

DOI 10.7764/rcia.v46i2.2145

RESEARCH PAPER

Genetic variability in vegetable *Chenopodium* for morphological and quality traits over different cuttings

Atul Bhargava^{1,2}, Francisco Fuentes³, Sudhir Shukla², Shilpi Srivastava¹,
Sajjasi Dubey¹, and Deepak Ohri^{2,4}

¹Amity University Uttar Pradesh (Lucknow Campus), Amity Institute of Biotechnology, Lucknow 226028, India.

²National Botanical Research Institute, Division of Genetics and Plant Breeding, Lucknow-226001, India.

³Pontificia Universidad Católica de Chile, Facultad de Agronomía e Ingeniería Forestal, Av. Vicuña Mackenna 4860, Macul. Casilla 306-22, Santiago, Chile.

⁴Amity University Uttar Pradesh (Lucknow Campus), Research Cell, Lucknow 226028, India.

Abstract

A. Bhargava, F. Fuentes, S. Shukla, S. Srivastava, S. Dubey, and D. Ohri. 2019. Genetic variability in vegetable *Chenopodium* for morphological and quality traits over different cuttings. Cien. Inv. Agr. 46(2): 179-186. The present study was performed to assess the genetic parameters for different quantitative and qualitative traits of 13 germplasm lines of *Chenopodium* spp. The lines were sown in a randomized block design with a plot size of 2 m², and data were recorded for foliage yield and 8 component traits over 4 successive cuttings. The foliage yield/plot was variable, ranging from 1.07-2.66 t ha⁻¹ with an average yield of 2.00±0.15. The protein and carotenoid contents averaged 3.70±0.09% and 13.47±0.56 mg 100 g⁻¹, respectively. The range and mean of individual cuttings for plant height, leaf size, protein and foliage yield increased with successive cuttings until the IIIrd cutting, and the yield declined thereafter. High heritability estimates for all the traits under study were obtained for individual cuttings as well as on a pooled basis. High heritability coupled with high genetic gain was observed for foliage yield, carotenoid content and protein content, indicating the presence of additive gene effects.

Keywords: *Chenopodium*, cuttings, foliage yield, genetic advance, heritability, protein.

Introduction

Underutilized or neglected crops are ancient plant species that have been used by local communities for a long time and have been maintained by cultural

preferences and traditional practices (Mayes *et al.*, 2011; Bhargava and Srivastava, 2013). These crops have played an important role in strengthening the food security, nutrition, and income generation of the rural poor in several countries worldwide. However, these crops have remained inadequately characterized and neglected in terms of research, extension services and conservation (Magbagbeola

et al., 2010; Mayes *et al.*, 2011). A number of other terms, such as orphan, minor, abandoned, lost, underused, local, promising, traditional, forgotten and alternative crops, are often used for these less utilized species (Padulosi and Hoeschle-Zeledon, 2004). The cultivation of these traditional crops has declined over time, yet many of these wild and underutilized plants have the potential for more widespread use and could contribute to agricultural diversification, income generation, food provision and nutritional security (Vietmeyer, 1986; Chivenge *et al.*, 2015; Bhargava and Srivastava, 2013). These crops are more important than other commercially cultivated crops since they can be cultivated with low inputs and therefore provide economic and environmental benefits. It can be safely said that the new century will see renewed interest and utilization of these underutilized crops. In the last few decades, chenopods have shown potential as food crops for agricultural diversification due to their climate adaptability and nutritional superiority (Bhargava *et al.*, 2010; Bhargava and Ohri, 2015).

The genus *Chenopodium* (family: Amaranthaceae), known as the goosefoot genus, comprises approximately 250 species (Giusti, 1970) and includes mostly facultatively autogamous annuals distributed in temperate regions of the Americas, Asia and Europe (Wilson, 1990; Jellen *et al.*, 2011). Of the several species of the genus that have been used, only three, *C. quinoa* (2n=36), *C. pallidicaule* (2n=18) and *C. berlandieri* ssp. *nuttalliae* (2n=36), have been cultivated as food crops (Bhargava *et al.*, 2010; Zurita-Silva *et al.*, 2014). However, the leaves and tender stems of several other species of the genus are used as food and fodder (Facciola, 1990; Moerman, 1998; Partap *et al.*, 1998; Bhargava *et al.*, 2007a, 2008a, 2008b; Fuentes and Paredes-González, 2015). Chenopods are a rich source of nutrients such as protein, vitamins and a wide range of minerals (Prakash *et al.*, 1993; Bhargava *et al.*, 2007a, 2007b; Miranda *et al.*, 2012). Recently, chenopods have been on the forefront of research, especially as an alternative crop for agriculturally marginal lands

and stressful environments in many parts of the world (Bhargava *et al.*, 2003a, 2006; Fuentes *et al.*, 2012; Bazile *et al.*, 2016).

