SHST
Horticulture and Forestry Society of Transylvania

Goncharovska I *et al.* (2022)
Notulae Scientia Biologicae
Volume 14, Issue 1, Article number 10684
DOI:10.15835/nsb14110684
Research Article

NSB
Notulae Scientia Biologicae

Flower and fruit morphological characteristics of different crabapple genotypes of ornamental value

Inna GONCHAROVSKA[1]*, Kuznetsov VLADIMYR[1], Galina ANTONYUK[1], Catalina DAN[2]*, Adriana F. SESTRAS[2]

*[1]M.M. Gryshko National Botanical Garden of National Academy of Sciences of Ukraine, Timiryazevska st. 1, Kyiv, 01014, Ukraine; inna_lera@ukr.net (*corresponding author); kyznetsov.volod@gmail.com; galina.antonyuk@gmail.com*
*[2]University of Agricultural Sciences and Veterinary Medicine, Faculty of Horticulture, 3-5 Mănăștur Street, 400372 Cluj-Napoca, Romania; catalina.dan@usamvcluj.ro (*corresponding author); adriana.sestras@usamvcluj.ro*

Abstract

Crabapples (*Malus* spp.) are frequently used as ornamental trees. However, selections differ in decorative impact through blossoming and fruiting traits, growth habit, disease tolerance, ecological adaptability, and fruit litter, so that there can be other valuable benefits. The aim of the present investigation was to determine morphometric characteristics of flowers, fruits, and seeds within 15 different genotypes of crabapples studied at M.M. Grishko National Botanical Garden in Kyiv, Ukraine. Their main morphometric parameters were as follows: the highest number of flowers in the inflorescence was recorded within trees of 'Professor Sprenger' with 5.78 flowers, whereas the corolla was mostly decorative for 'Royalty' cultivar, with 5.7 petals; fruit weight varied from 1.49 g ('Adirondak') to 20.56 g ('Era'), length from 12.87 mm ('Van Ezeltine') to 25.11 mm ('Ola'), diameter from 12.0 mm ('Batterball') to 26.74 mm ('Rayka Rozeva'), fruits number 1.0 ('Era') to 5.5 ('Evereste'). The relationships between flowers, fruit and seed traits, accounting 16 traits and 15 cultivars investigated was highlighted by Pearson correlation and were clustered by unweighted pair group method with arithmetic mean (UPGMA). The variability observed in the apple crab genotypes offers the possibility to choose and use some valuable ornamental cultivars for the beautification of the landscape, as well as for possible future *Malus* breeding projects.

Keywords: crabapple; flower; fruit; *Malus*; morphometric traits; seeds

Introduction

Early apple utilisation by humans started with the gathering of wild apples, then proceeded to increasingly managed wild stands and ultimately the intentional cultivation of apple trees (Cornille *et al.*, 2019); trees were further cultivated at larger scales and even more, ornamental uses were also added to the advantages of the genus. Crabapples are the most widely cultivated small landscape tree in the northern United States and southern Canada (Brewer *et al.*, 1979; Guthery and Hasselkus, 1992; Draper *et al.*, 1996). Crabapples are worldwide popular because of their wide variety of growth habits and mature sizes, wildlife-attracting capabilities, and excellent flower display during the blossoming period in spring (Dirr, 1998; Roloff *et al.*, 2018). Hamilton (1986) surveyed members of the National Landscaping Association and found

Received: 22 Mar 2020. Received in revised form: 22 Mar 2022. Accepted: 27 Mar 2022. Published online: 28 Mar 2022.
From Volume 13, Issue 1, 2021, Notulae Scientia Biologicae journal uses article numbers in place of the traditional method of continuous pagination through the volume. The journal will continue to appear quarterly, as before, with four annual numbers.

crabapple cultivars as the most popular flowering trees in 1956, 1970, 1976 and 1982. New cultivars are still established, with decorative flowers (Shen *et al.*, 2021), from white to red purple (Hu *et al.*, 2018), being highly appreciated and have great ornamental value because of their bright and colourful flowers, are useful pollinators (Campbell *et al.*, 1991) and valuable genetic pools for *Malus* breeding (Dan *et al.*, 2015).

The crabapple gets its name from English gardeners who divided apples into those that had a good taste and those that had a bitter or «crabbed» taste (den Boer, 1959). However, the major distinguishing feature between crabapples and dessert apples is the size of the fruit (Saracoglu and Altunta, 2021). Crabapple fruits are less than or equal to 5.1 cm (2 inches) in diameter, some having less than 2 cm. Fruits greater than 5.1 cm (2 inches) in diameter are considered commercial apples, with debatable limits. Thus, crabapple is the designation given to apple fruits that have a small diameter, wild or half-wild trees, which have high anti-adversity, adaptability, and close affinity with the main *Malus* cultivars.

Members of *Malus* genus are widespread and native throughout the Northern Hemisphere. Thousands of apple cultivars are grown worldwide to produce high-quality fruit for the fresh market, a range of beverages such as juice or cider, jelly, dried products, purees, etc. and other processed foods (Cornille *et al.*, 2019).

Recent studies concede tremendous progress in the reconstruction of apple history in regard with its origin, distribution, spread and hybridisation, given the increasing availability of genetic and phenotypic data, along with archeo-botanical information for both wild and cultivated *Malus* species. All these data have permitted the groundwork for a multidisciplinary re-evaluation of the biogeography of wild apples and the history of the cultivated species. There is still considerable debate surrounding the classification and nomenclature of crabapple (Way *et al.*, 1991; Coart *et al.*, 2003; Hussain *et al.*, 2021). For instance, a certain crabapple might be classified as a distinct species by some, while others might consider the selection a variety or hybrid (den Boer, 1959).

Because seed propagation is a method of sexual propagation, many seedlings do not resemble the parent plants due to genetic variability; however, seed propagation has led to the introduction of many new selections (Hartman *et al.*, 1990). Apple is also a model species for the study of the evolutionary processes and genomic basis underlying the domestication of clonally propagated perennial crops (Cornille *et al.*, 2019). Regional differences in appearance, seed propagation and the desire to introduce new species, hybrid, or cultivar, contributed to the misnaming or dual naming of many crabapple selections (Jefferson, 1970). Certain crabapples have been named and renamed several times with both common and botanically different names. For example, the Italian crabapple *Malus florentina* has been botanically reclassified for seven times (den Boer, 1959). Often, it is difficult, if not impossible, to trace the provenance of a particular cultivar since many species may have been involved in its development. Recent genetic analyses revealed a Central Asian origin for cultivated apple, together with an unexpectedly large secondary contribution from the European crabapple (Cornille *et al.*, 2014). Wild apple species display secure population structures and significant levels of introgression from domesticated apple and this may threaten their genetic integrity. Latter investigations have revealed a major role of hybridization in the domestication of the cultivated apple and has highlighted the value of apple as an ideal model for unravelling adaptive diversification processes in perennial fruit crops. The role of crabapple genotypes is critical for several valuable traits (Cornille *et al.*, 2019; Volk *et al.*, 2021).

