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Estimation of genetic variability parameters in aloe (*Aloe barbadensis* Mill.) genotypes to improve economic traits

Pavani Narigapalli[1] and Geetha K.A.[2]

[1]B.A. College of Agriculture, Anand Agricultural University, Gujarat, India - 388110
[2]ICAR-Directorate of Medicinal and Aromatic Plants Research, Boriavi, Anand, India - 387310

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ABSTRACT

A study was conducted on twenty-six accessions of *Aloe barbadensis* Mill. at ICAR-DMAPR, Boriavi, from 2019 to 2021 to assess morphological, chemical, and yield traits for identifying elite lines suitable for herbal drugs and cosmetics. Significant variation among accessions was observed among the evaluated genotypes. IC 310623 demonstrated superior gel and aloin yield, with high aloin content, making it ideal for medicinal and cosmetic applications. High genetic and phenotypic coefficients of variation (GCV and PCV) were noted for leaf thickness and exudates yield per plant, suggesting that direct selection for these traits could enhance future breeding programs. This study identifies promising accessions with potential for commercial exploitation in herbal and cosmetic industries.

Introduction

Aloe barbadensis Mill. (2n = 14) is a xerophytic, perennial species belonging to family *Asphodelaceae*. Aloe is a native of South Africa, now indigenous to dry sub-tropical and tropical climates, including the southern United States (Viljoen *et al*., 2000). Due to its pharmaceutical and industrial uses it is also called as "Miracle Plant" and "Healing Plant" (Okareh *et al*., 2012). There are about 500 species in the genus Aloe. Among the various species, *Aloe barbadensis* Mill. is widely known for its medicinal properties. According to an assessment by the International Aloe Science Council (IASC), nearly 23,600 hectares of aloe are cultivated globally, with 19,100 hectares located in the America (Samsai and Praveena, 2016).

A. barbadensis is successfully grown in all kinds of soil *i.e.*, from well drained sandy to loamy soils with a pH of 7.0 to 8.5. *Aloe vera* plants are prominent by their high-water content, which ranges from 99 to 99.5% (Atherton, 1998), 0.5–1.0% of the solid material contains about 75 distinct potentially active substances, including vitamins, minerals, enzymes, simple and complex polysaccharides, phenolic compounds, and organic acids. The leaves are thick and fleshy, green to grey green with serrated margins with prominent spines. Fruits are loculicidal capsules bearing an average of 4-9 seeds per fruit, but the seeds are mostly sterile and the crop is mainly propagated vegetatively by suckers (Manvitha and Bidya, 2014).

A. barbadensis has a vast traditional role in indigenous system of medicine like *Ayurveda*, *Siddha*, *Unani* and Homoeopathy. Aloe leaf consists of fleshy gel which helps in the synthesis of carbohydrates and proteins (Misir *et al*., 2014). The anti-inflammatory and the local anesthesia properties of gel have made it a household name. The exudates contain the anthraquinones which are active ingredients and glycosides which are important in pharmaceutical industry. Aloin, aloe emodin and aloe lectin are the important anthraquinones present in aloe. Aloin or barbaloin ($C_{21}H_{22}O_9$) is the major

Corresponding author
Email: pavaninarigapalli20@gmail.com (Pavani Narigapalli)

portion of the exudates which is yellow-brown in color (Saeed *et al.,* 2004). Some of the anthraquinones are used as cathartic (Bhat and Devi, 2010).

It contains about 75 potentially active constituents: vitamins, enzymes, minerals, sugars, lignin, active enzymes, saponins, salicylic acids, amino acids (Atherton, 1998) and phenolic compounds (Okamura *et al.,* 1996). Aloe polysaccharides have therapeutic properties such as immune-stimulation, anti-inflammatory, anti-obesity preparation, wound healing, anti-bacterial, anti-viral, anti-fungal and anti-oxidant (Reddy *et al*., 2011). Aloin and polysaccharide present in the leaves are medicinally and commercially useful (Liu *et al*., 2011).

