

MORPHOGENESIS AND DEVELOPMENTAL BIOLOGY OF AFRICAN VIOLET (*SAINTPAULIA IONANTHA* H. WENDL.)

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Abstract: African violet (*Saintpaulia ionantha* H. Wendl.) has been domesticated, bred and commercialized. It is the most famous and popular of the *Saintpaulia* species, its ornamental value arising from its attractive leaves and flowers. African violet plants are easy to propagate by adventitious organ regeneration and are very sensitive to environmental factors including light, temperature, humidity, CO₂ concentration and photoperiod. This review offers a short synthesis on advances made in conventional vegetative propagation by adventitious organ regeneration, select early historical *in vitro* developmental perspectives, and vegetative and reproductive development of African violet.

Keywords: development; Gesneriaceae; thin cell layers; vegetative propagation.

Introduction

African violet (*Saintpaulia ionantha* H. Wendl.; Gesneriaceae) has attractive leaves and flowers (Fig. 1) that are typical of many members of the Gesneriaceae. African violet is mainly used for ornamental purposes, thus aspects related to flower color, leaf patterning, or yield are of interest to horticulturalists, plant breeders, molecular biologists, physiologists, biotechnologists, and for the floriculture industry. Thus, the improvement of flower- and leaf-related traits via vegetative propagation, the creation of somaclonal variation, and mutation breeding are fundamental aspects of African violet research.

Plant morphogenesis is regulated by complex genetic networks in a synchronized manner, and these serve as determining factors for numerous crop traits. Many constituents of these networks have been extensively studied in the model plant, *Arabidopsis thaliana* L. [VANHAEREN & al. 2016]. Multicellular plants have a unique group of cells that form new organs and replenish the daily loss of cells, or regenerate organs after injury, the pluripotent stem cells [AICHINGER & al. 2012]. Stem cells are located in stem cell niches that provide

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intercellular signals for differentiation such as hormonal control [ZHAO & al. 2010], or transcription factors [STAHL & SIMON, 2010; SABLÓWSKI, 2011]. This review provides several details about traits related to development that could make this ornamental plant a possible model plant for the study of morphogenesis, differentiation and organ formation. It also addresses the environmental factors regulating vegetative growth and flowering, inflorescence development, specific conditions for propagation of African violet and biotechnological methods to improve flowering.



Fig. 1. A flowering African violet (*Saintpaulia ionantha* H. Wendl) (Gesneriaceae) plant. Initially redrawn from EASTWOOD & al. 1998 (p. 50), then modified.

Conventional vegetative propagation: possible model plant for adventitious organ regeneration (historical perspective)

FIGDOR (1907) may have been the first official report on adventitious regeneration in the Gesneriaceae, including African violet adventitious regeneration. FAIRBURN (1936) studied the propagation of African violet and other vegetatively propagated plants using leaf cuttings, noting how the inclusion of petioles was essential to induce roots. NAYLOR & JOHNSON (1937) described how portions of the leaf blade or petiole of African violet could regenerate one or more plants within 6-15 weeks if placed on wet sand or in water in Petri dishes when placed in a moist chamber. Even *ex vitro*, NAYLOR & JOHNSON (1937) noted the development of callus from the cut surface, with root initials forming within as little as 10 days, emerging from, but not derived from, the callus, i.e., originating from cells within the original explant. Their histological evidence showed that roots formed from thin-walled cells found underneath the leaf epidermis, while shoots formed from exogenous cells of the epidermal layer, i.e., shoots originated from epidermal cells.

Concept of thin cell layer and morphogenesis

Basic findings within earlier attempts made by FIGDOR (1907), FAIRBURN (1936) and NAYLOR & JOHNSON (1937) would later turn out to be an important reason for the success of thin cell layers (TCLs) [TEIXEIRA DA SILVA & al. 2007; TEIXEIRA DA SILVA & DOBRÁNSZKI, 2013, 2014; TEIXEIRA DA SILVA & al. 2015], especially longitudinal TCLs, in African violet tissue culture, making African violet an important ornamental plant model for developmental studies, like tobacco, and making it a possible viable form of *in vitro* regeneration for other *Saintpaulia* species [TEIXEIRA DA SILVA & al. 2015]. To date, only

