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Trait association studies in globe amaranth (*Gomphrena globosa* L.) genotypes

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Abstract

A study was conducted using 17 Gomphrena genotypes to investigate the relationship of yield traits and their direct and indirect impacts on flower production. Correlation studies revealed that at genotypic level, flower yield per plant recorded significant and positive connotation with number of flowers per plant (0.990) which was accompanied by traits like primary branches per plant (0.848), stem girth (0.835), plant height (0.829), secondary branches (0.812), shelf life (0.742), flowering duration (0.722), inflorescence length (0.718), plant spread in N-S direction (0.685), first flowering (days) (0.671), plant spread in E-W direction (0.667), individual flower weight (0.648), stalk length (0.606) and other traits. Path analysis disclosed that the number of flowers per plant (1.140) had the highest and positive direct impact on flower yield per single plant, followed by the days to first flowering (0.346), individual flower weight (0.217), plant height (0.189), primary branches per plant (0.168), days to 50 percent flowering (0.137), secondary branches (0.127), plant spread (0.006) and inflorescence length (0.002). These traits, especially the number of flowers per plant and primary branches plant, can be chosen as key indicator for selection criteria along with other traits in *Gomphrena* breeding programme.

Key words: Gomphrena (*Gomphrena globosa* L.), correlation, path analysis.

Introduction

Gomphrena globosa L., usually known as Globe amaranth or bachelor's button, is a traditional annual ornamental flower crop belonging to the Amaranthaceae family (Kumar *et al.*, 2023). It is native to Central America (Roriz *et al.*, 2014) and but now thrives well in all tropical and subtropical regions of the world. It is highly favoured in the gardens for its distinctive round-shaped inflorescences, which come in a variety of vibrant colours such as purple, pink, red, lilac, and white. This flower is popular for creating eye-catching flower beds, potted plants, colorful borders, vertical displays, and rockeries, significantly enhancing the aesthetic appeal of gardens. Additionally, gomphrena is widely used in crafting large, attractive and contrasting garlands for religious offerings. Its remarkable ability to retain colour and shape after drying makes it an ideal choice for dry flowers, including buttonholes, wreaths and various floral arrangements (Kumar *et al.*, 2022).

Beyond its ornamental uses, gomphrena's pigments, like betalains and its medicinal properties, have expanded their applications in the food, dye, and pharmaceutical industries. Despite these numerous advantages, only a limited number of cultivars are commercially available, and scientific reports on this crop remain scarce. Gomphrena is an outcrossing flower crop with inconspicuous true flowers within its flower heads (Jiang *et al.*, 2011). Pollination is facilitated by bees and butterflies attracted by floral volatiles. The crop exhibits high heat tolerance and moderate drought resistance, using the C4 pathway for carbon fixation (Herold *et al.*, 1976), which makes it the most chosen crop to fulfill the cultivation thirst with numerous benefits.

Given the limited scientific research and the need for superior genotypes, it is crucial to identify and understand the genetic contributions to yield. This involves distinguishing between genetic and environmental factors affecting crop productivity. The correlation coefficient can determine how closely different traits are related and identify constituent features that contribute to yield improvements. Investigating the correlation of these traits with flower yield is essential for the selection process. An efficient method for dividing direct and indirect causes of association is provided by path coefficient analysis. This plays a crucial role in distinguishing between realistic genetic effects and inflated environmental effects correlations. By determining the direct and indirect impact of different components on yield, analysis becomes invaluable in the selection of high-yielding genotypes.

Keeping sight of the above facts, the present study aimed to explore the relationships and direct and indirect effects among various growth and yield parameters of *Gomphrena globosa* L., with the goal of utilizing this knowledge to enhance the cultivation and quality of this ornamental flower crop.

Materials and methods

The study was conducted in the experimental fields of Floriculture and Landscape Architecture, the College of Horticulture-Bagalkot, University of Horticultural Sciences, Bagalkot, Karnataka. The experiment was conducted during the rabi season, spanning from the month of November 2020 to March-2021. Seventeen different globe amaranth genotypes, namely; AGS:1, AGS:2, AGS:3, AGS:4, AGS:5, AGS:6, AGS:7, AGS:8, AGS:9, AGS:10, AGS:11, AGS:12, AGS:13, AGS:14, AGS:15, AGS:16 and AGS:17 (AGS: Arabhavi Gomphrena Selection) were selected as these genotypes morphologically differ from each other and have been meticulously collected from various regions and maintained by the Floriculture Department at the Bagalkot campus over the past several years. All the genotype flower seeds were sown in the nursery beds in November 2020. The seeds were evenly sown in a well-managed nursery to raise seedlings.

