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Research Article

Identification of resistant genotypes against *Striga asiatica* (L.) Kuntze in kodo millet

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Abstract
Performance of 25 pre-release cultures and 13 released varieties of kodo millet were assessed for *Striga* resistance under artificial inoculation. Significant variation in *Striga* related parameters were recorded among the evaluated genotypes. Eight cultivars namely KOPN 21, RPS 594, RPS 531, KOPN 8, RPS 745, RBK 155, RPS 630 and KOPN 22 showed resistance against *S. asiatica* exhibiting lower estimates of *Striga* related parameters viz emerged *Striga* count row^{-1}(NS), *Striga* height index (SHI), *Striga* vigour ratings (SVR), *Striga* severity (SS) and area under *Striga* number progress curve (ASNPC). Four entries namely RPS 513, RPS 687, RPS 683 and RPS 517 were found susceptible to highly susceptible showing higher combined values of *Striga* related parameters. JK 155, a released variety of kodo millet has been found resistant to *S. asiatica*. Strong positive correlation of emerged *Striga* count row^{-1}(NS) with SS (0.922*) and ASNPC (0.860*), SHI with SVR (0.861*), SS with ASNPC (0.860*) and fresh weight *Striga* with dry weight *Striga* (0.952*) was recorded. This indicated that *Striga* related parameters are important for grouping of cultivars into different categories of reaction.

Key words
Kodo, resistance, *Striga asiatica*, correlation

Introduction

Kodo millet (*Paspalum scrobiculatum* L.) indigenous to India, is an important small millet crop belonging to the family *Poaceae (Gramineae*). It is grown by tribal as well as poor farmers in low fertile lands with fewer inputs for their own consumption under rainfed conditions. In India, among the small millets, the crop is grown in an area of 0.224 mha with productivity of 312 kg ha^{-1} and ranks third in cultivated area after finger millet and little millet Anonymous (2011). Madhya Pradesh ranks first in area of kodo millet, where the crop is cultivated in 0.143 mha with average yield of 525.5 kg ha^{-1} during 2013-14 (www.landrecords.mp.gov.in). It is highly tolerant to drought and other abiotic stresses. Among the biotic stresses, partial root parasitic flowering plant, *Striga* species popularly known as *witch weed* is an important constraint and a serious threat to subsistence of kodo millet production particularly in light and low fertile soils. *Striga hermonthica* (Del.) Benth. and *S. asiatica* (L.) Kuntze adversely affect grain production of cereal crops and cause substantial yield loss Ejeta(2007). Kumar (1940) reported considerable loss in kodo millet due to *Striga* species from India. Bharathalakshmi (1983) reported heavy infestation of *S. asiatica* in sorghum and kodo millet from Mandya district of Karnataka during field survey. Jain and Tripathi (2002) conducted roving field survey of kodo millet and recorded *Striga* incidence ranging from 0.0 to 17.5% with higher frequency of infestation varied from 66.7 to 100.0% in seven districts of Madhya Pradesh. Resistance in kodo millet cultivars against *Striga* species were also reported by Reddy and Dastagiraiah (1987). Hence the present study has been undertaken for screening of released and pre-released varieties of kodo millet for *S. asiatica* resistance.

Materials and Methods

Twenty five pre-release cultures of kodo millet received from Project Coordinating unit (Small millet), GKVK, Bangalore (Karnataka) and 13 released varieties of kodo millet from AICRP on Small Millets, College of Agriculture, Rewa (M.P.) were used for screening against *Striga asiatica* during *Kharif* 2015 under artificial inoculation. The experiment was laid out in randomized block design with 3 replications. Each plot consisted of two rows, each of 3.0 m length, spaced 22.5 cm apart with 7.5 cm spacing between plants within row. *Striga* seeds collected from fields of kodo millet during the previous growing season were used for artificial inoculation. *Striga* seeds were mixed with finely sieved sand at a ratio of 1:39 by weight and were applied at the rate of 5 g row^{-1} Kim(1994) at a depth of 4 to 5 cm, 10 days before sowing of kodo millet for uniform infestation. Seeds of 25 kodo millet cultures were sown and recommended fertilizer dose of 20:20:0 kg NPK/ha for better crop growth.

