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Makafaci and Wachangu improved doubled haploid rice (*Oryza sativa*) varieties recommended for lowland cultivation in Malawi

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The study was conducted in 2017/2018 and 2018/2019 rainy seasons at Nanzolo, Domasi and Mkondezi in three replications using the RCBD following the Mother-Baby Trial Approach. The objective of the study was to evaluate grain yield of twelve high-yielding rice (*Oryza sativa*) varieties that were selected and shared from elite Doubled Haploid germplasms of a Collaborative Project of KAFACI (RDA) and AGRA at Suwon in Korea and Africa Rice Centre, Senegal. An improved variety called Mtupatupa was used as a common check. Data collection was done on several traits including plant height at maturity, number of effective tillers and DUS as well as VCU. The two lines SR35285-HB3469-6 and Sahel 328 met farmers' preferences during participatory variety selection because of earliness to maturity, high grain yield, medium to slender grain shape and long to extra-long, moderate aroma and absence of the white belly on the endosperm. The Genotype × Environment interaction summarized by the biplot of the two principal component axes explains 96.56% of the Genetics and Genotype × Environmental (GGE) variation. The hierarchical clustering pattern showed two main clusters in the dendrogram description. Genotypes SR35285-HB3469-6 and Sahel 328 had been therefore released as Wachangu and Makafaci, respectively, for lowland cultivation in Malawi.

Key words: Doubled Haploid, principal component analysis, DUS and VCU, GGE biplot, grain quality, grain yield, lowland, PVS.

INTRODUCTION

Rice is the second most important cereal crop in Malawi, after maize. It is grown in three ecologies of rain fed

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Table 1. KAFACI Doubled haploid and other Rice genotypes used for trials in 2018 and 2019 rainy seasons.

Designation	Genotypes	Source
K150005	SR35300-HB3467-5	Korea
K150010	SR35300-HB3467-10	Korea
K150014	SR35285-HB3469-4	Korea
K150952	SR34590-HB3433-8	Korea
K150018	SR35285-HB3469-6	Korea
K150103	SR34034-HB3471-81	Korea
K150593	SR33705-HB3381-91	Korea
Sahel 134	Sahel 134	Senegal
Sahel 328	Sahel 328	Senegal
Sahel 177	Sahel 177	Senegal
K150839	SR34045-HB3487-16	Korea
K150590	SR33705-HB3381-88	Korea
Check	Mtupatupa	Malawi

lowland, irrigated lowland and rain fed upland with 80, 15 and 5% share, respectively.

The traditional rice cultivars in the rainfed ecosystem have many valuable genes possessing resistance to various biotic and abiotic stresses, unique grain quality and plant architecture. Among these local strains, selections had been done and resulted in pure lines namely Faya 14 M 69 and Kilombero. Farmers prefer these landraces because they are aromatic, have large grains and are non-glutinous (Abade et al., 2016). However, these pure lines have shortcomings such as low yield potential, photoperiod sensitivity and prone to lodging. Rice productivity in Malawi is thus very low, with mean yields of only <2 t/ha (FAOSTAT, 2013).

The advancement in Biotechnology has allowed breeders to develop varieties in a much quicker way than anticipated. Different molecular markers such as Simple Sequence Repeat (SSR) are being used not as a replacement for but a valued supplement to conventional breeding in order to study valuable traits such as grain yield (Jeke, 2019). In a similar manner, several Doubled Haploid germplasms were produced through anther-culture in South Korea where plantlets are produced from the second filial generation (F2) or third generation (F3) by applying tissue-culture techniques using chemicals such as colchicines. In this study varieties that were selected and shared from elite doubled haploid germplasms of a collaborative project of KAFACI (RDA) and AGRA at Suwon in Korea and other lines from Senegal were used as plant materials. Anther-culture helps to reduce the breeding duration as the lines reach homozygosity within a shorter period than conventional breeding (Osman et al., 2020).

The objective of the present study was to evaluate grain yield of improved KAFACI rice varieties and assess their potential, and farmers' preferences for growing under lowland conditions in Malawi.

MATERIALS AND METHODS

Plant

Prior to conducting of the mother-baby trials, other trials were conducted in 2015 and 2016. This involved an on-station screening of 694 KAFACI rice germplasms collected from Korea and Senegal mainly for adaptability and performance in 2015. Thereafter 200 lines were selected and advanced into Observation Yield Trials (OYT) and Advanced Yield Trials (AYT) in 2016. In 2018 irrigated conditions, 100 KAFACI germplasms were also evaluated and seed increase conducted as a continuation process after a one season recess towards the Mother – Baby trials. The traits of focus as selection criteria were earliness to maturity, resistance to lodging, threshability, grain quality, resistance to abiotic and biotic stress conditions, grain quality and grain yield among others (Table 1).

Experimental sites

The germplasms were evaluated at three (3) sites during the two seasons in a mother-baby trial approach. The description of the sites is presented in Table 2. The soils at the sites could be described as Vertisols comprising <45% clay and average pH 8.3 (Sistani et al., 1998).