In view of various industrial uses in cosmetic and pharmaceutical industries, leaf yield and aloin content are of paramount importance in aloe. Developing improved cultivars/ varieties with higher leaf yield and aloin content is an important step for promoting aloe cultivation. To date, there has been very little information available regarding genetic variability studies in *Aloe barbadensis*. Therefore, this study was mainly focused on assessing the genetic variability studies for morphological, chemical, reproductive and yield characters of *Aloe barbadensis*.

Material and Methods

Twenty-six accessions of *Aloe barbadensis* Mill. were evaluated from September 2019 to March 2021 at ICAR-Directorate of Medicinal and Aromatic Plants Research (ICAR-DMAPR), Boriavi, Anand, Gujarat. A total of twenty-six accessions were evaluated a randomized complete block design with two replications. Suckers of length 8-10 cm of each accession were used for planting with a spacing of 60 × 45 cm accommodating 21 plants in 1.8 × 3.15 m plot. All the recommended agronomic practices and plant protection measures were followed to ensure uniform, healthy and stable crop growth.

Five competitive plants (18 months old) from each plot were randomly selected to record observations from the net area of each replication. Observations related to the characteristics of inflorescence/ flowers were recorded during the months of February-March, 2021. Inflorescence emergence was observed from the axils of 2nd or 3rd from the base. Observations related to the characteristics of leaf and biochemical parameters were recorded at the time of harvest. Harvesting was done when the plants attained age of about 18 months. For morphological characters three leaves were used from the selected five plants of the net area from each replication. For yield related parameters *viz*., leaf yield, gel yield and exudates yield, all the mature leaves (leaf length >15 cm) of the plants from the net plot area (n=5) were used from each replication.

Chemical parameter aloin content (%) was estimated from the dry exudates collected from the leaf as reported by Gajbhiye and Maiti (2010). Gel obtained from each replication was weighed separately and were converted into fresh gel yield per hectare (kg).

Fresh gel yield (t ha^{-1}) = Fresh gel per plant Number of plants per hectare.

For expressing the gel yield on dry weight basis, gel dry matter % was obtained. Fresh gel of about 50 g (n=3) was kept in the hot air oven at 50°- 60°C for about 10-12 hours. The final dry weight was taken and the dry matter percent was calculated using the following formula:

Dry matter % of gel= Total weight of final dried gel obtained/ Fresh gel weight taken x 100

The mean values of different characters recorded from each accession per replication were used for statistical analysis. The analysis of variance was carried out for randomized complete block design separately for all the characters as per the standard procedure described by Panse and Sukhatme (1978).

Further, the statistical analysis for genotypic, phenotypic and environmental variances were calculated as per Johnson *et al*. (1955). GCV and PCV were computed using the following formula given by Burton (1952) and heritability (h^2) in the broad sense was estimated by the formula specified by Hanson *et al.* (1956). The expected genetic advance (GA) was calculated for each character as suggested by Allard (1960) and assessed the traits as high, medium and low as per Johnson *et al*. (1955).

Results and Discussion

The analysis of variance for morphological parameters (Table 1) and yield parameters (Table 3) showed significant differences except for reproductive traits (Table 2). Among them, IC 283943 (67.34 cm) and IC 112527 (66.70 cm) exhibited the greatest plant height, while IC 310596 (11.31) had the highest number of leaves per plant. Regarding chemical parameters, IC 310623 (27.07%) recorded the highest aloin content, followed by NMRM 2, IC 310594, IC 283655 and IC 283652. Meanwhile, IC 310609 (97.68%) along with 17 other accessions, demonstrated exceptional gel content, enhancing their medicinal value. In terms of biomass production, IC 310618 (339.63 g), IC 310619 (325.88 g) and IC 310623 (290.91 g) exhibited the highest leaf weights, with these same accessions also recording the highest leaf yield per hectare. Similarly, IC 310623 produced the highest exudates per plant (10.31 g), followed by NMRM 2 (9.86 g) and IC 112531 (9.69 g), while IC 112527, IC 283932 and IC 283655 had the highest exudates yield per hectare. For fresh gel yield, IC 310618 (93.55 t ha^{-1}), IC 310619 (90.20 t ha^{-1}) and IC 310623 (91.07 t ha^{-1}) were the top performers, whereas GUJ 2, IC 283652 and IC 310618 superior in dry gel yield.

