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Short title: **Response of Sorghum to Striga**

Evaluation of Western Ethiopian Sorghum Landraces for Resistance to *Striga hermonthica* (Delile) Benth

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Abstract

Purple witch-weed is a parasitic plant that significantly impacts sorghum yields in semi-arid regions. It also affects crops like corn, millets, and rice. Developing purple witch-weed-resistant sorghum varieties is essential for integrated purple witch-weed management. This study evaluated the response of 48 sorghum genotypes to purple witch-weed under both pot and field conditions. Resistant varieties (Berhan and Framida) and susceptible varieties (Assosa-1, Adukara, and/or ETSL102967) were used as controls. The findings revealed substantial variability among the sorghum landraces in their response to purple witch-weed. Early maturing genotypes exhibited lower purple witch-weed densities, while late maturing ones were more susceptible. Notably, the ETSL102969 landrace showed strong resistance, comparable to the resistant variety Berhan. Additionally, the ETSL102970 landrace demonstrated superior resistance compared to Framida. Based on these results, ETSL102969 and ETSL102970 are recommended as valuable sources of resistance for breeding programs aimed at improving sorghum resistance against purple witch-weed in Ethiopia.

Nomenclature

Purple witch-weed, *Striga hermonthica* (Delile) Benth.; corn, *Zea mays* L.; Millets, *Eleusine coracana* Gaertn. and *Cenchrus americanus* (L.) Morrone; rice, *Oryza sativa* L.; sorghum, *Sorghum bicolor* (L.) Moench

Keywords: Purple witch-weed; Resistance; Parasitic weed

Introduction

Purple witch-weed is a root parasitic flowering weed belonging to the *Orbanchaceae* family (Matusova et al. 2005; Mohamed and Musselman 2008). It is a globally widespread and damaging weed (Ejeta and Gressel 2007; Oswald 2005; Parker 2009), particularly prevalent in sub-Saharan Africa, including central, western, and eastern Africa (Gethi and Smith 2004; Mohamed and Musselman 2008; Rodenburg et al. 2016). This weed severely impact crops such as sorghum (*Sorghum bicolor* (L.) Moench), corn (*Zea mays* L.), millets (*Eleusine coracana* Gaertn. and *Cenchrus americanus* (L.) Morrone), tef (*Eragrostis tef* (Zucc.) Trotter), rice (*Oryza sativa* L.), and even sugarcane (*Saccharum officinarum* L.) (Addisu and Feleke 2021; Atera and Itoh 2011; Atera et al. 2012; Kountche et al. 2016; Parker 2012; Spallek et al. 2013). It drastically reduces agricultural productivity for small-scale subsistence farmers in sub-Saharan Africa, including Ethiopia, and is considered the most devastating biological barrier to cereal production in these regions (Omanya et al. 2004).

Several studies highlighted the widespread infestation of purple witch-weed in Ethiopia. Atsbha Gebreslasie et al. (2016) reported moderate to severe infestation throughout Tigray. Lemma Degebasa et al. (2022) found it to be the dominant species in Eastern and Western Hararghe, Oromia. In Benishangul Gumuz, purple witch-weed poses a significant challenge to sorghum production across almost all districts. The impact on sorghum production in Ethiopia is significant and widespread. Yield losses due to purple witch-weed infestation range from 65% to 100% (Bayable andMarcantonio 2013; Ejeta et al. 2002; Haussmann et al. 2000; Lemma Degebasa et al. 2022; Tesso et al. 2007). In Benishangul Gumuz, it is identified as the primary factor affecting sorghum production (Mesfin and Girma 2022). The detrimental effects extend beyond Ethiopia to other Eastern and West African countries (Ejeta and Gressel 2007).

These points underscore the necessity of developing effective strategies to manage and control purple witch-weed to mitigate its devastating impact on sorghum production in the Benishangul Gumuz region and other affected areas in Ethiopia. The use of resistant crop varieties has been proposed as a practical and cost-effective long-term strategy for managing purple witch-weed (Hearne 2009; Mandumbu et al. 2019). Therefore, this study aimed to identify sorghum genotypes that are resistant to purple witch-weed.

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Materials and Methods

Plant materials

The sorghum genotypes in this study were selected from landraces collected from farmers' fields in Ethiopia, specifically in Benishangul Gumuz and some parts of western Oromia. The study included 49 genotypes and four released varieties (Table 1). Resistant checks, Berhan and Framida, were obtained from the Melkassa Agricultural Research Center. The use of check varieties allowed for effective assessment of resistance to purple witch-weed. Purple witch-weed seeds used in this study were collected over three years (2019-2021) from heavily infested sorghum fields in various districts of Assosa Zone, including Bambasi, Abramo, and Ura. The seeds were stored in glass jars, kept in a dark environment at room temperature until needed for the trials.

