Effect of Plant Density and Variety on Allometry of Inflorescence Architecture in *Gypsophila paniculata* L.

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The effect of plant density and variety on allometry in *Gypsophila paniculata* L. was studied. Increasing plant density significantly reduced fresh weight, total branch length (the sum of the lengths of all primary branches), number of dichasia, number of florets per dichasium, and total number of florets in cut flowers in ‘New Face’. The relationships between fresh weight and the total branch length, number of dichasia, and total number of florets were negatively allometric, isometric, and positively allometric, respectively. There were allometric relationships between fresh weight and the number of dichasia, number of florets per dichasium, and total number of florets on each branch order. The allometric exponents of regression relating the number of dichasia and the total number of florets to fresh weight increased from lower- to higher-order branches. On the other hand, the allometric exponents of regression relating the number of florets per dichasium to fresh weight were similar in almost all orders. Significant differences were found in fresh weight and parameters of inflorescence architecture among varieties grown under identical plant density. Allometric exponents relating the total branch length and number of dichasia to fresh weight, varied, and those relating the total number of florets to fresh weight were stable among varieties grown under identical plant density.

Key Words: allometric exponent, cut flower, fresh weight, *Gypsophila paniculata*, inflorescence architecture.

Introduction

*Gypsophila paniculata* L., grown as cut flowers, is used as a “filler” in flower arrangements. One crucial determinant of filler flower quality is having clusters of multiple florets. This characteristic is decided by inflorescence architecture such as the total number of florets, number of branches, and branch length, however, understanding inflorescence architecture is difficult because the numbers of florets and branches per cut flower depend on environmental conditions and varieties (Doi et al., 1989; Hayashi et al., 1992; Hicklenton, 1986; Hicklenton et al., 1993; Shlomo et al., 1985). Moreover, particular inflorescence architectures have complex relationships with each other. Identifying the relationship between particular inflorescence architectures is important in evaluating cut flower quality.

Allometry is commonly used to measure the relative growth of one part of an organism in comparison with the whole or with other parts of the organism (Niklas, 1994). Allometric relationships have been found in a broad variety of plant species. Working with chrysanthemums, Langton et al. (1999) reported clear allometric relationships between the weight of the capitula and total plant weight. Mandak and Pysek (1999) reported that in *Atriplex sagittata*, total weight was allometrically related to the diameter of the shoot base, stem height, and number of branches. Allometric relationships are also usable as a breeding objective, for example, the ratio of flower weight to total plant weight. This ratio does not increase in many cases, even if plants are selected based on flower weight or total plant weight. A superior individual plant can be selected based on this ratio. Knowledge of allometry in horticultural plants is important for estimating relationships between characteristics and breeding objectives. Allometric analysis may function as a tool for evaluating cut flower quality in filler flowers.

The objective of this paper is to evaluate the effects of plant density and variety on inflorescence architecture and fresh weight, and to explore allometric relationships between particular inflorescence architectures.
Materials and Methods

Rooted cuttings of *Gypsophila paniculata* L. ‘New Face’, ‘Bristol Fairy’, and ‘Perfecta’ were obtained from a commercial nursery. ‘New Face’ was transplanted to containers (90 cm × 150 cm × 30 cm) filled with bark medium on 28 April 1994 at densities of 4.4, 8.9, 17.8, and 35.6 plants/m². ‘Bristol Fairy’ and ‘Perfecta’ were transplanted at a density of 17.8 plants/m². The interrow spacing at each density site (4.4, 8.9, 17.8, and 35.6 plants/m²) were 50, 25, 25 and 12.5 cm between each plant, respectively. The intrarow spacing at each density site were 45, 45, 22.5, and 22.5 cm between each plant, respectively. The containers were placed in an unheated plastic house during natural day-length. Each plant was pinched to bear three lateral shoots that were harvested from plants when at least 80% of the florets in an inflorescence had opened.

In *G. paniculata*, the cut flower is an aggregate of dichasias and each dichasium is formed of florets (Hayashi et al., 1992) (Fig. 1). In a dichasium, florets are initiated at the tip of the primary floral axis, and two axillary buds are arranged decussately in the lower part of the primary floral axis. Following terminal floret initiation, the two axillary buds develop into a secondary floral axis. In the secondary axis, a floret and two axillary buds are initiated again. This developmental pattern is repeated. Flowering starts from the floret at the apical tip of a shoot and progresses towards the base of the shoot. In a dichasium, flowering starts from the floret at the primary floral axis and progresses towards the higher order floral axis. In this study, an inflorescence was regarded as an aggregation of many dichasias. Total fresh weight was measured for 7 or 10 cut flowers from each site. The total branch length, number of dichasias, number of florets per dichasium, and total number of florets were also measured in each cut flower (Fig. 1). Aborted florets were not counted here. The total branch length corresponded to the sum of the lengths of all primary branches. Moreover, cut flowers were divided into a main stem and four branches (primary, secondary, third, and fourth) in ‘New Face’. Parameters of inflorescence architecture were measured on each branch order.

