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Performance Evaluation of Sorghum (*Sorghum bicolor* (L.) Moench) Genotypes for Lowland Areas of Eastern Amhara, Ethiopia

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Abstract

Sorghum is an important food security crop in Ethiopia. As the grain is preferred for food the biomass is equally important for farmers to use it as animal feed. It is a major crop in lowland parts of eastern Amhara as the environment of the area best fits for the crop. The study was conducted with the objective of identifying high yielder and adaptable sorghum varieties for moisture deficit areas of eastern Amhara region. Eleven sorghum genotypes including two checks were evaluated at eight different environments of four locations namely; Sirinka, Jari, Chefa and Shewarobit within two years in 2016 and 2017 under rain feed condition. The experiment was implemented using a randomized complete block design (RCB) with three replications. The combined analysis of variance over years and across locations revealed highly significant difference ($p < 0.01$) among genotype for all traits. Genotype × year × environment interaction was non-significant except for plant height. The smallest days to maturity recoded by G8 (125.8 days) while G11 took more number of days to mature (132.9 days). G8 also recorded the highest panicle/head weight (4.56 tonha^{-1}) whereas G11 recorded the lowest head weight (2.7 tonha^{-1}). Genotypes ranged from 2.363 tonha-1 for G11 to 3.95 tonha-1 for G8 in grain yield. As the highest grain yield (3.95 tonha^{-1}) was obtained by genotype G8 (Sima) while that of standard and local checks were 3.1 tonha^{-1} and 2.67 tonha^{-1}, respectively. Thus, G8 (Sima) was found superior over the rest of the tested sorghum genotypes and it has 47.4% and 27.29% yield advantages over local and standard check, respectively. As a result G8 (Sima) was selected, verified and officially released for its early maturing and high yielding in 2019 by the name of Kalu for production in moisture deficit areas of eastern Amhara region and similar agro ecologies of the country.

Keywords

Sorghum genotypes, Yield, Maturity, Yield components, Moisture deficit

Introduction

Sorghum (*Sorghum bicolor* (L.) Moench) is a diploid C_4 cereal crop which was domesticated in Africa. It has 2n = 20 chromosome and genome size of 750 Mb [1]. Sorghum is predominantly self-pollinated short day plant with the degree of spontaneous cross pollination, in some cases, reaching up to 30%, depending on the shape and type of panicles. The drier areas of the country (occupy 66%) are the major sorghum producing parts of sorghum as the crop also grown in different agro ecological zones of Ethiopia [2]. Thus, the crop grows from the lowland areas which receive lower amount of rainfall and high temperature to the highland characterized by low temperature and higher amount of rainfall [3].

Sorghum is the fifth major cereal crop in the world after rice, wheat, maize and barley grown in arid and semi-arid parts of the world [4] and it is third in Ethiopia which is the most important dry land crop grown by 6 million small holder farmers in more than 1.9 million hectare of land. It annually produced 4.7 million tone and has national average productivity of 2.72 tons per ha [5]. In Amhara region, sorghum covered a significant amount of cultivated land following tef. The area coverage and productivity of sorghum in Amhara region 672,491.78 hectare and 1,781,203.242 ton, respectively [5]. It is a major crop in lowland areas of eastern Amhara as the environment of the area best fits for the crop. It covered an estimated land area of 75802.33, 66550.27

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Table 1: Description of the testing environments.

Code	Locations	Altitude (m.a.s.l)	Soil type	Annual Rain fall (mm)	Temperature (°C)		Global position	
					Min	Max	Latitude	Longitude
E1	Sirinka	1850	Eutric vertisol	980	13	27	11°08'N	39°28'E
E2	Jari	1680	Vertisol	950	15	26	11°21' N	39°28'E
E3	Chefa	1400	Vertisol	850	16	32	10°57' N	39°47'E
E4	Shewarobit	1905	Vertisol	713	17.7	33	14° 6' N	39°54'E

Source: Sirinka Agricultural Research Center and Wikipedia for global position.

and 35,254.39 in North, South Wollo and Oromia zone, respectively [5].