two studies employed TCLs, but even so, the term TCL was not used for the earlier study. MURCH & al. (2003) used 0.25 mm thick petiole sections (i.e., transverse TCLs or tTCLs) to regenerate somatic embryos while KHOSARI-NASAB & al. (2014) induced callus and shoots from petiole and pedicel tTCLs. The ability to regenerate a large number of plantlets from a limited amount of tissue (in terms of surface area and volume) underlies the basic success of the TCL [TEIXEIRA DA SILVA & DOBRÁNSZKI, 2014], and thus the success of the tissue culture of African violet. The origin of knowledge about this development came from early studies on vegetative propagation in the 1930's. Later, BROERTJES (1968), ENGELS & al. (1980), GEIER (1983), BROERTJES & VAN HARTEN (1985), Ohki (1994) and HOSOKAWA & al. (1998) confirmed similar histological evidence showing the involvement of epidermal cells (Fig. 2) in the formation of adventitious shoots from the petioles of African violet, noting, using chimeric tissue to base their assumption, the single cell origin of shoots, and thus annulling the claim by NORRIS & al. (1983) that shoots are derived from multiple cells. FINER & SMITH (1983) noticed that plastids that were in an arrested state of development in the epidermis underwent changes after placing leaf cuttings on kinetin-supplemented medium. REDWAY (1991) showed the epidermal origin of shoot primordia, after callus formed, but also showed the formation of shoot primordia from palisade tissue, which lies about 10 cell layers below the epidermal surface. This single cell origin of shoots would allow solid (i.e., non-chimeric) mutants to be produced, forming an important basis for mutation breeding studies. In *Saintpaulia*, some pinwheel flower color cultivars are considered to be periclinal chimeras, with the petal margin arising from the L1 layer but the center of the petal from the L1+L2 layers. If shoot regeneration occurs from epidermal layers, then the flower color phenotype is identical to that of the flower margin of the mother plant. LINEBERGER & DRUCKENBROD (1985), ANDO & al. (1986) and PEARY & al. (1988) discuss shoot regeneration from the epidermal layer using pinwheel-flowered periclinal cultivars in more detail. LINEBERGER & DRUCKENBROD (1985) found that whereas leaves, petioles, peduncles, sepals and inflorescences formed plantlets within 3-5 months, it took 8-10 months from subepidermal tissues, suggesting that the organogenic outcome reported in that study, and possibly in all other African violet studies, depends on the timing of sampling, which is also a function of the type of explant used [TEIXEIRA DA SILVA & DOBRÁNSZKI, 2013]. In essence, regeneration from TCLs may be faster than from regular explants since a greater area and volume of cells is exposed to the exogenously applied plant growth regulators in the *in vitro* medium.

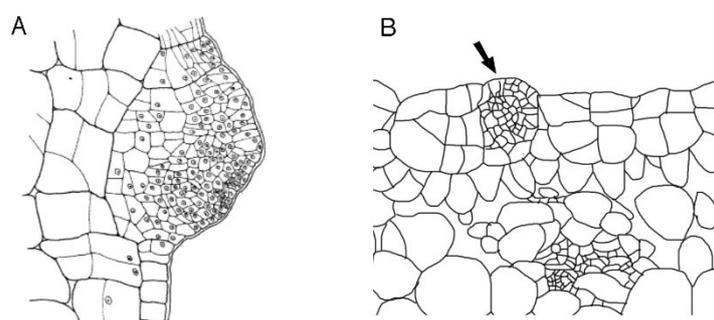


Fig. 2. Shoot development from epidermal tissue, as suggested by histological analyses by GEIER (1983), LO & al. (1997), and NAYLOR & JOHNSON (1937).
Arrow indicates a meristematic center.