Experimental design

The testing of Doubled Haploid and other KAFACI rice varieties was conducted in a "Mother-Baby Trial" approach (Hairmansis et al., 2008; Snapp, 1999) of which the Mother is a research-managed and the baby is farmer-managed trial. The "Mother-Trials" are research carefully managed and monitored trials where all entries are compared with each other. The "Baby trials" were mainly for obtaining farmers' qualitative data such as yield perceptions. The "Mother trial' was conducted in a Randomized Complete Block Design with three replications. Plant to plant and row to row spaces were maintained at 20 cm and three seedlings were transplanted per plant hill. Fertilizer was applied at the rate of 68+12+6+7.5+2.5S kg per ha NPK6S1Zn, in relation to the old recommended times and doses (Guide to Agricultural Production, 2012) of the NPK phased-out fertilizer in Malawi.

Table 2. Sites for evaluation of improved rice varieties, in 2018 and 2019 rainy seasons.

Site	District	EPA	Coordinates	Elevation (masl)
Domasi	Zomba	Domasi	15° 41'S; 35° 56'E	640
Nanzolo	Chikwawa	Livunzu	16° 08'S; 34° 57'E	72
Mkondezi	Nkhata Bay	Limphasa	11° 37'S; 34° 14'E	508

Data collection and analysis

The recording of data was done on productive tillers per square metre, plant height, days to attain 50% flowering, panicle length and grain yield (kg per ha) following the principles established by Jennings et al. (1979), at respective crop stages, using scoring procedures and scales prescribed in the Standard Evaluation System (SES) for rice (IRRI, 2013). Grain quality traits were determined for the genotypes, and results are presented in the form of DUS and VCU for the two varieties proposed for release. Data were analyzed statistically using GenStat software (VSN International, 2018). From the 'Baby trials", two traits were measured: days to maturity, as determined by the farmers, and grain yield measured from standard 5 m^2 plots. Genetics and Genotype × Environment (GGE) biplot analysis was adopted to evaluate the relative performance of genotypes for target environments based on principal component analysis and specifically the AMMI2 model that considers main effects and two axes (Kempton et al., 2012; Gomez and Gomez, 1984). The model for the GGE biplot (Yan, 2002), based on singular value decomposition of the first two principal components, was:

Yij – ì – aj = el îil cjl + e2 îi2 cj2 + εij,

where Yij is the measured mean of genotype i in environment j, ì is the grand mean, aj is the main effect of environment j, ì + aj is the mean yield across all genotypes in environment j, e1 and e2 are the singular values for the first and second principal components, respectively, îi1 and îi2 are eigenvectors of genotype i for the first and second principal components, respectively, c1j and c2j are eigenvectors of environment j for the first and second principal components, respectively, aij is the residual associated with genotype i in environment j.

During participatory variety selection (PVS) and sensory tests, visual assessment of grain quality and organoleptic assessment of cooked rice were recorded. The hierarchical clustering was also done using Genstat 18th edition (Euclidean distance) to assess the diversity existing among the test rice genotypes.

RESULTS

Plant height

There was significant difference (p<0.001 and p<0.001) at Domasi and Mkondezi in terms of plant height during 2017/2018 and 2018/2019 seasons. During the 2017/2018 rainy season, the Mother trial at Domasi had the check variety, Mtupatupa attaining the average height of 98 cm and was significantly different from all other studied KAFACI rice varieties. In the same season, the check variety had an average of 91 cm at Nanzolo and was insignificantly taller (p 0.045) than all the studied varieties except Sahel 328 (99 cm). Similarly, the check variety, Mtupatupa was 91 cm at Mkondezi and was significantly taller than all studied varieties. The minimum mean height of the twelve (12) studied genotypes was 75 cm and was 18 cm shorter than check variety (93 cm) while Sahel 328 (94 cm) was approximately equal to the check (93 cm).

In 2019 rainy season, the check variety had an average of 101 cm and was significantly different (p<0.001) from all other studied KAFACI rice varieties. Sahel 328 (102 cm) was taller than check variety (94 cm) at Nanzolo and equal to check (93 cm) at Mkondezi. The check variety, Mtupatupa attained an average plant height of 96 cm and the same average height (96 cm) was attained by Sahel 328 across all the three sites in 2019 season. The mean plant height range was 75 to 94 cm and 76 to 96 cm during the 2017/2018 and 2018/2019 growing seasons, respectively. The mean maximum height of the twelve (12) studied genotypes in 2019 was 96 cm and was equal to the check variety. This means the studied genotypes are equally responsive to nitrogen as the check, Mtupatupa.