Sorghum is considered as major food security crop in Ethiopia which is contributing 18% of the total grain production [6,7]. Sorghum in Ethiopian has multiple uses. As the grain is preferred for food the biomass is equally important for farmers to use it as animal feed. Farmers feed their cattle while the plant is at the field and also store the biomass for the drier season. Hence, variety development considered dual purpose interest both grain and biomass yield. Sorghum grain has a wide range of nutritional compositions and constituted about 11% water, 340 KCal of energy, 11.6% protein, 73% carbohydrate and 3% fat by weight [8].

Ethiopia has a wealth of sorghum genetic resources that could be used for increasing productivity and nutritional quality of sorghum. In north east Ethiopia, drought is usually occurring due to delay in onset, dry spell after sowing and drought during critical crop stage (flowering and grain filling stage) and too early cessation of rain. These situations can be overcome by developing sorghum genotypes which are resistance to moisture deficit [9]. Developments of early maturing varieties are the major strategies in the sorghum breeding program. Genotypes specifically developed for the target environment through crossing of elite materials likely to be tested for their suitability to the moisture deficit environments.

Therefore, the objective of this study was to identify high yielder and adaptable sorghum variety for moisture deficit areas of eastern Amhara region.

Material and Methods

Description of test environment

The field trial was conducted during the main cropping season of 2016-2017 at four locations (Sirinka, Jari, Chefa and Shewarobit), representing the moisture deficit lowland areas of eastern Amhara region (Table 1 and Table 2).

Experimental design and trial management

A total of 13 genotypes including one released variety Raya as a standard check and popular local check variety (Jigurity) were evaluated from 2016 to 2017 (Table 3). The experiment was conducted at four locations namely; Sirinka, Jari, Chefa and Shewarobit. Randomized Complete Block Design (RCB) was used to lay down the genotypes with three replications. Each plot contained 5 rows of 5m length separated by 0.75m.

Table 2: Description of sorghum genotypes used in the multi-location trials.

Line/variety identification	Code	Source
IESV-92066 DL	G1	MARC
IESV 92207 DL	G2	MARC
Kaguru × macia 2-1	G3	MARC
KARIM tana-1	G4	MARC
KAT 487	G5	MARC
Mugeta	G6	MARC
PP-290	G7	MARC
Sima	G8	MARC
ICSA 749 × 214855	G9	MARC
ICSA 749 × 214855	G10	MARC
ICSA-101 × 214865	G11	MARC
Standard Check (Raya)	G12	SARC
Local check (Jigurity)	G13	SARC

MAR: Melkasa Agricultural Research Center; SARC: Sirinka Agricultural Research Center

The seed rate was 10 $kgha^{-1}$ while the fertilizer was applied at the recommended rate of 39 $kgha^{-1}$. Urea and 121 $kgha^{-1}$ NPS. All the NPS and half of urea were applied during planting while the remained half of urea was applied at knee stage. Sowing was done in between end of June to first week of July when effective rain was received. The seeds were sown by hand in the rows as uniformly as possible and covered with soil manually and population was adjusted by thinning two weeks after emergence considering 0.15 m spacing between plants. Weeding was conducted three times during the growing period in each of the test sites.

Data collection and statistical analysis

All the data were collected from central three rows. Days to heading and days to maturity were taken when 50% of the plants in a plot reached half-bloom stage and 90% of the plants in a plot reached at physiological maturity, respectively. Plant height (cm) was taken from five randomly selected plants from the base of the plant to the tip of the panicle. Head/panicle weight and 1000 seed weight were recorded from each plot while grain yield was taken by adjusting to 12.5% moisture content. Data on phenological parameters, growth parameters, yield and yield components were subjected to analysis of variance (ANOVA). Analyses of variance for collected data were performed using the general statistics (Gen Stat) program version 18. Duncan's Multiple Range Test (DMRT) was used for mean separation.

Results and Discussion

The combined analysis of variance for all locations in 2016 showed that highly significant ($p < 0.01$) difference among genotypes on days to heading maturity, plant height, head weight and thousand seed weight (Table 3). A significant ($p < 0.05$) difference also observed among genotypes on days to heading and grain yield (Table 3). Genotype by environment interaction revealed highly significant difference ($p < 0.01$)

Table 3: The combined mean grain yield and yield related traits of sorghum genotypes in 2016 at Sirinka, Jari, Chefa and Shewarobit.

