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Review Article

Selection process in ornamental plant breeding

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Abstract

The selection is a process in which the best genotypes are chosen according to the desired characteristics for the specific use of the plant. Novelty, health, particular characteristics of each market and, increasingly, the low environmental impact of its production, are valued. One of the most questionable points in the selection of ornamental plants is the fact that beauty is subjective. To reduce subjectivity, breeders have chosen to delimit the selection criteria previously, generating a ranking and assigning values to each of the characters for the new cultivar. The selection criteria and traits to be evaluated depend on the use for which the crop is intended: cut flowers and foliage, pot plants, and landscape plants. In addition, the selection of functional plants (green walls and curtains, green roofs and ecological function plants) have their own criteria.

Keywords: characteristics in ornamental plants, cut flowers and foliage, functional cultivars, indoor plants, landscaping plants, selection criteria.

Resumo

A seleção é um processo do qual são escolhidos os melhores genótipos de acordo com as características desejadas para o uso específico da planta. Valorizam-se a novidade, a saúde, as particularidades de cada mercado e, cada vez mais, o baixo impacto ambiental da sua produção. Um dos pontos mais questionáveis na seleção de plantas ornamentais é o fato de que a beleza é subjetiva. Para reduzir a subjetividade, os melhoristas optaram por delimitar previamente os critérios de seleção, gerando um ranking e atribuindo valores a cada um dos caracteres para a nova cultivar. Os critérios de seleção e características a serem avaliadas dependem do uso a que se destina a cultura: flores e folhagens de corte, plantas de vaso e plantas de paisagismo. Além disso, a seleção de plantas funcionais (paredes e cortinas verdes, telhados verdes e plantas de função ecológica) tem seus próprios critérios.

Palavras-chave: características em plantas ornamentais, critérios de seleção, cultivares funcionais, flores e folhagens cortadas, plantas de interior, plantas de paisagismo.

Introduction

From the beginning of agriculture, the humans decided to grow some plants and discard others. It is estimated that 2,500 plant species have been domesticated worldwide, however, only 10 percent of them are for food use and a few others for forestry (Altman et al., 2022). Historically, flowers form an integral part of human life, having symbolic significance, therapeutic and emotional value, and traditional uses (van Tuyl et al., 2014). There are in fact more ornamental plant species cultivated today than all other agricultural and horticultural crops for food combined (Altman et al., 2022).

At the Institute of Floriculture of National Institute of Agricultural Technology, Argentina (IF-INTA) have been developed many cultivars of *Nierembergia*, *Glandularia*, *Mecardonia*, *Tecoma*, *Handroanthus* and *Alstroemeria* that were transferred to farmers and are nowadays available in the market (Facciuto et al., 2021b).

Plant breeding begins with the exploration and collection of germplasm and the assembly of a work collection of the genus or species in question (Soto et al., 2011). Then, the genetic variation of the collection must be characterized through morphological and agronomical descriptors. In parallel, it is necessary to study their reproductive characteristics to establish the most appropriate methods to address later the breeding work. These tasks involve the selection of parents, intra and interspecific crosses, mutagenic treatments or genetic transformation (Datta, 2022).

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Although breeding methods are becoming more sophisticated, selection remains the fundamental step of the process. In this procedure, the best genotypes must be chosen according to the desired characteristics of the crop, but avoiding breeder subjectivities.

Despite the importance of the selection process in the improvement of ornamental plants, its criteria and methods have not been addressed in depth and remain elusive. The aim of this review is to determine the selection criteria and methods for the development of ornamental varieties.

General selection criteria

The general criteria contemplate the attributes that must be taken into account in all crops, whether ornamental, food, medicinal, etc. All cultivars must be distinguishable from their predecessors, possess tolerance to pests and diseases, and have market interest. For this reason, these selection criteria are common to plants of all kind of crops. In all cases, novelty, health, the particular characteristics of each market and, increasingly, the low environmental impact of its production, are valued. Aesthetic appeal, novelty, novel flower patterns of colour, colour range and hue, flower size, foliar characteristics, plant proportions, tolerance to environmental stress, among others are major factors in ornamental selection (Datta, 2022). In ornamental plants, the novelty not only has to do with the requirement imposed by the institutions that deal with the registration of cultivars, but also with the visual difference from what exists in the market, which is highly valued. *Rose*, *Chrysanthemum*, *Lilium*, *Dianthus* and *Gerbera* are the major ornamental cut flower plants. However, none of these plants had bluish coloured flowers because they have no related wild species with these colours to use for breeding. In these cases, genetic engineering technologies are an alternative to apply (Noda, 2018). For example, the companies Florigene (Australia) and Suntory (Japan) have been using biotechnology to obtain blue roses since they do not exist naturally (Gowthami, 2019).

