KW 641 had a special adaptation to dry conditions. Those clones have the potential to be developed as drought tolerant planting material to overcome the impact of climate change on cocoa production. The observation results of pest and disease attacks obtained a pattern that the drought-tolerant clones have good resistance to VSD.

Keywords: Climate change, drought tolerant, superior planting material

INTRODUCTION

Impacts of global climate change include the emergence of a long dry season (7-9 months) with shorter time intervals are commonly called the El Nino impact. The El Nino impact has threatened world food security since it causes less optimal environmental conditions for plant growth that leads to plant productivity reduction. The El Nino impact is also felt in the business of cocoa plantations since cocoa plants are known to be very sensitive to environmental changes so that the decline in production is very noticeable. Indonesian cocoa production recorded in world trade has significantly declined from 440 thousand tons in 2011 to 270 thousand tons in 2017 (ICCO, 2019). During 2012-2016, the average growth of Indonesian cocoa production was only 1.6% far lower than the average production growth in 1980-2011 which reached 16.01% (Pusdatin, 2016). The decline in cocoa production growth is simultaneously affected by the decrease in plant productivity and yield quality as well as the increased intensity of pest and disease attacks. Besides, environmental conditions due to a long dry season also require higher production inputs in terms of adding organic materials, shade management and soil conservation. In other words, the efficiency of production processes become lower if it is not matched by increased plant productivity. Thus, to maintain the sustainability of cocoa production needs cultivation technology that is adaptive to climate changes, especially to anticipate the El Nino impact.

The success of future cocoa cultivation will be determined by the availability of specific cultivation technologies related to climate changes, especially dry climatic conditions. Besides, the current expansion of cocoa development also leads to areas with dry climate-type land conditions such as East Nusa Tenggara (NTT) province and cocoa planting area in the southern part of Java. The cultivation technology components for dry climate cocoa include drought-tolerant planting materials, soil fertility, and shade management. The implementation of dry climate-adaptive cocoa cultivation is generally implemented in form of integrated cultivation by prioritizing soil and water conservation. Reidsma *et al.* (2010) state that the magnitude of the impact of climate change is highly dependent on farm management factors and plant adaptability. The adaptability is not only determined by plant genetic factors but also by environmental mitigation through soil and water conservation to reduce the rate of soil erosion and degradation and microclimate modification for making soil temperature and the environment remain optimum for plant growth (Smith & Olesen, 2010). Cocoa planting material which is adaptive to dry climatic conditions is a critical factor in the success of cocoa cultivation on dry climate-type land.

To set up the dry land specific cocoa cultivation technology needs superior planting material components adaptive to dry climatic conditions. At present, the establishment of drought-tolerant cocoa plant materials is an important topic of global cocoa breeding programs (Laliberté & Medina, 2017). Other research related to construct drought-tolerant cocoa is also conducted by Santos *et al.* (2014) that evaluated hybrids planting materials and de Almeida *et al.* (2016) on clonal planting materials at seedling phase with controlled water treatment. In Indonesia, the recommended planting materials for cocoa is generally still with those resistant to pests and diseases therefore it needs to focus more on assembling planting materials adaptive to dry climatic conditions. Superior planting materials of hybrid ICCRI 08H which is resistant to vascular-streak dieback (VSD) also shows good adaptation to dry climatic conditions so that it can be recommended for planting in areas with dry climate type. In line with this, the cocoa breeding program began to be directed towards obtaining dry climatic conditions-tolerant cocoa planting materials, carried out in parallel with the establishment of superior planting materials resistant to pests and diseases. The selection activity was carried out at Kaliwining Experimental Station, Jember which is a dry climate-type area. Factually, in the field, differences have been identified in the response of the resistance of superior cocoa promising clones to dry climatic conditions (Susilo, 2015). The phenomenon of long dry season (El Nino) occurring at the Kaliwining Experimental Station in 2015 was used to evaluate the response of the tolerance of selected clones to dry climatic conditions to obtain promising clones adaptive to dry climatic conditions. This paper reports the results of the evaluation based on yield parameters evaluated from 2013 to 2017. Specifically, in 2015, a long dry season occurred while a wet season happened in 2016, which can be used as a comparison of two extremely different seasonal conditions. Based on yield performance evaluation from promising clones test, it can be obtained adaptive (tolerant) cocoa clone types to dry climate condition and can be selected some clones for development as planting materials in dry climate-type lands.