S/No	Identification	Days to heading	Days to maturity	Plant height(cm)	TSW (g)	HW (kgha^{-1})	GY (kgha^{-1})
1	IESV-92066 DL	80^{ab}	125.4^{a}	168.4^{d}	31.06^{c}	2534^{df}	1977de
2	IESV 92207 DL	80^{ab}	124.5^{a}	169^{d}	31.75^{bc}	3023^{cd}	2420^{cd}
3	Kaguru × macia 2-1	80^{ab}	126.2^{a}	168.2^{d}	28.12^{e}	3021^{cde}	2372^{cd}
4	KARIM tana-1	79^{ab}	125.2^{a}	140.9^{f}	31.89^{bc}	3378^{bc}	2681^{bc}
5	KAT 487	81^{b}	126^{a}	157^{e}	31.86^{bc}	3028^{cd}	2429^{cd}
6	Mugeta	83^{bc}	125.5^{a}	134.9^{f}	27.94^{e}	2476^{f}	1877de
7	PP-290	82^{bc}	125^{a}	162.9^{de}	30.62^{cd}	3615^{ab}	3058^{ab}
8	Sima	77^{a}	123.9^{a}	171^{d}	33.98^{ab}	3937^{a}	3349^{a}
9	ICSA 749 × 214855	86^{c}	130.1^{bc}	201.2^{b}	28.62^{de}	2376^{f}	1603^{e}
10	ICSA 749 × 214855	83^{bc}	128.5^{b}	187.5^{c}	29.95^{cde}	2422^{f}	1818de
11	ICSA-101 × 214865	83^{bc}	130.3^{bc}	180^{c}	35.03^{a}	1888^{g}	1839de
12	Standard Check (Raya)	82^{bc}	124.3^{a}	168.1^{d}	22.44^{f}	3179^{bc}	2343^{cd}
13	Local check (Jigurity)	82^{bc}	131.2^{c}	228.5^{a}	34.97^{a}	3192^{bc}	2427^{cd}
	Grand Mean	81	127	172.13	30.63	2928	2322
	CV (%)	5.9	2.2	6	4.21	19.7	21.8
	G	*	**	**	**	**	*
	E	**	**	**	**	**	**
	G*E	Ns	**	**	*	**	Ns

G: Genotype; E: Environment,* = Significant at 5% Probability Level, ** = Significant at 1% Probability Level; Ns: Non-Significant; TSW = 1000 Seed Weight; HW: Head Weight and GY: Grain Yield.

Table 4: The mean grain yield (kgha^{-1}) of sorghum genotypes tested under regional variety trial in **2016 a**t Sirinka, Jari, Chefa and Shewarobit.

S/No	Identification	E1	E2	E3	E4	Combine mean
1	IESV-92066 DL	1068^{d}	1312de	3594^{c}	2135^{b}	2027de
2	IESV 92207 DL	1660de	2089^{ab}	3910^{b}	2021^{b}	2420^{cd}
3	Kaguru × macia 2-1	1900^{b-e}	1893^{abc}	3786^{b}	1910^{b}	2372^{cd}
4	KARIM tana-1	2455^{ab}	2077^{ab}	4028^{b}	2164^{b}	2681^{bc}
5	KAT 487	1609^{ef}	1631^{bcd}	4310^{a}	2167^{b}	2429^{cd}
6	Mugeta	1755^{cde}	1454^{cd}	2877^{c}	1420^{b}	1877de
7	PP-290	2200^{a-d}	2225^{a}	4365^{a}	3441^{a}	3058^{ab}
8	Sima	2748^{a}	2362^{a}	4773^{a}	3512^{a}	3349^{a}
9	ICSA 749 × 214855	1397^{efg}	1411^{e}	2398^{d}	2205^{b}	1603^{e}
10	ICSA 749 × 214855	1377^{efg}	937^{ef}	3146^{c}	1811^{b}	1818de
11	ICSA-101 × 214865	1066^{fg}	744^{fg}	4236^{a}	1310^{b}	1839de
12	Raya	2272^{abc}	441^{cd}	4339^{a}	1320^{b}	2343^{cd}
13	Local jigurite	1420^{efg}	1301de	4614^{a}	2372^{b}	2427^{cd}
	Grand Mean	1479	1529	3875	2137	2326
	CV	17.5	17.2	21.2	16.6	21

E1: Sirimka, E2: Jari, E3: Chefa and E4: Shewarobit.

on days to maturity, plant height, head weight and thousand seed weight, while it was not significant for days to heading and grain yield. This indicates that genotypes were showed consistence performance in across all locations. In 2016 the genotypes perform best in E3 (Cheffa) with environment mean of 3875 kgha^{-1} to the least E1 (Sirinka) with grain yield of 1479 kgha^{-1} even though no rank change showed between the genotypes. Genotype mean ranged from 1603 kgha^{-1} for G9 to 3349 kgha^{-1} for Sima, the candidate (Table 4).