Rosy-bloom crabapples, so named because of their deep pink, rose or purple-rose petals, are either open-pollinated seedlings of the red vein crabapple – *Malus pumila* or crosses between *M. pumila* and the Siberian crabapple *M. baccata* (Fiala, 1994). The decorative value is given also by the number of flowers per tree, time of flowering, the persistence of flowers, the smell. Further, the fruit of crabapple can be considered ornamental or undesired. The value of crabapple fruit has been the subject of much controversy because of its litter potential, but, the ornamental value of the flowers and fruits is unquestioned (Green, 1996). Some selections, such as 'Doubloons' and 'Hargozam' have fruits that change from light green to lemon-yellow in summer, while they turn to lemon-gold after frost (Iles, 1999). Ecological factors, especially light conditions, may affect fruit colouration and biochemical compounds. The more or less coloured flesh (pulp) extracts of crabapple tissues have been associated with anti-oxidative activities, inhibition of fatty acid synthase, the flavonoids are present in high quantity (Wang *et al.*, 2015), as well as volatile compounds (Zhao *et al.*, 2014). Crabapples (especially red crabapples) are recognised for their great potential as healthy food because are rich in phenolic compounds with high antioxidant and anti-proliferative activities to cancer cells (Han *et al.*, 2019).

Malus crabapple genotypes represent one of the most important germplasm resources in ornamental landscaping, food processing and nutritional products within the genus (Volk *et al.*, 2021; Yu *et al.*, 2021). Hence, the aim of the present study was to distinguish morphometric features of the crabapple collection established within M.M. Gryshko National Botanical Garden of Ukraine, investigate the most appropriate traits and thus prospect the cultivars that could be successfully grown and for wide stake use. The introduction population within the investigated phenotypes can contribute to successful results of directed selection work.

Materials and Methods

Location and biological material

The objects of the study were crabapple trees from the collection of the Department of Acclimatization of Fruit Plants of the National Botanical Garden (NBG) M.M. Grishko, National Academy of Sciences (NAS) of Ukraine. NBG is located on the South-Eastern outskirts of Kyiv on the Pechersk slopes of the low Kyiv hills in the Zverinets tract. The main type of soil on the territory of the NBG is dark gray podzol, which lies on loess and forest-bearing rocks and brown clays (the amount of humus is 0.5-2.0%).

Observations on the collection's forms of crabapples were performed during mass blossom and fruiting respectively, when the trees were eight years old. There were analysed and described phenotypic variation of floral organs in 15 crabapple genotypes used as ornamental trees, as follows: 'Adirondack', 'Butterball', 'White Jade', 'Van Eseltine', 'Golden Hornet', 'John Downie', 'Evereste', 'Era', 'King Beauty', *M. niedzwetzkyana*, 'Ola', 'Professor Sprenger', 'Rayka Rozeva', 'Royalty', 'Royalty Red'.

Morphometric characteristics

Pomological characteristics represented by reproductive traits of the investigated genotypes were analysed and statistically processed using 30 samples as mean of the trait and standard error of the mean (i.e., flowers, fruit, seed chamber, seeds, stalk etc.).

For a detailed analysis of the investigated genotypes, the following measurements were taken: a) Flower traits: number of flowers in the inflorescence, number of petals (corolla analysis), number of pistils within flowers (gynoecium analysis), number of stamina (androecium analysis), flower diameter (mm) and peduncle length (mm); b) Fruit traits: weight, expressed in g; height (mm); fruit width (mm); c) Seed traits: height and width (mm), seed chambers' height and width (g), number of seeds inside the seed chamber per fruit; d) Stem traits: stalk length and thickness (mm). All data used for further analysis were tested for normal distribution and were presented as mean per trait.

Statistical analyses

The data obtained on the physical and morphological characteristics recorded for flowers, fruit and seeds were processed as average values. These were presented in figures as mean traits and standard error of the mean (SEM), performed using Microsoft Excel Spreadsheet Software. Analysis of variance (ANOVA) was applied to the analyzed features and then the Duncan Multiple Test Range (Duncan MRT, $p < 0.05$) was used as a post-hoc test for the analysis of differences.

The correlations between the characteristics were analyzed by linear Pearson correlation ($p < 0.05$). The data were subjected to multivariate analysis, namely correspondence analysis (CA), both for the characters studied and for the genotypes. Clustering analyzes were performed by Paired group algorithm, UPGMA method, Gover similarity index. Calculations and graphical representations were performed with Past software (Hammer *et al.*, 2001).

Results and Discussion

There were significant differences among the investigated crabapple cultivars in regard with flower analysis. Flower traits are summarised in Figure 1, whereas it can be noted that there were several cultivars that stand out, being superior and statistically assured: the highest number of flowers in the inflorescence was recorded within trees of 'Professor Sprenger' with 5.78 flowers, closely followed by 'White Jade', 'Van Eseltine' and *M. niedzwetzkyana.* With significant negative data for the number of flowers were noted cultivars 'Adirondack' (4.32 flowers), 'Ola' and 'Rayka Rozeva'. This trait is closely relevant in regard with the ornamental impact with the number of petals for each flower. So that, cultivars with flower abundance and more petals are of interest.