For the pot trials, 48 sorghum genotypes were used, including both susceptible and resistant checks. Assosa-1 and Adukara served as the susceptible checks, while Berhan was the resistant check. From these initial tests, 33 genotypes were selected for further evaluation in a specially designed purple witch-weed sick plot at the Assosa Agricultural Research Center. This phase included another resistant check, Framida. To validate the pot and sick plot trials, seven sorghum genotypes, including resistant checks Berhan and Framida and promising resistant landraces ETSL102969, ETSL102970, and ETSL102975, alongside susceptible checks Assosa-1 and ETSL102957, were evaluated in hot-spot farmers' fields at three locations in Assosa, Benishangul Gumuz, Ethiopia.

Study sites, trial design and procedures

The trials were established at the Assosa Agricultural Research Center located between 34°34.10" E and 10° 02.55" N, with an elevation of 1553 m above sea level, in the Assosa Zone of the Benishangul Gumuz region, Ethiopia. The area receives a mean annual rainfall of 1177 mm and has a mean temperature of 26.8 C.

The pot trials were laid out in a randomized complete block design with two replications in 2020 and 2021 under Lath-house conditions (temperature of 21-28 C, 12 h light and 12 h night

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photoperiod, and the trials were watered twice per week). A mix of sand, peat, and compost (1:3:1 v/v) filled 96 round plastic pots with a diameter of 27 cm at the top, 22 cm at the bottom, and height of 28.5 cm. Each pot received 4 mg of purple witch-weed seeds, which were covered with a thin layer of soil mix (up to 5-cm depth). After a 10-day preconditioning period for the purple witch-weed seed, six sorghum seeds of each genotype were sown and later thinned to three plants per pot. The pots were not fertilized to enhance purple witch-weed emergence.

In 2022, 33 sorghum genotypes were evaluated in purple witch-weed sick plots at the center. The site was plowed twice with a tractor, and furrows spaced 70 cm apart were prepared with a furrow maker. The trial was laid out in a randomized complete block design with two replications. Furrows within each plot (2 m x 1.40 m) were infested uniformly with purple witch-weed seeds collected during the 2021 cropping season. These seeds were covered with a thin soil layer and preconditioned for 10 days. Sorghum genotypes were then sown in the furrows at a rate of 10 kg ha^{-1}. Aside from purple witch-weed, other weeds were hand weeded as observed and recommended fertilization such as 100 kg ha^{-1} NPS (19 kg Nitrogen, 38 kg P_2O_5, and 7 kg Sulfur) at sowing and 50 kg ha^{-1} urea after thinning was followed.

For validation, a trial was designed in a randomized complete block design with three replications, using farmers' fields as replications. Seven selected sorghum genotype were tested using plot sizes of 4.20 m X 4.05 m for each genotype. Weeds, except purple witch-weed, were manually removed, and recommended fertilization was followed.

Data collection and analysis

Data were collected on both sorghum and purple witch-weed parameters. For sorghum, the data included days to 50% anthesis, days to maturity, plant height, number of leaves, biomass, and dry matter (g pot^{-1}). For purple witch-weed, recorded data were emerged purple witch-weed height and count at weekly intervals from the 7th to 12th week after crop emergence (WACE). Additionally, we measured purple witch-weed biomass and dry matter.

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To determine the maximum above-ground purple witch-weed, we followed the methods suggested by Rodenburg et al. (2006). The area under purple witch-weed number progress curve (ASNPC) was calculated as suggested by (Haussmann et al., 2012) as follows:

$$ASNPC = \sum_{i=0}^{n-1} \left(\frac{Y_i + Y_{(i+1)}}{2}\right)(t_{(i+1)} - t_i)$$

Where n is the number of purple witch-weed recording dates, Y_i is the purple witch-weed count at the i^{th} assessment date, and t_i is the number of days after sowing at the i^{th} assessment date.

The analysis of variance was done using lmer() package of the R software (R Core Team 2023), where sorghum genotypes were fixed effect, while years, replication, and errors were random effects. Residual analysis was performed using shapiro.test package to ensure the normal distribution of residuals. The randomized complete block design model utilized was

$$Y_{ij} = \mu + \alpha_i + \beta_j + \varepsilon_{ij}$$

Where, Y_{ij} is observed value for the experimental unit in the j^{th} replication (r) assigned to the i^{th} genotype, $j = 1, 2. . . r$ and $i = 1, 2,. . ,$ μ is the overall mean, α is the effect due to the i^{th} treatment, β is the effect due to the j^{th} block, and ε_{ij} is the error term where the error terms, are independent observations from an approximately normal distribution with mean equal to zero and constant variance σ^2_{ε}.

An independent sample t-test assessed the significant differences in sorghum genotypes' performance against purple witch-weed. Treatment means were separated using Tukey's studentized range (HSD) procedure at a 5% probability level. Additionally, sorghum genotypes were hierarchically clustered based on the number of purple witch-weed plants that emerged per sorghum plant using the Euclidean distance matrix. Ward's linkage method was utilized using MINITAB software version 14.