Although the crop is nutritionally very important, information on the genetic improvement of vegetable chenopods is scarce (Bhargava *et al.*, 2003b, 2003c, 2007a, 2019) and is restricted to a single species, *C. album*. Improvement of foliage requires knowledge of the extent of genetic variability in the available germplasm, the interrelationships between different traits, the extent of the environmental effects on these characters, trait heritability and the potential genetic gain of the material (Bhargava *et al.*, 2007b; Litrico and Violle, 2007; Pistorale *et al.*, 2008). Surprisingly, this information is completely absent for numerous species of *Chenopodium*. To fill this gap, the present investigation was conducted to obtain in-depth knowledge of the different selection parameters for different quantitative and qualitative traits of vegetable *Chenopodium*.

Materials and Methods

The experiment was carried out in the experimental field of the CSIR-National Botanical Research Institute, Lucknow (26.5°N and 80.5°E), situated at an altitude of 120 meters above mean sea level. The region has a subtropical climate characterized by long, hot summers, cool winters and a marked rainy season between these two seasons. In the northern part of India, *Chenopodium* is generally grown as a winter crop, when the temperature ranges from 2-29 °C. The experimental material for the present study comprised 13 germplasm lines of *Chenopodium* spp. (Table 1), which included 7 lines of *C. giganteum*, 2 of *C. murale* and 1 each of *C. bushianum*, *C. strictum*, *C. ugandae* and *C. opulifolium*. These lines, obtained from different sources, have different ploidy levels and have been maintained for several years at the research institute.

The germplasm lines were sown in a randomized block design with 3 replications. The plot size for

each treatment was 4 m² with 6 rows per plot. The plant-to-plant distance was maintained at 30 cm. Irrigation was provided as required, and hand weeding was periodically carried out. No chemical fertilizer or pesticide was used. A total of 4 cuttings were performed. The first cutting was carried out the 4th week after sowing, and thereafter, three more cuttings were performed at intervals of 15 days. Foliage yield was recorded on a plot basis for different cuttings in kg/plot and then converted to t ha⁻¹. Observations were recorded for each cutting of 10 randomly selected plants in each replication for five morphological traits, namely, plant height (cm), leaves per plant, leaf size (cm²), branches per plant and stem diameter (cm). Fresh leaves of each cutting were analyzed separately for three qualitative traits, namely, moisture (%), carotenoid content (mg 100 g⁻¹) and protein content (%). Qualitative data were collected from randomly selected samples for all 4 cuttings separately. Moisture content was estimated as the ratio of fresh leaf weight to 100 °C dry weight. The extraction and estimation of leaf carotenoid and leaf protein contents were carried out per the methods suggested by Jensen (1978) and Lowry *et al.* (1951), respectively.

The data were subjected to statistical analysis of variance according to Panse and Sukhatme (1978). The phenotypic and genotypic coefficients of variation (PCV and GCV), heritability in broad

sense (%) and genetic advance (%) were calculated according to the methods outlined by Singh and Chaudhary (1985) and Johnson *et al.* (1955).

Results and Discussion

The analysis of variance (ANOVA) revealed significant differences in the germplasm for individual cuttings and traits, except for branches per plant and moisture content in the IVth cutting (Table 2). The foliage yield was variable, ranging from 1.07-2.66 t ha⁻¹, with an average yield of 2.00±0.15 (Table 2). Plant height ranged from 12.89-22.40 cm with an average of 15.97±1.68, while branches per plant ranged from 7.76-12.65, with a mean of 9.39±0.60. The leaf size and number of leaves per plant ranged from 16.35-35.90 cm² and 10.20-28.94, with average values of 27.94±2.96 and 17.28±3.25, respectively. The stem diameter ranged from 0.37-0.51 cm with a mean of 0.46±0.03. Among the quality traits, carotenoid and protein content ranged from 12.12-16.24 mg 100 g⁻¹ and 3.26-3.98%, with average values of 13.47±0.56 and 3.70±0.09, respectively. Leaf moisture was in the range of 78.23-85.48%, with an average of 81.00±1.22.