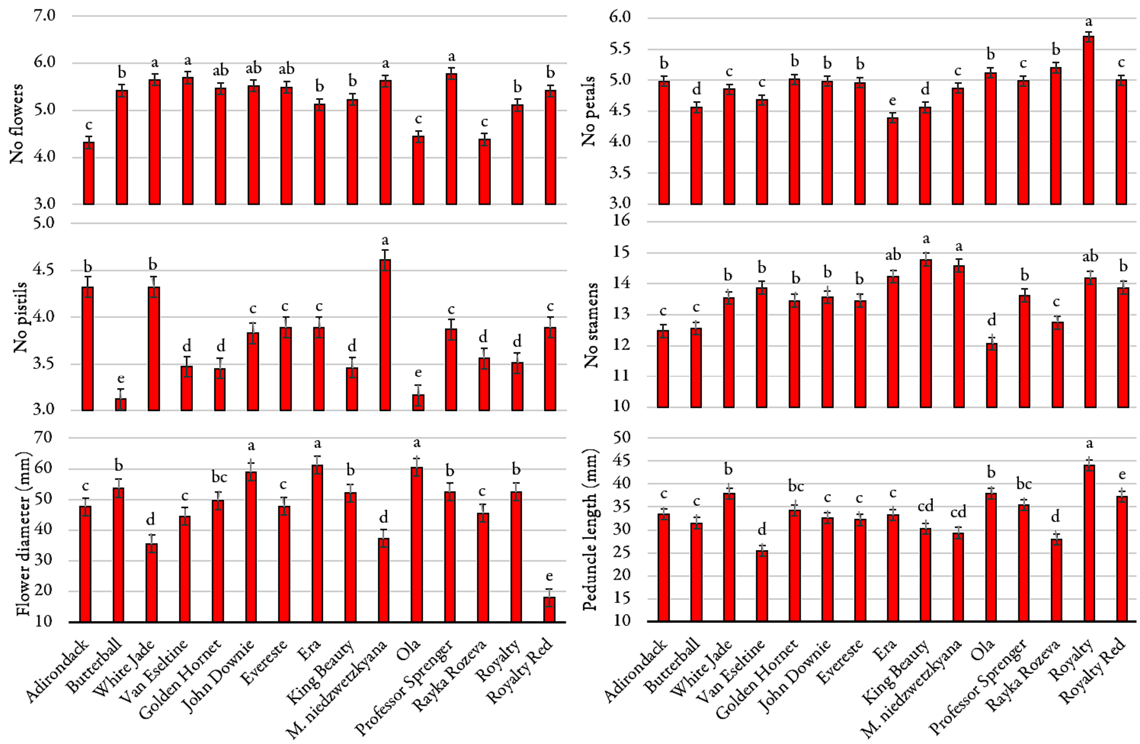

Figure 1. The main flower characteristics of the 15 cultivars of ornamental crabapples analyzed

Corolla was mostly decorative within 'Royalty' cultivar, with 5.7 petals, being statistically superior compared to the rest of the investigated phenotypes. The cultivars with a high value for the number of flowers had a typical pentamer corolla for Rosaceae, whereas the number of petals was close to 5. The smallest number of petals was identified for 'Era', statistically inferior, but the same cultivar was among the ones with the largest diameter of flowers, 61.23 mm respectively (Figure 1). It is interestingly to further investigate the fact that the cultivars with more flowers, had inferior data for the diameter of flowers and number of petals. *M. niedzwetzkyana* remarked for the reproductive flower organs, having superior data for pistil and stamina. Pistil is directly influencing the fruit and seeds, while stamina is important for the pollination (Volk *et al.*, 2015), whereas apple cultivars can be self-incompatible or self-pollinated (Kemp, 1996; Saito *et al.*, 2007).

The highest number of stamens was recorder for 'King Beauty' cultivar, followed by *M. niedzwetzkyana* and 'Royalty'. Crabapple cultivars can be useful as germplasm resources and sometimes used for pollination, even though the distribution of pollen can be unbalanced among parental and progeny populations. Zhang *et al.* (2017) compared the pollen characteristics of 128 flowering crabapple germplasms (44 natural species and

84 varieties) and their results showed that no progeny had a degree of ornamentation greater than the maximal score of any of its parental genitor, which suggested that there is a high degree of consistency between individual evolution and population evolution. According to the morphometric parameters of the flowers, the longest peduncle was noted in crabapple 'Royalty' (44.09 mm), while the shortest was for cultivar 'Van Ezeltine' with 25.45 mm.

Based on the main characteristics of the fruits of the investigated genotypes (Figure 2), it can be accepted that they fall within the morphometric characteristics specific to crab apples (Saracoglu and Altuntas, 2021). The one cultivar that strike out was 'Era', with the largest fruits in terms of height, width and weight with 42.56 mm, 46.59 mm, and 20.56 g, respectively. To the opposite side, was 'Royalty' cultivar, which had the smallest fruit, with statistically assured data for height, width and weight, along with most of the investigated genotypes. Fruit shape index is an important indicator of marketability and attractiveness of apple fruits. According to the form index, varietal specificity was manifested. Fruit traits are genetically inherited in most part, with little influence by the technology of culture, thus future selection can use a vast variability within the studied genotypes.

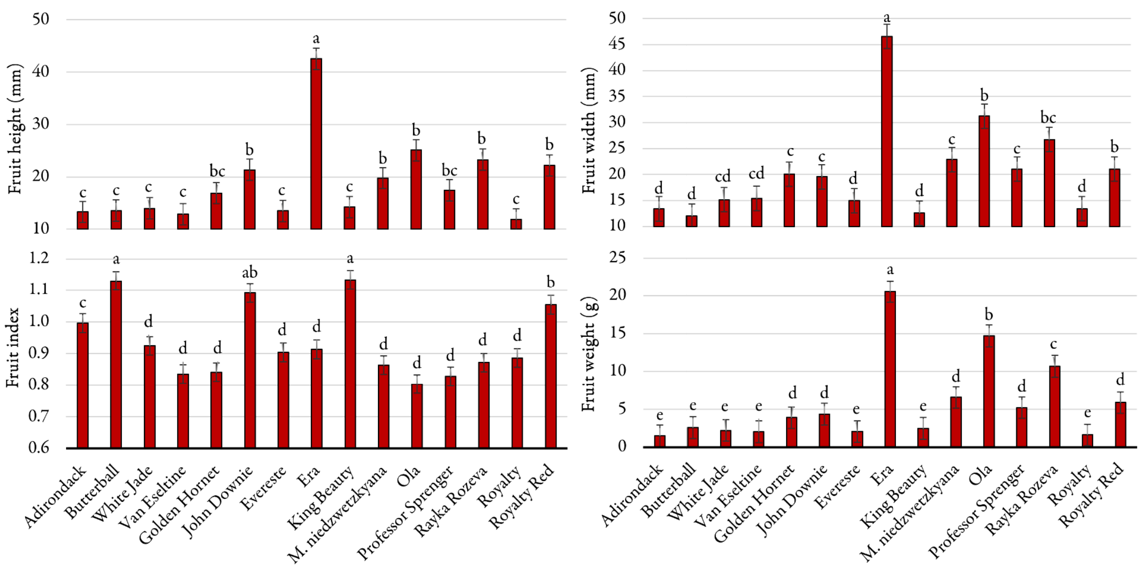

Figure 2. The main fruit characteristics of the 15 cultivars of ornamental crabapples analyzed

It will be interestingly to survey in the future the skin and the pulp of the crabapple fruit in the collection and the biochemical composition, as is already acknowledged that the products of colourful ornamental plants have great potential for human use (Wang *et al.*, 2015). Understanding the molecular mechanisms underlying fruit formation will be important, particularly for documenting the transcriptional regulatory networks of different coloured fruits and the differences in the accumulation and distribution of different compounds. This insight will contribute to the selection of plant germplasm resources for bioengineering and for exploiting the nutritional and medicinal value of decorative plants.

The stalk as part of the fruit attached to the stem often has specific features in ornamental apples compared to edible apples. Therefore, stalk length and thickness were recorded for the investigated *Malus* cultivars (Figure 3). The shortest stalk was noted within crabapple 'Era', having 16.89 mm, statistically inferior compared with the others, while the longest had 43.56 mm, within 'King Beauty'. Even so, the largest diameter was registered also for 'Era', followed by several cultivars with no significant differences, whereas a small thickness was registered for 'White Jade' and 'John Downie' cultivars. The variability of these traits was eloquent, denoting the possibility to select different genotypes for inducing the desired shape, from spur type to large spreading canopy for ornamental or breeding future *Malus* cultivars.