An experimental design of Randomized Block Design [RBD] with three replications was used for the layout. Uniform and vigorous seedlings were then transplanted at row-to-row and the plant-to-plant spacing of 30 and 30 cm correspondingly, with each plot having a size of 1.8 X 1.5 m^2. Observations from the investigation plots were documented on 17 traits including plant height (cm), primary and secondary branches per plant, stem girth (mm), plant spread (cm^2), number of leaves per plant, days to initial flower bud initiation, days to initial flowering, days to bud initiation to flowering, days to fifty percent flowering, flowering duration (days), stalk-length (cm), flower-diameter (cm), inflorescence-length (cm), individual flower weight (g), number of flowers per plant and flower yield per plant (g) from five indiscriminately selected plants from each different genotype, considering several vegetative, flowering and the quality parameters. For the analysis, correlation and path studies were performed using the methods suggested by Al-Jibouri *et al*. (1958) and Dewey and Lu (1959). Al-Jibouri's method involves the calculation of correlation coefficients to measure the strength and direction of linear relationships between traits, whereas Dewey and Lu extended this approach by introducing path analysis, which partitions correlation coefficients into direct and indirect effects, thereby providing a deeper understanding of the causal relationships among variables. Correlation and path analysis were estimated using INDOSTAT 4.1 software. These analyses were focused in identifying the trait association with economic parameters, flower yield per plant for superior quality genotypes and facilitating further improvement of the Gomphrena crop.

Results and discussion

Flower yield, a complex trait, emerges from the intricate interplay between various growth and flowering-related characteristics. Correlation coefficients were assessed between flower yield and other characters under investigation, represented in Table 1. The magnitudes of genotypic correlations exceeded their corresponding phenotypic correlation coefficients for all traits studied, demonstrating a strong inherent association between these traits. This observation aligns with the findings of Singh *et al*. (2019). Results indicated that flower yield was positively associated with the number of flowers per plant at the genotypic and phenotypic level with values of 0.990 and 0.973 respectively, which was accompanied by other characters *viz.*, leaves per plant (0.914 and 0.888), primary branches (0.848 and 0.789), stem-girth (0.835 and 0.736), plant height (0.829 and 0.803), secondary branches (0.812 and 0.782), duration of flowering (0.722 and 0.698), inflorescence length (0.718 and 0.581), plant spread (0.671 and 0.648), days to initial flowering (0.671 and 0.663), stalk-length (0.606 and 0.594), days to fifty percent of flowering (0.591 and 0.548) as well as days to bud initiation to flowering (0.576 and 0.549). These findings closely align with the results, *i.e.,* flower yield per individual plant was significant and positively interrelated strongly with other characteristics as stated by Ashwini *et al*. (2019) in gomphrena, Bharathi *et al.*, 2014 and Vishnupriya *et al.*, 2015 in marigold with the case of number of flowers, Nair and Shiva (2003) with respect to number of leaves, Karuppaiah and Kumar (2010) with number of the branches per plant, Kumar *et al*. (2014) in Gerbera with stem girth character. The results were consistent with those reported by Rai *et al*. (2017) for China aster regarding plant height, plant spread, and the number of flowers, as well as by Panwar *et al*. (2017) for the marigold crop concerning the duration of flowering.

The positive correlation related to days to initial flower bud initiation, days to the flower opening and stalk length were found

Table 1. Genotypic and phenotypic correlation estimates above and below the diagonal, respectively in various gomphrena genotypes