Days to 50% flowering

There was no significant difference (p 0.313) in terms of all the studied KAFACI rice genotypes at Domasi in 2017/2018 rainy season. However, there were significant differences (p<0.001 and 0.011) at Nanzolo and Mkondezi, respectively among the studied. Significant differences were recorded at all the three sites (p<0.001, <0.001 and 0.004) during the 2018/2019 season. The mean flowering duration at Domasi was 80 days during 2017/2018 season. Generally, all the studied genotypes flowered in 77-88 days at Domasi, 76-95 days at Nanzolo and 83-92 days at Mkondezi trial site. The check variety flowered late at Mkondezi (92 days) after Sahel 328 (89 days). The rest of the genotypes flowered earlier at this site during 2017/2018 rainy season. The mean flowering dates for SR35285-HB3469-6 and Sahel 328 were 80 and 80 days, respectively and were earlier than the check variety, Mtupatupa (93 days) at all sites during both seasons.

Tillering ability

There were significant differences in terms of tillering ability during 2018 (p0.023) and 2019 (p<0.001) rainy seasons only at Domasi trial site. There was no significant difference for this trait among the studied rice genotypes for the rest of the trial sites across both seasons. The tillering ability of varieties is illustrated by number of panicles/m^2. The results in the current study indicated that during both seasons, Sahel 328 and the check variety, Mtupatupa attained similar number of panicles/m^2 which ranged from 398 to 438 pan/m^2. The studied genotypes produced between 357 and 438 panicles/m^2 of which the maximum mean was comparatively closer to that of the check variety (421 panicles/m^2). The highest site mean of numbers of panicles m^2 were obtained at Domasi (434 and 438 panicles/m^2) during both seasons, respectively. Mean results of tillering ability of the varieties, represented by number of panicles/m^2 recorded in both seasons also indicate that Sahel 328 was at the top list of high tillering and similar to the check variety, Mtupatupa.

Genotype performance based on number of spikelets/panicle and other traits

Genotype mean performance based on number of spikelets/panicle illustrated that there was significant difference (p<0.001) among the studied rice varieties. Many spikelets/panicle were obtained in the check variety, Mtupatupa (155 spikelets/panicle) followed by Sahel 328 with 151 spikelets/panicle.

Significant differences in ripening ratio were noticed among all the studied rice varieties with Sahel 134 having the highest ripening ratio (91 %) and were at par with SR35300-HB3467-10. The spikelet fertility ranged from 75 to 91% with the overall mean of 85%.

There was significant difference (p0.002) in terms of panicle length among the studied rice varieties. Sahel 328 had the longest panicle (27 cm) over all the studied varieties and SR35300-HB3467-5 had the shortest panicle (20 cm). In terms of 1000 grain weight, SR33705-HB3381-91 had the highest 1000 grain weight score (28 g) and SR34590-HB3433-8 had the least 1000 grain weight of 21 g. There was however, non-significant difference (p0.080) in terms of 1000 grain weight among the studied rice varieties.

Grain yield from mother trials

The 2017/2018 grain yield data depicted that there were significant differences among the studied KAFACI rice genotypes (p0.005, 0.004 and <0.001) at Domasi, Nanzolo and Mkondezi, respectively. The results showed that among the three sites, the highest average grain yield was attained at Mkondezi (6963 kg/ha) and closely followed by Domasi (6845 kg/ha) while Nanzolo (5403 kg/ha) was the lowest yielding site. The highest yielding variety at Mkondezi was SR35285-HB3469-6 (7924 kg/ha) and was closely followed by Sahel 328 (7742 kg/ha). At Nanzolo, the highest yielder was Sahel 134 (6696 kg/ha) and was closely followed by Sahel 328 (6096 kg/ha), Sahel 177 (5986 kg/ha) and SR34045-HB3487-16 (5849 kg/ha) and were all above the check (5640 kg/ha). At Domasi, the highest yielding genotype was Sahel 328 (7530 kg/ha) and was closely followed by SR34045-HB3487-16 (7422 kg/ha), Sahel 177 (7329 kg/ha), SR35300-HB3467-5 (7247 kg/ha) and SR35285-HB3469-6 (7127 kg/ha) and were all above the check variety Mtupatupa (6117 kg/ha).