Specific seeds traits were also analysed. In order to promote generative reproduction of the valuable cultivars, is useful to investigate from start such aspects as well. In regard with the seeds chamber' dimensions and seed number, 'Era' genotype stands out, with superior values statistically assured for height and width (Figure 4), as well as seeds' weight (Figure 5). On the opposite side, 'King Beauty' and 'Adirondack' were noted to have small values, so that in the future propagation through seeds those genotypes should be treated with much attention. According to morphometric indicators, the largest number of seeds in one fruit was noted for 'Evereste' with 5.3 seeds, while the smallest value was 2.1 in 'King Beauty'. The smallest weight of seeds from one fruit had crabapple 'Adirondack', with only 9 mg (0.009 g), whereas the heaviest seeds were noted for 'Era' that summed up to 500 mg (0.5 g) (Figure 5).

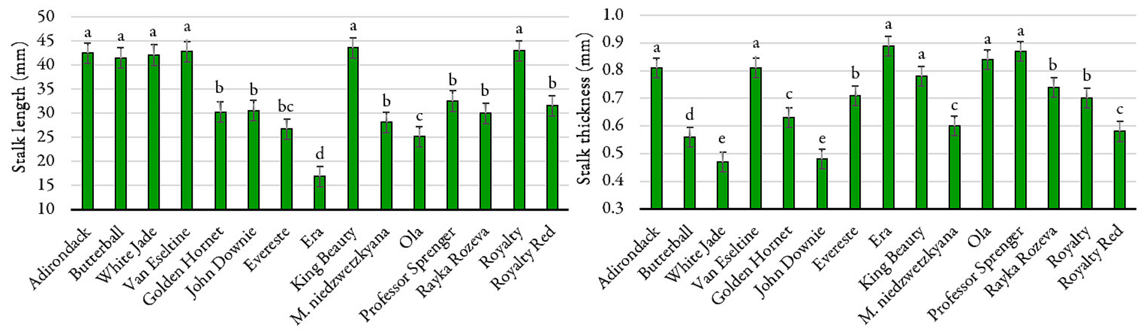

Figure 3. The main stalk characteristics of the 15 cultivars of ornamental crabapples analyzed

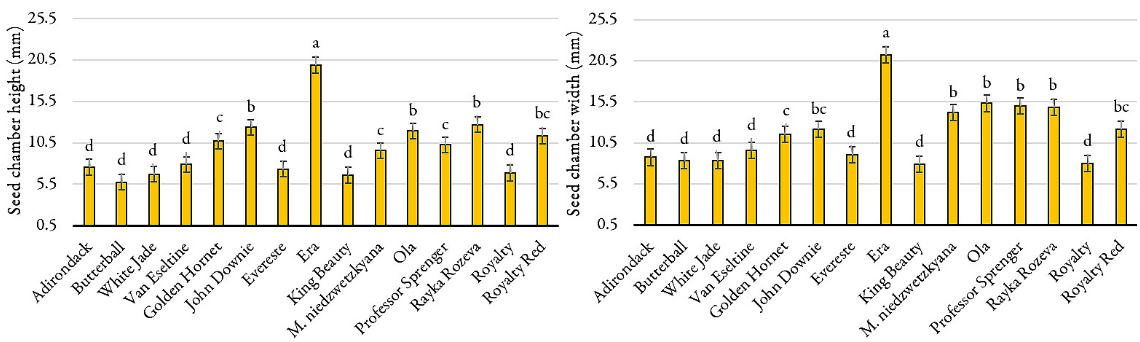

Figure 4. The main characteristics of the seed chamber of fruit in the 15 cultivars of ornamental crabapples analyzed

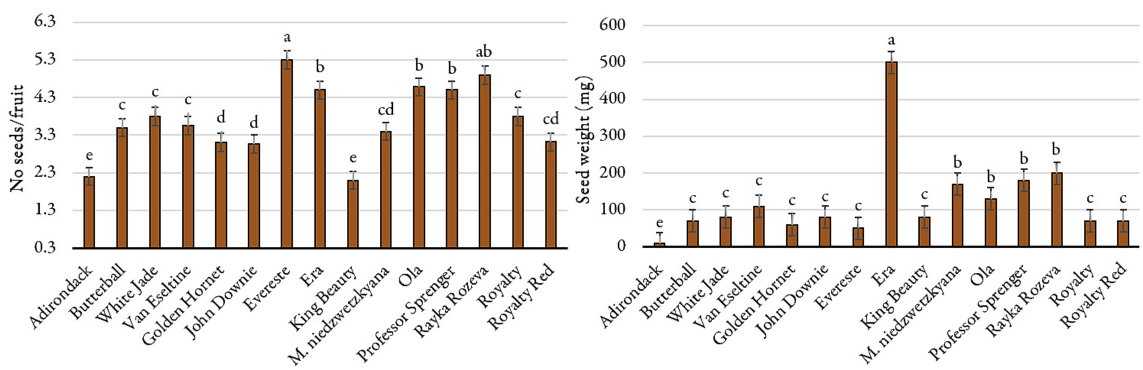

Figure 5. The main seeds characteristics of the 15 cultivars of ornamental crabapples analyzed

The gynoecium of *Malus* has been assumed to be imperfectly syncarpic, even though not accepted for all genotypes (Endress, 2001), whereby pollination of each stigmatic surface can result in fertilization within only one of the five carpels. Such aspects are essential for domestic species, being closely related with fruit quality (Sheffield *et al.*, 2005), as well as for crabapples and breeding programs. Researchers investigated the pollination, gynoecium structure and the pollen-tube pathway, fruiting and relationships of seed number and fruit weight and found variable carpel fusion (Ward *et al.*, 2001), thus different production and distribution of seeds.

The relationship between flowers and further fruit and seeds formation is a complex research keynote. It may refer to an economy in flower construction (Endress, 1994), thus the importance of crabapples genotypes with spectacular blossoming as a constant resource for valuable gene pool. Going further to the fact that *Malus* flowers attract a wide range of pollinators which are not specialized (Cambell *et al.*, 1991), so that the investigation of flower, fruit and seed traits as a starting point for the description of the genotypes in the NBG collection is justified.

The relationships between flower, fruit and seed traits investigated for the 15 *Malus* genotypes was highlighted by Pearson correlation (Figure 6). Positive correlations, which show a directional dependence, were displayed in blue colour and negative correlations in red colour. Colour intensity and the size of the circle are considered to be proportional to the correlation coefficients. The grey background boxes present in some cells illustrate the statistically assured values ($p < 0.05$).