Results and Discussion

Response of Sorghum landraces to purple witch-weed

Pot-trial

The mean number of emerged purple witch-weed plants per pot across all sorghum genotypes was 12.13, while the mean number of purple witch-weed plant per sorghum plant was 4.04

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(Table 2). This indicates there was an adequate level of infestation to determine the resistance of sorghum genotypes to purple witch-weed.

The pot experiment results showed a highly significant difference (P <0.0001) in the response of sorghum landraces to purple witch-weed infestation (Table 2). The average number of emerged purple witch-weed plants per pot ranged from 0.25 for the Berhan variety (resistant check) to 29.75 for the ETSL102973 landrace. Similarly, the number of purple witch-weed plant per sorghum plant ranged from 0.08 for Berhan to 9.92 for ETSL102973. These findings suggest that ETSL102973 had higher purple witch-weed emergence compared to Berhan, indicating its susceptibility to purple witch-weed (Table 2 and Figure 1). On the other hand, sorghum landraces ETSL102969, and ETSL102970 showed reduced purple witch-weed emergence compared to other landraces (Table 2; Figure 2).

Purple witch-weed sick-plot trial

The purple witch-weed sick-plot experiment revealed significant variation (P<0.05) among sorghum landraces in the mean number of emerged purple witch-weed plants per plot at 12 WACE. Sorghum genotypes exhibited varied purple witch-weed emergence per plot, ranging from 3.0 for Berhan and ETSL102969 to 148.5 for ETSL102944. Similarly, the number of emerged purple witch-weed plants per sorghum plant ranged from 0.22 for ETSL102966 to 5.48 for ETSL102954 (Table 3 and Figure 1). The results indicated that the resistant check Berhan and sorghum landrace ETSL102969 had the lowest purple witch-weed emergence (3.0 per plot). Sorghum landraces ETSL102970, ETSL102975, ETSL19001, and ETSL100053 also exhibited lower purple witch-weed emergence than the resistant check variety Framida in the sick-plot trial. The results are consistent with the findings from previous pot trials (Table 2 and Table 3).

The study showed that the resistant sorghum genotypes were early maturing, with maturity periods of 125 days for Berhan, 142 days for ETSL102970, and 144 days for ETSL102969 (Table 3). This finding aligns with Ayana et al. (2019), who reported that early maturing sorghum genotypes show resistance to purple witch-weed. Franke et al. (2006) also found that earlier maturing sorghum genotypes responded positively to purple witch-weed stress. Additionally, the purple witch-weed-resistant sorghum genotypes in this study had heights

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ranging from 102 cm for ETSL102969 to 140 cm for Berhan. They also had fewer leaves per plant, ranging from 4 for ETSL102969 to 6 for Berhan (Table 3).

Figure 2 illustrates those genotypes ETSL102970, Berhan, and ETSL102969 had lower ASNPC values compared to other genotypes, indicating slower or less severe emergence of purple witch-weed in these resistant sorghum genotypes. The cluster analysis grouped these genotypes into one group (Figure 3). Conversely, genotypes ETSL102957 and ETSL102944 exhibited higher ASNPC values, suggesting a higher incidence and more rapid emergence of purple witch-weed in these susceptible genotypes. The resistant checks, Berhan and Framida, also demonstrated low ASNPC values, confirming their resistance to purple witch-weed infestation. These findings further support the potential resistance of sorghum genotypes Berhan, ETSL102969, and ETSL102970 to purple witch-weed infestation in Assosa, Benishangul Gumuz region (Figure 1 and Figure 3).

Validation trials in purple witch-weed hot-spot farmer's fields

As illustrated in Table 4, the validation trial confirmed that the resistant check Berhan and the sorghum landrace ETSL102969 had the fewest emerged purple witch-weed plants per plot. Additionally, the sorghum landrace ETSL102970 had fewer purple witch-weed plants compared to the resistant check Framida. The number of purple witch-weed plants per sorghum plant was also low for Berhan, ETSL102969, and ETSL102970. Conversely, the susceptible checks ETSL102957 and Assosa-1 showed the highest counts of emerged purple witch-weed plants. These findings indicate that Berhan, ETSL102969, and ETSL102970 exhibit strong resistance against purple witch-weed infestation. Overall, this validation trial confirmed that ETSL102969 and ETSL102970 sorghum landraces have comparable or superior resistance to purple witch-weed compared to resistant checks like Berhan and Framida.

Furthermore, the promising sorghum landraces ETSL102969 and ETSL102970 demonstrated higher yields compared to the resistant checks in the validation trial. The larger seed size and white seed color of sorghum landrace ETSL102969 are particularly desirable traits for local farming communities (Alemu et al. 2024; Legesse et al. 2019). These traits are beneficial for breeding programs as they can be combined with the purple witch-weed resistance trait to develop sorghum varieties with both resistance and preferred seed characteristics. Incorporating these traits into breeding programs increases the likelihood of obtaining F-generations with both white color and large seed size, along with resistance to purple witch-weed. This approach not only benefits farmers but also improves productivity and enhances market value for sorghum in the region.