Generally, the grain yield data for the three sites indicated that the highest average grain yield obtained at Mkondezi (6963 kg/ha) was slightly higher than that of Domasi (6845 kg/ha) while Nanzolo (5403 kg/ha) was the lowest of the three. During the season 2018, all the genotypes had an increase of +3 to +17% over the check, except two (2) genotypes; SR33705-HB3381-91 and SR33705-HB3381-88 which had a -6% decline each over the check. In this instance, Sahel 328, SR35285-HB3469-6 and SR34045-HB3487-16 showed increases of +3 to +17 % over the check variety, Mtupatupa, except two (2) genotypes; SR33705-HB3381-91 and SR33705-HB3381-88 which had a -6% decline each over the check. In this instance, Sahel 328, SR35285-HB3469-6 and SR34045-HB3487-16 showed high increases of +17, 13 and 13%, respectively as in Table 3. The 2018/2019 rainy season grain yield results from mother trials in Table 4 illustrates that there were significant differences for grain yield across all the three sites with p 0 .005, 0.004 and p < 0.001 for Domasi, Nanzolo and Mkondezi, respectively. The highest average yields were 7054 kg/ha for Mkondezi and 6888 kg/ha for Domasi with the lowest yield of 5473 kg/ha for Nanzolo. This indicates that Nanzolo is comparatively the lowest yielding environment among the three sites and that there was a negative G × E interaction which resulted into low yield. The results also depicts that at Domasi, Sahel 328 gave the highest yield of 7589 kg/ha followed by SR35285-HB3469-6 and SR35300-HB3467-5 with 7421 and 7299 kg/ha, respectively. The highest yield at Nanzolo was obtained from SR35285-HB3469-6 (6800 kg/ha), followed by Sahel 328 (6185 kg/ha). Furthermore, the highest yield of 7938 kg/ha was obtained from Sahel 177 followed by Sahel 328 (7851 kg/ha) and SR34045-HB3487-16 (7257 kg/ha) at Mkondezi site. At Nanzolo, four (4) KAFACI lines namely SR35285-HB3469-6, Sahel 328, Sahel 134 and SR34045-HB3487-16 were above the check variety Mtupatupa (5717 kg/ha) with yields of 6800, 6185, 6072 and 5939 kg/ha, respectively. Interestingly, eleven (11) genotypes were above the check variety, Mtupatupa in terms of yield at Domasi and all (12 genotypes) were above the check variety at Limphasa. Generally, the four (4) KAFACI rice genotypes, namely, SR35285-HB3469-6, Sahel 328, Sahel 134 and SR34045-HB3487-16 showed yield stability across all sites as they maintained their

Table 3. Grain yield (kg/ha) of 13 rice varieties at three sites during 2018 rainy season.

Variety	Domasi	Nanzolo	Mkondezi	Mean	% increase over check
SR35300-HB3467-5	7247	5424	7366	6679	+11
SR35300-HB3467-10	6993	4653	6995	6214	+5
SR35285-HB3469-4	6825	5527	7329	6560	+10
SR34590-HB3433-8	6646	4924	6511	6027	+2
SR35285-HB3469-6	7329	5143	7924	6799	+13
SR34034-HB3471-81	6870	5698	6772	6447	+8
SR33705-HB3381-91	5736	4551	6363	5550	-6
Sahel 134	6754	6696	6995	6815	+13
Sahel 328	7530	6096	7742	7123	+17
Sahel 177	7127	5986	6809	6641	+11
SR34045-HB3487-16	7422	5849	7552	6701	+13
SR33705-HB3381-88	6382	4047	6139	5523	-6
Mtupatupa (check)	6117	5640	6028	5928	
Range	5736 - 7530	4047 - 6696	6028 - 7924	5523 - 123	
Mean	6845	5403	6963		
LSD0.05	841.7	1121.6	846.3		
Prob	0.005	0.004	<0.001		
CV%	7.3	12.4	7.2		

Table 4. Grain yield (kg/ha) of 13 Rice varieties at three sites during 2019 wet season.

Variety	Domasi	Nanzolo	Mkondezi	Mean	% increase over check
SR35300-HB3467-5	7299	5495	7467	6754	+11
SR35300-HB3467-10	7040	4704	7086	6277	+5
SR35285 -HB3469-4	6869	5601	7429	6633	+9
SR34590-HB3433-8	6686	4982	6590	6086	+2
SR35285-HB3469-6	6796	6800	7086	6894	+13
SR34034-HB3471-81	6914	5777	6857	6516	+8
SR33705-HB3381-91	5756	4598	6438	5597	-7
Sahel 134	7177	6072	6895	6715	+ 11
Sahel 328	7589	6185	7851	7208	+ 17
Sahel177	7383	5207	7938	6843	+12
SR34045-HB3487-16	7421	5931	7257	6870	+12
SR33705-HB3381- 88	6415	4081	6210	5569	-7
Mtupatupa (check)	6145	5717	6095	5986	-
Range	5756 - 7589	4081 - 6800	6095 - 7938	-	-
Mean	6888	5473	7054	-	-
LSD0.05	859.8	1151.5	867.2	-	-
Prob	0.005	0.004	<.001	-	-
CV%	7.4	12.5	7.3	-	-

superiority against the check variety though not maintain the order of superiority across the three sites. The percentage yield increase over the check ranged from 2 to 17% with a -7% decline over the check as in Table 4.

Grain yields from farmer-managed "baby" trials

The grain yields at Domasi in the farmers' fields ranged from 2100 to 4575 kg/ha with Sahel 328 (4575 kg/ha), SR35285-HB3469-6 (4500 kg/ha) topping the list and higher than the farmers' variety (3.1 t/ha). At Nanzolo, three varieties namely Sahel 328 (3750 kg/ha), SR35285-HB3469-6 (3540 kg/ha), and Sahel 177 (3500 kg/ha) ranked highly in terms of grain yield and were superior to the farmers' variety (2350 kg/ha).