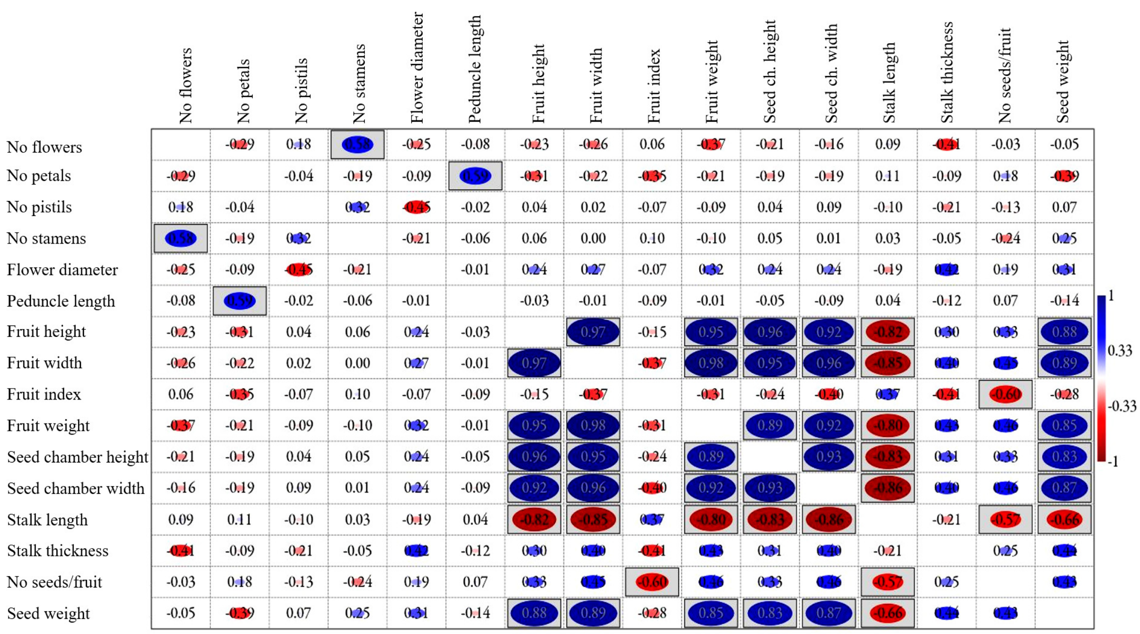

Figure 6. Phenotypic correlations between physico-morphological characteristics in 15 cultivars of ornamental crabapples analyzed (linear Pearson correlation; significant positive or negative correlations are enclosed in a grey box, $p < 0.05$)

Deriving out from the association between variables, respectively the investigated traits, it can be seen that fruit and seed traits were positively correlated and statistically assured, with numerous relationships established. The strength of the relationship for these traits was evidenced by positively statistically assured data among fruit dimensions and their weigh, dimensions of seed chamber respectively, where stronger relationship between the variables, closer to r = 1, can be seen. It is interestingly to further investigate flower traits and thus the ornamental impact, whereas the correlations hereby were not significant.

Multivariate method can be useful to elucidate and to represent the relationships between multiple traits (Figure 7) and several genotypes (Figure 8), such as in the current investigation. By identifying new variables as linear functions, it was found that the most distant *Malus* genotype was 'Adirondack', which was in negative correlation with 'Era'.

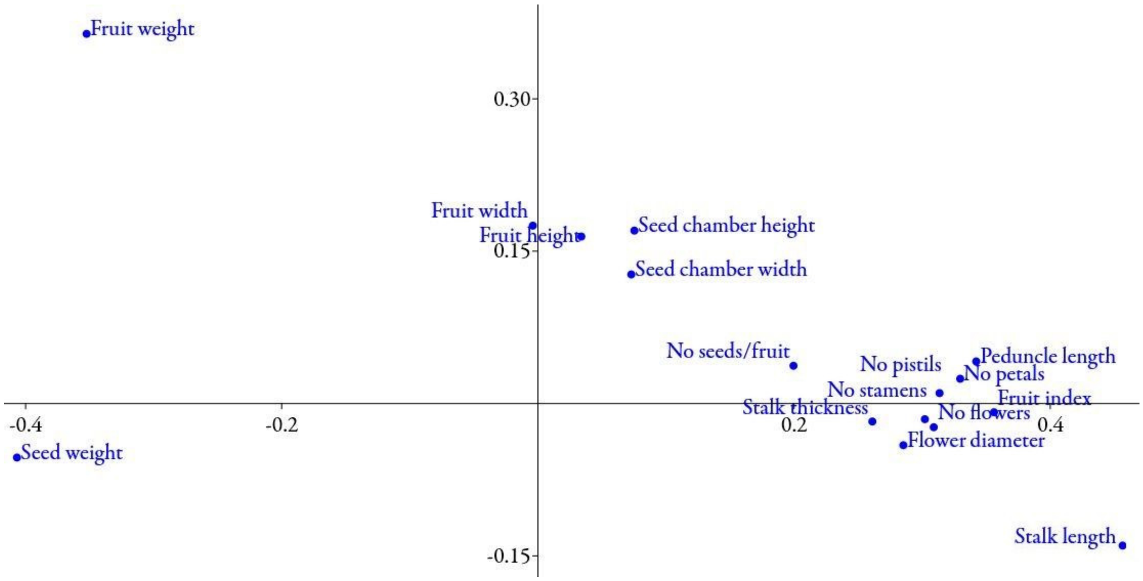

Figure 7. Multivariate analysis performed using correspondence analysis (CA) for the analysed physico-morphological traits, based on 15 ornamental crabapple cultivars

The first two axes explain 91.8% of the variation (of this total, axis 1 contributes 84.2% and axis 2 contributes 7.6%)

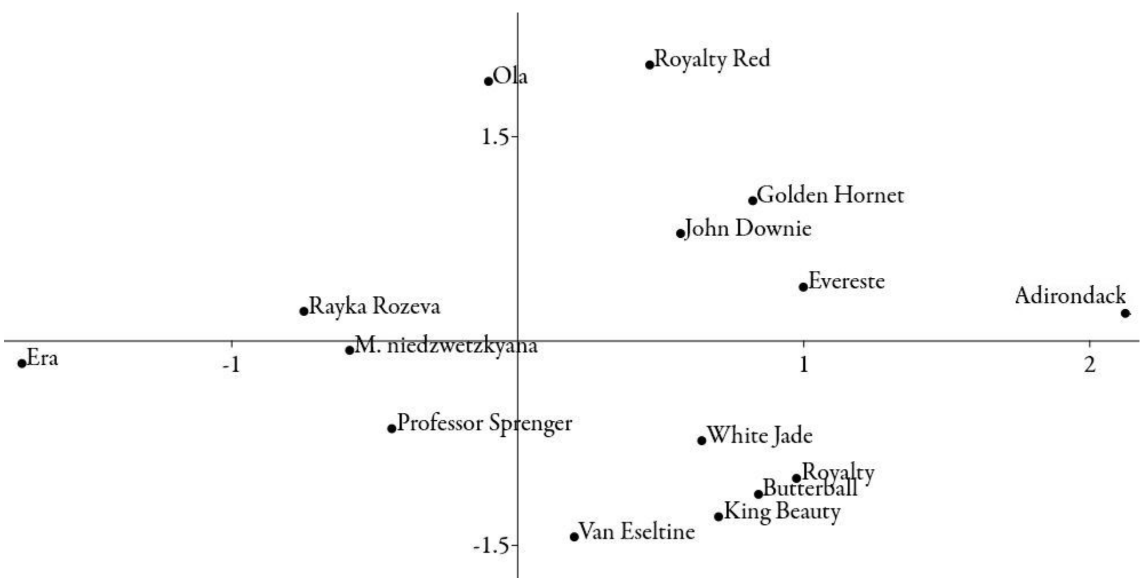

Figure 8. Multivariate analysis performed using correspondence analysis (CA) for the 15 ornamental crabapple cultivars, based on analysed physico-morphological traits