Practical Implication

This research reveals that Berhan, ETSL102969, and ETSL102970 showed strong resistance against purple witch-weed. Additionally, the white seed color and large seed size of ETSL102969; a trait highly preferred by farmers, make this genotype more suitable for the breeding program aimed at developing purple witch-weed-resistant and locally preferred sorghum varieties to improve yields and food security in regions plagued by this parasite. Genotypes like Berhan, ETSL102969, and ETSL102970, when incorporated into breeding programs, could lead to more robust and resistant sorghum crops, benefiting farmers in purple witch-weed-affected regions.

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Competing Interests

The authors declare none.

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Table 1. List and sources of 49 sorghum genotypes used in the study

S/N	Genotypes	Standardized name	Sources	S/N	Genotypes	Standardized name	Sources
1	Mok 079/1	ETSL102954	Mao-Komo, BGR	26	AScol19-Kok001	ETSL102976	Keshmando, BGR
2	ETSCAs 10020-2-116-2	ETSC20001	AsARC/Ethiopia	27	AScol19-SG 002	ETSL102952	Selga, BGR
3	AScol19-Al25	ETSL102971	Assosa, BGR	28	ETSCAs 10015-2-102-1	ETSC19003	AsARC/Ethiopia
4	AScol19-KA021/1	ETSL102972	Kamashi, BGR	29	Y039-1	ETSL102956	Yaso, BGR
5	ETSCAs 10015-2-103-1	ETSC19001	AsARC/Ethiopia	30	AScol19-As-7	ETSL102946	Assosa, BGR
6	AScol19-As-2	ETSL102943	Assosa, BGR	31	AScol19-SG 001	ETSL102951	Selga, BGR
7	ETSCAs 10019-1-110-1	ETSC19002	AsARC/Ethiopia	32	ETSCAs 10007-2-61-1	ETSC19004	AsARC/Ethiopia
8	Ya 036/1	ETSL102957	Yaso, BGR	33	AScol19-As -14	ETSL102940	Assosa, BGR
9	ETSCAs 10001-1-4-1	ETSC20002	AsARC/Ethiopia	34	AScol19-Krm122	ETSL102969	Kurmuk, BGR
10	AScol19-As-6	ETSL102945	Assosa, BGR	35	ETSCAs 10019-1-115-1	ETSC19005	AsARC/Ethiopia
11	AScol19-As-13	ETSL102942	Assosa, BGR	36	Bam075	ETSL102918	Bambasi, BGR
12	AScol19-As-1	ETSL102941	Assosa, BGR	37	Bmb097	ETSL102905	Bambasi, BGR
13	AScol19-JW128	ETSL102973	Jawi, AmR	38	Bmb095	ETSL102920	Bambasi, BGR
14	AScol19-As-8	ETSL102947	Assosa, BGR	39	NJ003	ETSL102912	Nejo, OrR
15	AScol19-Krm 124	ETSL102974	Kurmuk, BGR	40	Mok087	ETSL102925	Mao Komo, BGR
16	AScol19-As-5	ETSL102944	Assosa, BGR	41	Man069	ETSL102922	Mao Komo, BGR
17	ETSCAs 10002-2-13-1	ETSC20003	AsARC/Ethiopia	42	Boj007	ETSL102904	Bambasi, BGR
18	Mok 079/2	ETSL102955	MaoKomo, BGR	43	Mok085	ETSL102919	Mao Komo, BGR
19	ETSCAs 10020-2-116-1	ETSC20004	AsARC/Ethiopia	44	ETSC 300382-1	ETSC20006	AsARC/Ethiopia

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20	ETSCAs 10003-3-32-1	ETSC20005	AsARC/Ethiopia	45	Qon072	ETSL102896	Qondala, OrR
21	Adukara (Susceptible)	Adukara	Released in 2015	46	Y047	ETSL100053	Yaso, BGR
22	AScol19-Krm123	ETSL102970	Kurmuk, BGR	47	Assosa-1 (2015)	Assosa-1	Released in 2015
23	AScol19-AB126	ETSL102975	Abramo, BGR	48	Berhan (2002)	Berhan	MARC/Ethiopia
24	AScol19-JW127	ETSL102949	Jawi, AmR	49	Framida	Framida	MARC/Ethiopia
25	AScol19-BS 082/1	ETSL102948	Bambasi, BG				

Abbreviations: AmR, Amhara Region/Ethiopia; AsARC, Assosa Agricultural Research Centre; BGR, Benishangul Gumuz region/Ethiopia; ETSL, Ethiopian sorghum landrace; MARC, Melkassa Agricultural Research Center/Ethiopia; OrR, Oromia Region/Ethiopia; S/N, serial number.