***In vitro* morphogenesis and variability, sports and variegation**

ANDO & al. (1986) cultured 19 edged-type cultivars with a white corolla and a pigmented outer edge, and 9 Geneva edged-type cultivars with a pigmented corolla and a white outer edge, either as leaf cuttings, or in tissue culture. They found that single-colour cultivars did not form sports whereas single-colour sports, except for two cultivars, were produced in the remaining (edged-type and Geneva edged-type) cultivars at an average of 22%, but with a wide range of frequencies (0.9% to 68.8%), as a result of mutations. In contrast, the sports from edged-type cultivars had single-coloured corollas, and those from Geneva edged-type cultivars had white or extremely pale corollas, except for a single cultivar. Whereas the edged form ('Ms. Pretty') could produce single colour sports through tissue culture (i.e., reversion was possible), single colour sports of the same cultivar could never produce an edged form. PEARY & al. (1988) found that the variegated pattern of a foliar variegated cultivar ('Tommie Lou') was not caused by periclinal chimeras because the pattern of leaf variegation did not change in potted plants derived from the tissue culture of leaf and petal sections, or from subepidermal tissue. In contrast, tissue cultured plants of a variegated flower cultivar ('Candy Lou') segregated into the chimeral components, i.e., the chimera could not be stably propagated by tissue culture. Curiously, DÜMMER (1912) observed the phenomenon of peloria (i.e., reversion of asymmetric flowers into symmetric flowers) in *S. ionantha*.

Morphogenetic efficiency of explants: effects of age, season, and position

SCOTT & MARSTON (1967) noted that 24 °C and misting were suitable for the development of *S. ionantha* plantlets from leaf cuttings. According to HENTIG (1976), reflecting studies conducted in the early 1970's by this author, and using 'Rhapsodie in Blau' Typ 32 as the experimental material, there is a relationship between the length of the petiole of leaf cuttings and adventitious shoot formation. HENTIG (1976) formulated three important claims: 1) tissue from the fifth to tenth month of growth are most receptive; 2) leaves of the middle leaf zone and youngest leaves from the upper zone regenerate earlier (by 4-5 days) than older leaves (i.e., in the lower zone), forming within 56 days; 3) shorter petioles (1-3 cm) formed more adventitious shoots (and faster) than longer petioles (4-6 cm). In HENTIG's study, there were significant differences in the regeneration potential of young, middle-aged and old leaves before 56 days, but after 56 days, leaves from all three age categories were able to form adventitious shoots in 100% of explants. Even when leaves of all three age categories with petioles of different lengths were used, no less than 60% of all leaves were responsive, fortifying the notion that this is an ornamental plant that can be easily propagated vegetatively. Depending on the age of the leaf and on the length of the petiole, anything from 1 to 4 shoots could be produced per leaf.

Vegetative and reproductive development: role of environmental factors

JOHANSSON (1978) described members of the *Saintpaulia* genus as typically being shade plants while POST (1942) and STROMME (1985) described African violet as being day-neutral with respect to flower initiation and development. Inflorescences arise from leaf axils. During plug production, daily integrated photosynthetic photon flux (PPF_{DI}) reaching African violet plants in summer range from 10-15 mol/m²/day but are as low as < 2 mol/m²/day in winter. However, temperature and PPF_{DI} can influence the vegetative growth of African violet. For example, HANCHEY (1955) noted that by increasing PPF_{DI} from 0.31 to 1.9 mol/m²/day, the number of leaves doubled from 22 to 44. HILDRUM &

KRISTOFFERSEN (1969) noted that the number of flowers, buds, and inflorescences per plant and flowers and buds per inflorescence of 'Biedermeier Rhapsodie' and 'Biedermeier Rosa' increased when PPF_{DI} was augmented from 3.1 to 9.3 mol/m²/day. This treatment induced a maximum of 6.8 flower stalks/plant at 18 °C, but a maximum number of flowers and buds/flower stalk (9.1) at 24 °C. A maximum of 42 flowers/plant can be produced when daylight (i.e., most likely fluence rate) was cut by 75%, and when plants were exposed to 27 °C. In contrast, flower initiation and development was inhibited when plants grown in a greenhouse were exposed to < 2 mol/m²/day [STINSON & LAURIE, 1954]. HILDRUM & KRISTOFFERSEN (1969) showed that both day and night temperature must be high to stimulate a greater number of flower stalks, and that flower production is linked to leaf production, given the source of inflorescences from leaf axils. This indicates that African violet is not only highly sensitive to environmental variables such as temperature and PPF_{DI}, but that these variables can be used to manipulate plant growth and development, both of leaves and floral organs.