Ornamental crops cannot tolerate fungal disease damage, as they directly affect the visual quality, critical point for the aesthetic value. In addition, increased tolerance against abiotic factors such as drought tolerance and less input of chemicals during production are big challenges in selection.

One of the most questionable points in the selection of ornamental plants is the fact that beauty is subjective. To reduce the bias of the breeder, one of the best ways is to establish, prior to the act of selection, a set of criteria that discriminates classes and that can be valued numerically (Weiss, 2002; Stumpf et al., 2007; Callaway and Callaway, 2000; Facciuto et al., 2021a).

Another important rule to follow is the one mentioned by Anderson (2005), citing Allard: the breeder has to be ruthless in selection. "S/he must dispel the feeling that among the plants s/he discards may be the one that will lead to the variety s/he has in mind. Unless s/he keeps this natural inclination under control, s/he will shortly find they are overwhelmed with materials, and his/her effectiveness as a plant breeder may be impaired or lost".

Cut flowers and foliage

Undoubtedly, the main quality that cut flowers and foliage must have, is post-harvest life because it often takes several days from the time the plant material is harvested until it reaches the consumer. Weiss (2002) proposes three criteria for the selection of cut flowers: aesthetic quality, compact inflorescence architecture and longevity of at least 10 days. He emphasizes that an ideal cut flower should have a long and an unbranched stem.

Different selection values must be considered if it is about fillers, or main flowers. Recent innovations in bouquet design, incorporates new combinations of flower varieties and particular colours that creates new selection criteria. For example, for some bouquet designs, shorter stems can be specially selected.

Flower aroma, character well appreciated by consumers, was lost in many crops or is not present. Aros et al. (2019) focus in this topic through the aroma evaluation of segregating lines of *Alstroemeria caryophyllaea*.

In IF-INTA, participatory selection was used as a tool for the selection of *Alstroemeria* genotypes to be used as cut flowers. A trial with flowers in vase of the candidate genotypes was carried out, surveying several people about their preference in attributes such as flower colour and shape, inflorescence architecture, etc. (Facciuto and Bugallo, 2021).

In the selection of native species to be used as cut flowers, Stumpf et al. (2007) established 9 criteria to be qualified, each one as high (10 points), medium (5) and low (0), generating a numerical ranking for each of the plants evaluated. The characteristics to value were: length, rigidity, balance, attractiveness, sanitary state, aroma, originality, vase life and public preference. To award 10 points to the length of the stem length it had to be longer than 40 cm, while, to obtain 5 points, had to be between 21 and 39 cm. For the vase life characteristic, the 10 points were assigned to genotypes with a duration of 10 days or more and, due to their importance for this use, the score was zero if the flower did not persist 10 days. The third criterion that had a numerical rating was the preference of the public.

Regarding to cut foliage, Facciuto et al. (2021a) delimited the criteria for the selection of fern fronds. The descriptors used were: length of the petiole, length and width of the leaf blade, vase life, number of frond planes, brightness, consistency, abundance of spores and health status. Each of the descriptors has four numerical scores, which describe the length of the stem and the size of the blade, as well as the postharvest duration (Figure 1d). For the assignment of 4 score points in postharvest life, fern fronds had to last 20 days or more. In addition to the characteristics of the foliage for cutting, the productive capacity of the plant was studied.

One of the most sophisticated examples in cut flower improvement is the case of genetic transformation that delays the wilting of flowers, such as the search for resistance to ethylene or inhibition of ethylene biosynthesis genes can increase shelf life. For example, transgenic carnation plants containing an antisense ACC oxidase gene exhibited low ethylene production and delayed petal senescence (Boutigny et al., 2020).