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Table 2. The response of Sorghum landraces to artificially infested purple witch-weed (at 12th WACE) in 2020 to 2021 under pot experimentation at Assosa, Benishangul Gumuz, Ethiopia

Genotypes	Purple witch-weed per sorghum		Genotypes	Purple witch-weed per sorghum	
	----------- # ----------			-------- # ----------	
Berhan	0.08	c	ETSC19004	3.92	a-c
ETSL102969	0.17	c	ETSL102925	3.92	a-c
ETSL102970	0.33	c	ETSL102944	4.00	a-c
ETSC20003	0.67	c	ETSC20006	4.08	a-c
ETSL102971	0.75	c	ETSL102948	4.25	a-c
ETSL102975	0.75	c	ETSC20001	4.34	a-c
ETSL102904	0.92	c	ETSL102922	4.42	a-c
ETSC19001	1.25	bc	Assosa-1	4.83	a-c
ETSC19003	1.42	bc	ETSL102942	4.92	a-c
ETSC20005	1.67	bc	ETSC19005	4.92	a-c
ETSL102949	1.67	bc	ETSL102972	5.42	a-c
ETSC20002	1.75	bc	ETSL102946	5.67	a-c
ETSL102920	2.50	a-c	ETSL102918	5.83	a-c
ETSL102974	2.67	a-c	ETSL102952	6.08	a-c
ETSL102941	3.17	a-c	ETSL102955	6.42	a-c
ETSL102951	3.17	a-c	ETSC20004	6.58	a-c
ETSC19002	3.42	a-c	ETSL102956	6.67	a-c
ETSL102912	3.42	a-c	ETSL100053	6.83	a-c
ETSL102976	3.50	a-c	Adukara	6.92	a-c
ETSL102919	3.50	a-c	ETSL102905	7.00	a-c
ETSL102896	3.67	a-c	ETSL102947	7.17	a-c
ETSL102954	3.84	a-c	ETSL102940	8.50	ab
ETSL102945	3.84	a-c	ETSL102957	9.42	a
ETSL102943	3.92	a-c	ETSL102973	9.92	a
Mean	4.04			4.04	
Tukey’s MSD	7.43			7.43	
CV	63.97			63.97	
P value	<0.0001			<0.0001	

Means within the same column followed by the same letter are not statistically different according to Tukey’s MSD ($\alpha = 0.05$); #, mean number of purple witch-weed; CV, coefficient of variation; TMSD, Tukey’s minimum significant difference; WACE, weeks after crop emergence.

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Table 3. The response of sorghum landraces to purple witch-weed under artificially infested sick plot in 2022 at Assosa, Benishangul Gumuz, Ethiopia

Genotypes	Sorghum parameters								Purple witch-weed parameters					
	Days to flowering		Days to maturity		Plant height		Leaf number		Density		Plant height		Witch-weed per sorghum	
	---- d ---		--- d ----		---- cm -----		---- # ----		----- # -----		------ cm -----		------ # -------	
ETSL102969	99.0	k-m	144.0	c-h	101.96	j	3.45	h	3.5	c	26.34	ab	0.22	b
Berhan	98.0	lm	125.0	gh	139.79	h-j	5.87	b-h	3.0	c	36.63	ab	0.25	b
ETSL102970	73.0	n	142.0	d-h	121.91	j	3.95	gh	3.0	c	19.84	b	0.22	b
ETSL102975	116.0	h-j	157.0	a-g	207.78	b-j	9.65	a-d	7.5	c	30.03	ab	0.31	b
ETSC19001	134.0	d-g	161.5	a-g	151.04	g-j	5.30	d-h	7.5	c	22.08	ab	0.30	b
ETSL100053	152.0	bc	160.0	a-g	240.30	a-i	10.25	ab	7.5	c	38.33	ab	0.28	b
Framida	117.0	h-j	135.0	e-h	122.89	ij	5.89	b-h	8.0	c	28.69	ab	0.59	b
ETSL102976	130.0	d-h	180.5	a-d	234.36	a-i	8.90	a-f	11.5	c	32.05	ab	0.53	b
ETSL102955	152.0	bc	169.0	a-f	258.30	a-g	10.15	ab	14.0	c	29.01	ab	0.52	b
ETSL102949	114.0	h-l	154.0	a-g	242.95	a-i	7.91	a-g	14.5	c	30.31	ab	0.58	b
ETSL102925	119.0	g-j	168.0	a-f	265.10	a-g	11.22	a	15.0	c	28.86	ab	0.53	b
ETSC20006	116.0	h-j	160.0	a-g	209.70	b-j	9.11	a-f	17.5	c	29.35	ab	0.79	b
ETSL102896	136.5	c-f	159.0	a-g	244.97	a-i	11.81	a	18.5	c	38.57	ab	0.62	b
ETSC19002	99.0	k-m	152.0	b-g	220.33	a-j	11.55	a	19.0	c	26.01	ab	0.79	b
ETSC20002	94.0	m	150.0	c-g	154.70	g-j	9.83	a-c	19.5	c	93.44	a	0.72	b
ETSL102974	193.0	a	148.0	c-g	97.60	j	4.28	gh	20.0	c	29.77	ab	0.78	b
ETSL102951	124.0	e-i	169.0	a-f	171.86	c-j	11.25	a	21.5	c	33.05	ab	0.69	b
ETSC20003	91.0	m	146.0	c-h	161.45	f-j	9.60	a-e	22.5	c	26.07	ab	0.99	b
ETSC20005	123.0	e-i	158.0	d-l	201.65	b-j	10.55	a	23.0	c	22.72	ab	0.98	b
ETSC19003	115.0	h-k	159.0	a-g	161.70	f-j	8.83	a-f	23.5	c	39.00	ab	1.16	ab
ETSC20004	152.0	bc	194.5	ab	313.00	a	10.78	a	23.5	c	31.14	ab	0.86	b
ETSC19004	119.0	g-j	155.0	a-g	198.47	b-j	10.40	a	24.0	c	30.67	ab	1.19	b