In 2017 the over location combined analyses of variance showed there were significant difference ($p < 0.01$) among genotypes for all traits (Table 5). Genotype by environment interaction (Table 5) revealed highly significant difference ($p < 0.01$) for all traits except for head weight which showed non-significant. This result agrees with Habte, et al. [10] and Fentaye, et al. [11] who reported that genotype by environment interaction revealed highly significant difference on grain yield. Eight genotypes at Sirinka, seven genotypes

Table 5: The combined mean grain yield and yield related traits of sorghum genotypes in 2017 at Sirinka, Jari, Chefa and Shewarobit.

S/No	Identification	Days to heading	Days to maturity	Plant height(cm)	TSW(g)	HW (kgha^{-1})	GY (kgha^{-1})
1	IESV-92066 DL	74^{ab}	128^{a}	184.6^{cd}	29.27^{bc}	3914^{cde}	3406def
2	IESV 92207 DL	76^{c}	127.4^{a}	182^{cde}	30.75^{b}	4733^{ab}	3954^{bc}
3	Kaguru × macia 2-1	75^{bc}	125.8^{a}	183.9^{cde}	27.7^{c}	4259^{bcd}	3581^{cde}
4	KARIM tana-1	76^{bc}	127.1^{a}	142.8^{f}	27.33^{c}	4556^{abc}	3619^{cde}
5	KAT 487	77^{c}	127.1^{a}	170.7^{e}	29.51^{bc}	5007^{a}	4043^{bc}
6	Mugeta	76^{c}	127.7^{a}	145.4^{f}	27.56^{c}	3611de	3006^{fg}
7	PP-290-290	77^{c}	128.4^{a}	174.9^{de}	29.72^{bc}	4933^{a}	4175^{ab}
8	SIMA	73^{a}	127.7^{a}	183.2^{cde}	31.83^{b}	5187^{a}	4551^{a}
9	ICSA 749 × 214855	81^{d}	134.8^{b}	237.5^{b}	30.11^{bc}	3844de	3192^{efg}
10	ICSA 749 × 214855	80^{d}	132.7^{b}	194.1^{c}	27.45^{c}	4200^{bcd}	3425^{def}
11	ICSA-101 × 214865	81^{d}	135.5^{b}	189.1^{c}	34.65^{a}	3519^{e}	2886^{g}
12	Raya	77^{c}	127.3^{a}	185.1^{cd}	24.07^{d}	5037^{a}	3863^{bcd}
13	Local (Jigurite)	80^{d}	135.2^{b}	266.7^{a}	29.92^{bc}	3786de	2932^{fg}
	Grand Mean	77	130	187.7	29.22	4353	2587
	CV (%)	3.5	2.5	8	10.2	16.9	15.8
	G	**	**	**	**	*	**
	E	**	**	*	**	**	**
	G*E	**	**	**	**	Ns	**

G: Genotype; E: Environment, Significant At 5% Probability Level, **Significant At 1% Probability Level, Ns: Non -Significant; DH: Days to Heading; DM: Days to Maturity; PH: Plant Height; SW: 1000 Seed Weight; HW: Head Weight; GY: Grain Yield.

Table 6: The mean grain yield (kgha^{-1}) of sorghum genotypes tested under regional variety trial in **2017 a**t Sirinka, Jari, Chefa and Shewarobit.