Pot Plants: indoor and outdoor

Indoor plants live in conditions of low intensity and quality of light. For this reason, the main criterion for selecting an indoor plant is that it can be grown in a pot in an environment with limited light, while maintaining acceptable aesthetic characteristics. The indoor plants can be classified according to light requirement: low light intensity (*Dracaena sanderiana* 'Gold'), moderate light intensity (*Cyclamen persicum*) and high light intensity as *Polyscias fruticose* (Shagol et al., 2018). The places of origin of the species commonly used for this purpose are, generally, understory environments or shady places that provide filtered light, an important characteristic, for example, for the cultivation of ferns (Jang et al., 2020).

The quality of flowering and foliage potted plants is essentially defined by visual appearance, which depends on shape, size, colour of flowers and leaves. For that reason, aspects such as leaf/flower drop and wilting and chlorosis of leaves are considered in selection of better genotypes (Ferrante et al., 2015).

One of the most studied examples is African violets (*Saintpaulia*). The American African Violet Association stipulates a series of characteristics that breeders can use at variety selection. Plants must be larger than 20 cm in diameter and symmetry in leaf pattern; condition (cultural perfection); number, size and type and flower colour are valued (Callaway and Callaway, 2000).

A new cultivar of *Seemannia* (Gesneriaceae), "Farolito del Monte INTA", has been selected and registered at IF-INTA, as an indoor plant. The attributes that were taken into account, in addition to the possibility of growing in a pot at low light intensity, were a compact plant architecture, the number of its intense red colour flowers (Bologna and Stancanelli, 2019). It is noteworthy that the origin of this genus is in humid and shaded environments at the Yungas.

A group of plants that also generally live under the canopy of trees and are used as houseplants are some species of ferns. New cultivars of ferns are mainly derived through the isolation of sports during micropropagation and present different shapes or colour of the fronds (Chen and Henny, 2008). The foliage plant industry needs to respond to the expanding demand by providing high quality and durable plants, resistant to pest, draught, low light and provide new leaf colour and growth habits (Chen and Henny, 2008).

A particular case of a pot plant cultivar is "Sorpresa Rosa INTA" (*Handroanthus heptaphyllus*) due to it is a woody plant. This cultivar was selected because of the short period from propagation to flowering. The novelty lies in the fact that flowering occurs between six and nine months of cultivation since it is grafted (Facciuto and Perez de la Torre, 2017).

Another trend in pot plants are the ornamental fruits and vegetables. In peppers, the quantitative criteria of selection are the days to flowering and to maturation, plant height, fruit pedicel length, number of fruits per plant, its persistence, characteristics of the fruit, leaves, etc. (Costa et al., 2019; Acevedo et al., 2020; Guo et al., 2021). In tomato, the colour of the fruits is the main character to determine a new cultivar, as well as the plant compact size (Safaei et al., 2020; Long et al., 2020).

Landscape plants

Plants for landscape use present a wide range of variability in size and plant types. One of the most practical ways to generate categories is to separate by strata. In this way, they can be distinguished in trees, shrubs and herbaceous plants and, within each class, by height.

Among herbaceous plants for landscape use, INTA has numerous cultivars. Among them, those of the genus *Mecardonia* that stand out by acting in the lowest stratum, as ground cover. This characteristic was decisive for the selection of the variety "Magic Carpet" by the company Sakata (Japan). This cultivar has 5 cm height, dense foliage and a large number of flowers, which give it the appearance of a carpet. Other higher cultivars of *Mecardonia*, are more appropriate for low flowerbeds or to use in pots outdoors.

Other plants for low landscape strata are those belonging to the genus *Calibrachoa* (Solanaceae), with plants between 5 to 30 cm. This genus, shows a high phenotypic variability and the selection of genotypes is carried out giving special value to plant architecture, number of flowers and colour. As *Calibrachoa* can be used as pot plant and in hanging baskets, pot coverage in cultivation was studied as an important characteristic for selection in the breeding process (Facciuto et al., 2006).

Another genus that has been widely studied at IF-INTA is *Glandularia*. These plants have the advantage of their rusticity, with heights ranging from 10 to 40 cm in height and white, red, pink, violet and purple flower colours. The cultivars of *Glandularia*, like those of *Calibrachoa*, also have as main selection criteria, the compactness of the plants, the number and colour of the flowers (Bologna, 2018). One of the selection methods used for both is testing the genotypes obtained in a Field Trial (Figure 1a). In this type of trials, the pre-selected plants are planted in plots and contrasted with cultivars obtained in previous years and with those available on the market. In this way, the phenotypes can be observed at the same cultivation conditions, compare the performance and evaluate if they can compete with the existing offer.