MATERIALS AND METHODS

This research was conducted in Kaliwining Experimental Station, Indonesian Coffee and Cocoa Research Institute, Jember at an altitude of 45 m above sea level (a climate type D according to the Schmidt & Ferguson classification) and flat topography. The results of recording Climatology Station was known that the average rainfall in the Kaliwining Experimental Station in the period 2011-2018 was 2,102 mm per year. In particular, the longest dry season during the last 10 years occurred in 2015, characterized by the occurrence of dry climate for 6 consecutive months (May-October), total rainfall of 1,688 mm (an average of 140.7 mm/ month) and the Q value = 1 or the moderate dry category. The opposite condition occurred in 2016 which was the longest wet condition for the past 10 years, characterized by the absence of dry month, total rainfall of 3,082 mm (an average of 257 mm) and the Q value of 0 or the very wet category. Climatic conditions in that two years were extremely different, which can be used to evaluate the response of the tolerance of experimental cocoa clones to different climatic conditions, especially dry climatic conditions.

The experiment was arranged in a randomized complete block design with 3 blocks as replications and each plot was planted with 5 plants clonally propagated using the rootstock of F_1 ICS 60 x Sca 12 hybrids. Planting was carried out in 2008 at 3 m x 3 m plant spacing used of *Lamtoro* (*Leucaena* sp.) as permanent shade trees. The treatments were cocoa clones derived from the results of introduction, selection, and exploration based on the criteria for yield, resistance to VSD and pod rot, and the physical quality of the seeds (Table 1). Initially, 44 cocoa clones were tested which, in its development, not all of these clones could grow appropriately because the plants of those susceptible to VSD mostly died. In this report, the number of clones analyzed was 22 clones based on the condition of experimental plants that meet the statistical rules for analysis of variance. The plant conditions when evaluating the response of the tolerance to dry climatic conditions in 2015 aged 7 years after planting or yielded in the fourth year.

Table 1. The list of cocoa clones (*Theobroma cacao* L.) tested for drought tolerance at Kaliwining Experimental Station

KW series	Synonym name/ selection code	Origin
KW215	Sulawesi 1	Recommended clone for VSD resistance
KW255	JTC 25	Selected clone from Jatirono Estate
KW443	RU I - SPA 9	Introduced clone from ICQC, the University of Reading
KW444	RU I - BORNE 7 A2	Introduced clone from ICQC, the University of Reading
KW454	RU I - KER 3	Introduced clone from ICQC, the University of Reading
KW514	ICCRI 07	Recommended clone for CPB resistance
KW516	PABA/VIII/78B/2	Selected clone of UAH at Pabatu Estate, North Sumatra
KW535	ADO 1	Selected clone of UAH at Adolina Estate, North Sumatra
KW562	PABA/I/90C/2	Selected clone of UAH at Pabatu Estate, North Sumatra
KW564	PABA/IX/90O/2	Selected clone of UAH at Pabatu Estate, North Sumatra
KW567	PABA/IX/90O/3	Selected clone of UAH at Pabatu Estate North Sumatra
KW570	Sulawesi 03	Recommended clone for CPB resistance
KW606	BLITAR 01	Selected clone from Blitar District East Java
KW616	ADO/IV/91FU/149/96	Selected clone of UAH at Adolina Estate North Sumatra
KW617	ICCRI 09	Selected progeny of TSH 858 x Sul-1 at Kaliwining
KW618	KWN/III/10/1	Selected progeny of KW162xTSH858 at Kaliwining
KW623	SBRM 01	Selected clone from Sumber Mangis block of PDP Pekutatan at Jembrana District
KW630	GNRG 02	Selected clone from Gunung Raung at Jatirono Estate
KW636	KEMBU 06	Selected clone at Kendeng Lembu Estate
KW641	KATE II/13/11	Selected progeny of KW163xKEE 2 at Kalitelepak
KW642	KATE II/3/7	Selected progeny of TSH858xNIC7 at Kalitelepak
KW685	MCC 01	Local clone from Masamba South Sulawesi which was recommended as cocoa clonal material