Similarly, Sahel 328 (4575 kg/ha), SR35285-HB3469-6

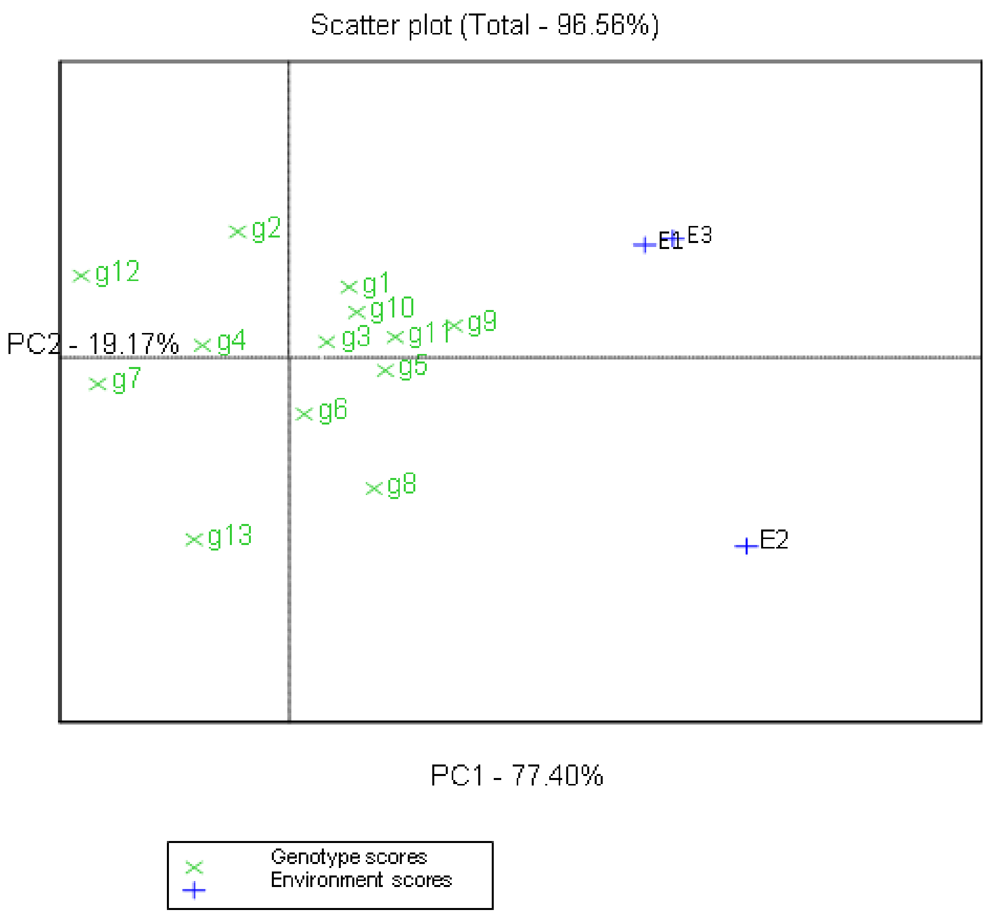

Figure 1. Scatter plot.

(4470 kg/ha), SR34034-HB3471-81 (4560 kg/ha) and Sahel 134 (4515 kg/ha) ranked highly in terms of grain yield and were superior to farmers' variety (2999 kg/ha) at Mkondezi. The varieties in the farmers' fields matured in 109 days on average across all sites. Generally, Mkondezi had the highest mean yield (3596 kg/ha) while Domasi (3176 kg/ha) and Nanzolo (2818 kg/ha) were second and third, respectively.

Genotype × Environment biplot

The Genotype × Environment interaction is summarized by the biplot of the two (2) principal component axes presented in Figure 1. The first principal component explains 77.40% of the Genotype × Environmental interaction whereas the second principal component explains 19.17% of the Genotype × Environmental interaction. The first two principal components thus explain 96.56% of the Genetics and Genotype × Environmental (GGE) variation. Domasi and Mkondezi environments influenced the genotypes in a similar way as evidenced by their clustering together and the narrow angle between the two environments in a biplot (E1 and E3). Furthermore, g12, g7, g4 and g13 were the poorest yielding varieties across all environments. The GGE biplot indicated that varieties g9, g10, g11 and g5 gave the highest yield at Domasi and Mkondezi (E1 and E3). The variety g2 had a negative interaction with Nanzolo (E3) while g9 had a positive interaction with the same (E3) as illustrated by the environmental vectors pointing in the direction of negative and positive interactions, respectively. Generally, g1 g6, g5, g4, g3, g9, g10 and g11 are insensitive to environmental interaction thus more stable and broadly adapted as evidenced by the short vectors and nearness to the biplot origin. On the contrary, g13, g12, g7, g2 and g8 are sensitive to environmental interactions, thus specifically adapted as are far from the biplot-origin. The Distinctness Uniformity and Stability (DUS) as well as the Value for Cultivation and Use (VCU) data for the two varieties are presented in Appendix 1.