The range and mean of individual cuttings for leaves per plant increased with increasing cuttings and were highest in the IVth cutting (Table 2), while the plant height, leaf size, protein and

Table 1. Germplasm lines, ploidy levels, chromosome numbers and origins.

S.No	Germplasm lines	Accession number	2n	Source
1.	<i>C. giganteum</i> D. Don	CHEN 86/85	54	IPK Gatersleben, Germany
2.	<i>C. giganteum</i> D. Don	CHEN 32/78	54	IPK Gatersleben, Germany
3.	<i>C. giganteum</i> D. Don	Ames 19046	54	USDA
4.	<i>C. giganteum</i> D. Don	Ames 86650	54	USDA
5.	<i>C. giganteum</i> D. Don	PI 596371	54	USDA
6.	<i>C. giganteum</i> D. Don	PI 596372	54	USDA
7.	<i>C. giganteum</i> D. Don	local	54	India
8.	<i>Chenopodium murale</i> L.	CHEN 48/82	18	IPK Gatersleben, Germany
9.	<i>Chenopodium murale</i> L.	local	18	India
10.	<i>Chenopodium bushianum</i> Allen	Ames 22376	54	USDA
11.	<i>Chenopodium strictum</i> Roth.	CHEN 47/79	54	IPK Gatersleben, Germany
12.	<i>Chenopodium ugandae</i> (Aell.) Aell.	CHEN 77/78	36	IPK Gatersleben, Germany
13.	<i>Chenopodium opulifolium</i> Schrad. ex DC.	CHEN 43/96		IPK Gatersleben, Germany

Table 2. Genetic variability, heritability and genetic advance for various traits in different cuttings in *Chenopodium* spp.