Aloin yield was highest in IC 310623 (74.80 kg ha^{-1}), followed by IC 285629 and GUJ 1 with NMRM 2 also demonstrating high aloin content. Overall, IC 310618, IC 310619 and IC 310623 emerged as outstanding accessions due to their superior leaf yield, gel yield and aloin content. Additionally, GUJ 2 and IC 283652 were notable for dry gel production, while IC 285629, IC 310623 and NMRM 2 were ideal for aloin extraction, making them highly valuable for medicinal and industrial applications. In terms of yield, IC 310618, IC 310623 and IC 310619 proved to be exceptional. However, in medicinal plants, commercial success is ultimately determined by the yield of active ingredients rather than total biomass. Accessions with remarkable morphological, chemical and yield characteristics can be classified as elite varieties, making them ideal candidates for breeding programs focused on genetic enhancement or direct cultivation as high-yielding aloe selections.

The variation among accessions in this study was assessed using the coefficient of variation. The Genotypic Coefficient of Variation (GCV) and Phenotypic Coefficient of Variation (PCV) are essential for determining the extent of variability within accessions. Minimal differences were observed between GCV and PCV for most recorded traits, except for a few where PCV was significantly higher than GCV (Table 4 and Fig. 1).

In this study, high GCV was recorded for all yield-related traits, including leaf weight, leaf thickness, and the number of leaves per plant. The high GCV values suggest that direct selection may be effective for improving these traits. Conversely, traits such as flowers per inflorescence, inflorescence length, and gel content (%) exhibited low GCV, indicating that direct selection for these characteristics may not be effective. These findings align with those of Nejatzadeh *et al.* (2012).Heritability plays a crucial role in understanding a trait's response to selection. In this study, broad-sense heritability ranged from 2.27% (inflorescence length) to 97.78% (plant height). Similar results for leaf yield and gel content (%) were reported by Alagukannan and Ganesh (2008) and Ahmad and Gupta (2016). High heritability was observed for all studied traits, suggesting that selection based on phenotypic values could be effective. However, selection is most efficient when high heritability is coupled with high genetic advance (Falconer, 1981; Johnson *et al.*, 1955).

High heritability combined with high genetic advance as a percentage of the mean was recorded for plant height (h^2_{bs} = 97.78%, GAM = 25.49%), fresh gel yield (h^2_{bs} = 93.60%, GAM = 49.98%), leaf yield (h^2_{bs} = 88.50%, GAM = 55.19%), number of leaves per plant (h^2_{bs} = 91.95%, GAM = 39.26%), leaf thickness (h^2_{bs} = 90.44%, GAM = 50.72%), leaf weight (h^2_{bs} = 86.82%, GAM = 61.16%), exudates yield per plant (h^2_{bs} = 90.56%, GAM = 49.27%), leaf breadth (h^2_{bs} = 89.57%, GAM = 38.66%), aloin content (h^2_{bs} = 89.93%, GAM = 30.95%), aloin yield (h^2_{bs} = 89.31%, GAM = 50.23%), dry gel yield (h^2_{bs} = 91.11%, GAM = 64.41%) and leaf rind thickness (h^2_{bs} = 80.00%, GAM = 26.25%). These results indicate the predominance of additive gene action, suggesting that direct selection for these traits would be effective.

However, gel content (%) exhibited high heritability with low genetic advance, suggesting the influence of non-additive gene action. In such cases, high heritability is likely due to environmental factors rather than genetic factors, making selection for these traits less effective. This study highlights that traits with high heritability and substantial genetic advance are ideal for direct selection, while those influenced by non-additive genetic effects require alternative breeding strategies to achieve genetic improvement.