Hierarchical clustering analysis

The agglomerative clustering performed on the Euclidean distance matrix utilizing the Ward's linkage method and

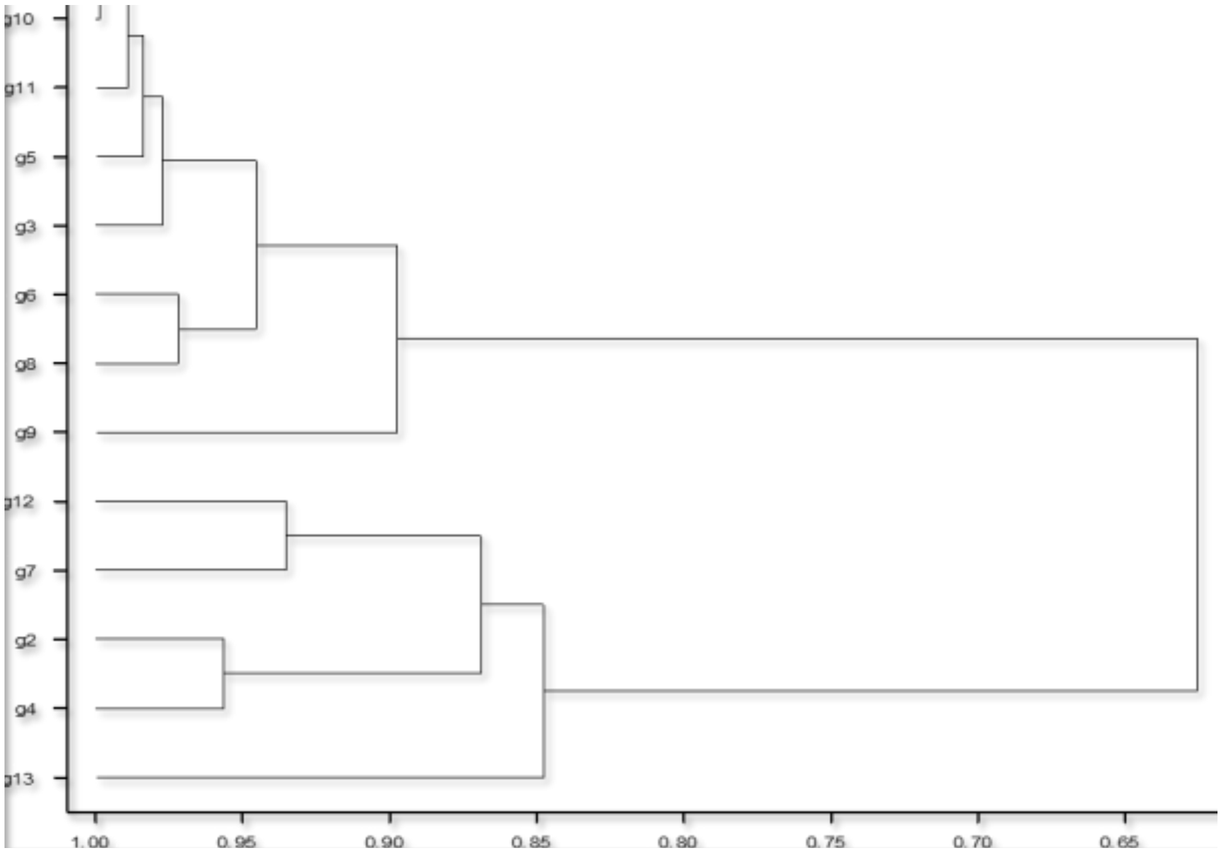

Figure 2. Genetic diversity of the studied KAFACI Doubled haploid and other Rice genotypes depicted in a dendrogram.

the resulting dendrogram indicate that there are two (2) clusters which emerged at <0.65% similarity coefficient index. The dendrogram showed that g1, g10, g11, g5, g3, g6, g8 and g9 belonged to cluster 1 whereas g12, g7, g2, g4 and g13 belonged to cluster 2. The genotypes in cluster 2 were identified at 0.86% while those of cluster 2 were identified at 0.90% of the coefficient of similarity index (Figure 2).

Grain quality and organoleptic assessment

Most of the varieties were visually scored as having grain shape of medium to slender. The grain length comprised extra-long for the three (3) varieties, long for the eight (8) varieties and medium length for the two (2) varieties. Though rated as extra-long, Sahel 177 had a high white belly trait and was scored non-tasty and non-aromatic. Sahel 328 was rated as extra-long, tasty, slight aroma and mostly preferred by many participants during palatability "sensory" test. On the other hand, SR35285-HB3469-6 was preferred because it was tasty, long grain, slender shape and absence of white belly on the endosperm. Both Sahel 328 and SR35285-HB3469-6 had medium cooking time. The check variety, Mtupatupa was rated very tasty, high aroma and medium cooking duration. The six (6) genotypes were rated as tasty, one genotype (Mtupatupa) was very tasty and the rest were not tasty. Generally, besides the check (Mtupatupa), other three (3) genotypes were preferred, namely, SR35285-HB3469-6, SR34034-HB3471-81 and Sahel 328 because of being tasty, medium cooking duration and slight aroma and lack of a white belly on the endosperm. The only genotype with the longest cooking duration was SR33705-HB3381-91 and was also the lowest yielding variety of all studied KAFACI rice varieties.