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ETSL102904	126.0	d-i	169.0	a-f	267.30	a-f	9.75	a-c	25.0	c	29.84	ab	1.25	ab
ETSL102956	119.0	g-j	186.0	a-c	276.84	a-e	9.72	a-d	25.0	c	93.35	a	0.99	b
Assosa-1	142.0	b-d	177.0	a-e	127.85	ij	10.71	a	25.5	c	27.88	ab	0.97	b
ETSL102920	157.0	b	173.0	a-f	289.61	a-d	10.90	a	28.0	c	26.85	ab	0.95	b
Adukara	130.0	d-h	176.0	a-f	163.85	e-j	11.17	a	48.5	bc	33.79	ab	1.51	ab
ETSL102940	115.0	h-k	134.0	f-h	194.57	b-j	10.85	a	49.5	bc	26.83	ab	2.47	ab
ETSL102947	120.0	f-i	105.0	h	303.75	a	12.08	a	58.0	bc	29.02	ab	4.14	a
ETSL102919	125.0	e-i	169.0	a-f	222.09	a-j	10.59	a	58.0	bc	36.19	ab	2.73	ab
ETSL102912	122.0	e-i	171.0	a-f	258.09	a-g	10.68	a	62.0	bc	35.24	ab	1.94	ab
ETSL102918	152.0	bc	165.0	a-g	292.84	a-c	10.99	a	64.5	b	34.89	ab	2.27	ab
ETSL102957	154.0	b	167.0	a-g	244.92	a-i	10.74	a	95.5	ab	27.71	ab	4.81	a
ETSL102954	137.0	c-e	163.0	a-g	241.72	a-i	11.09	a	104.5	a	28.08	ab	5.48	a
ETSL102944	124.0	e-i	196.0	a	249.90	a-h	11.05	a	148.5	a	24.13	ab	5.11	a
Mean	124		160.13		216.85		9.35		33.54		31.81		1.61	
Tukey's MSD	16.55		42.68		127.74		4.44		61.57		72.60		4.02	
CV	3.14		6.27		13.64		11.16		58.37		59.24		58.37	

Means within the same column followed by the same letter are not statistically different according to Tukey's MSD (α = 0.05); #, mean number of purple witch-weed; CV, coefficient of variation; d, days; TMSD, Tukey's minimum significant difference; WACE, weeks after crop emergence.

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Table 4. Validation of purple witch-weed-resistant sorghum landraces at hot spot farmers' fields in 2023 at Assosa, Benishangul Gumuz, Ethiopia

Genotypes	Purple witch-weed per plot at 13 WACE		Sorghum plant height		Days to flowering		Purple witch-weed per Sorghum		Yield	
	------ # --------		----- cm -------		---- d ---		------ # --------		----t ha^{-1}----	
Berhan	47.30	d	117.00	c	74.33	d	1.01	b	1.77	c
ETSL102969	51.70	d	117.93	c	81.00	c	2.45	b	3.84	a
ETSL102970	136.33	cd	196.00	a	81.00	c	2.51	b	3.53	ab
Framida	267.67	cd	173.60	ab	86.67	b	12.06	ab	3.14	a-c
ETSL102975	529.70	c	116.87	c	155.00	a	30.05	a	3.81	a
Assosa-1	1156.33	b	133.27	bc	157.00	a	13.72	a	2.29	bc
ETSL102957	1638.33	a	140.53	bc	155.33	a	17.68	a	2.11	bc
Means	546.76		142.17		112.91		11.26		2.93	
Tukey's MSD	460.24		50.57		2.15		27.54		1.67	
CV	19.08		12.45		3.46		21.31		23.12	
P value	0.037		0.0006		<0.0001		0.022		0.05	

Means within the same column followed by the same letter are not statistically different according to Tukey's MSD ($\alpha = 0.05$); #, mean number of purple witch-weed; CV, coefficient of variation; d, days; t ha^{-1} , ton per hectare; TMSD, Tukey's minimum significant difference; WACE, weeks after crop emergence.