KWACK & KIM (1969) noted that sunlight reduced by half in the greenhouse was the best condition in terms of the growth and ornamental quality of African violet plants. As light intensity was decreased from full sunlight (5000-8000 foot-candles (f.c.)) to half sunlight (1000-2000 f.c.) and shade (500 f.c.), leaf area increased, i.e. 9.26, 12.44 and 13.38 cm², respectively. Full sunlight induced solarization, chlorosis in leaves or backward leaf curling, even though it produced higher dry weight (1.29, 1.21 and 0.90 g for full sunlight, half sunlight and shade, respectively). KIM & SANG (1982) argued that light intensity was critical for four varieties ('Monique', 'Robert O', 'Julianne' and an undefined local variety) of *S. ionantha*, since it is a semi-shaded plant. They confirmed that a light intensity of 5,000-10,000 lux (6.25-12.50% of natural sunlight in a plastic house) was the best condition for growth and ornamental value, i.e., photosynthesis, flowering percentage, number of peduncles, number of florets/peduncle, petiole length and leaf area.

In an experiment assessing the effect of illumination and culture medium on *S. ionantha* 'Oriental Red', LEE (1986) noted that 7000-8000 lux combined with a substrate composed of 40% peatmoss, 25% sand, 20% perlite, 10% vermiculite, and 5% compost was the best for producing wider leaves with greater leaf area (34-36 cm²), best petiole length (5.8-6.2 cm), number of lateral shoots/explant (3.2), flowering rate (100%) and earliest flowering (number of days to flowering = 70 days), and number of peduncles (8.2-12.0).

PARK (2008) examined the effect of nitrogen fertilizer and light intensity on three varieties of *S. ionantha* and found that half-sunlight (4000 lux) and 200 mg/L NaNO₃ was the most effective combination for obtaining maximum fresh weight (FW) (e.g., for var. 'Narita' 1.9 g/cutting vs 0.9 g/cutting in full-sunlight and 0 mg/L NaNO₃). The combination of 4000 lux and 500 mg/L NaNO₃ increased the number of roots, the number of shoots (4.7/cutting vs 0/cutting), and chlorophyll content (52.4 mg/g FW vs 28.2 mg/g FW).

Using 'Utah' as the model cultivar combined with linear modeling to base their assumptions, FAUST & HEINS (1993) determined maximum leaf unfolding rate (LUR) to be 0.27 leaves/day when temperature was 25 °C while PPF_{DI} was 10 mol/m²/day by using shade cloth to cut natural PPF_{DI} from a maximum of around 300 mol/m²/day. When they decreased PPF_{DI} from 10 to 1 mol/m²/day, optimal temperature was 23 °C, but this resulted in a lower LUR (0.18 leaves/day). Only when the leaf blade extended from 38-46 mm could an inflorescence begin to develop in the leaf axis [FAUST & HEINS, 1994]. Being able to predict and balance temperature, PPF_{DI} and thus LUR, would allow growers to plan their greenhouse cultures for the market. For example, FAUST & HEINS (1993), by applying a

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PPF_{DI} of 7 mol/m²/day at 22 °C, with a LUR of 0.244 leaves/day, formed 10.5 unfolded leaves/plant within 45 days ($R^2=0.99$). Also using non-linear models, FAUST & HEINS (1994) showed that as daily temperature was increased from 18 to 26 °C, days from leaf emergence to first open flower on the inflorescence of 'Utah' decreased from 86 to 55. They concluded that PPF is the primary factor influencing flower initiation while average daily temperature is the primary factor influencing the rate of inflorescence development. The three cardinal temperatures (T_{min} , T_{opt} , and T_{max}) for leaf appearance rate [FAUST & HEINS, 1993] are 8 °C, variable (as this depends on PPFD) and 30.8 °C, respectively and for leaf elongation rate [FAUST & HEINS, 1994], the values are 13.8 °C, 24 °C and 29 °C, respectively. In contrast, STRECK (2004) found that T_{min} was 10 °C and T_{max} was 33 °C for both leaf appearance rate and leaf elongation rate, and T_{opt} was 24 °C, as also modeled by FAUST & HEINS. CONOVER & POOLE (1981) were able to increase the percentage of inflorescences that formed in African violet 'Inge' within 9 months from 6% to 62%, and then to 100%, by exposing plants to 0.8, 1.6, and 3.2 mol/m²/day, respectively. However, as FAUST & HEINS (1994) cautioned, even if LUR increases, a PPF of < 4 mol/m²/day will negatively affect the number of developing inflorescences. Inflorescence development is acropetal [HASTON & DE CRAENE, 2007] (Fig. 3). Consequently, for African violet, the production of potted plants for season-dependent events such as Valentine's Day, Mother's Day, or Christmas, can be perfectly timed with the desired number of leaves and flowers.