Figure 1. Selection of ornamentals at the Institute of Floriculture, INTA, Argentina. a. Field trial for low stratum landscape use, b. *Salvia* genotype in field, c. *in situ* test for plants for ornamental meadows, d. post-harvest evaluation test for native ferns selection.

Bertsouklis et al. (2022) selected genotypes of *Salvia* for xeriscaping by vigour and growth in greenhouse culture. A *Salvia* breeding programme with selection objectives such as flower characteristics (colour, size, morphology, and aroma), foliage and growth habits among others is in development at IF-INTA (Figure 1b) (Bugallo et al., 2021).

Grasses are also important in sustainable landscaping, and traits such as cold hardiness, propagation capacity and invasiveness need to be considered (Thetford and Salinas, 2019).

In rosebushes, the focus is on the evaluation of flowers and leaves, two of the principal determinants for the selection of the visual quality. Also, relative flower area (area covered by flowers) was considered as an important character (Santagostini et al., 2014).

Among ornamental trees, Callaway and Callaway (2000) describe the criteria for various species. In English oaks (*Quercus robur*), the easiness to graft, apical dominance and tolerance to winter damage stands out. In North American oaks (*Q. alba*, *Q. montana* and *Q. michauxii*), characters such as the colour of the foliage in autumn, the variegation of the leaves and the shape of the treetop are relevant. In *Magnolia*, *Rhododendron* and *Syringa sp*., the characters associated with flowering, such as colour, shape, size, fragrance, as well as flowering period and precocity, are added to the aforementioned characteristics for the foliage (Callaway and Callaway, 2000).

For urban trees, the requirements, in addition to health, are oriented towards more practical attributes such as cold tolerance, saline soils, low light intensity and water stress (Sæbø et al., 2003). Selecting and breeding urban trees for pest and drought tolerance improves their survival in harsh environments, reduces the need of water, fertilizer, and pesticide inputs, and ensures that ecosystem-service benefits, such as storm water management, evapotranspiration cooling, and improved air quality (Brummer et al., 2011).

Functional cultivars

Walls and Green curtains

The use of functional cultivars, especially in the construction of green structures, is a hot topic at the moment. Solutions have been proposed that involve the integration of vegetated surfaces in buildings (Radic et al., 2019). Several countries have even proposed legislation in this regard, promoting its use (Liberalesso et al., 2020; Burszta-Adamiak and Fiałkiewicz, 2019; Bozhilova et al., 2020; Barros Ramalho Alves et al., 2020; Zhang et al., 2022). Green roofs and walls provide social, economic and environmental benefits (Liberalesso et al., 2020; Teotónio et al., 2021). Bandehali et al. (2021) and Tomson et al. (2021) studied phytoremediation for the removal of indoor air pollution with potted plants and green walls. Also, walls and green curtains improve urban air quality through the capture of particulate matter by some types of vegetation (Vera et al., 2021).

The improvement of functional ornamental plants has, so far, an asymmetric degree of progress. Although there is bibliography on the selection of species suitable for green structures and functional cultivars, most of them are not

plants that have gone through a breeding process. In addition, the number of species studied and available for this use is still limited (Manso et al., 2021). Despite this, the methods used for the selection of species contribute to generating the criteria to be applied in an improvement program.

In the characterization of green wall systems (any system that allows the growth of plants vertically), Manso et al. (2021) divide them into green facades and living walls. In the first, they are usually climbing plants that grow on a wall, covering it; while the second include supporting materials and technology to achieve a covered surface. Because the functional and ecological objective of these plants is to protect from the sun exposure and generate less need for air conditioning, the main characteristics are coverage, survival and good appearance. These attributes would be the most relevant in a ranking for selection. Some secondary breeding purposes could be aimed at obtaining colour variability for this type of structure (variegated leaves, coloured leaves, etc.). In addition, it is important to differentiate whether the plants are for outdoors, for which they should withstand the summer period in full sun, or if their function will be merely aesthetic indoors.