Table 1. Mean performances in morphological and chemical characters among *Aloe barbadensis* genotypes

Accessions	Morphological characters							Chemical characters	
	Plant height (cm)	Leaves/ plant	Leaf length (cm)	Leaf breadth (cm)	Leaf thick-ness (cm)	Spines/ leaf	Suckers/ plant	Gel content (%)	Aloin content (%)
IC 112521	53.70	6.61	44.94	6.32	1.31	44.61	8.56	96.94	16.79
IC 112527	66.70	10.28	53.82	7.61	3.47	53.48	5.72	97.30	23.08
IC 112531	54.37	8.61	47.48	7.57	1.32	47.15	7.63	96.06	20.97
IC 112532	54.94	9.61	44.98	8.67	2.31	44.65	6.74	96.86	19.22
IC 283652	65.04	11.61	55.14	10.62	3.44	54.26	4.75	94.98	25.40
IC 283655	49.37	11.28	54.87	10.60	3.38	53.54	5.84	96.00	25.64
IC 283670	62.37	8.45	54.48	8.06	2.06	44.15	6.50	97.64	20.48
IC 283928	62.00	9.95	46.93	9.34	2.24	46.60	5.17	97.07	20.20
IC 283932	52.34	10.55	47.04	9.67	2.06	46.71	6.00	96.88	24.13
IC 283934	63.34	8.71	51.71	7.41	1.00	41.37	7.45	94.00	15.53
IC 283943	67.34	9.38	50.48	7.88	1.91	50.15	8.79	96.46	17.00
IC 283945	61.34	9.55	50.82	9.73	2.05	50.48	6.96	97.43	19.24

IC 285626	50.34	9.55	43.52	9.50	2.15	43.18	5.67	97.41	23.46
IC 285629	55.67	10.66	45.74	8.77	2.11	45.41	5.00	96.02	23.82
IC 285630	51.80	9.11	48.76	8.42	2.24	48.42	6.61	96.92	21.55
IC 310594	38.27	6.88	31.96	6.02	2.27	31.63	7.41	96.88	25.75
IC 310596	47.10	13.31	43.81	10.01	2.09	43.47	7.57	97.12	19.44
IC 310609	43.20	8.91	41.12	9.50	1.75	40.78	6.17	97.68	20.54
IC 310618	52.60	11.35	50.85	8.00	2.41	40.52	6.34	96.46	20.04
IC 310619	59.94	9.98	47.63	9.93	2.01	37.30	8.09	97.20	22.50
IC 310623	58.27	10.98	45.72	9.03	1.91	40.38	8.57	97.29	27.07
GUJ 1	57.27	9.58	47.66	8.67	2.08	45.83	7.31	97.38	22.95
GUJ 2	54.60	10.81	45.94	8.90	2.72	45.61	5.45	94.68	21.90
K 98	55.94	8.81	45.38	9.12	2.17	45.05	9.34	97.35	13.96
MP 1	56.94	10.48	45.61	9.52	2.61	45.27	5.62	96.57	17.69
NMRM 2	50.27	8.81	42.61	8.13	2.31	42.27	6.17	97.50	26.90
SEm±	0.32	1.52	0.28	0.14	0.62	0.01	0.31	0.36	0.81
CD at 5%	0.93	4.42	0.80	0.39	1.81	0.02	0.91	1.04	2.34

Table 2. Mean performances in reproductive characters among *Aloe barbadensis* genotypes