Traits	Cuttings	F value	Mean±SE	Range	σ^2_p	σ^2_g	σ^2_e	PCV	GCV	Heritability (%)	Genetic advance	Genetic advance (%)
Plant height (cm)	I	6.92	11.92±0.30	7.10-15.49	9.84	7.74	2.10	26.32	23.34	78.66	5.08	42.62
	II	4.66	14.60±0.73	10.82-18.15	23.00	19.40	3.60	32.85	30.17	84.35	8.33	57.05
	III	3.99	19.41±1.09	11.70-26.10	37.56	30.15	7.41	31.57	28.29	81.27	10.13	52.19
	IV	4.80	17.96±1.14	13.36-24.55	41.40	34.50	6.90	35.69	32.70	83.33	11.04	61.47
	P	-	15.97±1.68	12.89-22.40	11.27	7.21	4.06	21.02	16.81	63.97	4.42	27.68
Leaves /plant	I	5.16	9.63±0.39	6.94-16.45	10.40	8.45	1.95	33.49	30.18	81.25	5.40	56.07
	II	9.42	14.16±0.87	11.79-19.10	17.39	14.19	3.20	29.45	26.60	81.60	7.01	49.50
	III	12.65	22.40±1.96	17.34-29.00	25.17	19.55	5.62	22.40	19.74	77.67	8.03	35.85
	IV	4.89	22.94±1.40	19.49-34.13	21.60	18.34	3.26	20.26	18.67	84.91	8.13	35.44
	P	-	17.28±3.25	10.20-28.94	5.25	3.26	1.99	13.26	10.45	62.02	2.93	0.17
Leaf size (cm ²)	I	9.02	20.57±1.43	13.60-24.52	20.29	18.19	2.10	21.90	20.73	98.65	7.64	37.14
	II	4.57	26.91±1.71	21.29-30.17	40.50	33.36	7.14	23.65	21.46	82.37	10.80	40.13
	III	6.11	34.85±1.39	24.85-39.50	46.55	36.45	10.10	19.58	17.32	78.30	11.00	31.56
	IV	5.19	29.42±2.02	20.92-34.47	35.64	29.14	6.50	20.29	18.35	81.76	10.05	34.16
	P	-	27.94±2.96	16.35-35.90	20.25	15.15	5.10	16.10	13.93	74.81	6.93	24.8
Branches /plant	I	12.00	7.59±0.34	6.12-8.99	11.22	6.32	4.90	44.13	33.12	56.33	3.89	51.25
	II	7.15	10.18±0.83	6.55-12.34	10.29	8.11	2.18	31.51	27.97	78.81	5.21	51.18
	III	4.22	9.82±0.79	5.19-11.67	5.73	4.82	0.91	24.38	22.36	84.12	4.15	42.26
	IV	NS	9.96±0.34	5.82-12.44	6.20	5.07	1.13	25.00	22.61	81.77	4.19	42.07
	P	-	9.39±0.60	7.76-12.65	1.91	1.10	0.81	14.72	11.17	75.88	2.16	23.00
Stem diameter (cm)	I	8.19	0.42±0.06	0.31-0.48	0.04	0.01	0.03	47.62	23.81	25.00	0.10	23.81
	II	5.66	0.40±0.04	0.33-0.48	0.06	0.04	0.02	61.24	50.00	66.67	0.34	85.00
	III	7.03	0.49±0.05	0.38-0.54	0.05	0.03	0.02	45.63	35.35	60.00	0.28	57.14
	IV	14.60	0.53±0.05	0.41-0.59	0.07	0.04	0.03	49.92	37.73	57.14	0.31	58.49
	P	-	0.46±0.03	0.37-0.51	0.004	0.001	0.003	13.75	6.87	49.97	0.06	13.04
Moisture (%)	I	13.65	80.76±7.80	76.58-84.98	6.57	5.14	1.43	3.17	2.81	78.23	4.13	5.11
	II	10.40	84.43±9.44	77.54-85.90	26.91	14.90	12.01	6.14	4.57	55.37	5.92	7.01
	III	11.81	80.12±7.39	77.19-83.00	13.17	8.81	4.36	4.53	3.70	66.89	5.00	6.24
	IV	NS	78.70±3.21	76.38-80.64	9.66	7.24	2.42	3.95	3.42	74.95	4.80	6.10
	P	-	81.00±1.22	78.23-85.48	23.59	18.89	4.70	6.00	5.36	80.08	8.01	9.89
Carotenoid (mg 100 g ⁻¹)	I	6.17	13.52±1.20	10.90-15.65	14.06	9.86	4.20	27.73	23.22	70.13	5.42	40.09
	II	4.73	14.94±1.57	12.48-16.41	16.10	12.48	3.62	26.86	23.64	77.51	6.41	42.90
	III	8.60	13.18±1.23	12.03-13.92	17.35	13.44	3.91	31.6	27.81	77.46	6.65	50.45
	IV	5.09	12.26±1.01	11.30-12.65	14.67	12.19	2.48	31.24	28.48	83.09	6.55	53.42
	P	-	13.47±0.56	12.12-16.24	18.70	12.50	6.20	32.10	26.25	66.84	5.95	44.17
Protein (%)	I	7.54	3.49±0.49	2.96-3.70	4.42	2.50	1.92	60.24	45.30	56.56	2.45	70.20
	II	9.88	3.63±0.41	3.18-3.82	3.53	3.08	0.45	51.76	48.35	88.00	3.40	93.66
	III	4.54	3.92±0.32	3.64-4.09	3.12	1.98	0.14	45.06	35.90	63.46	2.31	58.93
	IV	4.98	3.75±0.43	3.59-3.86	1.71	1.09	0.62	34.87	27.84	63.74	1.72	45.87
	P	-	3.70±0.09	3.26-3.98	0.86	0.62	0.24	25.06	21.28	84.92	1.62	43.78
Foliage yield (t ha ⁻¹)	I	7.69	1.58±0.19	1.14-1.73	0.92	0.74	0.18	60.71	54.44	80.43	1.59	100.63
	II	5.82	2.10±0.43	1.49-2.25	0.36	0.26	0.10	28.57	24.28	72.22	0.89	42.38
	III	6.91	2.28±0.26	1.96-2.89	0.69	0.48	0.21	36.43	30.39	69.56	1.19	52.19
	IV	5.57	2.03±0.33	1.82-2.44	0.81	0.58	0.23	44.33	37.52	71.6	1.33	65.52
	P	-	2.00±0.15	1.07-2.66	0.97	0.69	0.28	49.24	41.53	71.13	1.44	72.00

σ^2_g = Genotypic variance, σ^2_p = Phenotypic variance, σ^2_e = Environmental variance, PCV = Phenotypic coefficient of variation, GCV = Genotypic coefficient of variation

foliage yield values increased with each cutting until the IIIrd cutting. However, the values for these traits decreased after the IIIrd cutting.