Ip et al. (2010) mentioned selection criteria for climbing plants to be used in green curtains or facades such as: vigorous growing rate, large leaf size, high level of growing, fully hardy winter temperature, low maintenance and full sun tolerance among others. Also, to support façade plant growth and coverage when grown in containers, the rooting volume needs to be considered (Chung et al., 2021).

Green roofs

The selection of plants for green roofs was primarily based on succulent plants, mainly of the *Sedum* genus due to the short structure of its roots, its low water need and tolerance to solar radiation (Manso et al., 2021). *Sedum* roofs appear to be more effective in providing cooling benefits, due to higher substrate moisture and vegetation cover in the summer (Schindler et al., 2019). However, other vegetation types can also be used in extensive roof systems like grasses, wildflowers, and other CAM plants. Schneider et al. (2014) studied 112 plant taxa on a green roof in a semi-arid climate and evaluate survival and visual rating data. Then, they grouped species into three categories: perish, survive, and thrive.

In IF-INTA, plant species have been evaluated for using in extensive green roofs such as *Gomphrena celosioides*, *Glandularia perakii*, *Acaena pinatifida*, *Nierembergia* sp., *Grahamia bracteata*, *Sedum acre* and *Portulaca gilliesii*. Some important characteristics considered in the selection of species/cultivars for green roofs were colonization capacity, community behaviour, coverage and appearance during the four seasons (Soto et al., 2014).

Suárez-Cáceres et al. (2023) studied 6 ornamental grasses to be used on green roofs and living walls. The species were selected considering their ornamental aspects (e.g. colour, flowering, height) and growth characteristics to guarantee the coverage of the structures. *Carex flagellifera* and *C. oshimensis* showed the best performance in terms of coverage and visual quality.

Ecological functions

In recent years, numerous ecological functions fulfilled by plants have been studied. Among the objectives that aim to environmental sustainability, are air bioremediation (Suszanowicz and Kolasa-Więcek, 2019; Wu and Yu, 2022; Francini et al., 2022), water remediation (Pradhan et al., 2019), and removal of contaminants (Zamora et al., 2019) through the use of ornamental plants. Another ecological functions studied in ornamental plants are related to flower meadows which, in addition to reducing human intervention, favouring soil structure and plant diversity, also benefits insects and birds, increasing biodiversity (Erickson et al., 2021; Vega and Küffer, 2021). In addition, sustainable landscaping has also become popular. This approach proposes natural gardens, including native vegetation with less water and maintenance requirement, and also provide food and/or shelter for native species of insects and animals (Vega and Küffer, 2021). Research in this topic is being initiated in IF-INTA (Figure 1c).

Erickson et al. (2022) mentioned that the identification of single or joint floral traits that exclude or encourage taxonomic groups of pollinators could help the selection of plants in domestic habitats, from gardens to urban green spaces. In addition, results of these authors suggested that floral display area might serve as general signals across taxa, whereas others, such as plant height, are more taxon-specific, even to the species level. For example, large-bodied bee species were positively associated with plant height in three plant genera. Also, regarding birds, the herbaceous meadows rich in biodiversity collaborate by providing bird food and nesting resources (Schmidt et al., 2022).

Among IF-INTA breeding plans, *Handroanthus*, as well as *Passiflora*, and *Salvia* genera attract hummingbirds, a characteristic that gives additional value in the urban landscape (Lunardi et al., 2019).

These selection criteria are often added to the traditional criteria mentioned above. Partnerships between plant breeders, ecologists, urban planners, and policy makers are needed to make ornamental ecologically functional cultivars (Brummer et al., 2011).

Conclusions

Selection is one of the most important and strategic steps in the breeding process. Although there are general criteria for all plants such as novelty, health, quality and demand, in ornamental plants, it is essential to establish the use to which the crop in improvement is directed. In addition, the best way to avoid subjectivities is to establish the criteria and valued characteristics prior to select, in order to build a ranking. Although the improvement of ornamental plants has not been sufficiently addressed in functional cultivars, the study of the characters in the species, their advantages and disadvantages, and the determination of a selection method can contribute to their development in the near future.

Author Contribution

VB: data collection, information analysis and writing. **GF:** data collection, information analysis and writing.

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