The leaves of African violet are very sensitive to light, temperature, humidity and photoperiod [CHEN & HENNY, 2009], and minor changes in any of these factors can cause yellow or brown leaf spots [ELLIOT, 1946; YUN & al. 1997a; YANG & al. 2001]. Leaf spot is a cellular response confined to palisade cells in leaves, whose ultrastructure is destroyed [YUN & al. 1996a, 1996b], caused by a rapid drop in temperature, as may occur in overhead irrigation, especially at night, or by transferring plants from indoor to outdoor conditions, as was shown for 'Ritali' plants [YUN & al. 1997a]. Unlike chilling injury, leaf spot is irreversible. Outer leaves, which are more exposed to the surrounding environment, are more susceptible to leaf spot, and even exposure to 20 °C water can induce this disorder [MAEKAWA & al. 1987], which results from electrolyte leakage [MAEKAWA & al. 1990]. Leaf spot is a stress response caused by the rapid production of reactive oxygen species (ROS) following sudden temperature shifts [YASUDA & al. 1997], and an increase in the activity of antioxidant enzymes (superoxide dismutase and catalase). However, this response may be cultivar-dependent since 'Ritali' and 'Tamiko' (with about 75% and 95% incidence of leaf spot, respectively) were more susceptible to a drop from 30 °C to 15 °C than 'Maui' and 'New Jersey' (about <5% and 22% incidence, respectively) [YANG & al. 2001]. Sudden drops in temperature causing leaf spot are also characteristic of 'Ritali' leaves that display additional physiological disorders, namely a decrease in photosynthetic activity (especially a negative effect on PSI and PSII activity and a decrease in chlorophyll fluorescence) [YUN & al. 1997b, 1998], and plasmolysis [YUN & al. 1996a]. Recently, OHNISHI & al. (2015) revealed evidence of the involvement of calcium ions (specifically Ca²⁺ channels) after the degradation of the vacuolar membrane of palisade cells.

In a practical greenhouse trial to examine the response of stock plants and leaf cuttings (with 15 mm long petioles, according to HENTIG, 1976) to different commercial light sources (Grolux-low, Grolux-high, Verilux-low, Verilux-high, Fluora 77, Cool White 20, Cool White 30, Warm-White 30, Warm-White de Luxe 32, Interna 39 and Natura 36), SCHNEIDER-MOLDRICKX & AMBERGER (1982) discovered significant differences in the number of shoots that could be regenerated and in shoot FW. In their experiment, bulbs emitted 36-72 μmol/m²/s, all test material was grown under a 16-h photoperiod, and data was pooled for three cultivars ('RH-26/74', 'Meta', and 'OP-50/75'). Cuttings cultivated under

light bulbs emitting higher radiant energy formed more and heavier shoots than those exposed to light bulbs emitting low levels of light energy. Grolux (emitting $63 \mu\text{mol}/\text{m}^2/\text{s}$) was the most effective light source, forming 81 and 89 shoots/plot from stock plants and cuttings, respectively, and 598 mg/shoot. The response was strongly cultivar-dependent, with 'RH-26/74', 'Meta', and 'OP-50/75' forming 56, 94 and 80 shoots/plot and 589, 235 and 598 mg/shoot, respectively. A separate trial by the same authors showed that Warm-White 30 bulbs could induce the formation of as many as 122.1 shoots/plot in a cultivar-independent manner. The use by BOSCHI & al. (2000) of red and blue spectral filters, with different red, blue and far red ratios, on greenhouse African violet (cultivar unspecified) plants reduced most growth parameters (shoot and root dry weight, chlorophyll content, chlorophyll/protein ratio, net carbon dioxide (CO_2) exchange), in some cases significantly, compared to control polyethylene film, but did not alter the transpiration rate.