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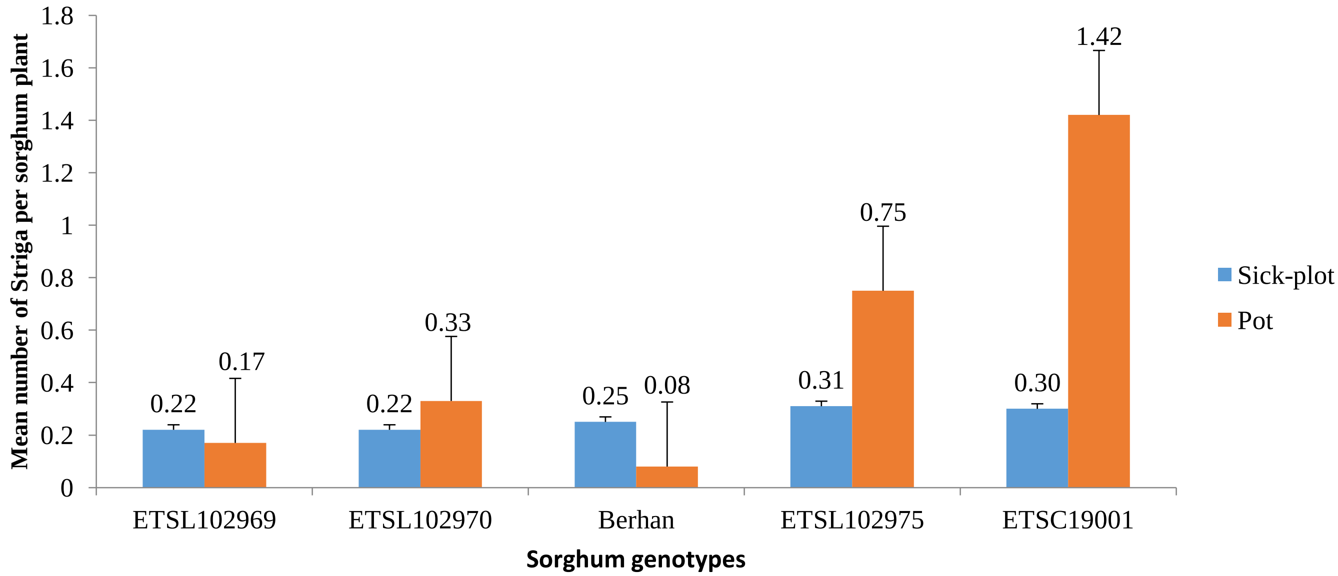

Figure 1. Top five sorghum genotypes with lowest emerged purple witch-weed count per sorghum plant from 2020 to 2022 at Assosa, Benishangul Gumuz, Ethiopia. Error bars indicate standard error of uncertainty in average number of purple witch-weed per sorghum plant. TMSD = 1.02.

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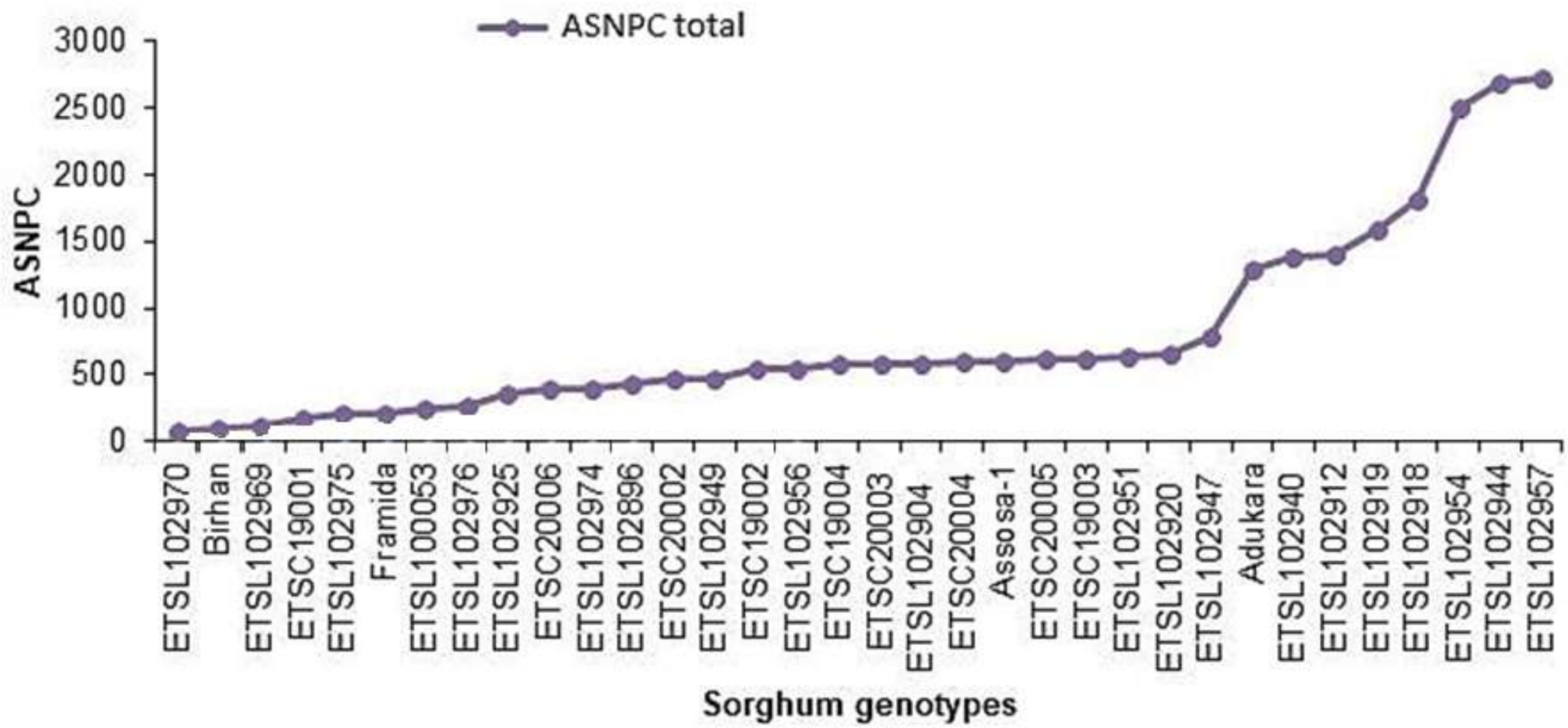