Accessions	Inflorescence/ plant	Flowers/ inflorescence	Length of inflorescence (cm)	Capsules/ inflorescence	Seeds/ capsule
IC 112521	2.20	123.50	97.20	11.15	6.24
IC 112527	1.50	103.20	104.44	8.84	8.15
IC 112531	1.67	115.80	110.35	0.22	10.09
IC 112532	1.60	124.17	106.04	0.50	9.17
IC 283652	1.20	115.64	142.47	3.50	8.74
IC 283655	1.65	116.45	109.40	0.50	8.07
IC 283670	1.60	103.50	111.00	0.30	9.27
IC 283928	1.00	89.08	104.75	0.20	6.78
IC 283932	1.80	130.30	112.85	0.00	0.00
IC 283934	1.17	90.30	90.70	17.80	7.47
IC 283943	1.75	99.30	106.48	17.80	8.64
IC 283945	1.40	87.65	107.04	0.50	7.78
IC 285626	1.25	107.25	97.75	0.52	6.24
IC 285629	1.50	114.20	112.80	2.20	8.15
IC 285630	1.60	138.40	117.20	3.10	10.09
IC 310594	1.50	122.70	114.90	25.00	9.17
IC 310596	1.68	99.75	110.40	1.10	9.20
IC 310609	1.33	97.75	92.00	1.00	7.78
IC 310618	0.90	96.65	81.85	1.55	7.10
IC 310619	1.79	89.30	108.20	8.30	7.06
IC 310623	2.20	145.90	102.00	10.15	7.51
GUJ 1	1.10	94.80	104.00	3.10	10.59
GUJ 2	1.90	110.90	100.40	0.00	0.00
K 98	1.00	95.50	101.84	3.50	8.15
MP 1	0.63	60.38	52.88	4.90	7.07

NMRM 2	1.10	104.38	107.25	1.25	7.78
SEm±	0.286	15.43	14.71	1.17	0.46
CD at 5%	0.83	44.92	42.87	3.41	1.34

Table 3. Mean performances in yield characters among *Aloe barbadensis* genotypes

Accessions	Leaf weight (g)	Leaf yield (t ha^{-1})	Exudates yield plant^{-1}	Exudates yield (kg ha^{-1})	Fresh gel yield (t ha^{-1})	Dry gel yield (t ha^{-1})	Aloin yield (kg ha^{-1})
IC 112521	151.99	45.93	4.47	189.45	44.56	1.39	31.95
IC 112527	261.86	88.84	9.69	258.89	70.31	1.91	59.64
IC 112531	146.93	55.64	5.94	220.00	45.30	1.78	46.27
IC 112532	148.48	58.71	5.12	165.56	47.86	1.51	31.95
IC 283652	278.11	91.46	8.15	251.67	68.27	3.43	63.82
IC 283655	245.18	98.20	8.62	248.26	78.12	3.14	63.62
IC 283670	243.35	76.73	6.35	235.19	45.59	1.09	48.23
IC 283928	248.18	76.88	6.28	232.60	61.36	1.84	47.04
IC 283932	252.74	103.20	9.94	257.63	81.16	2.53	62.21
IC 283934	106.11	44.00	7.23	196.12	36.50	2.20	30.52
IC 283943	162.27	56.18	4.75	324.07	56.24	1.90	55.00
IC 283945	253.54	85.47	7.58	299.26	67.48	1.74	57.51
IC 285626	199.53	79.44	7.69	276.67	62.56	1.63	64.87
IC 285629	242.13	89.6	9.63	289.67	70.24	2.81	69.00
IC 285630	171.63	75.13	6.65	246.30	60.22	1.86	53.13
IC 310594	96.45	41.74	5.05	186.74	34.69	1.10	47.79
IC 310596	182.60	82.64	8.31	307.59	67.31	1.95	59.51
IC 310609	120.01	56.55	4.91	181.86	45.79	1.06	37.33
IC 310618	339.63	117.6	8.32	315.00	93.55	3.32	62.50
IC 310619	325.88	114.48	8.11	269.63	90.20	2.54	60.66
IC 310623	290.91	114.52	10.31	270.37	91.07	2.48	74.80
GUJ 1	245.04	89.15	8.00	296.30	70.35	1.86	68.15
GUJ 2	189.67	93.86	7.13	263.89	72.70	3.87	57.71
K 98	127.00	60.89	3.56	131.85	50.39	1.33	18.41
MP 1	189.99	83.38	7.49	277.04	66.80	2.30	49.26
NMRM 2	127.14	63.80	9.86	278.15	52.39	1.32	73.10
SEm±	18.05	3.54	0.42	16.97	3.53	0.25	3.38
CD at 5%	52.57	10.31	1.22	49.41	10.26	0.71	9.86

