BG Pulse Journal USA
ISSN:1947-2536 http://www.bgpulseusa.com/index.php/bg
BG PULSE JOURNAL

IN VITRO MICROPROPAGATION OF ORNAMENTAL AND MEDICINAL SHRUBS: A COMPARATIVE ANALYSIS OF CULTURE MEDIA, PHYTOHORMONES, AND REGENERATION EFFICIENCY

Jamshid Temirov, Nargiza Jo‘rayeva , Shuxratbek Inomjonov, Dilorom Abdullayeva, Bahodirjon Oxunjonov, Ro'ziyeva Zilola
Research Institute of Forestry, Tashkent, Uzbekistan
E-mail: jgtemirov@mail.ru, nargizajorayeva2124@.com
Doi: https://doi.org/10.5281/zenodo.21802110

Abstract: This study presents a comparative analysis of the efficiency of in vitro micropropagation systems for five major ornamental and medicinal shrub genera: barberry (*Berberis L.*), cotoneaster (*Cotoneaster Medik.*), photinia (*Photinia Lindl.),* smoke tree (*Cotinus Mill.*), and viburnum (*Viburnum L.*). The analysis encompassed the mineral composition of culture media, the type and concentration of cytokinins and auxins, shoot proliferation, root induction, and ex vitro acclimatization. Evidence from the literature demonstrated species-specific responses to Murashige–Skoog (MS) and Woody Plant Medium (WPM). The MS medium was generally associated with higher regenerative responses in Berberis, Cotoneaster, and Cotinus species, whereas WPM was more effective for Viburnum and certain Photinia species. During the multiplication stage, BA/BAP emerged as a broadly effective cytokinin, while thidiazuron (TDZ) produced particularly high proliferation rates in Cotoneaster. In Cotoneaster wilsonii, supplementation with 0.5 mg/L TDZ and 0.1 mg/L NAA resulted in 34 shoots per explant. In Berberis asiatica, the combination of BA with IAA/NAA on MS medium achieved 100% shoot proliferation, while ½ MS supplemented with 0.05 µM IAA resulted in 70% rooting. For Cotinus coggygria, systems based on meta-methoxytopolin cytokinins enabled shoot multiplication rates of up to 10.4–10.7 shoots per explant. In Viburnum species, WPM supplemented with combinations of BA, TDZ, and IBA/NAA supported high rates of regeneration and rooting. Overall, the findings demonstrate that in vitro micropropagation is important not only for the rapid production of planting material but also for the conservation of rare genotypes, the production of medicinal bioactive compounds from standardized plant material, and the reduction of anthropogenic pressure on natural populations.

Keywords: in vitro micropropagation; microclonal propagation; Berberis; Cotoneaster; Photinia; Cotinus; Viburnum; Murashige–Skoog medium; Woody Plant Medium; cytokinins; auxins; regeneration; acclimatization.

Annotatsiya. Ushbu maqolada manzarali va dorivor butalarni in vitro mikroko‘paytirish texnologiyalarining samaradorligi beshta asosiy turlar- zirk (*Berberis L.*), irg‘ay (*Cotoneaster Medik.*), fotiniya (*Photinia Lindl.*), skumpiya (*Cotinus Mill.*) va kalina (*Viburnum L.*) misolida qiyosiy tahlil qilindi. Tahlil ozuqa muhitining mineral tarkibi, sitokinin va auksinlarning turi hamda konsentratsiyasi, novda proliferatsiyasi, ildiz hosil bo‘lishi va ex vitro akklimatizatsiya ko‘rsatkichlarini qamrab oldi. Adabiyot ma’lumotlari MS (Murashige-Skoog) va WPM (Woody Plant Medium) muhitlarining turga xos samaradorligini ko‘rsatdi. MS muhiti zirk, irg‘ay va skumpiya turlarining ko‘pchiligida yuqori regenerativ javob bilan bog‘liq bo‘lsa, WPM muhiti kalina hamda ayrim fotiniya turlarida samaraliroq bo‘lgan. Ko‘paytirish bosqichida BA/BAP universal sitokinin sifatida namoyon bo‘lsa, TDZ irg‘ay uchun ayniqsa yuqori proliferatsiya

ko‘rsatkichlarini ta’minlagan. Cotoneaster wilsonii da 0,5 mg/L TDZ va 0,1 mg/L NAA qo‘llanilganda 34 shoot/explant hosil bo‘lgan. Berberis asiatica da MS muhitida BA va IAA/NAA kombinatsiyasi 100% shoot proliferatsiyasini, ½ MS + 0,05 µM IAA esa 70% ildizlanishni ta’minlagan. Cotinus coggygria uchun meta-metoksitopolinlar asosidagi tizimlar 10,4–10,7 shoot/explant darajasigacha ko‘payish imkonini bergan. Kalina turlarida esa WPM muhiti va BA, TDZ hamda IBA/NAA kombinatsiyalari yuqori regeneratsiya va ildizlanish ko‘rsatkichlarini ta’minlagan. Tahlil natijalari in vitro mikroko‘paytirishning nafaqat tezkor ko‘chat yetishtirish, balki kamyob genotiplarni saqlash, dorivor bioaktiv moddalarni standartlashtirilgan xomashyo sifatida olish va tabiiy populyatsiyalarga tushadigan antropogen bosimni kamaytirishdagi strategik ahamiyatini ko‘rsatdi.