The present study clearly indicates that the species assessed can serve as potential vegetable crops due to their high biomasses and ample amounts

of proteins and carotenoids. The protein content, though lower than that of the commonly used foliage crop *C. album* (Prakash *et al.*, 1993; Bhargava *et al.*, 2007a), was higher than those reported for amaranth (Shukla *et al.*, 2003) and spinach (Kuti and Kuti, 1999). Likewise, the material contained appreciable amounts of carotenoids, with levels

higher than that of *C. album*. These species seem to have more regeneration capacity in comparison to *C. album*, since 4 cuttings were performed for the species in this study, whereas a maximum of 3 cuttings have been reported for *C. album* by Bhargava *et al.* (2003a). Thus, there is a need to further explore the potential of these underutilized species of *Chenopodium* for use as fodder crops and for human consumption.

The estimates of variance, phenotypic coefficient of variation (PCV), genotypic coefficient of variation (GCV), heritability in broad sense and genetic advance are shown in Table 2. The PCV had higher estimates than the corresponding GCV for all the characteristics, and in most cases, the two values differed only slightly. The small difference between PCV and GCV for all the traits except stem diameter indicates that the variability was primarily due to genotypic differences. Foliage, followed by plant height and leaf size among the morphological traits, and carotenoid and protein content among the quality traits exhibited high PCV and GCV values, which indicates the potential for improvement of these traits through selection to enhance the potentiality of foliage yield. A high coefficient of variability for foliage yield has previously been reported in other foliage crops, such as vegetable amaranth (Shukla and Singh, 2000) and *C. album* (Bhargava *et al.*, 2003b). However, the lower estimates for one or both of these parameters observed for the rest of the traits implies that the chances of obtaining substantial gain under selection are likely to be lower for these traits.

It is difficult to determine the amount of the variation that is heritable merely based on the extent of the coefficient of variation values. Knowledge of the heritability of a trait is important because it indicates the amount of advance to be expected through phenotypic selection (Robinson *et al.*, 1949; Burton and DeVane, 1953). Heritability, the proportion of the individual differences in a trait due to genetic

difference, has been extensively utilized as an effective tool to assess the degree to which a trait is transmitted from parent to progeny (Piepho and Möhring, 2007). This important parameter in quantitative genetics also indicates the relative importance of heredity and environment in the expression of these traits. Narrow-sense heritability (designated as h^2) is the ratio of additive genetic variance to the total phenotypic variance and includes only the additive effects of variation (Nishio *et al.*, 2014). In the present investigation, the heritability estimates were high for all the traits in most cuttings individually as well as on a pooled basis, which suggests that all of the variability in traits comes from genetic differences. High heritability values have also been obtained for different foliage cuttings of lamb's quarters (Bhargava *et al.*, 2003a; Basavaraj *et al.*, 2018) and *Amaranthus tricolor* (Shukla *et al.*, 2004).

High heritability alone does not guarantee a large improvement from selection unless sufficient genetic gain attributable to additive gene action is present (Mora and Saavedra, 2012). Genetic advance in a trait is the product of the heritability and selection differential, expressed in units of standard deviation, and has an added advantage over heritability as a guiding factor in a selection program where improvement in particular traits is desired (Xu *et al.*, 2017; Li *et al.*, 2018). The expected genetic advance, expressed as a percentage of the mean, was lowest for leaves per plant, moisture and stem diameter, which indicates the presence of non-additive gene effects; hence, these traits are unlikely to respond favorably to selection. In contrast, foliage yield, carotenoid content and protein content had high values for genetic advance (72.00, 44.17 and 43.78%, respectively). These traits also had high heritability and high coefficients of variability, indicating that the genotypic variance for these characters was due to additive gene effects. Hence, the selection based on the phenotypic performance for these characters would be beneficial for achieving the desired gain.