Observation data included yield components. The observed yield component is number of pods at the 1-month interval and then converted to production data forms using pod value data. The observation was performed when the condition of the plants have entered the fruiting period from 2013 to 2017. From the observation data results, combined variance analysis of clone and year factors to all observational variables was carried out. Further analysis was performed to separate median values between clones based on Tukey’s HSD, principal component analysis for grouping clones and multivariate analysis to determine the relationship between clon responses and measured observational variables.

RESULTS AND DISCUSSION

The variance analysis results showed that the variance of plant yield was significantly affected by clone and year factors, but there was no significant interaction between clones and years. Thus, it can be seen that the comparison of inter-clone production rates was relatively the same between the years, not affected by differences in seasonal conditions and plant ages over the years. Therefore, differences in the level of production between clones are a picture of the genetic potential of the character of yield.

Separation of the mean value of plant production showed a significant variation between cocoa clones during observations in 2013–2017 (Table 2). Based on these data, it appears that some promising clones (KW 617 and KW 562) showed production rates which were not different from the superior clone controls (Sulawesi 1, MCC 01, ICCRI 07) and higher than Sulawesi 3. The two clones, besides showing a high level of production or insignificantly difference from the control, also indicated stable production among the years so it is feasible to be selected as a superior promising clone based on the production rate. Further selection would be done based on the characters of resistance to pests and diseases and the quality of seeds so that the clones met the criteria as superior clones to be further used by farmers.

The results of the comparative evaluation of production rates during 2013-2017 showed that the average production of KW 617 was relatively more stable than Sulawesi 1. The data in Figure 1 show that Sulawesi 1 production is more fluctuate between years compared to other superior clones. During the long dry climatic conditions in 2015 (6 dry months), the average of KW 617 was 2.0 kg/tree, indicating good adaptability. In contrast, during the wet climatic conditions in 2016 (no dry month), yield of KW 617 was higher, reaching 2.64 kg/tree (Table 2). In other words, the production of KW 617 is estimated to be higher in the environmental conditions with optimal water sufficiency. Based on these results, it is also known that Sulawesi 3 production shows a better level of adaptation during the dry climatic conditions as the highest production rate was achieved in 2015 (during the long dry climatic conditions). Sulawesi 1 in 2016 had an estimated production of about 4.20 kg/tree which is the highest compared to other clones tested, this shows that Sulawesi 1 is a clone that has a good adaptation to conditions with high rainfall in 2016.

The treatments in this research were 44 clones, only 22 clones of which could grow well based on the recapitulation of production data that met the statistical rules for variance analysis. Clones that could grow well in the Kaliwining Experimental Station showed a better of resistance to VSD because the experimental location was an endemic area of VSD and dry climate-typed. Based on the data, it can be seen that only 50% of the experimental material clones could grow well under conditions of biotic stress on VSD disease attacks or these clones had relatively good resistance to VSD. In this case, the superior clones used as a comparison including ICCRI 07, Sulawesi 1, Sulawesi 3, and MCC 01 showed a good level of resistance to VSD so that it can be used as a reference for the superiority of other important traits.