A pot experiment was conducted in a green house during *kharif* 2015 in randomized block design with 3 replications comprising of 13 released Kodo millet varieties received from AICRP on small millets under artificial *Striga* infestation. Earthen pots of 20 cm diameter were filled with a sand:soil: FYM mixture (3:3:2). *Striga* seeds and finally sieved sand mixed in 1:39 (Kim, 1994) by weight was applied at the rate of 2.0 g per pot by mixing the top 4-5 cm soil in each pot 10 days before sowing of Kodo millet seeds. Surface sterilized Kodo millet seeds (5 per pot) were sown and pots were watered regularly to prevent moisture deficit. Weeds other than *Striga* were handpicked regularly. Emerged *Striga* plants per pot were counted at 7 days interval after *Striga* emergence.

Data were collected on *Striga* related parameters and statistically analyzed. All emerged *Striga* count row^{-1} (NS) were recorded before harvesting the crop. All the NS were classified into different height group with 10 cm class intervals and *Striga* height index (SHI) was calculated as the summation of the NS multiplied by the respective mid class values Kulkarni and Shinde(1985). *Striga* vigour ratings (SVR) were scored per row on a scale of 0-9 depending on height and number of branches in *Striga* plant for each cultivar Haussmann *et al*.(2000). *Striga* severity (SS) was estimated for each cultivar by multiplying number of emerged *Striga* plant with *Striga* vigour ratings Rodenburg *et al*.(2005). Area under above ground *Striga* number progress curve (ASNPC) was calculated using following formula as outlined by Haussmann *et al.* (2000).

ASNPC=

$$\sum n-1i=0\,[Si+S\,(i+1)2\,](t\,(i+1)-\,ti)$$

Where,
n is the number of *Striga* assessment dates.
Si is the *Striga* number at ith assessment date
ti is the days after sowing at ith assessment

Fresh weight and dry weight of total emerged *Striga* plants row^{-1} for each cultivar were recorded. Correlation coefficients among *Striga* related parameters in all possible combinations were estimated in twenty five cultivars of kodo millet using WASP -1 software.

Results and Discussion

The *Striga* related parameters recorded in 25 cultures of kodo millet are presented in Table 1. All the cultivars were found infested with *S. asiatica* and genotypic difference among the cultivars was significant for all the *Striga* infection related parameters. Emerged *Striga* count row^{-1} (NS) ranged 1.7 to 10.7 with a mean of 3.6 and was maximum in RPS 513 followed by KOPN 24 (6.0), RPS 517 (5.0), RPS 683, RPS 869 and RPS 525 (4.7). Whereas, minimum NS was recorded in RPS 531 followed by RPS 745 (2.0), KOPN 21, RPS 744, RPS 907 (2.3), RPS 594, RPS 630, KOPN 22, RBK 155, and JK 13 (2.7). *Striga* height index (SHI) varied 15.8 to 48.3 with a mean of 33.6 in 25 cultivars of kodo millet infested with *S. asiatica*. Lowest SHI was noted in KOPN 21 followed by RPS 630 (17.8), TANU 141 (21.1) and RBK 155 (23.7), whereas highest SHI was recorded in RPS 513 followed by RPS 687 (48.1), RPS 517 (46.7), RPS 744 (43.3), JK 76 (41.2), RPS 927 (40.2) and RPS 745 (40.0). Significant differences were observed among the *Striga* infected kodo millet cultivars for *Striga* vigour rating (SVR) and ranged from 3.0 to 7.6 with a mean of 5.9. Minimum SVR was recorded in KOPN 21 followed by RPS 630 (3.3), RBK 155 (4.0), TNAU 141 (4.1), RPS 594 and RPS 531 (4.5), whereas maximum SVR was recorded in RPS 517 followed by RPS 745 (7.4), RPS 927 (6.8), RPS 744 (6.7), RPS 687 and JK 13 (6.5). Average SS ranged from 6.7 to 64.7 with a neam of 23.7. Lowest SS was recorded in KOPN 21 followed by RPS 531 (8.5), RPS 630 (9.6), TNAU 141 (11.0), and RBK 155 (11.1) whereas, highest SS was noted in RPS 513 followed by RPS 517 (38.3), RPS 687 (29.2), RPS 927 (27.7) and KOPN 24 (27.1). Among the 25 kodo millet cultivars, values of area under *Striga* number progress curve (ASNPC) varied from 29.5 to 221.5 with a mean of 79.9. A maximum value of ASNPC was recorded in RPS 513 followed by RPS 683 (147.0), RPS 687 (136.3), KOPN 24 (122.5), RPS 525 (117.0) and RPS 517 (111.8). Where as minimum values were observed in RPS 745 and RPS 594 followed by KOPN 21 (34.5), KOPN 14, RPS 531 (44.0), KOPN 8 (44.5), KOPN 22 and RBK 155 (54.0). Significant variations was recorded in fresh weight of *Striga* plants (FWS) were recorded with an average value of FWS (8.21g) varying from of 2.77 to 15.19 g and maximum in RPS 687 followed by RPS 927 (13.23 g), RPS 525 (11.02) and RPS 683 (10.27), whereas minimum FWS was recorded in RPS 630 followed by TNAU141 (3.04 g), KOPN 21 (3.26 g), KOPN 8 (4.21), RPS 869 (4.71 g), RBK 155 and RPS 907 (4.79 g). Dry weight of *Striga* plant (DWS) was ranged between 0.16 to 4.73 g with a mean of 2.01 g. Minimum value of DWS was recorded in KOPN 21 followed by RPS 630 (0.34 g), RPS 594 (0.43 g), KOPN 8 (0.57 g), where as maximum value of DWS was recorded in RPS 687 (4.73 g), followed by RPS 927 (4.39 g), RPS 525 (3.11g), RPS 683 (2.95 g), RPS 513 (2.60 g) and KOPN 24 (2.10 g).