Conclusion

From the present study, it was concluded that many species of *Chenopodium* could be utilized as vegetables with high protein and carotenoid contents. Significant enhancements in foliage yield and foliage quality traits can be achieved through rigorous selection of plant types based on the component traits.

Acknowledgements

Atul Bhargava is grateful to CSIR for the fellowship and to the Director of CSIR-NBRI for providing the necessary facilities to carry out the present investigation.

Resumen

A. Bhargava, F. Fuentes, S. Shukla, S. Srivastava, S. Dubey, y D. Ohri. 2019. Variabilidad genética en el *Chenopodium* vegetal para rasgos morfológicos y de calidad sobre diferentes esquejes. Cien. Agr. 46(2): 179-186. El presente estudio se realizó para evaluar los parámetros genéticos de diferentes rasgos cuantitativos y cualitativos de 13 líneas de germoplasma de *Chenopodium* spp. sembradas en un diseño de bloques aleatorios con un tamaño de parcela de 2 m², y se registraron datos de rendimiento foliar y 8 rasgos componentes en 4 esquejes sucesivos. El rendimiento foliar/parcela fue variable, oscilando entre 1,07-2,66 t ha⁻¹ con un rendimiento medio de 2,00±0,15. El contenido de proteínas y carotenoides promedió 3.70±0.09% y 13.47±0.56 mg 100 g⁻¹, respectivamente. El rango y la media de los esquejes individuales para la altura de la planta, el tamaño de la hoja, la proteína y el rendimiento foliar aumentaron con esquejes sucesivos hasta el III corte, y el rendimiento disminuyó posteriormente. Se obtuvieron estimaciones de alta heredabilidad para todos los rasgos bajo estudio, tanto para cortes individuales como sobre una base combinada. Se observó una alta heredabilidad junto con una alta ganancia genética en el rendimiento foliar, el contenido de carotenoides y el contenido de proteínas, lo que indica la presencia de efectos genéticos aditivos.

Palabras clave: Avance genético, chenopodium, esquejes, heredabilidad, proteína, rendimiento foliar.

References

- Basavaraj, C.N., Hanchinamani, S.J. Imamsaheb, H.P. Hadimani, and S.H. Ramanagouda. 2018. Genetic variability studies among various morphological and quality traits in bathua (*Chenopodium album* L.). International Journal of Current Microbiology and Applied Biosciences 7:4147–4151
- Bazile, D., S.E. Jacobsen, and A. Verniau. 2016. The global expansion of quinoa: trends and limits. Frontiers in Plant Science 7:622.
- Bhargava, A., and D. Ohri. 2015. Quinoa in the Indian subcontinent. In: 'FAO and CIRAD: State of the Art Report of Quinoa in the World in 2013' (Eds. Bazile et al.). FAO, Rome, Italy. pp:511–523.
- Bhargava, A., S. Shukla, R.S. Katiyar, and D. Ohri. 2003a. Selection parameters for genetic improvement in *Chenopodium* grain in sodic soil. Journal of Applied Horticulture 5:45–48.
- Bhargava, A., S. Shukla, and D. Ohri. 2003b. Genetic variability and heritability of selected traits during different cuttings of vegetable *Chenopodium*. Indian Journal of Genetics and Plant Breeding 63:359–360.
- Bhargava, A., S. Shukla, and D. Ohri. 2003c. Relative selection efficiency for foliage yield and quality characters in vegetable *Chenopodium*