Table 4. Genetic parameters for various traits in *Aloe barbadensis* genotypes

Traits	Mean ± SE	Range	σ^2_g	σ^2_p	GCV (%)	PCV (%)	$h^2_{(bs)}$ (%)	$h^2_{(bs)}$ inference	GA %	GA % inference
Plant height (cm)	55.58± 0.75	38.27 - 67.34	48.35	49.45	12.51	12.66	97.78	High	25.49	High
Leaves per plant	9.65±0.32	6.61 - 13.31	2.31	2.52	19.88	20.73	91.95	High	39.26	High
Leaf length (cm)	47.27±1.52	31.96 - 55.14	22.35	26.95	10.01	10.99	82.93	High	18.77	Moderate

Leaf breadth (cm)	8.74±0.28	6.02 - 10.62	1.30	1.45	19.83	20.95	89.57	High	38.66	High
Leaf thickness (cm)	2.21±0.14	1.00 - 3.47	0.33	0.36	25.89	27.22	90.44	High	50.72	High
Spines/ leaf	45.09±0.62	31.63 - 54.26	25.01	25.77	11.09	11.26	97.02	High	22.51	High
Leaf rind thickness (cm)	0.15±0.01	0.12 - 0.19	0.01	0.01	14.23	15.91	80.00	High	26.25	High
Suckers/ plant	6.75±0.31	4.75 - 9.34	1.47	1.66	17.95	19.09	88.41	High	34.77	High
Inflorescence/ plant	1.43±0.286	0.63 - 2.20	0.35	1.62	37.19	79.98	21.61	Low	35.62	High
Flowers/ inflorescence	106.79±15.43	60.38 - 145.9	91.58	567.48	8.96	22.30	16.13	Low	7.41	Low
Length of inflorescence (cm)	104.08±14.71	52.88 - 142.47	10.07	443.39	3.04	20.23	2.27	Low	0.94	Low
Capsules/ inflorescence	4.87±1.17	0.00 - 25.00	48.25	48.35	155.3	155.48	99.79	High	319.6	High
Seeds/ capsule	7.55±0.46	6.24-10.54	6.02	6.44	32.51	33.63	93.4	High	64.70	High
Gel content (%)	96.7±0.36	94.00 - 97.68	0.75	1.00	0.90	1.03	74.77	High	1.59	Low
Aloin content (%)	21.36±0.81	13.96 - 27.07	11.44	12.72	15.84	16.71	89.93	High	30.95	High
Leaf weight (g)	205.63±18.05	96.45-339.63	4293.82	4945.55	31.86	34.20	86.82	High	61.16	High
Leaf yield (t ha^{-1})	78.62±3.54	41.74 - 117.6	467.33	492.39	27.5	28.23	88.50	High	55.19	High
Exudates yield $plant^{-1}$	7.28±0.42	3.56 - 10.31	3.35	3.69	25.14	26.41	90.56	High	49.27	High
Exudates yield (kg ha^{-1})	248.83±16.97	131.85 - 324.07	2122.10	2697.85	18.51	20. 87	78.66	High	33.82	High
Fresh gel yield (t ha^{-1})	62.74±3.53	34.69 - 93.55	254.24	279.05	25.42	26.63	93.60	High	49.98	High
Dry gel yield (t ha^{-1})	2.08±0.25	1.06 - 3.87	0.52	0.64	34.6	38.29	91.11	High	64.41	High
Aloin yield (kg ha^{-1})	53.61±3.38	18.41-74.80	191.40	214.30	25.80	27.30	89.31	High	50.23	High

σ^2_g: Genotypic variance; σ^2_p: Phenotypic variance; GCV: Genotypic Coefficient of Variation; PCV: Phenotypic Coefficient of Variation; $h^2_{(bs)}$: Heritability (Broad Sense); GA: Genetic Advance.