On the basis of *Striga* infection related parameters depicted in Fig. 1, none of the evaluated kodo

millet cultures was immune or highly resistant to *S. asiatica*. However, eight cultivars KOPN 21, RPS 594, RPS 531, KOPN 8, RPS 745, RBK 155, RPS 630 and KOPN 22 possessed resistance. Thirteen cultivars namely KOPN 14, TNAU 141, RPS 852, RPS 907, KOPN 10, RPS 869, RPS 506, JK 13, RPS 927, JK 76, RPS 744, RPS 525 and KOPN 24 were moderately resistant or moderately susceptible and four cultivars namely RPS 513, RPS 687, RPS 683 and RPS 517 were found in a range of susceptible to highly susceptible against *S. asiatica* showing higher values of *Striga* related parameters. In the previous studies, few kodo millet cultivars namely GPUK 1, GPUK 5, GPUK 3 Reddy and Dastagiraiah (1987), JK 41, GPUK 5 Jain and Tripathi (2002), RPS 517, RPS 531, RPS 541, RPS 606, RPS 687, RPS 697, RPS 743, RPS 744, DPS 36 and TNAU 141 Jain *et al* (2016) were reported as least affected with *Striga* species. However, in the present study, RPS 687 and RPS 517 were found susceptible to highly susceptible against *S. asiatica*.

The data for correlation studies at the phenotypic level showed positive and significant association among the *Striga* related parameters (table 2). NS was positively correlated with SHI, SS, ASNPC, FWS and DWS. Positive correlation of SHI with SVR, SS, ANSPC, FWS and DWS was recorded. SVR was correlated positively with SS, FWS and DWS. SS was positively correlated with ASNPC, FWS and DWS. Positive and significant correlation of ASNPC with FWS and DWS was noted. FWS was positively correlated with DWS. Strong positive and significant correlation of NS with SS (0.922*), and ASNPC (0.860*), SHI with SVR (0.861*), SS with ASNPC (0.860*), FWS with DWS (0.952*) was recorded. This implies that these *Striga* related parameters are important for classifying cultivars as resistant (lower values) or susceptible (higher values). Kulkarni and Shinde (1983) also suggested that *Striga* dry weight and *Striga* height index are important parameters, while grading genotypes for *Striga* resistance in sorghum. ASNPC as introduced by Haussmann *et al.* (2000) is an appropriate measure as it incorporates infection time. Rodenburg *et al*. (2005) reported that ASNPC and maximum above ground *Striga* number (NSmax) are important discriminative and consistent *Striga* selection measure proved over years with respect to resistance in sorghum against *S. hermonthica*. Significant positive genotypic correlation between *Striga* count one with count two and highly significant positive phenotypic association with *Striga* count two and *Striga* rating were reported by Halidu *et al.*(2015) in maize. Further, *Striga* count one showed highly significant positive environmental correlation with *Striga* count two and *Striga* rating confirm with the findings of Gethi and Smith (2004) in maize to *S.hermonthica* .