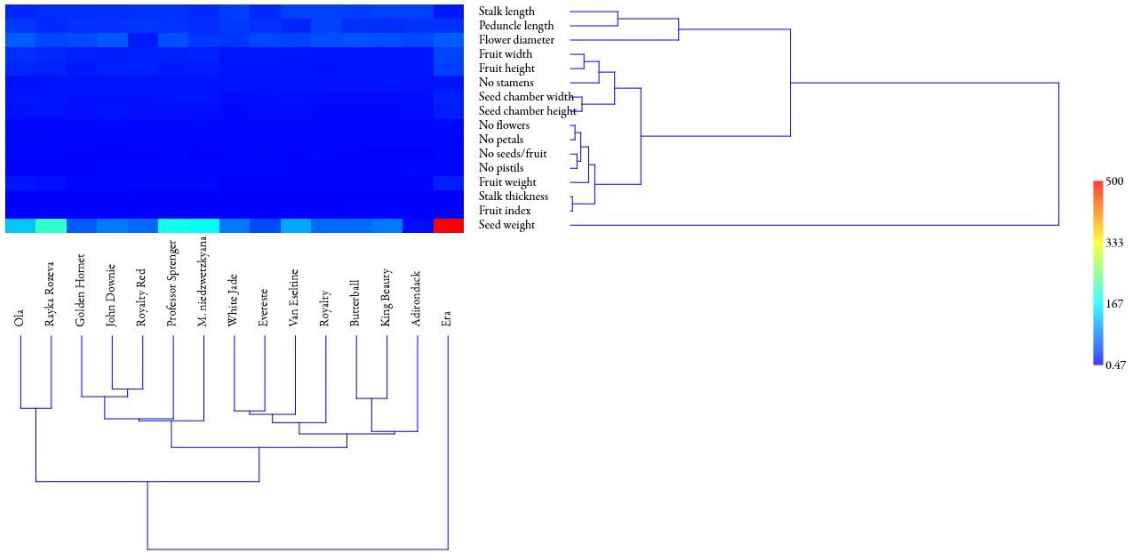

Figure 9. Clustering analyzes for 16 physico-morphological traits and 15 ornamental crab apple cultivars, performed by paired group algorithm – unweighted pair group method with arithmetic mean (UPGMA), Gover similarity index

In the case of the 16 analyzed morphometric characteristics and 15 crabapple cultivars, a distinct and obvious cluster was observed for 'Era' (Figure 9), sustained by the data registered within the study and the correlations pointed out. For the investigated traits, there are two major clusters, one referring to the seeds' weight and the other completed by the rest of criteria. The tree diagram confirmed the dispersed results, both by the pattern by which the clusters were formed and also by the similarity or distance levels of the clusters. Out of the many distinct subclusters, it worth mentioning the close grouping of the number of flowers and number of petals, respectively the number of pistils and the number of seeds per fruit.

The present study reveals both the differences in floral organs between ornamental apple cultivars and the relationships between flowers and reproductive traits given by the multivariate analysis. The genotypes analyzed showed different characteristics of floral and reproductive interest, which were well separated by the correspondence analysis (CA). The close correlations indicate links between essential characters for the decorative value of the ornamental apple, which could be useful in apple breeding and used as indirect selection indices. Multivariate analysis and Pearson correlations are working methods that have been well validated in crabapple genotypes (Yu *et al.*, 2021; Zhou *et al.*, 2021). The obtained results contribute to the knowledge of the taxonomic significance of the floral phenotypic variation at the level of some ornamental apple cultivars, completing similar information in the field (Zhou *et al.*, 2019, 2021). The phenotypic diversity of reproductive and decorative organs could better explore the genetic relationship between *Malus* genotypes, but also the manifestation of characteristics of ornamental interest in specific environmental conditions in which the evaluation was performed.

A thorough evaluation of these varieties tested for the first time under NBG conditions, could highlight all the features of ecological, landscape, ornamental interest. Many properties of crab apples are known in this regard. Their potential to capitalize on and beautify various urban areas, with different pedological and climatic conditions, to provide food sources for wild animals, wild birds, insects, etc. is well known (Fiala, 1994). Ornamental varieties are good pollinators and can be used to ensure foreign pollination in orchards, for commercial, edible apple varieties. Phenotypic and molecular assessment may also be of interest for the analysis of genetic diversity and phylogenetic relationships for use as parental forms in artificial hybridizations (Coart *et al.*, 2003; Sestras *et al.*, 2009). They can be a source of genes of great interest for inducing an extremely heterozygous structure in hybrid offspring, providing a good basis for the selection of new ornamental or edible apple genotypes, fresh consumption or processing in various forms and use in food. It is accepted that selection process among natural mutations or progenies of collection populations of various cultivars (commercial, dessert or ornamental genotypes) use vegetative multiplication (cloning). Even more, referring mostly to the consecrated cultivars for *Malus* breeding the genetic base is narrowing (Dan *et al.*, 2015), so that crabapples could be valuable for manifesting favourable traits, both for commercial and ornamental apple cultivars. Breeding apple with genetic resistance to pests and diseases are also necessary for durable and environmentally friendly apple culture, along with the interest for production, fruit quality and the desire to beautify the surroundings. Crab apples offer a wide variability of response to the pathogens and pests attacks and are a valuable source of genes for apple breeding (Smith and Treaster, 1990; Spicer *et al.*, 1995; Sestras *et al.*, 2011; Volk *et al.*, 2015; Denoirjean *et al.*, 2021).

Unlike large-fruited dessert apples, small and even very small fruits (i.e., 1 cm in diameter) are preferred to ornamental apples, so that they do not produce dirt on the ground after ripening and falling and do not attract rodents, birds, and insects. Such fruits can have very beautiful colours, can remain on the tree long after the leaves fall and can significantly increase the ornamental appearance of the trees. Anyway, ornamental crabapple trees are generally valued for their landscape properties rather than their fruits (Volk *et al.*, 2021). Instead, the resistance to diseases and pests of trees is an objective pursued both at the apple for consumption and the ornamental one. Resistant or tolerant genotypes do not require so many phytosanitary treatments, are more beautiful, economical and contribute to a clean, healthy, ecological environment (Mitre *et al.*, 2010; Sestras *et al.*, 2011; Dan *et al.*, 2015).