Trait	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	rG
1	1.00	0.77**	0.98**	0.94**	0.72**	0.82**	0.34	0.80**	0.79**	0.70**	0.87**	-0.21	0.84**	0.66**	-0.52**	0.86**	0.83**
2	0.72**	1.00	0.85**	0.78**	0.38*	0.88**	0.43*	0.65**	0.53**	0.64**	0.59**	0.19	0.42*	0.34*	-0.19	0.82**	0.83**
3	0.93**	0.72**	1.00	0.96**	0.74**	0.86**	0.34	0.81**	0.78**	0.75**	0.84**	-0.21	0.84**	0.75**	-0.27	0.83**	0.85**
4	0.93**	0.71**	0.95**	1.00	0.73**	0.87**	0.31	0.80**	0.79**	0.73**	0.83**	-0.19	0.85**	0.77**	-0.47**	0.84**	0.81**
5	0.69**	0.33	0.69**	0.71**	1.00	0.67**	0.03	0.50**	0.61**	0.36*	0.74**	-0.21	0.85**	0.94**	-0.41*	0.70**	0.67**
6	0.81**	0.80**	0.84**	0.86**	0.66**	1.00	0.28	0.64**	0.60**	0.63**	0.76**	0.09	0.66**	0.78**	-0.39*	0.93**	0.91**
7	0.31	0.36*	0.32	0.29	0.04	0.27	1.00	0.64**	0.07	0.75**	0.03	-0.13	0.01	-0.05	-0.01	0.37*	0.38*
8	0.79**	0.60**	0.76**	0.78**	0.47**	0.62**	0.63**	1.00	0.81**	0.98**	0.61**	-0.35*	0.63**	0.50**	-0.31	0.69**	0.67**
9	0.78**	0.48**	0.74**	0.78**	0.59**	0.59**	0.06	0.80**	1.00	0.70**	0.77**	-0.37*	0.81**	0.68**	-0.38*	0.61**	0.58**
10	0.65**	0.53**	0.62**	0.65**	0.31	0.56**	0.66**	0.91**	0.66**	1.00	0.49**	-0.32	0.49**	0.33	-0.41*	0.64**	0.59**
11	0.84**	0.55**	0.79**	0.80**	0.71**	0.74**	0.02	0.58**	0.73**	0.45**	1.00	-0.23	0.80**	0.72**	-0.46**	0.75**	0.72**
12	-0.18	0.15	-0.15	-0.16	-0.24	0.07	-0.13	-0.31	-0.32	-0.25	-0.21	1.00	-0.48**	-0.31	-0.24	0.21	0.20
13	0.83**	0.39*	0.81**	0.84**	0.83**	0.66**	0.01	0.62**	0.79**	0.45**	0.79**	-0.43*	1.00	0.93**	-0.41*	0.63**	0.61**
14	0.57**	0.32	0.57**	0.65**	0.82**	0.65**	-0.08	0.40*	0.57**	0.33	0.64**	-0.29	0.79**	1.00	-0.227	0.72**	0.72**
15	-0.36*	-0.19	-0.29	-0.38*	-0.31	-0.30	0.02	-0.22	-0.30	-0.16	-0.36*	-0.18	-0.30	-0.12	1.00	-0.422*	-0.291
16	0.83**	0.74**	0.80**	0.82**	0.67**	0.91**	0.37*	0.68**	0.58**	0.56**	0.73**	0.17	0.62**	0.58**	-0.39*	1.00	0.99**
rP	0.80**	0.74**	0.80**	0.78**	0.65**	0.65**	0.39*	0.66**	0.55**	0.55**	0.70**	0.15	0.59**	0.58**	-0.17	0.97**	1.00

*Significant at P=0.05 and **Significant at P=0.01

Traits: 1. Plant height, 2. Stem girth, 3. Primary branches per plant, 4. Secondary branches per plant, 5. Plant spread, 6. Number of leaves per plant, 7. Days to first flower bud initiation, 8. Days to first flowering, 9. Bud initiation to flowering(days), 10. Days to 50 per cent flowering, 11. Duration of flowering, 12. Flower diameter, 13. Stalk length, 14. Inflorescence length,15. Individual flower weight, 16. Number of flowers per plant.

to be similar to the reporting of Kumar *et al.*, 2015 in gerbera. In our findings, it is also noted that flower diameter had a non-significant positive correlation, as also reported by Sargent *et al.*, 2007.

A negative correlation was noticed with the unitary weight of the flower, which are similar to the findings of Gresta *et al.*, 2008 in the saffron. In comparison to the phenotypic correlation coefficients, the genotypic correlation coefficients typically showed greater values. The combination of genetics and environment may be responsible for this discrepancy, signifying a robust association between the different growth and flowering traits under examination (Sharma *et al.*, 2023). These Correlation coefficients of gomphrena are important and offer invaluable insights into the intricate relationships between various growth factors, environmental conditions and yield outcomes. Furthermore, these correlations inform the selection of desirable traits for gomphrena breeding programs, driving the development of new cultivars with improved yield, quality and adaptability to changing environmental conditions. This comprehensive understanding allows for the optimization of agricultural practices and the creation of robust globe amaranth varieties that meet the evolving demands of both growers and consumers.