Striga related parameters used as criteria to identify resistance in 13 released kodo millet varieties against *S. asiatica* are presented in Table 3 and Fig.2. Data revealed significant differences among the kodo millet varieties for NS at dough stage. The mean NS (8.4) with a range of 4.3 to 23.4 was highest in GPUK 3 followed by JK 76 (13.7), whereas lowest NS was recorded in JK 155 closely followed with TNAU 86 (4.7) and JK 13 (5.0). Values of NS in rest of the varieties were significantly at par with these varieties. There was significant differences among the kodo millet varieties for SHI ranging from 6.6 to 19.0 with a mean of 12.7. The minimum SHI was recorded in JK 155 closely followed by JK 41 (6.7), TNAU 86 (7.1), JK 106 (9.2) and JK 65 (9.9), where as maximum SHI was noted in JK 137 (19.0) followed by RK 390-25 (17.5) and JK 48 (16.7). *Striga* vigour ratings (SVR) ranged between 2.3 to 4.4 with a mean of 3.3 among the 13 varieties of kodo millet. Lowest SVR was noted in JK 155 followed by JK 41 (2.4), TNAU 86 (2.5), JK 106 (2.6) and JK 65 (2.9). The highest SVR was recorded in JK 137, followed by GPUK 3 (4.3) and JK 76 (4.1). Significant variations in SS were recorded which varied from 10.0 to 107.5 with a mean of 30.0 in kodo millet varieties. JK 155 exhibited lowest SS closely followed by TNAU 86, whereas highest SS was recorded in GPUK 3 followed by JK 76 (54.7). Area under *Striga* number progress curve (ASNPC) was calculated in 13 kodo millet varieties using periodic emerged *Striga* count and it varied from 70.0 to 271.8 with a mean value of 132.8. The lowest value of ASNPC was recorded in JK 13 followed by JK 155 (79.5), JK 137 (96.6) and TNAU 86 (98.3), while highest value was recorded in GPUK 3 followed by JK 76 (227.3), JK 98 (154.2), and JK 439 (132.7). On the basis of *Striga* infection parameters, kodo millet variety JK 155 has shown resistance, whereas GPUK 3 and JK 76 were found susceptible to *S. asiatica*. Rest of the varieties were shown moderately resistance or moderately susceptible reaction to *S. asiatica*.

It may be concluded that eight cultivars namely KOPN 21, RPS 594, RPS 531, KOPN 8, RPS 745, RBK 155, RPS 630 and KOPN 22 were found resistant against *Striga asiatica* exhibiting lower estimates of *Striga* related parameters. Released variety of kodo millet JK155 have shown resistance exhibiting lower values of *Striga* related parameters. Strong positive and significant correlation of emerged *Striga* count row^{-1}(NS) with *Striga* severity (0.922*) and area under *Striga* number progress curve (0.860*), *Striga* height index (SHI) with *Striga* vigour ratings (0.861*), *Striga* severity with area under *Striga* number

progress curve (0.860*) and fresh weight of *Striga* with dry weight of *Striga* (0.952*) were recorded.