Adequate response of the trees to the attack of the main diseases of the species, respectively resistance or tolerance (i.e., to apple scab – *Venturia inaequalis*, and powdery mildew – *Podosphaera leucotricha* etc.), or pests, obtaining fruits with special qualitative characteristics (i.e. taste, aroma), or food and nutritional properties of the fruits, or suitable for processing in the form of juices, jellies, jams, etc. are breeding objectives in which the potential of crab apples can still be exploited effectively (Sestras *et al.*, 2011; Wang *et al.*, 2018; Yu *et al.*, 2021; Muresan *et al.*, 2022). Probably a survey among NBG visitors during apple flowering using basic criteria for assessing characteristics of interest in ornamental varieties (e.g., after Romer, 2002: flower colour, fruit colour and persistence, environmental tolerance, growth habit - tree size and shape, disease resistance, food for wildlife etc.) would provide interesting and useful information both as a perception of respondents, as well as the direction of the future activity on conservation and ornamental apple breeding.

Conclusions

The study provided a good knowledge of the floral peculiarities of 15 crab apple genotypes, as well as the differences between them in the conditions of an area where the ornamental apple is not one of the most widespread and appreciated decorative tree species. The identification of genotypes with a high ornamental value under experimental conditions could be advantageous in order to extend them for the beautification of urban areas, or for use in new apple breeding works. Further surveys of the diversity of 'wild' and crabapple apple genotypes should facilitate the conservation of genetic resources *in situ* (e.g., conservation of genetically differentiated species and *Malus* cultivars) or *ex situ* (e.g., establishment of core collections of genetic resources, maximizing genetic diversity), along with dessert apple cultivars and ornamental ones.

Authors' Contributions

Conceptualization: IG and AFS; Data curation: IG, KV, GA; Formal analysis: IG and AFS; Investigation: IG, KV and GA; Methodology: IG, CD and AFS; Software: IG and AFS; Supervision: AFS; Writing - original draft: IG; Writing - review and editing: CD and AFS.

All authors read and approved the final manuscript.

Ethical approval (for researches involving animals or humans)

Not applicable.

Acknowledgements

This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

Conflict of Interests

The authors declare that there are no conflicts of interest related to this article.

References

Brewer JE, Nichols LP, Powell CC, Smith EM (1979). The flowering crabapple – a tree for all seasons. Cooperative Extension Service of the Northeast States.

Campbell CS, Greene CW, Dickinson TA (1991). Reproductive biology in subfam. Maloideae (Rosaceae). Systematic Botany 16:333-349.

Coart E, Vekemans X, Smulders MJ, Wagner I, Van Huylenbroeck J, Van Bockstaele E, Roldán-Ruiz I (2003). Genetic variation in the endangered wild apple (*Malus sylvestris* (L.) Mill.) in Belgium as revealed by amplified fragment length polymorphism and microsatellite markers. Molecular Ecology 12(4):845-857. *https://doi.org/10.1046/j.1365-294X.2003.01778.x*

Cornille A, Antolín F, Garcia E, Vernesi C, Fietta A, Brinkkemper O, Kirleis W, Schlumbaum A, Roldán-Ruiz I (2019). A multifaceted overview of apple tree domestication. Trends in Plant Science 24(8):770-782. *https://doi.org/10.1016/j.tig.2013.10.002*

Cornille A, Giraud T, Smulders MJ, Roldán-Ruiz I, Gladieux P (2014). The domestication and evolutionary ecology of apples. Trends in Genetics 30(2):57-65. *https://doi.org/10.1016/j.tig.2013.10.002*

Dan C, Sestras AF, Bozdog C, Sestras RE (2015). Investigation of wild species potential to increase genetic diversity useful for apple breeding. Genetika 47(3):993-1011. *https://doi.org/10.2298/GENSR1503993D*

den Boer AF (1959). Flowering crabapples. American Assoc. of Nurserymen, Washington, D.C. 226 p.

Denoirjean T, Doury G, Cornille A, Chen X, Hance T, Ameline A (2021). Genetic structure of *Malus sylvestris* and potential link with preference/performance by the rosy apple aphid pest *Dysaphis plantaginea*. Scientific Reports 11, 5732 (2021). *https://doi.org/10.1038/s41598-021-85014-x*

Dirr MA (1998). Manual of woody landscape plants: Their identification, ornamental characteristics, culture, propagation, and uses. Stipes Publishing LLC Champaign, Illinois USA 1187 p.

Draper EA, Chatfield JA, Cochran KD (1996). The magic of *Malus*. American Nurseryman 184(4):46-55.

Endress PK (1994). Diversity and evolutionary biology of tropical flowers. Cambridge: Cambridge University Press.

Endress PK (2001). Origins of flower morphology. Journal of Experimental Zoology Molecular and Developmental Evolution 291:105-115.

Fiala JL (1994). Flowering crabapples: The genus *Malus*. Timber Press, Portland, Oregon 340 p.

Green TL (1996). Crabapples – when you're choosing one of those apple cousins, make flowers your last consideration. American Horticulturist 75:18-23.

Guthery DE, Hasselkus ER (1992). Jewels of the landscape. American Nurseryman 175(1):28-41.

Hamilton D (1986). Supply and demand information – The most popular shade and flowering trees. Ornamentals Northwest Newsletter and Index 4:108.

Hammer Ø, Harper, DAT, Ryan PD (2001). Past: paleontological statistics software package for education and data analysis. Palaeontologia Electronica 4(1):1-9. *http://palaeo-electronica.org/2001_1/past/issue1_01.htm*

Han M, Li G, Liu X, Li A, Mao P, Liu P, Li H (2019). Phenolic profile, antioxidant activity and anti-proliferative activity of crabapple fruits. Horticultural Plant Journal 5(4):155-163. *https://doi.org/10.1016/j.hpj.2019.01.003*

Hartmann HT, Davies FT (1990). Plant propagation principles and practices. Fifth edition. Prentice Hall Inc., Englewood Cliffs, New Jersey 6-7.

Hu D, Han Y, Xu J, Wang L, Shengxiang ZH, Dun X (2018). A new ornamental crabapple cultivar 'Changhui'. Acta Horticulturae Sinica 45(S2):2811-2812.

Hussain SZ, Naseer B, Qadri T, Fatima T, Bhat TA (2021). Apples (*Pyrus Malus*) - Morphology, Taxonomy, Composition and Health Benefits. In: Fruits Grown in Highland Regions of the Himalayas Springer, Cham pp 17-34.

Iles JK (1999). Crabapples for Midwestern landscapes. Iowa State University Extension publication 1814.

Jefferson RM (1970). History, progeny, and locations of crabapples of documented authentic origin. National Arboretum Contribution 2:1-107.