African violet plants ('Rosa Roccoco' and 'Big Star') exposed to continuous CO_2 enrichment, in which CO_2 concentration was increased from 330 to 1000-15,000 ppm, showed 50-100% higher net photosynthetic rate and 23-30% higher relative growth rate, most likely caused by the 39.6% increase in the number of formed leaves [MORTENSEN, 1984]. More refined experiments by MORTENSEN (1986) on 'Nicole', 'Lena' and 'Rosa Roccoco' showed that CO_2 enrichment (900 $\mu\text{L}/\text{L}$) had a more profound and/or significant effect in all three cultivars and in all parameters measured (greater dry weight, relative growth rate, number of leaves, leaf diameter, and number of flowers and flower buds, but reduced number of days to flowering) than ambient CO_2 (335 $\mu\text{L}/\text{L}$), a 1-h daily pulse at 900 $\mu\text{L}/\text{L}$, or a morning plus an evening pulse, each at 900 $\mu\text{L}/\text{L}$. For example, in 'Nicole', CO_2 enrichment resulted in 7.95 g/plant, a relative growth rate of 37.1 mg/g/day, 51.1 leaves/plant, 19.3 cm wide leaves, 56.1 days to flowering, and 168.7 flowers and flower buds/plant. The equivalent values for ambient (control) CO_2 levels were 3.56, 28.4, 35.3, 17.6, 66.4 and 66.8, respectively.

Vegetative growth can also be stimulated by the application of maleic hydrazide (MH). LEMATTRE (1977) found that spraying three African violet cultivars ('Rhapsodie', '2000', and '2738') with 0.1 to 0.2% MH resulted in a 47- to 176-fold increase in the number of vegetative shoots that formed, depending on the concentration and the cultivar. For example, in '2000', while control plants formed only an average of 0.1 vegetative buds per plant, the application of 0.2% MH resulted in the formation of 17.6 vegetative buds, which could in essence be used as clones, and to inhibit early flowering, although the genetic stability of such clones was not tested. By applying 10 mg/L gibberellic acid (GA_3) at two-week intervals to four-month-old 'Rhapsody blue' plants, DVORSKÁ (1979) was able to increase the number of flower stalks by about 25% (10-12 vs 6-9 in controls). Furthermore, in the same study, a constant temperature of 22 °C resulted in the formation of 4-6 flower stalks in control plants, whereas a 14 °C/22 °C (day/night) temperature gradient resulted in the formation of 7-11 flower stalks. HERKLOTZ (1964) found that a day and night temperature of 25 °C favored regeneration from leaf cuttings than all other day/night temperature combinations ranging from 15 °C to 30 °C. MARTÍN-MEX & al. (2005) found that the application of 0.001 μM salicylic acid significantly increased the number of leaves (19 vs 16 in the control) and floral buds (14 vs 8 in the control), as well as rosette diameter (177 mm vs 139 mm in the control), and shortened the days to flowering (74 vs 89 in the control). A similar finding by JABBARZADEH & al. (2009) also confirmed the positive effects of a foliar application of $1 \times 10^5 \text{ M}$ salicylic acid on vegetative growth and flowering of African violet in terms of the number of leaves, rosette diameter, the number of flower buds and the number of days from planting to anthesis. These chemical methods provide means of delaying and/or enhancing vegetative growth and/or flowering in African violet to meet market needs.