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Table 1. *Striga* related parameters in 25 kodo millet cultivars under field conditioned

S. No.	Entry No.	Emerged *Striga* count row^{-1} (NS)	*Striga* height index (SHI)	*Striga* vigour ratings (SVR)	*Striga* severity (SS)	ASNPC[#]	Fresh weight of *Striga* (g)	Dry weight of *Striga* (g)
1	TNAU 141	3.0(0.390)	21.1	4.1	11.0	68.5	3.04	0.49
2	RPS 745	2.0(0.253)	40.0	7.4	14.3	29.5	5.51	0.65
3	KOPN 21	2.3(0.300)	15.8	3.0	6.7	34.5	3.26	0.16
4	RPS 594	2.7(0.414)	28.9	4.5	11.8	29.5	5.76	0.43
5	KOPN 8	3.3(0.460)	26.1	5.3	14.0	44.5	4.21	0.57
6	RPS 630	2.7(0.253)	17.8	3.3	9.6	64.0	2.77	0.34
7	KOPN 22	2.7(0.333)	25.3	4.8	11.9	54.0	5.10	0.73
8	KOPM 14	3.3(0.493)	31.6	5.9	18.7	44.0	8.10	1.18
9	KOPN 10	3.7(0.517)	34.4	5.9	21.2	68.5	7.69	1.09
10	RPS 506	3.0(0.357)	31.7	6.1	13.9	83.0	4.90	0.56
11	KOPN 24	6.0(0.690)	37.7	5.4	27.1	122.5	9.61	2.10
12	RPS 513	10.7(1.000)	48.3	6.3	64.7	221.5	8.44	2.60
13	RBK 155	2.7(0.333)	23.7	4.0	11.1	54.0	4.79	0.65
14	RPS 683	4.7(0.654)	33.3	5.2	24.8	147.0	10.27	2.95
15	RPS 927	4.0(0.540)	40.2	6.8	27.7	65.7	13.23	4.39
16	RPS 531	1.7(0.150)	30.0	4.5	8.5	44.0	6.36	1.05
17	RPS 687	4.4(0.611)	48.1	6.5	29.2	136.3	15.19	4.73
18	RPS 744	2.3(0.300)	43.3	6.7	14.1	92.5	4.94	0.83
19	RPS 852	3.0(0.460)	33.9	6.3	20.3	58.5	6.52	1.52
20	RPS 869	4.7(0.610)	35.7	4.8	17.9	73.5	4.71	0.96
21	RPS 525	4.7(0.611)	33.9	5.1	23.3	117.0	11.02	3.11
22	RPS 517	5.0(0.713)	46.7	7.6	38.3	111.8	9.06	1.93
23	RPS 907	2.3(0.300)	35.8	6.1	12.9	73.7	4.79	0.59
24	JK 76	3.3(0.507)	41.2	6.1	22.3	83.0	7.32	1.39
25	JK 13	2.7(0.403)	36.7	6.5	16.7	78.6	8.33	1.37
	Mean	3.6(0.466)	33.6	5.9	23.7	79.9	8.21	2.01
	LCD(5%)	0.296		2.741	16.259		5.559	1.937

Figures in parentheses are log transformed values

[#] Area under *Striga* number progress curve

Table 2. Phenotypic correlation among *Striga* related parameters in kodo millet

-	NS	SHI	SVR	SS	ANSPC	FWS	DWS
NS	1.000	**0.508***	0.225	**0.922***	**0.860***	**0.437***	**0.510***
SHI		1.000	**0.861***	**0.712***	**0.606***	**0.667***	**0.617***
SVR			1.000	**0.490***	0.303	**0.505***	**0.427***
SS				1.000	**0.849***	**0.571***	**0.614***
ANSPC					1.000	**0.520***	**0.603***
FWS						1.000	**0.952***
DWS							1.000

NS= Emerged *Striga* row^{-1}, SHI- *Striga* height index, SVR= *Striga* vigour ratings, SS=*Striga* severity, ANSPC= Area under number of *Striga* progress curve, FWS= Fresh weight of *Striga*, DWS= Dry weight of *Striga*,
* Significant at 5% level.

Table 3. *Striga* related parameters in 13 released varieties of kodo millet.