Further, to address the cause-and-effect associations between flower yield per single plant and the vegetative and flowering traits, which is limited through correlation coefficients, employed the path coefficient analysis, a powerful tool that allows us to disentangle the direct and the indirect possessions of each specific yield component. Path-coefficient analysis, both at genotypic and phenotypic levels, was carried out by considering the flower yield per plant as the dependent trait (Table 2 and 3). Flower yield per plant, the dependent variable, has been directly and positively affected at genotypic level by number of flowers per

Table 2. Genotypic path analysis of Gomphrena genotypes

Trait	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	rG
1	**0.19**	-0.14	0.16	0.12	0.04	-0.05	-0.14	0.28	-0.31	0.10	-0.06	0.03	-0.20	0.01	-0.11	0.98	0.83
2	0.14	**-0.18**	0.14	0.10	0.02	-0.05	-0.17	0.22	-0.21	0.09	-0.04	-0.03	-0.10	0.01	-0.04	0.93	0.83
3	0.18	-0.16	**0.17**	0.12	0.04	-0.05	-0.14	0.28	-0.31	0.10	-0.05	0.03	-0.20	0.01	-0.06	0.95	0.85
4	0.18	-0.14	0.16	**0.13**	0.04	-0.05	-0.12	0.28	-0.31	0.10	-0.05	0.03	-0.20	0.01	-0.10	0.95	0.81
5	0.13	-0.07	0.12	0.09	**0.06**	-0.04	-0.01	0.17	-0.24	0.05	-0.05	0.03	-0.20	0.02	-0.09	0.79	0.67
6	0.15	-0.16	0.14	0.11	0.04	**-0.06**	-0.11	0.22	-0.24	0.09	-0.05	-0.01	-0.16	0.01	-0.08	1.06	0.91
7	0.06	-0.08	0.06	0.04	0.01	-0.02	**-0.40**	0.22	-0.03	0.10	-0.02	0.02	-0.02	0.01	-0.01	0.42	0.38
8	0.15	-0.12	0.13	0.10	0.03	-0.04	-0.26	**0.35**	-0.32	0.13	-0.04	0.05	-0.15	0.01	-0.07	0.79	0.67
9	0.15	-0.10	0.13	0.10	0.04	-0.04	-0.03	0.28	**-0.39**	0.10	-0.05	0.06	-0.19	0.01	-0.08	0.69	0.58
10	0.13	-0.12	0.13	0.09	0.02	-0.04	-0.30	0.34	-0.28	**0.14**	-0.03	0.05	-0.12	0.01	-0.09	0.73	0.59
11	0.16	-0.11	0.14	0.10	0.05	-0.05	-0.01	0.21	-0.30	0.07	**-0.07**	0.04	-0.19	0.01	-0.10	0.85	0.72
12	-0.04	-0.03	-0.04	-0.02	-0.01	-0.01	0.05	-0.12	0.14	-0.04	0.01	**-0.02**	0.11	-0.01	-0.05	0.24	0.20
13	0.16	-0.08	0.14	0.11	0.05	-0.04	-0.03	0.22	-0.32	0.07	-0.05	0.07	**-0.24**	0.02	-0.09	0.72	0.61
14	0.12	-0.06	0.12	0.10	0.06	-0.05	0.02	0.17	-0.27	0.04	-0.05	0.05	-0.22	**0.02**	-0.05	0.82	0.72
15	-0.10	0.03	-0.05	-0.06	-0.03	0.02	0.02	-0.11	0.15	-0.06	0.03	0.04	0.10	0.01	**0.22**	-0.48	-0.29
16	0.16	-0.15	0.14	0.11	0.04	-0.06	-0.15	0.24	-0.24	0.09	-0.05	-0.03	-0.15	0.01	-0.09	**1.14**	0.99

Residual effect= -0.00062. rG = Genotypic correlation coefficient of flower yield per plant. Bold diagonal figures indicate direct effect. For trait details see Table 1.