Allometry is the relationship between the size (Y) of a part of an organism and the size (X) of other parts or the whole body. The allometric equation is generally stated as $Y = bX^k$. Applying the logarithm function to both sides of the equation, $\log Y = \log b + k \log X$ is obtained. The logarithmic equation is a straight line with gradient $k$ and intercept $\log b$ on the log-log graph. Constant $k$ is an allometric exponent and represents the relationship between $Y$ and $X$, that is, when $k > 1$, the growth of $Y$ is superior to $X$ (positively allometric); $k < 1$, the growth of $Y$ is inferior to $X$ (negatively allometric); $k = 1$, $Y$ and $X$ do not vary in proportion (isometric).

Results and Discussion

Plant density significantly affected the fresh weight, total branch length, number of dichasias, number of florets per dichasium, and total number of florets in ‘New Face’ (Fig. 2). These values increased from high to low densities. The fresh weight, total branch length, number of dichasias, number of florets per dichasium, and total number of florets differed among the three varieties.

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**Fig. 1.** Diagram showing parameters of inflorescence architecture in *Gypsophila paniculata* L.
grown under identical plant density (Table 1). The total branch length, total number of florets per dichasium, and total number of florets in ‘Perfecta’ were fewer than in ‘New Face’ and ‘Bristol Fairy’. Fresh weight in ‘Perfecta’ was highest among the three varieties. Our results confirm other studies that indicated that parameters of inflorescence architecture or fresh weight depend on environmental conditions (i.e., temperature, photosynthetic photon flux, supplemental lighting), varieties, and application of plant growth substances.

**Table 1.** Fresh weight and parameters of inflorescence architecture per cut flower of three varieties in *Gypsophila paniculata* L.

| Variety   | Fresh weight (g) | Total branch length (cm) | Number of dichasia | Number of florets per dichasium | Total number of florets |
|-----------|------------------|--------------------------|--------------------|-------------------------------|-------------------------|
| ‘New Face’ | 48 b             | 360 a                    | 228 b              | 6.9 a                         | 1619 a                  |
| ‘Bristol Fairy’ | 60 b          | 420 a                    | 281 ab             | 6.1 a                         | 1696 a                  |
| ‘Perfecta’ | 107 a            | 182 b                    | 357 a              | 1.9 b                         | 677 b                   |

* Plant density was 17.8 plants/m².

* Values followed by the same letter within a column were not significantly different at $P < 0.05$ by Scheffe’s test.
Figure 3 plots parameters of architecture against fresh weight grown under four densities in 'New Face'. There were allometric relationships between fresh weight and the total branch length, number of dichasia, and total number of florets in the complete data set. Regressions relating the total branch length, number of dichasia, and total number of florets to fresh weight was calculated as $Y = 21.145 X^{0.748}$ ($R^2 = 0.928, P < 0.01$); $Y = 3.866 X^{1.068}$ ($R^2 = 0.941, P < 0.01$); and $Y = 13.640 X^{1.237}$ ($R^2 = 0.942, P < 0.01$), respectively. Regression relating the number of florets per dichasium to fresh weight was not significant. In this study, allometric relationships were found between fresh weight and parameters of inflorescence architecture in *G. paniculata* 'New Face' grown under four densities. The relationship between fresh weight and total number of florets was positively allometric ($k = 1.237$) (Fig. 3). Hicklenton et al. (1993) reported that temperature and photosynthetic photon flux affected the total number of florets per plant and fresh weight of inflorescence in 'Bristol Fairy' and 'Bridal Veil'. From those data, regression relating the total number of florets to fresh weight in 'Bristol Fairy' and 'Bridal Veil' was calculated as $Y = 23.881 X^{1.155}$ ($R^2 = 0.995, P < 0.01$) and $Y = 28.596 X^{1.162}$ ($R^2 = 0.992, P < 0.01$), respectively (Y: total number of florets; X: fresh weight).
weight of shoot). These allometric exponents resembled regression relating the total number of florets to fresh weight in this study.