- over different cuttings. *Journal of Applied Horticulture* 5:85–86.
- Bhargava, A., S. Shukla, and D. Ohri. 2006. *Chenopodium quinoa*- an Indian perspective. *Industrial Crops and Products* 23:73–87.
- Bhargava, A., S. Shukla, and D. Ohri. 2007a. Evaluation of foliage yield and leaf quality traits in *Chenopodium* spp. in multiyear trials. *Euphytica* 153:199–213.
- Bhargava, A., S. Shukla, and D. Ohri. 2007b. Genetic variability and interrelationship among various morphological and quality traits in quinoa (*Chenopodium quinoa* Willd.). *Field Crops Research* 101:104–116.
- Bhargava, A., S. Shukla, J. Srivastava, N. Singh, and D. Ohri 2008a. Genetic diversity for mineral accumulation in foliage of *Chenopodium* spp. *Scientia Horticulturae* 118:338–346.
- Bhargava, A., S. Shukla, and D. Ohri. 2008b. Genotype x environment interaction studies in *Chenopodium album* L.: an underutilized crop with promising potential. *Communications in Biometry and Crop Science* 3:3–15.
- Bhargava, A., S. Shukla, and D. Ohri. 2010. Mineral composition in foliage of some cultivated and wild species of *Chenopodium*. *Spanish Journal of Agricultural Research* 8:371–376.
- Bhargava, A. and S. Srivastava. 2013. Quinoa: Botany, Production and Uses. CABI, UK.
- Bhargava, A., F. Fuentes, S. Shukla, S. Srivastava, and D. Ohri. 2019. Genetic association between foliage yield and contributing traits in vegetable chenopods: implications for genetic improvement. *Notulae Botanicae Horti Agrobotanici Cluj-Napoca* 47:24–33.
- Burton, G.W., and E.H. DeVane. 1953. Estimations of heritability in tall fescue (*Festuca arundinacea*) from replicated clonal materials. *Agronomy Journal* 45:478–481.
- Chivenge, P., T. Mabhaudhi, A.T. Modi, and P. Mafongoya. 2015. The potential role of neglected and underutilised crop species as future crops under water scarce conditions in sub-Saharan Africa. *International Journal of Environmental Research and Public Health* 12:5685–5711.
- Facciola, S. 1990. *Cornucopia - A Source Book of Edible Plants*. Kampong Publications, CA.
- Fuentes, F., D. Bazile, A. Bhargava, and E.A. Martinez. 2012. Implications of farmers' seed exchanges for on-farm conservation of quinoa, as revealed by its genetic diversity in Chile. *Journal of Agricultural Sciences (Cambridge)* 150:702–716.
- Fuentes, F., and X. Paredes-Gonzalez. 2015. Nutritional perspectives of quinoa: biological properties and functional applications. In: Bazile et al. (Eds). *FAO and CIRAD: state of the art report of quinoa in the world in 2013*. FAO, Rome, Italy pp:286–299.
- Giusti, L. 1970. El genero *Chenopodium* en Argentina 1: Numeros de cromosomas. *Darwiniana* 16:98–105.
- Jellen, E.N., B.A. Kolano, M.C. Sederberg, A. Bonifacio, and P.J. Maughan. 2011. *Chenopodium*. In: Kole, C. (ed.), *Wild Crop Relatives: Genomic and Breeding Resources, Legume Crops and Forages*. Springer-Verlag, Berlin Heidelberg, Germany, pp:35–61.
- Jensen, A. 1978. Chlorophylls and carotenoids. In: Hellebust, J.A., Craigie, J.S., (Eds.), *Handbook of Physiological Methods: Physiological and Biochemical Methods*, Cambridge University Press, Cambridge, pp:5–70.
- Johnson, H.W., H.F. Robinson, and R.E. Comstock. 1955. Estimates of genetic and environmental variability in soybean. *Agronomy Journal* 47:314–318.
- Kuti, J.O., and H.O. Kuti. 1999. Proximate composition and mineral content of two edible species of *Cnidoscolus* (tree spinach). *Plant Foods for Human Nutrition* 53:275–283.
- Li, H., A. Rasheed, L.T. Hickey, and Z. He. 2018. Fast-forwarding genetic gain. *Trends in Plant Science* 23:184–186.
- Litrico, I., and C. Violle. 2007. Diversity in plant breeding: a new conceptual framework. *Trends in Plant Science* 20:604–613.
- Lowry, O.H., N.J. Rosebrough, A.L. Farr, and R.J. Randal. 1951. Protein measurement with the Folin phenol reagent. *Journal of Biological Chemistry* 193:265–275.
- Magbagbeola, J.A.O., J.A. Adetoso, and O.A. Owolabi. 2010. Neglected and underutilized species (NUS): a panacea for community focused development to poverty alleviation/poverty re-