Table 2. Phenotypic path analysis of Gomphrena genotypes

Trait	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	rp
1	**0.11**	-0.04	-0.03	0.02	-0.02	0.08	-0.08	0.01	-0.01	-0.08	-0.02	-0.04	0.01	-0.01	-0.09	0.80	0.80
2	0.08	**-0.05**	-0.02	0.01	-0.01	0.08	-0.09	0.01	-0.01	-0.07	-0.01	0.03	0.01	-0.01	-0.05	0.79	0.74
3	0.10	-0.03	**-0.03**	0.02	-0.02	0.08	-0.08	0.01	-0.01	-0.08	-0.02	-0.04	0.01	-0.01	-0.07	0.85	0.79
4	0.10	-0.03	-0.03	**0.02**	-0.03	0.08	-0.08	0.01	-0.01	-0.08	-0.02	-0.04	0.01	-0.02	-0.10	0.87	0.78
5	0.07	-0.02	-0.02	0.01	**-0.01**	0.07	-0.01	0.01	-0.01	-0.04	-0.02	-0.06	0.01	-0.02	-0.08	0.72	0.65
6	0.09	-0.04	-0.03	0.02	-0.02	**0.01**	-0.07	0.01	-0.01	-0.07	-0.02	0.02	0.01	-0.02	-0.08	0.96	0.89
7	0.03	-0.02	-0.01	0.01	0.01	0.03	**-0.03**	0.01	-0.01	-0.08	0.01	-0.03	0.01	0.02	0.01	0.40	0.39
8	0.08	-0.03	-0.03	0.02	-0.02	0.01	-0.02	**0.01**	-0.01	-0.01	-0.01	-0.07	0.01	-0.01	-0.06	0.72	0.66
9	0.08	-0.02	-0.03	0.01	-0.02	0.01	-0.01	0.01	**-0.01**	-0.08	-0.02	-0.08	0.01	-0.01	-0.08	0.62	0.55
10	0.07	-0.03	-0.02	0.01	-0.01	0.05	-0.02	0.01	-0.01	**-0.01**	-0.01	-0.06	0.01	-0.01	-0.04	0.60	0.55
11	0.09	-0.03	-0.03	0.02	-0.03	0.07	0.01	0.01	-0.01	-0.06	**-0.03**	-0.05	0.01	-0.02	-0.09	0.78	0.70
12	-0.02	-0.01	0.04	-0.03	0.01	0.01	0.03	-0.04	0.05	0.03	0.01	**0.02**	-0.01	0.01	-0.05	0.18	0.15
13	0.09	-0.02	-0.03	0.02	-0.03	0.06	0.01	0.01	-0.01	-0.06	-0.02	-0.10	**0.02**	-0.02	-0.08	0.65	0.59
14	0.06	-0.01	-0.02	0.01	-0.03	0.06	0.02	0.05	-0.01	-0.04	-0.02	-0.07	0.01	**-0.03**	-0.03	0.61	0.58
15	-0.04	0.010	0.01	-0.01	0.01	-0.03	-0.01	-0.03	0.04	0.02	0.01	-0.04	-0.05	0.03	**0.26**	-0.41	-0.17
16	0.09	-0.04	-0.03	0.02	-0.02	0.09	-0.01	0.09	-0.01	-0.07	-0.02	0.04	0.01	-0.0	-0.10	**1.06**	0.97

Residual effect= 0.008 Bold diagonal figures indicate direct effect rP = Phenotypic correlation coefficient of flower yield per plant. For trait details see Table 1 plant (1.140) accompanied by the days to first flowering (0.346), individual flower weight (0.217), plant height (0.189), primary branches per plant (0.168), days to fifty percent flowering (0.137), secondary branches per plant (0.127), plant spread (0.006) and inflorescence length (0.002). Similarly, Bharathi *et al*. (2014), Karuppaiah and Kumar (2010), and Vishnupriya *et al*. (2015) in marigold conveyed that number of flowers per plant had a positive direct impact on the flower yield of a plant. While, the flower yield per plant at genotypic level is influenced negatively and directly by several other independent variables like days to initial flower bud initiation (-0.404), bud initiation to flowering (-0.394), stalk length (-0.240), stem girth (-0.184), duration of flowering (-0.066), number of leaves per plant (-0.062), and flower-diameter (-0.016). All have negative coefficients, indicating that an increase in these variables leads to a decrease in the flower yield per plant.

At phenotypic phase, the trait, flower yield per plant had represented a direct and positive consequence on number of flowers per plant (1.064), individual flower weight (0.263), plant height (0.108), flower diameter (0.023), secondary branches per plant (0.020), stalk length (0.016), days to first flowering (0.013), number of leaves per plant (0.009). The findings of Panwar *et al.*, 2017 are in accordance with the results as reported in marigold with respect to direct effect of flower diameter on flower yield. Flower yield per plant exhibited negative direct impact with stem girth (-0.048), primary branches per plant (-0.035), duration of flowering (-0.027), inflorescence length (-0.027), days to initial flower bud initiation (-0.026), days to bud initiation to flowering (-0.015), days to fifty percent flowering (-0.013) and plant spread (-0.004) indicating negative influence on flower yield per plant and may influenced by the external environmental factors which are familiar with the reports of Gresta *et al*. (2009) in saffron. A very low residual effect of the genotypic and the phenotypic path analysis (-0.0006 and 0.0018, respectively) signifies that the traits considered for path analysis were appropriate. Thus, the path analysis examination in gomphrena indicates that the number of flowers per plant, individual flower weight, plant height and number of secondary branches per plant are the characteristics that are crucial for which the selections can be taken up.

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