Kemp H (1996). Pollination results of apple, malus, pear, plum and cherry of the international working group on pollination. Acta Horticulturae 423:243-298. *https://doi.org/10.17660/ActaHortic.1996.423.31*

Mitre V, Mitre I, Sestras AF, Sestras RE (2010). New products against apple scab and powdery mildew attack in organic apple production. Notulae Botanicae Horti Agrobotanici Cluj-Napoca 38(3):234-238.

Mureșan AE, Sestras AF, Militaru M, Păucean A, Tanislav AE, Pușcaș A, Mateescu M, Mureșan V, Marc RA, Sestras RE (2022). Chemometric comparison and classification of 22 apple genotypes based on texture analysis and physico-chemical quality attributes. Horticulturae 8(1):64. *https://doi.org/10.3390/horticulturae8010064*

Roloff A, Gillner S, Kniesel R, Zhang D (2018). Interesting and new street tree species for European cities. Journal of Forest and Landscape Research 3(1):1-7. *https://doi.org/10.13141/jflr.v3i1.1995*

Romer JP (2002). A survey of selection preferences for crabapple cultivars and species. Retrospective Theses and Dissertations 17486. Iowa State University, Ames, Iowa. *https://lib.dr.iastate.edu/rtd/17486*

Saito A, Fukasawa Akada T, Igarashi M, Sato T, Suzuki M (2007). Self-compatibility of 3 apple [*Malus pumila*] cultivars and identification of S-allele genotypes in their self-pollinated progenies. Horticultural Research pp 27-33.

Saracoglu O, Altunta E (2021). Assessment of some biotechnical characteristics of Japanese crabapple depending on fruit size and maturity stage. Alinteri Journal of Agriculture Sciences 36(1):21-26. *10.47059/alinteri/V36I1/AJAS21004*

Sestras AF, Pamfil D, Dan C, Bolboaca SD, Jäntschi L, Sestras RE (2011). Possibilities to improve apple scab (*Venturia inaequalis* (Cke.) Wint.) and powdery mildew [*Podosphaera leucotricha* (Ell. et Everh.) Salm.] resistance on apple by increasing genetic diversity using potentials of wild species. Australian Journal of Crop Science 5(6):748-755. *http://www.cropj.com/sestras%20_5_6_2011_748_755.pdf*

Sestras R, Pamfil D, Ardelean M, Botez C, Sestras A, Mitre I, Dan C, Mihalte L (2009). Use of phenotypic and MAS selection based on bulk segregant analysis for study of genetic variability induced by artificial hybridization on apple. Notulae Botanicae Horti Agrobotanici Cluj-Napoca 37(1):273-277.

Sheffield CS, Smith RF, Kevan PG (2005). Perfect syncarpy in apple (*Malus × domestica* 'Summerland McIntosh') and its implications for pollination, seed distribution and fruit production (Rosaceae: Maloideae). Annals of Botany 95(4):583-591. *https://doi.org/10.1093/aob/mci058*

Shen T, Han M, Liu Q, Yang C, Meng J, Li H (2021). Pigment profile and gene analysis revealed the reasons of petal colour difference of crabapples. Brazilian Journal of Botany 44(2):287-296. *https://doi.org/10.1007/s40415-020-00682-9*

Smith EM, Treaster SA (1990). Evaluation of flowering crabapple susceptibility to apple scab in Ohio – 1990. Ornamental plants – A summary of research 1991. Special Circular 137. The Ohio State University, Ohio Agricultural Research and Development Center, Wooster, Ohio. *https://core.ac.uk/download/pdf/159603459.pdf*

Spicer PG, Potter DA, McNiel RE (1995). Resistance of flowering crabapple cultivars to defoliation by the Japanese beetle (Coleoptera: Scarabaeidae). Journal of Economic Entomology 88(4):979-985. *https://doi.org/10.1093/jee/88.4.979*

Volk GM, Chao CT, Norelli J, Brown SK, Fazio G, Peace C, McFerson J, Zhong GY, Bretting P (2015). The vulnerability of US apple (*Malus*) genetic resources. Genetic Resources and Crop Evolution 62(5):765-794. *https://doi.org/10.1007/s10722-014-0194-2*

Volk GM, Cornille A, Durel CE, Gutierrez B (2021). Botany, taxonomy, and origins of the apple. In: Korban SS (Ed) The Apple Genome. Compendium of Plant Genomes. Springer, Cham. *https://doi.org/10.1007/978-3-030-74682-7_2*

Volk GM, Henk AD, Baldo A, Fazio G, Chao CT, Richards CM (2015). Chloroplast heterogeneity and historical admixture within the genus *Malus*. American Journal of Botany 102(7):1198-1208. *https://doi.org/10.3732/ajb.1500095*

Wang W, Lai X, Zhang E, Xu Q, Zhang D, Zhang W (2018). Analysis of fruit quality of 15 ornamental crabapple varieties. Journal of Jiangsu Forestry Science and Technology 45(1):1-9.

Wang YR, Lu YF, Hao SX, Zhang ML, Zhang J, Tian J, Yao YC (2015). Different colouration patterns between the red- and white-fleshed fruits of *Malus* crabapples. Scientia Horticulturae 194:26-33. *https://doi.org/10.1016/j.scienta.2015.07.041*

Ward DL, Marini RP, Byers RE (2001). Relationships among day of year of drop, seed number, and weight of mature apple fruit. HortScience 36:45-48.

Way RD, Aldwinckle HS, Lamb RC, Rejman A, Sansavini S, Shen T, Watkins R, Westwood MN, Yoshida Y (1991). Apples (*Malus*). Acta Horticulturae 290:3-46. *https://doi.org/10.17660/ActaHortic.1991.290.1*

Yu C, Wang M, Liu F, Wang M (2021). Nutrient compositions and functional constituents of 12 crabapple cultivars (*Malus* Mill. species): Aptitudes for fresh consumption and processing. Journal of Food Processing and Preservation 45:e15341. *https://doi.org/10.1111/jfpp.15341*

Zhang WX, Zhao MM, Fan JJ, Zhou T, Chen YX, Cao FL (2017). Study on relationship between pollen exine ornamentation pattern and germplasm evolution in flowering crabapple. Scientific Reports 7:39759. *https://doi.org/10.1038/srep39759*

Zhao J, Wang R, Huang CX, Mao ZQ, Guo L, Shen X (2014). Taxonomic analysis of volatiles emitted by ornamental crabapple flowers. Acta Ecologica Sinica 34(4):213-218. *https://doi.org/10.1016/j.chnaes.2014.01.003*

Zhou T, Fan J, Zhao M, Zhang D, Li Q, Wang G, Zhang W, Cao F (2019). Phenotypic variation of floral organs in *Malus* using frequency distribution functions. BMC Plant Biology 19:574. *https://doi.org/10.1186/s12870-019-2155-6*

Zhou T, Ning K, Zhang W, Chen H, Lu X, Zhang D, El-Kassaby YA, Bian J (2021). Phenotypic variation of floral organs in flowering crabapples and its taxonomic significance. BMC Plant Biology 21:503 (2021). *https://doi.org/10.1186/s12870-021-03227-8*