S. No.	Variety	NS	SHI	SVR	SS	ASNPC
1	JK 41	7.7(0.884)	6.7	2.4	18.2	126.8
2	JK 76	13.7(1.081)	14.6	4.1	54.7	227.3
3	JK 155	4.3(0.633)	6.6	2.3	10.0	79.5
4	JK 106	5.7(0.746)	9.2	2.6	14.1	123.0
5	JK 13	5.0(0.611)	15.5	3.4	18.8	70.0
6	JK 65	6.3(0.784)	9.9	2.9	19.5	101.6
7	JK 98	7.3(0.851)	12.8	3.0	21.7	154.2
8	JK 137	6.3(0.794)	19.0	4.4	28.0	96.6
9	RK 390-25	8.0(0.884)	17.5	3.5	27.0	128.3
10	JK 439	9.3(0.900)	15.0	3.7	35.3	132.7
11	JK 48	7.0(0.794)	16.7	3.5	24.8	116.5
12	GPUK 3	23.4(1.340)	15.0	4.3	107.5	271.8
13	TNAU 86	4.7(0.610)	7.1	2.5	10.7	98.3
	Mean	8.4(0.839)	12.7	3.3	30.0	132.8
	LSD (5%)	0.327	8.329	1.146	36.509	51.980

Figures in parentheses are log transformed values

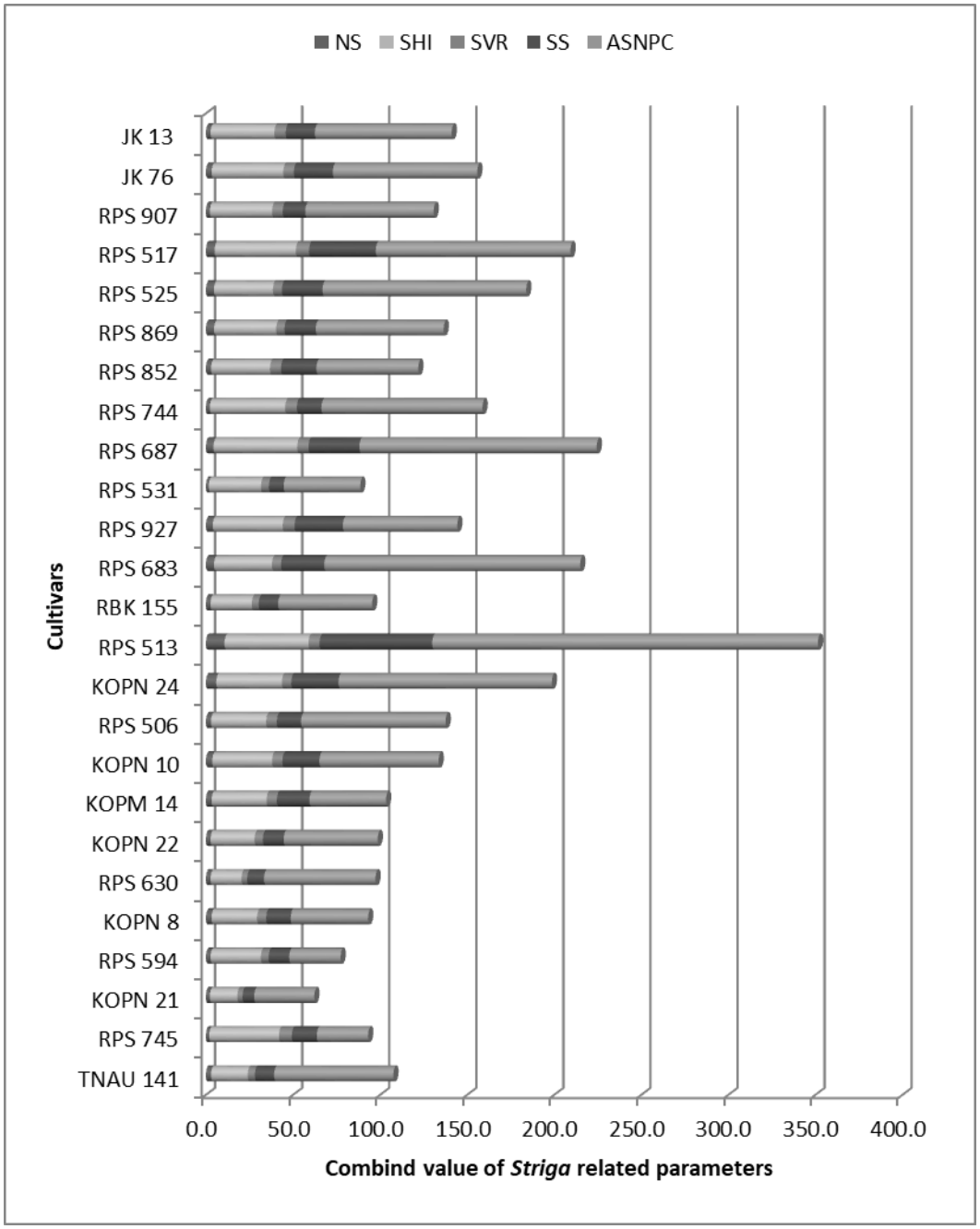

Fig. 1. Combined value of *Striga* related parameters in 25 cultivars of kodo millet

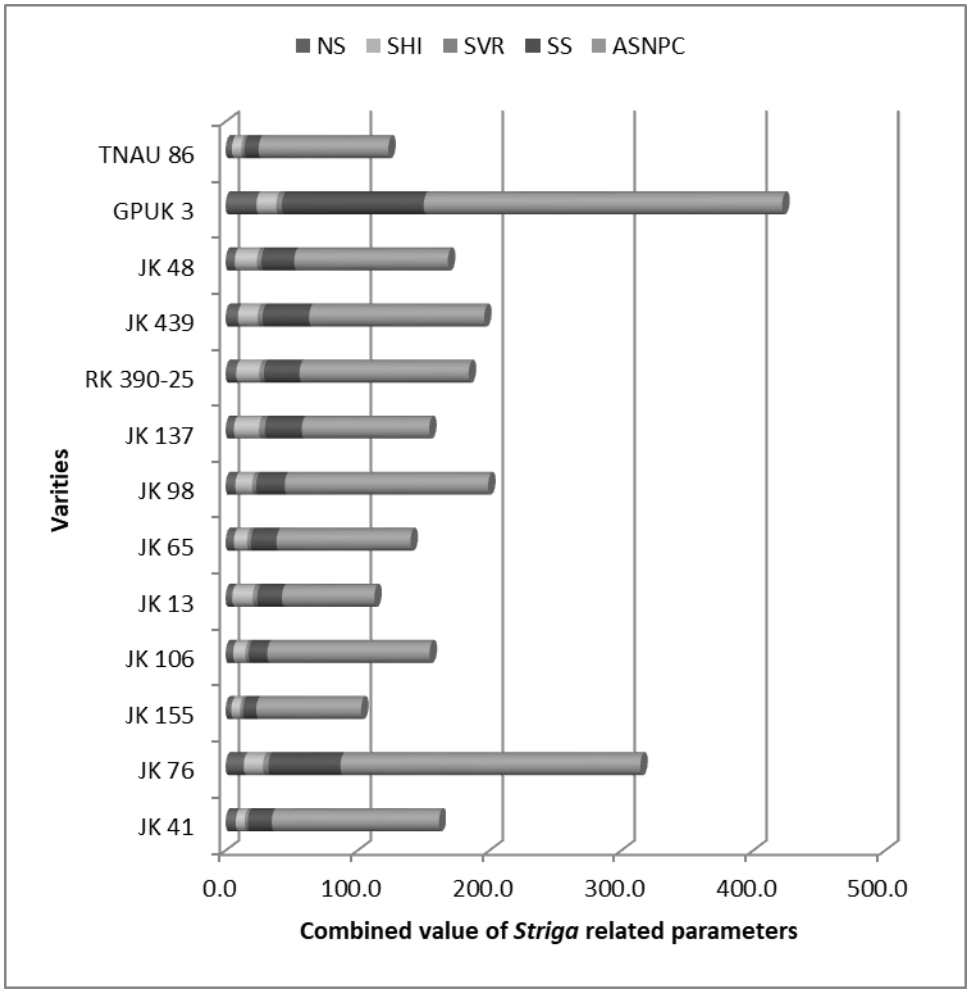

Fig. 2. Combined value of *Striga* related parameters in 13 released varieties of kodo millet