- duction in Nigeria. *Journal of Economics and International Finance* 2:208–211.
- Mayes, S., F.J. Massawe, P.G. Alderson, J.A. Roberts, S.N. Azam-Ali, and M. Hermann. 2011 The potential of underutilized crops to improve security of food production. *Journal of Experimental Botany* 63:1075–1079.
- Miranda, M., A. Vega-Gálvez, E. Martínez, J. López, M.-J. Rodríguez, K. Henríquez, and F. Fuentes. 2012. Genetic diversity and comparison of physicochemical and nutritional characteristics of six quinoa (*Chenopodium quinoa* willd.) genotypes cultivated in Chile. *Food Science and Technology* 32:835–843.
- Moerman, D. 1998. *Native American Ethnobotany*. Timber Press. Oregon.
- Mora, F., and J. Saavedra 2012. Combining genetic gain and diversity under an individual selection method in a selected provenance of *Eucalyptus cladocalyx*. *Ciencia e Investigación Agraria* 39:177–184.
- Nishio, S., M. Yamada, N. Takada, H. Kato, N. Onoue, Y. Sawamura, and T. Saito. 2014. Environmental variance and broad-sense heritability of nut traits in Japanese chestnut breeding. *HortScience* 49:696–700.
- Padulosi, S., and I. Hoeschle-Zeledon. 2004. Underutilized plant species: what are they? *LEISA* 20:5–6.
- Panse, V.G., and P.V. Sukhatme. 1978. *Statistical methods for Agricultural Workers*. ICAR, New Delhi.
- Partap, T., B.D. Joshi, and N.W. Galwey. 1998. *Chenopods: Chenopodium* spp. promoting the conservation and use of underutilized and neglected crops. Institute of Plant Genetics and Crop Plant Research, Gatersleben, Rome, Italy.
- Piepho, H.P., and J. Möhring. 2007. Computing heritability and selection response from unbalanced plant breeding trials. *Genetics* 177:1881–1888.
- Pistorale, S.M., L.A. Abbott, and A. Andres. 2008. Genetic diversity and broad sense heritability in tall wheatgrass (*Thinopyrum ponticum*). *Ciencia e Investigación Agraria* 35:259–264.
- Prakash, D., P. Nath, and M. Pal. 1993. Composition, variation of nutritional contents in leaves, seed protein, fat and fatty acid profile of *Chenopodium* species. *Journal of the Sciences of Food and Agriculture* 62:203–205.
- Robinson, H.F., R.E. Comstock, and P.H. Harvey. 1949. Estimates of heritability and the degree of dominance in corn. *Agronomy Journal* 41:353–359.
- Shukla, S., V. Pandey, G. Pachauri, B.S. Dixit, R. Banerji, and S.P. Singh, 2003. Nutritional contents of different foliage cuttings of vegetable amaranth. *Plant Foods for Human Nutrition* 58:1–8.
- Shukla, S., and S.P. Singh. 2000. Studies on genetic parameters in vegetable amaranth. *Journal of Genetics and Breeding* 54:133–135.
- Shukla, S., S.P. Singh, A. Bhargava, A. Chatterjee, and S.P. Singh. 2004. Estimates of genetic parameters to determine variability for foliage yield and its different quantitative and qualitative traits in vegetable amaranth (*A. tricolor*). *Journal of Genetics and Breeding* 58:169–176.
- Singh, R.K., and B.D. Chaudhary. 1985. *Biometrical Methods in Quantitative Genetic Analysis*. Kalyani Publishers, New Delhi.
- Vietmeyer, N.D. 1986. Lesser-known plants of agricultural use in agriculture and forestry. *Science* 232:1379–1384.
- Wilson, H.D. 1990. Quinoa and relatives (*Chenopodium* sect. *Chenopodium* subsect. *Cellulata*). *Economic Botany* 44: 92–110.
- Xu, Y., P. Li, C. Zou, Y. Lu, C. Xie, X. Zhang, B.M. Prasanna, and M.S. Olsen. 2017. Enhancing genetic gain in the era of molecular breeding. *Journal of Experimental Botany* 68:2641–2666.
- Zurita-Silva, A., F. Fuentes, P. Zamora, S.E. Jacobsen, and A. R. Schwember. 2014. Breeding quinoa (*Chenopodium quinoa* Willd.): potential and perspectives. *Molecular Breeding* 34:13–30.