S/No	Identification	E1	E2	E3	E4	Combine mean
1	IESV-92066 DL	3730^{cd}	2107de	5057^{a-d}	3025^{b-f}	3406^{d-f}
2	IESV 92207 DL	4326^{a-d}	2713^{a-d}	5426^{a-c}	3834^{ab}	3954^{bc}
3	Kaguru × macia 2-1	3852^{b-d}	2607^{b-d}	4951^{a-d}	3341^{a-e}	3581^{c-e}
4	KARIM tana-1	4859^{ab}	2967^{a-c}	4793^{b-d}	2978^{b-f}	3619^{c-e}
5	KAT 487	5215^{b}	2551^{b-d}	6005^{a}	3575^{a-d}	4043^{bc}
6	Mugeta	3793^{b-d}	2502^{b-d}	5004^{a-d}	1148^{g}	3006^{fg}
7	PP-290	4978^{a}	2879^{a-d}	5794^{ab}	3785^{a-c}	4175^{ab}
8	SIMA	4759^{a-c}	3494^{a}	6066^{a}	4409^{a}	4551^{a}
9	ICSA 749 × 214855	4711^{a-c}	1497^{e}	4662^{b-d}	2420^{d-f}	3192^{e-g}
10	ICSA 749 × 214855	4622^{a-c}	2107de	5426^{a-c}	2059^{fg}	3425^{d-f}
11	ICSA-101 × 214865	3437^{d}	1475^{e}	4425^{cd}	2589^{c-f}	2886^{g}
12	Standard check(Raya)	4385^{a-d}	3292^{ab}	5742^{ab}	2920^{b-f}	3863^{b-d}
13	Local check(Jigurity)	3733^{cd}	2344^{cd}	4214^{d}	2117^{e-g}	2932^{fg}
	Grand Mean	4338	2503	5167	2939	3587
	CV%	13	17.3	11.4	21.9	15.8

at Jari and Shewarobit and six genotypes at Chefa lie above the grand mean of each location (Table 6). In 2017 genotypes perform best at Chefa (5167 $kgha^{-1}$) and Sirinka (4338 $kgha^{-1}$) followed by Shewarobit (2939 $kgha^{-1}$) and Jari (2503 $kgha^{-1}$) (Table 6). Genotypes mean ranged from G11 (2886 $kgha^{-1}$) to (4551 $kgha^{-1}$) for G11 (Table 6).

Homogeneity of residual variances was tested prior to analysis over locations using Bartlett's tests [12]. The result of homogeneity error variance was homogeneous. Combined analysis of variance (2016 and 2017) revealed highly significant ($P < 0.01$) difference among sorghum genotypes for all traits (Table 7), implying the presence of genotypes differences for the traits considered. Genotype × environment × year interaction was non-significant (except plant height)which contradictory to the findings of Habte, et al. [10] and Al-Naggar, et al. [13] that showed highly significant difference between genotypes by environment by year interaction. The highest grain yield 6.06 $tonha^{-1}$ was recorded for the year 2017 as compared to the grain yield 4.77 $tonha^{-1}$ for the year 2016 (Table 6) because of the optimum rain fall distribution for sorghum production in 2017. The combined analysis of variance (Table 7) revealed the candidate genotype, Sima took the smallest number of days to heading (74.7 days) even earlier than the standard check Raya (76.8 days) while G11 took more number of days to mature (81.7 days). Also the same genotype (Sima) took the smallest days to maturity (125.8 days) still better than standard check (126.7 days) while G11 took maximum days to mature (132.9) which resulted in low grain yield (2363 $kgha^{-1}$). The highest panicle/head weight was recorded by the candidate genotype, Sima (4562 $kgha^{-1}$) whereas the lowest panicle/head weight goes to genotype G11 (ICSA-101 × 214865) (2703 $kgha^{-1}$) (Table 6). This result in agreement with Mulualem, et al. [14] who reported sorghum genotypes showed high variability to head weight which has direct effect on grain yield.

The mean grain yield of tested genotypes ranged from 2.67 $tonha^{-1}$ from local check (Jigurty) to 3.95 $tonha^{-1}$ for Sima, the candidate genotype while the standard check (Raya) was 3.10 $tonha^{-1}$ (Table 7). Among the tested sorghum genotypes, Sima was continuously outsmarted in grain yield and earliness over the rest of the genotypes in all testing environments. The candidate genotype, Sima had 47.44% and 27.29% yield advantages over the local and standard check, respectively. The overall average grain yield for the candidate genotype (Sima) was obtained 3.95 $toneha^{-1}$ which is higher than the current sorghum productivity in small scale farmers in Amhara region produced 2.72 $toneha^{-1}$ [5]. The candidate genotype gave a grain yield which is comparable with yield of the varieties released previously for eastern Amhara region at Sirinka agriculture research center and Melekasa agriculture research center [15].