DISCUSSION

Grain weight is a key determinant of grain yield in rice. The weight of the grain reflects capacity of the rice leaves to carry out photosynthesis processes in order to provide assimilates for grain formation. In essence, rice genotypes that contribute large 1000 grain weight may imply ability to give higher spikelet fertility due to large assimilate sink size per panicle during early maturity stages. In this study, genotypes with the highest 1000 grain weight were SR33705-HB3381-91 followed by

SR35285-HB3469-6, Sahel 177 and SR33705-HB3381-88 which were at par. Also, nine (9) genotypes had been classified as medium (21-25 g) while four (4) genotypes as high (26-30 g). In this regard, SR33705-HB3381-91 has the largest grain filling ability followed by Sahel 177, SR33705-HB3381-88 and SR35285-HB3469-6, and all surpassed the check variety. These results are in great agreement with earlier reports by Efisue et al. (2014). The number of spikelets per panicle is one of the basic traits in the development of high yielding crops. It is the contribution of several spikelets within a plant which result into yield thus varieties with a reasonable number of spikelets result into increased yield. In this regard, the high mean number of spikelets/panicle in Sahel 328 (151) may be a contributing trait of making it a high yielding line while keeping other traits constant. The length of the panicle is a very important parameter in yield of crops because it helps to determine the number of spikelets which can be carried by a rice crop. The likelihood is that a rice crop with a longer panicle will possess more spikelets than a crop with a shorter panicle. In the present study, when other traits are kept constant, Sahel 328 (27 cm) Mtupatupa (26 cm), Sahel 177 (25 cm), Sahel 134 (24 cm) and SR-HB-6 (24 cm) would likely give high yield than those with shorter panicles, for example, SR35300-HB3467-5.

One of the selection criteria in rice breeding is plant height and is a fundamental agronomic trait for crop yield (Mathan et al., 2016). The International Rice Research Institute proposed that the “new plant type” should ideally have plant height of 90 to 100 cm. Furthermore, Li et al. (2014) hypothesized that in order to attain high grain yield in rice, plant height range of 110 to 125 cm should be attained. This is exacerbated by the fact that tall plants are well exposed to sunlight for the processes of photosynthesis thus increased yield. In the present study, the range of plant height for the KAFACI rice varieties was 76 to 95 cm as measured across three environments over the two seasons. According to the Standard Evaluation System for Rice (IRRI, 2013), these varieties are categorized as semi-dwarf. This implies that between the two varieties under release, Sahel 328 belongs to a new plant height category (92 cm) while SR35285-HB3469-6 does not belong to a new plant type. Nonetheless, the semi-dwarf plants have an advantage of withstanding lodging to which tall plants are prone.

The flowering behaviour of the test genotypes could be described as early maturing and therefore desirable for the rice cropping system in Malawi.

Days to 50% flowering, also defined as days to pre-heading period (PHP), can estimate growth period of varieties. Longer PHP gives vigorous rice plants and improves grain yield. Li et al. (2014) stated that average PHP of 97 days was ideal for high-yielding varieties. The PHP results in this study showed that the mean PHP for the test varieties was less than 90 days. This suggests that the test varieties are early maturing and are all ideal for terminal drought escape and improving grain yield.

The tillering ability of varieties is illustrated by number of panicles/m^2 and is a key component of grain yield (Xing and Zhang, 2010). Panicle number is the basis for increasing the source and sink, and often guarantees higher yields. Li et al. (2014) reported that mean panicle numbers of 308 m^{-2} was ideal to increase grain yield. Across the three sites in 2018/2019 season, the best two varieties produced 396 panicles/m^2 for SR35285-HB3469-6 and 414 panicles/plant for Sahel 328 and these were above the check variety. The number of panicles per plant directly controls the yield of a particular variety, Joachim (2015) and the general yield trend scales up from low to high for few to many panicles per plant, respectively.

The range of panicle number in this study for the test varieties was between 357 and 438 panicles/m^2, and this could be regarded as very ideal.

The determination of physical dimension of rice varieties is of great importance because rice marketing is dependent on grain size and shape in addition to aroma. The grain length and width are fundamental attributes that determine rice shape. According to SES for rice (IRRI, 2013) on the brown rice length, the varieties were classified as medium (5.51 to 6.6 mm) for 3 varieties, long (6.6 to 7.5 mm) for 8 varieties and extra-long (more than 7.5 mm) for 3 varieties. Joachim (2015) reported that long grain rice is highly demanded by the rice consuming people and this also reflects well for consumers of rice in Malawi. In terms of grain length and width ratio, varieties of this study were categorized into two groups as medium (2.1 to 3.0) for 6 varieties and slender (over 3.0) for 7 varieties using the Standard Evaluation System for rice (IRRI, 2013) scale. Despite that the preference for rice grain traits differs with consumer groups, long and slender grains are generally preferred by Malawian consumers and farmers and are good valuable attributes that could be exploited to improve characteristics of the rice grain. The long and extra-long grains obtained in SR35285-HB3469-6 and Sahel 328, respectively, therefore can be used to meet the need of rice consumers in Malawi. The medium and slender shapes have also been used to describe the two varieties, namely, SR35285-HB3469-6 and Sahel 328, respectively.