Table 2. The average production (kg/ tree) of superior promising cocoa clones resulted from the evaluation in Kaliwining Experimental Station during 2013-2017

Clone	Year					Mean[2)]
	2013	2014	2015	2016	2017	
ICCRI 07[1)]	0.75	1.33	2.68	2.55	2.49	1.96 abc
KW 255	0.34	0.74	1.35	1.23	0.80	0.89 efgh
KW 443	0.20	0.35	0.67	0.98	0.82	0.61 fgh
KW 444	0.19	0.46	0.52	0.70	0.54	0.48 gh
KW 454	0.05	0.11	0.15	0.10	0.02	0.09 h
KW 516	0.43	2.66	2.12	2.79	1.35	1.87 abcd
KW 535	0.71	1.34	2.30	3.35	0.65	1.67 abcde
KW 562	1.00	2.70	3.21	2.94	2.20	2.41 ab
KW 564	0.67	1.96	2.71	3.37	1.26	1.99 abc
KW 567	1.01	1.34	2.24	2.77	1.34	1.74 abcde
KW 606	1.11	1.09	1.98	1.29	1.13	1.32 cdefg
KW 616	0.05	0.13	0.31	0.19	0.00	0.14 h
KW 617	1.27	2.22	2.03	2.64	2.59	2.15 abc
KW 618	1.11	2.35	1.82	1.91	1.55	1.75 abcde
KW 623	0.31	0.74	0.61	1.29	0.48	0.69 fgh
KW 630	0.81	1.26	1.56	1.19	1.49	1.26 cdefg
KW 636	0.40	0.57	1.74	1.08	0.98	0.95 defgh
KW 641	0.23	1.15	2.71	1.16	1.41	1.33 cdefg
KW 642	0.72	0.84	1.28	2.26	0.87	1.19 cdefg
MCC 01[1)]	0.79	1.44	1.95	1.31	1.12	1.32 cdefg
Sulawesi 01[1)]	1.72	2.67	2.40	4.20	1.51	2.50 a
Sulawesi 03[1)]	0.80	1.36	2.08	1.68	1.52	1.49 bcdef
Mean	0.67 c	1.31 b	1.75 a	1.86 a	1.19 b	

Notes: [1)]the recommended clones were used as the control; [2)]numbers in the same columns followed by same letters are not significantly different according to Tukey's Studentized Range (HSD) at α = 5%.

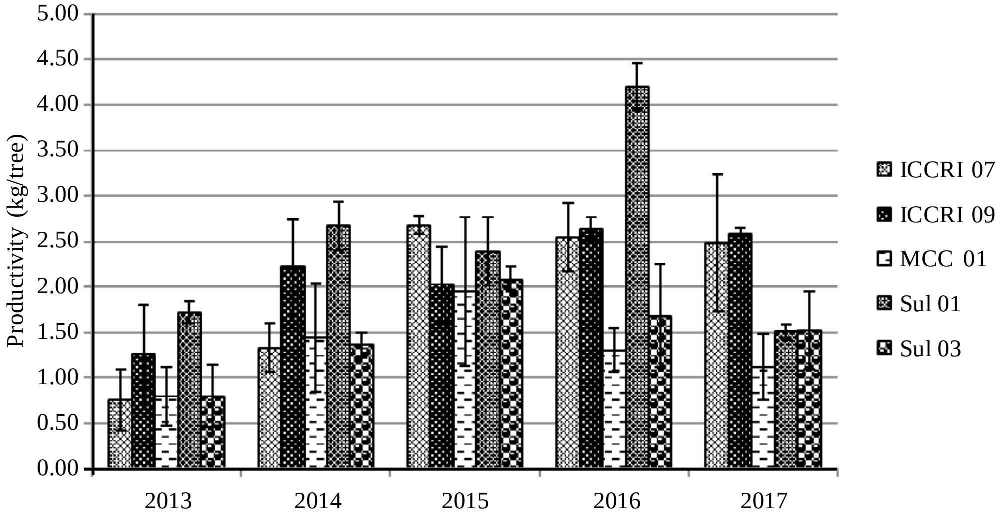


Figure 1. Comparison of production dynamics between KW 617 clones and other superior clones in the Kaliwining Experimental Station during 2013-2017 (vertical lines in the histogram show the standard deviation)