Table 7: The combined mean grain yield and yield related traits of sorghum genotypes in 2016 and 2017 at Sirinka, Jari, Cheffa and Shewarobit.

S/No	Identification	Days to heading	Days to maturity	Plant height(cm)	TSW(g)	HW (kha^{-1})	GY(kha^{-1})
1	IESV-92066 DL	76.83^{ab}	126.7^{a}	176.5^{d}	30.17^{cde}	3224^{fg}	2692^{cd}
2	IESV 92207 DL	$78b^{c}$	126^{a}	175.5^{d}	31.25^{bc}	3878^{bcd}	3187^{b}
3	Kaguru × macia 2-1	77.46^{bc}	126^{a}	176^{d}	27.91^{fg}	3640^{cde}	2977^{bc}
4	KARIM tana-1	77.33^{bc}	126.1^{a}	141.8^{f}	29.61^{c-f}	3967^{bc}	3150^{b}
5	KAT 487	79.21^{bcd}	126.0^{a}	163.9^{e}	30.68^{cd}	4018^{bc}	3236^{b}
6	Mugeta	79.75^{cde}	126.6^{a}	140.2^{f}	27.75^{g}	3043^{gh}	2441^{d}
7	PP-290	79.25^{bcd}	126.7^{a}	168.9^{de}	30.17^{cde}	4274^{ab}	3616^{a}
8	Sima	74.79^{a}	125.8^{a}	177.1^{d}	32.91^{b}	4562^{a}	3950^{a}
9	ICSA 749 × 214855	83.21^{f}	132.4^{c}	219.4^{b}	29.36^{defg}	3110^{fg}	2397^{d}
10	ICSA 749 × 214855	81.33^{def}	130.6^{b}	190.8^{c}	28.7^{efg}	3311^{efg}	2621^{cd}
11	ICSA-101 × 214865	81.79^{ef}	132.9^{c}	184.5^{c}	34.84^{a}	2703^{h}	2363^{d}
12	Raya	76.83^{ab}	126.7^{a}	176.5^{d}	30.17^{cde}	4108^{b}	3103^{b}
13	Local (Jigurity)	78^{bc}	126^{a}	175.5^{d}	31.25^{bc}	3489^{def}	2679^{cd}
	Grand Mean	79.18	128.12	179.92	29.93	3641	2955
	CV	4.9	2.4	7.2	9.4	18.14	17.9
	G	**	**	**	**	**	**
	E	**	**	**	**	**	**
	Y	**	**	**	**	**	*
	G*E	**	**	**	**	*	Ns
	G*E*Y	Ns	Ns	**	Ns	Ns	Ns

G: Genotype, E: Environment,* = Significant At 5% Probability Level, ** = Significant At 1% Probability Level, Ns: Non-Significant; SW: 1000 Seed Weight; HW: Head Weight; GY: Grain Yield

Conclusion and Recommendation

Sorghum is vital crop to Ethiopia where it is grown in a wider area of adaptation ranging from hot, dry lowland, intermediate to the highland environments. The crop is among the most important crops cultivated in Ethiopia with most of the acreages located in parts of the country affected by drought, *Striga* weed, insect, disease, low soil fertility and lack of improved varieties. In Ethiopia, the crop grown entirely by subsistence farmers to meet needs for food, income, feed, traditional brewing and construction purposes. Drought is one of the major yield's limiting factors. Most farmers grow long maturing local varieties some of which take 7-8 months to mature further complicating the drought problem. The research emphasis for drought is developing early maturing sorghum varieties that can be able to escape terminal drought. The tested genotypes did show consistent performance across locations and years. The present study showed that grain yield was not significantly influenced by change of environmental condition. The highest grain yield of 3.95 tha^{-1} was recorded from Sima. As a result, G8 (Sima) was selected, it was verified and officially released by the name of Kalu in 2019. This genotype relatively takes shorter days to maturity which will adapt easily to the low moisture areas of the Northeastern lowland parts of the country. So Kalu is recommended for sorghum production to Sirinka, Jari, Chefa and Shewarobit and other similar agroecologies of the country.

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Conflict of Interest

The authors confirm that the content of this article has no competing interests.

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