Across the three sites in 2017/2018, the best two varieties were SR35285-HB3469-6 and Sahel 328, whose respect yields were 17 and 13% above the average yield of the check variety. The best two varieties in 2019 were also SR35285-HB3469-6 and Sahel 328, whose yields were 17 and 13% above the mean yield of the check variety, Mtupatupa.

GGE biplot analysis applies the functions of joint regression (Joachim, 2015) and additive main effects and multiplicative interaction (AMMI) (Gauch, 1992) to depict patterns of G×E interaction. The varieties SR35285-HB3469-6 and Sahel 328 gave high yields at three sites, suggesting above average adaptability. In a GGE Biplot, genotypes near to origin and with shortest vector illustrate both high mean and insensitive to the environmental interaction thus highly stable. Two main clusters have been identified in a hierarchical clustering pattern before other sub-clusters were identified among the studied rice varieties.

CONCLUSION AND RECOMMENDATION

The two varieties, namely, SR35285-HB3469-6 and Sahel 328, showed grain yield superiority above the other 11 varieties (check variety inclusive) during both years of testing in all three locations. The plant height class for the test varieties was determined to be semi-dwarf, which is an idle character to minimize the risk of lodging which could result into the loss of grain. The two varieties also exhibited early maturity traits, and could be planted twice in a year. The variety Sahel 328 was high yielding and deemed to possess above average adaptability while SR35285-HB3469-6 also had high mean yields as well as high stability. Farmers preferred these two varieties because of acceptable grain qualities that included medium to slender shape and length, average cooking time, absence of white belly and slight aroma good taste. The two varieties SR35285-HB3469-6 (a doubled haploid) and Sahel 328 were therefore released for lowland cultivation in Malawi mainly because results from this study had shown that they are high yielding, early maturing, have acceptable grain quality traits and very stable. The two varieties SR35285- HB3469-6 and Sahel 328 had been therefore released as Wachangu and Makafaci, respectively. The local name Wachangu translates to “earliness to maturity” while Makafaci is a borrowed acronym for Ma to mean Malawi and KAFACI to mean Korea-Africa Food and Agricultural Cooperation Initiative, thus Makafaci.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Appendix 1. Distinctiveness uniformity and stability (DUS), and value for cultivation and use (VCU) data for SR35285-HB3469-6 and Sahel 328 rice varieties.

No.	Trait/character	Variety	
1	Variety name	SR35285-HB3469-6	Sahel 328
2	Local name	Wachangu	Makafaci
3	Year of official release	2020	2020
4	Variety type	Japonica	Indica
5	Origin	Korea	Senegal
6	Chemical (optional)	Not determined	Not determined
7	**Morphological characteristics**		
	Awn type	0 (awnless)	0 (awnless)
	Plant height (cm)	90	90
	Grain type	Long	Extra-long
	Panicle type	Intermediate (2)	Intermediate (2)
	Panicle length (cm)	24	27
	Maturity (days)	105	110
	Grain traits		
	Aroma	2 on a 5-point scale	2 on a 5-point scale
	Amylose	not determined	not determined
	Hull color	Straw	Straw
	Seed length (mm)	8.1	9.2
	Seed width (mm)	2.9	2.63
	Seed shape	2.8 (medium)	3.5 (slender)
	Spikelet fertility	85	90
	Milling recovery	68	70
	Bran color	Straw	Straw
	Lodging	0 (non-lodging)	0 (non-lodging)
	Days to 50% flowering (days)	80	85
	Shattering ability	5 (intermediate)	5 (intermediate)
	Cookability	15-20 min	15-20 min
	Taste	Good	Good
8	**Production**		
	Yield (kg/ha)	6700	7100
	1000 grain weight (g)	26	24
9	Resistance/tolerance to diseases	Resistant/toler#ant (0-3)	Resistant/Tolerant (0-3)
10	Resistance/tolerance to insects	High	High
11	Resistance/tolerance to stress	High	High
12	Zones of adaptation	Both rain fed and irrigated ecologies (50-2250 masl)	Both rain fed and irrigated ecologies (50-2250 masl)
13	Performance over check (Mtupatupa variety)	Earlier maturing (15days)	Earlier maturing (10 days)
14	AGRA/KAFACI (RDA) & Malawi Government Support	Evaluation, Release and Promotion	Evaluation, Release and Promotion
15	Photo of seed	Appended	Appended
16	Photo of milled rice	Appended	Appended

Source: International Rice Research Institute (IRRI, 2013).

Wachangu (SR35285-HB3469-6)

Makafaci (Sahel 328)

Participatory Variety Selection “sensory test” at the three trial sites, 2019, (Malawi)

AGRA / KAFACI Rice Participatory Variety Selection (PVS), 2019, Mkondezi trial site (Malawi)