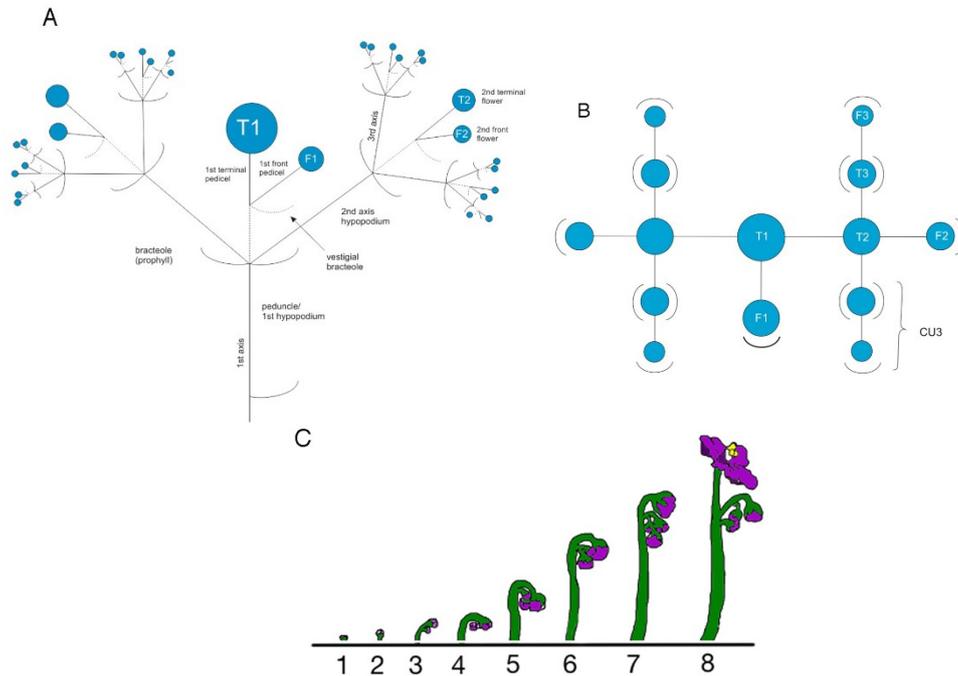


Fig. 3. Inflorescence development typical for the Gesneriaceae. (A) A pair-flowered inflorescence displays dichasial branching. (B) A plan view of the same inflorescence represented in (A). In A and B, T = terminal flower, F = front flower, parentheses indicate directions of growth / flower expansion, and numbers indicate the level of branching on the inflorescence axis. In B, CU represents a single cyme unit with a hypopodium (peduncle supporting the cyme unit) with a terminal pair of lateral bracteoles, subtending a terminal and an associated front flower. (C) The development of a *Saintpaulia ionantha* inflorescence, divided into 8 stages (according to FAUST & HEINS 1994): 1) visible reproductive bud (2 mm long) in the leaf axil; 2) visible peduncle subtending the primary bud; 3) peduncle starts to curve; 4) pedicel curves 90° relative to the peduncle; 5) pedicel curvature relative to the peduncle <90° and secondary buds are at the top of the inflorescence; 6) angle between peduncle and primary bud and pedicel increases, the pedicel is at the top of the inflorescence, and the primary bud emerges from the leaf canopy; 7) upper half of pedicel and primary bud are perpendicular to lower half of pedicel (i.e., at 90° angle); 8) the petals are perpendicular to the pedicel. (A and B) retraced, redrawn and modified from HASTON & DE CRAENE (2007) Fig. 1A and 1B (p. 15); (C) redrawn and modified from FAUST & HEINS (1994) Fig. 1 (p. 728).

Conclusions and future perspectives

The easy regeneration potential of African violet, as evident from as far back as the NAYLOR & JOHNSON (1937) study, alongside the debate about the single or multiple cell origin of shoot buds in earlier work, are some interesting aspects that require additional attention from molecular cell biologists to address the factors that regulate morphogenesis in African violet. African violet can be easily and rapidly cloned. This, together with its ability to regenerate organs from different tissues, has facilitated several studies with the aim of understanding organogenesis, organ development and its related *in vitro* physiology. Hence,

African violet is valued as a model plant at the research/laboratory level and this potential can and should be further explored. Vegetative growth, flowering and floral organ development of African violet can be manipulated in a greenhouse or growth chamber by adjusting environmental variables including light source, intensity and quality, temperature, CO₂ enrichment, as well as chemical applications. Therefore, commercially, the production of potted African violet plants can be planned for the market to meet consumer demands.

Acknowledgements

We are thankful to Ravi R. Sonani, Sardar Patel University and Sylvia DeMar, Managing Editor, American Society for Horticultural Science for providing difficult-to-access literature.

Author contribution statement and conflicts of interest statement

The authors contributed equally to all aspects of review development and writing. The authors have no conflicts of interest to declare.

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How to cite this article:

TEIXEIRA DA SILVA J. A., DEWIR Y. H., WICAKSONO A., KHER M. M., KIM H., HOSOKAWA M. & ZENG S. 2016. Morphogenesis and developmental biology of African violet (*Saintpaulia ionantha* H. Wendl.). *J. Plant Develop.* **23**: 15-25.

Received: 13 October 2016 / Revised: 24 November 2016 / Accepted: 5 December 2016