Based on the multi-year additive main effect and multiplicative interaction (AMMI) graph (Figure 2), KW 617 and KW 255 are clones that have stable yield performance from 2013-2017. Genotypes distributed at the center of the AMMI biplot graph are genotypes showing the same performance at certain environmental conditions (Yan *et al.*, 2007). KW 617 clone is selected clone of ICCRI 06H hybrid populations (Sulawesi 1 x TSH 858) planted in the Kaliwining Experimental Station, which is classified into dry areas. Therefore, the occurrence of El Nino or even normal conditions has no significant effect. In general, plants that have known for a long time grown in the same place where they grow will be easier to adapt to the same environmental conditions (Flood & Hancook, 2017). KW 255 clones are selected clones from Jatinoro Plantation which is a moderately wet climate area. Despite being considered stable, this clone has a relatively low production potential (< 1 ton/ha/year). One of the tested genotype with specific adaptability in dry conditions is KW 641. In El Nino condition in 2015, this clone showed superior production performance compared to other clones. During the 2015 El Nino dry period, KW 641 clones survived because it has narrow stomata opening width, stomata density that is slightly lower than other clones and has considerable leaf proline production capability during the dry period (Zakariyya *et al.*, 2017). Morphological and physiological characters that support plant growth and development during dry conditions will have a significant effect on the production of a plant. If in dry conditions, plants can carry out physiological processes such as undisturbed photosynthesis, dry conditions will not much affect the yield of the plants (Huang *et al.*, 2019).

The resistance of plants to drought is also related to the intensity of pest and disease attacks (Yadav *et al.*, 2013). In a fairly dry environment, VSD attack shows a quite high intensity. The response of some clones to the dry environment also varies depending on the genes of each plant genotype. In the principal component analysis graph (Figure 3), some clones have a high intensity of VSD attack, including KW 567, KW 535, and Sulawesi 3. This indicates that in fairly dry conditions,