Relationships between parameters of inflorescence architecture and fresh weight for the main stem and fourth branches in ‘New Face’ grown under four densities are shown in Figure 4. There were allometric relationships between fresh weight and the number of dichasia on primary, secondary, and third branches. In these relationships, the allometric exponents of higher-order branches were higher than those of lower-order branches. The number of dichasia on the main stem was constant regardless of fresh weight. There were no allometric relationships between fresh weight and parameters of inflorescence architecture on the fourth branch. There were allometric relationships between fresh weight and the number of florets per dichasium on each branch order except for the fourth branch. These regressions became almost parallel on both logarithm scales. The intercept (b) of the regressions decreased from lower to higher order branches. In addition, there were allometric relationships between fresh weight and the total number of florets on each branch order except for the fourth branch. The allometric exponent increased from lower- to higher-order branches, therefore, it was estimated that the total number of florets increased from high to low densities mainly because of the remarkable increase in the number of dichasia on higher-order branches and an equal increase of the number of florets per dichasium on each branch. Each branch on the lower node position had fewer florets in plants grown under high density, and the length of primary branches decreased from low to high densities (data not shown). These data showed that parameters of inflorescence architecture changed according to cut flower size in ‘New Face’.

VARIetal differences between regressions relating particular parameters of inflorescence architecture to fresh weight in allometric analysis are shown in Figure 5. The allometric exponents of regressions relating the total number of florets to fresh weight hardly varied among varieties (k = 1.060–1.190). In contrast, the allometric exponents of regressions relating the total branch length and number of dichasia to fresh weight varied among varieties. Regression of the number of florets per dichasium to fresh weight for particular plant varieties was not significant. Regression relating the total number of florets to fresh weight is represented in a linear function in Figure 6. The linear functions of ‘New Face’, ‘Bristol Fairy’, and ‘Perfecta’ were Y = 33.511 X + 8.005 (R² = 0.742, P < 0.05); Y = 30.061 X – 98.839 (R² = 0.775, P < 0.05); and Y = 6.972 X – 69.285 (R² = 0.800, P < 0.01), respectively. The linear function of ‘Perfecta’ was obviously different from that of the other two varieties. It was not clear that the ratio of the total number of florets to flower weight hardly varied among these varieties, until the allometric relationships between them were investigated.

The characteristics of cut flowers were different among these varieties. ‘New Face’ has a compact plant form and bears white double florets with a diameter of about 5 mm. ‘Bristol Fairy’ bears florets similar in size and form to ‘New Face’ with long stems and branches. ‘Perfecta’ bears white double florets of more than 10 mm in diameter. The stem length in ‘Perfecta’ was the greatest among these varieties (Fudano et al., 2002). The
allometric exponents of regression of the total number of florets to fresh weight was stable, despite differences in the parameters of inflorescence architecture among varieties, therefore, it is suggested that the relationship between fresh weight and the total number of florets is common, essentially in *G. paniculata* L. Contrary to our results, the allometric exponents of the weight of the capitula to total plant weight differed among varieties in chrysanthemums (Langton et al., 1999). Further research is needed to confirm whether allometric exponents relating the total number of florets to fresh weight are stable among varieties.

The intercept (b) of the regressions of the total number of florets to fresh weight differed among varieties. ‘New Face’ and ‘Bristol Fairy’ are small-flowered varieties, and these intercepts of the regressions of the total number of florets to fresh weight are 26.4 and 17.3, respectively. On the other hand, ‘Perfecta’ is a large-flowered variety whose intercept is 2.5. The intercept values tend to correspond to flower size, hence, variety characteristics in flower size may be denoted by the intercept of regressions relating the total number of florets to fresh weight.

The allometric equation is generally stated as $Y = bX^k$. There were allometric relationships between fresh weight and parameters of inflorescence architecture in *G. paniculata* L. The allometric exponents (k) of regression relating the number of dichasia and the total number of florets to fresh weight differed among branch orders. The results show that parameters of inflorescence architecture change according to the cut flower size. Allometric exponents relating the total number of florets (Y) to fresh weight (X) are stable among varieties grown under identical plant density. Variety characteristics in flower size will possibly be denoted by the intercept of regressions of the total number of florets to fresh weight, therefore, allometric analysis may be used to describe the parameters of inflorescence architecture of a cut flower in *G. paniculata* L.

**Fig. 6.** Variety difference of the relationship between fresh weight and total number of florets of *Gypsophila paniculata* L. cut flower. The solid line is the least squares regression line. ** and *: Significant at 1% and 5% levels by F test, respectively. ○: ‘New Face’, ●: ‘Bristol Fairy’, □: ‘Perfecta’.

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