Figure 2 Reaction of sorghum genotypes to area under purple witch-weed number progress curve (ASNPC) at Assosa, Benishangul Gumuz, Ethiopia

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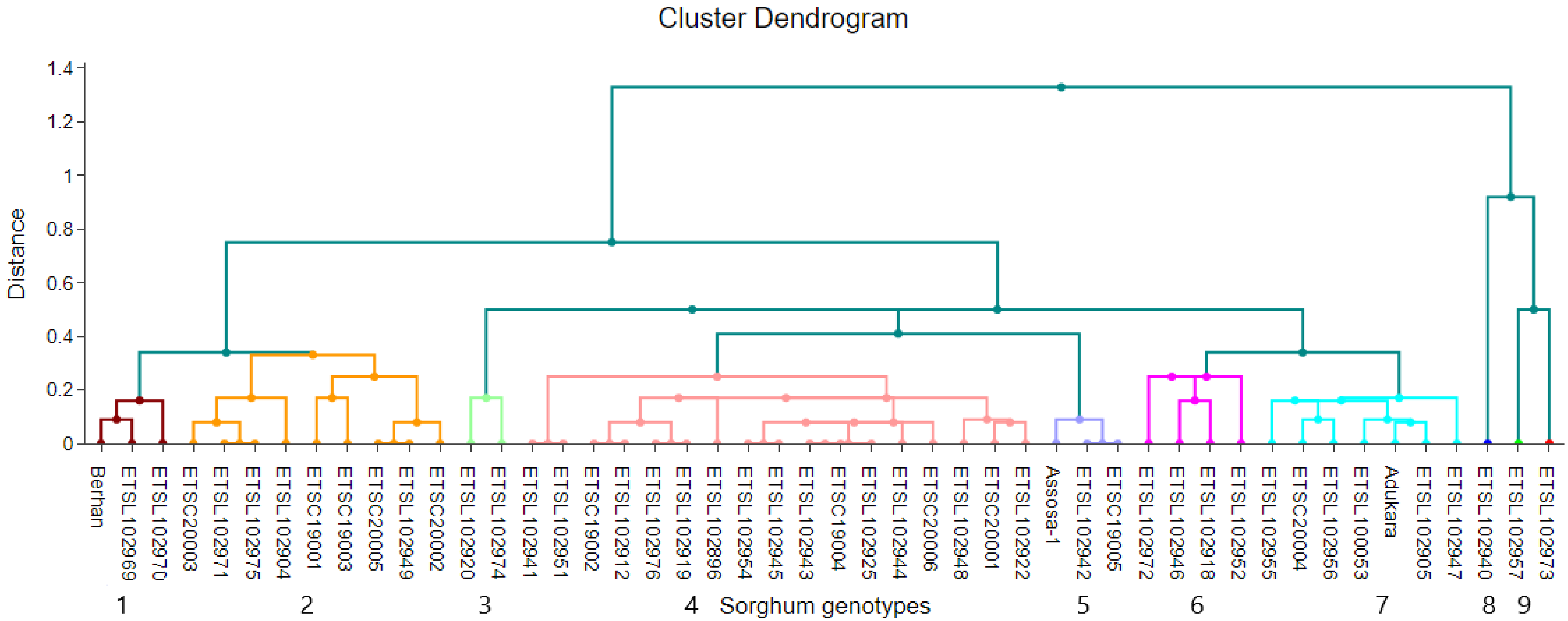

Figure 3. Cluster analysis showing the relationship among sorghum genotypes for their resistance to purple witch-weed at Assosa, Ethiopia

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