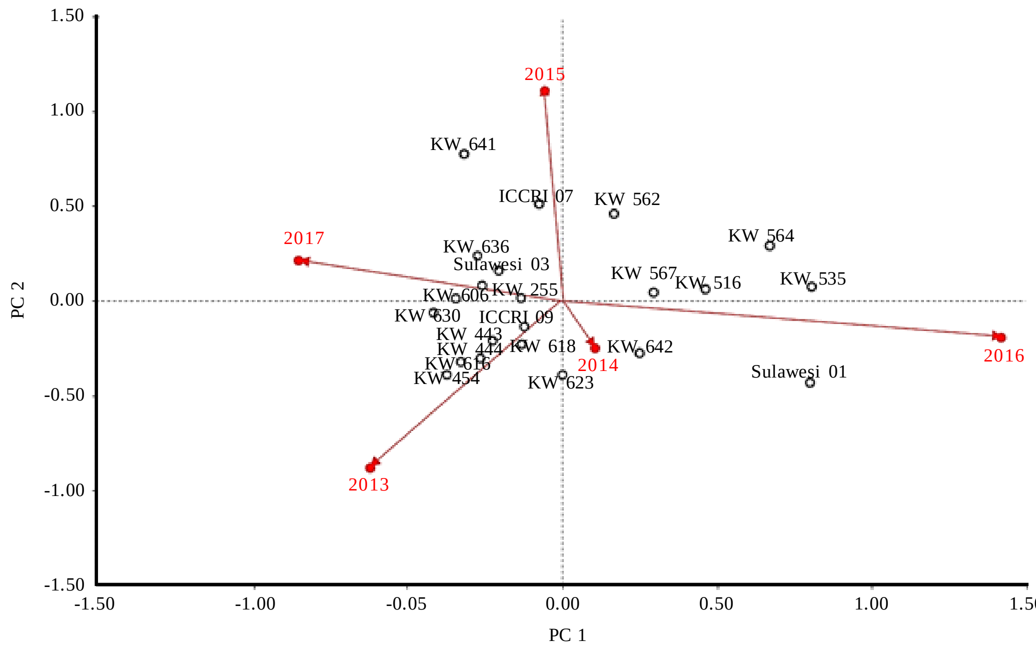
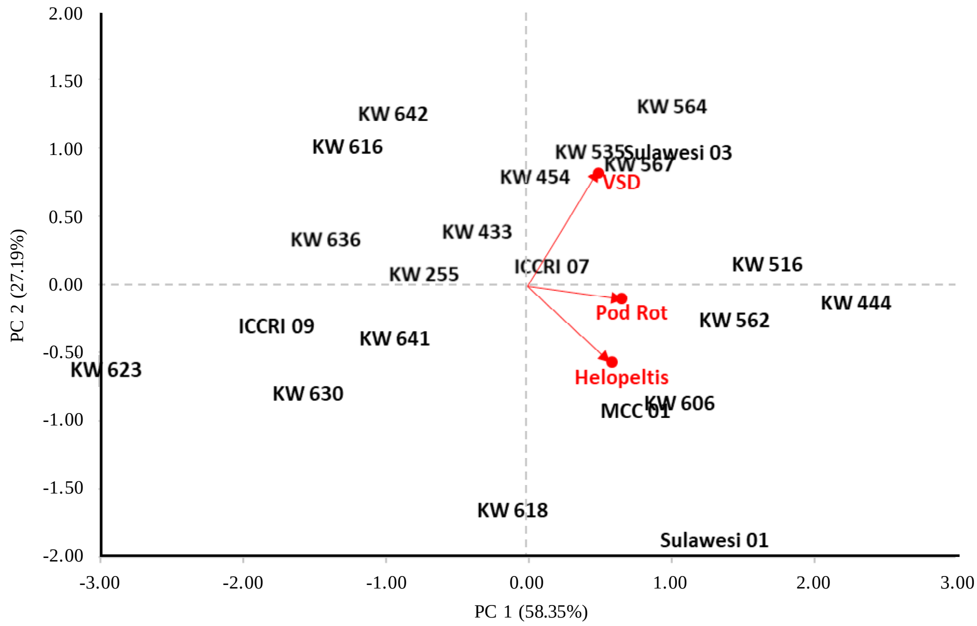


Figure 2. Multi-year AMMI trials of superior cocoa promising clones



Graph 3. Principal component analysis of cocoa pest and disease resistance biplots

these clones have high VSD attack symptoms. Based on information on the origin, KW 567 and KW 535 clones are selected clones from North Sumatra with wet environmental conditions. When these two clones were planted in the Kaliwining Experimental Station to be tested for its adaptability to a new condition (dry), it turned out that these two clones do have adaptability specifically in wet environments. Plant adaptability to the environments is divided into adaptability to a specific environmental condition or adaptability to some environmental conditions (Suzuki *et al.*, 2019) such as dry and wet climatic conditions, depending on physiological and biochemical responses such as differences in the rate of transpiration and the production of osmolyte compounds such as proline (Farooq *et al.*, 2009). Clones with a high drought tolerance such as ICCRI 09 and KW 641 have the opposite relationship to VSD or have a low attack rate (Figure 3). In the clones tolerant to dry conditions, the plant competition with VSD in getting water through the xylem (Guest & Keane, 2007) is invisible so the attacks caused by VSD are not high.

CONCLUSIONS

KW 617 is a clone model that has a stable yield performance in dry and normal conditions with an average production rate per tree of > 2 kg/year (qualify as superior clone category). Among some promising clones tested, KW 562, KW 641, and ICCRI 07 clones have specific adaptability to dry conditions compared to other clones. Drought tolerance is indicated to be related to resistance to VSD which is known from the pattern of dry tolerant clone groups. The more tolerant the clone to drought, VSD symptoms in plants will be smaller. KW 617 is an Indonesian superior cocoa clone that has been released in 2017 under the name KW 617 through the Decree of the Minister of Agriculture of the Republic of Indonesia Number 47/KPTS/KB.020/2/2019.

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