Conclusion

Among the accessions studied, IC 310623 is superior in terms of leaf yield, gel yield and aloin yield with high aloin content and hence can be selected as a superior genotype for both medicinal and cosmetic purposes. Considering GCV, heritability and genetic advance, it can be concluded that selection for increasing leaf yield should be made by giving the highest priority to characters *viz.,* leaves per plant, leaf breadth, leaf thickness, leaf weight and exudates yield per plant. These characters should be given due importance during the planning of breeding strategy in aloe.

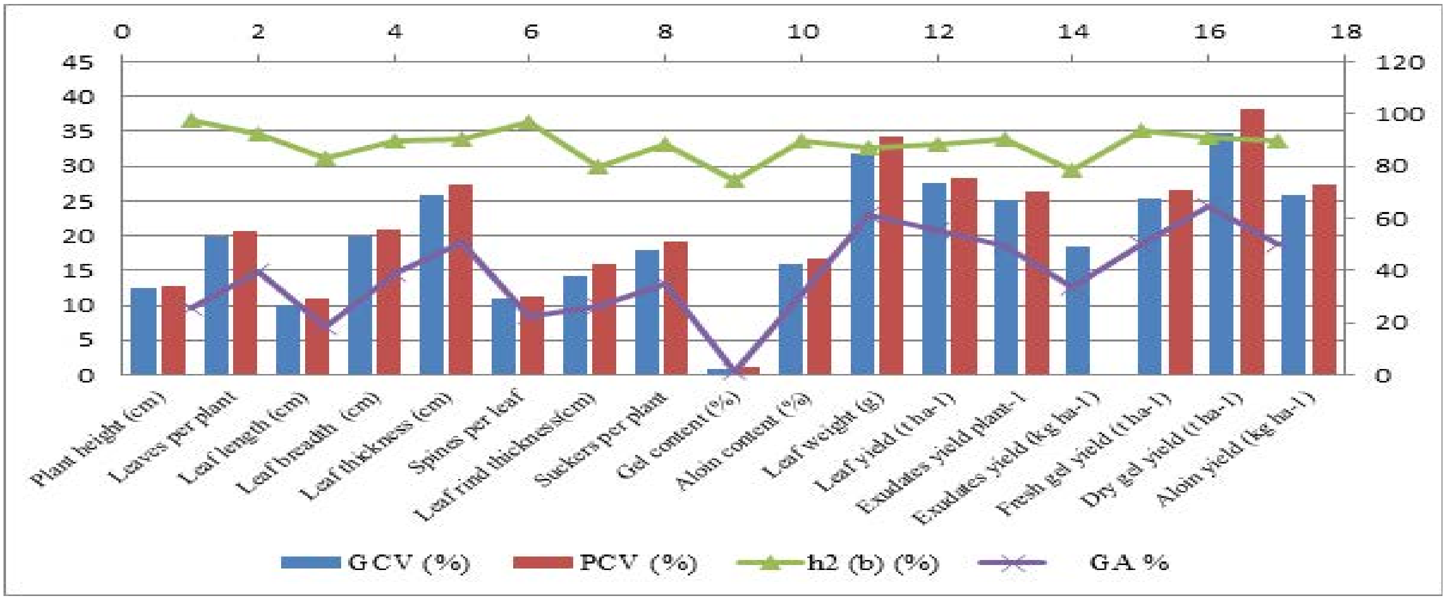

Fig. 1. Genetic parameters of morphological and yield characters

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Conflict of Interest

The authors have no conflict of interest.

Data Sharing

All relevant data are within the manuscript.

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