Kalit so‘zlar: in vitro mikroko‘paytirish; mikroklonal ko‘paytirish; Berberis; Cotoneaster; Photinia; Cotinus; Viburnum; MS muhiti; WPM; sitokinin; auksin; regeneratsiya; akklimatizatsiya.

1. INTRODUCTION

Ornamental and medicinal shrubs have substantial practical value from ecological, pharmacological, and landscape-architectural perspectives. However, conventional propagation methods are often constrained by poor seed propagation, physiological seed dormancy, intergenotypic variability, low rooting capacity of cuttings, and seasonal limitations. These constraints are particularly critical for rare and declining species, for which the limited availability of propagation material can substantially reduce the effectiveness of conservation programs.

In vitro micropropagation represents a biotechnological approach capable of overcoming many of these limitations. Its principal advantages include the rapid production of large quantities of genetically uniform planting material, the possibility of maintaining propagation cycles throughout the year, and the ex situ conservation of valuable genotypes under controlled conditions.

A study on Berberis asiatica demonstrated that supplementation of Murashige–Skoog (MS) medium with 1.0 µM BA resulted in 50% seed germination, whereas combinations of BA and auxins induced 100% shoot proliferation from callus cultures. During the rooting stage, ½ MS medium supplemented with 0.05 µM IAA achieved a 70% rooting rate, with an average of 2.36 roots produced per shoot.

A study on Cotoneaster wilsonii using nodal explants demonstrated that MS medium supplemented with 0.5 mg/L TDZ and 0.1 mg/L NAA produced an average of 34 shoots per explant. In the same study, ½ MS medium containing 0.5 mg/L IBA was identified as the optimal treatment for root induction, while post-acclimatization survival reached 98%. However, higher concentrations of TDZ increased the incidence of hyperhydricity, whereas silicon supplementation helped alleviate this physiological disorder. Despite these advances, protocols developed for different woody shrub species have generally been reported as individual, species-specific studies. Therefore, a unified comparative assessment of culture media, phytohormonal treatments, and regeneration efficiency is needed.

This study aimed to comparatively evaluate in vitro micropropagation protocols for plants belonging to the genera Berberis L., Cotoneaster Medik., Photinia Lindl., Cotinus Mill., and Viburnum L.; identify species-specific optimal culture media and phytohormone combinations; and assess the practical potential of this technology for plant propagation and biodiversity conservation.

2. Materials and Methods

2.1. Collection and Analysis of Literature Data

The study employed a comparative scientific review approach. Data on the in vitro micropropagation of species belonging to the genera Berberis, Cotoneaster, Photinia, Cotinus, and Viburnum, as reported in the scientific literature provided for analysis, were systematically compiled and evaluated. The extracted data were grouped according to culture medium, plant growth regulators, explant type, multiplication rate, rooting percentage, and post-acclimatization survival.

For each taxon, the following key parameters were compared:

- sterilization efficiency;
- in vitro response of seeds or explants;
- shoot regeneration;
- number of shoots per explant (shoots/explant);
- rooting percentage;
- root-to-shoot ratio;
- post-acclimatization survival rate;
- physiological constraints limiting regeneration.

2.2. Culture Media and Phytohormones

The analysis primarily included protocols employing Murashige–Skoog (MS), Woody Plant Medium (WPM), Gamborg B5, Quoirin–Lepoivre (QL), Lloyd–McCown, and other culture media.

Plant growth regulators were classified into two major groups:

Cytokinins: BA/BAP, TDZ, kinetin, 2iP, MemT, and MemTR;

Auxins: IBA, IAA, and NAA.

Particular attention was given to the effect of the cytokinin-to-auxin ratio on shoot proliferation and root differentiation.

2.3. Comparative Assessment

Technological efficiency across species was evaluated based on the number of shoots per explant (shoots/explant), rooting percentage, and post-acclimatization survival rate. The results were interpreted not only in terms of the maximum values achieved but also with respect to the species-specific responses to culture media and plant growth regulators.

3. Results

3.1. Micropropagation in the Genus Berberis

In vitro regeneration in the genus Berberis was strongly dependent on the composition of the culture medium and the type of cytokinin used. In B. asiatica, MS medium supplemented with 1.0 µM BA increased seed germination to 50%. During callus induction, the combination of MS medium with 1.0 µM BA and 0.1 µM 2,4-D resulted in 100% callus formation. Shoot regeneration from callus reached 100% on MS medium supplemented with either 2.0 µM BA + 0.5 µM IAA or 6.0 µM BA + 0.5 µM NAA. During the rooting stage, ½ MS supplemented with 0.05 µM IAA achieved a 70% rooting rate and a mean of 2.36 roots per shoot. Post-acclimatization survival reached 65% in a vermiculite:soil:sand substrate at a 1:1:1 ratio.

For B. aristata and B. chitria, WPM was found to be more effective. In particular, the application of 0.5 µM TDZ in B. aristata resulted in 26.5 shoots per callus. In B. chitria, WPM supplemented with 8.88 µM BA and 1.34 µM NAA, together with casein hydrolysate and GA_3, produced 22.89 shoots per explant. These findings indicate that no single universal micropropagation protocol can be applied across the genus Berberis. MS appears to be more effective for species such as B. asiatica and B. vulgaris, whereas WPM may provide superior results for certain woody or physiologically demanding species.

3.2. Micropropagation in the Genus Cotoneaster

Species of Cotoneaster generally exhibited high regenerative responses on MS medium. In C. horizontalis, MS supplemented with 3 mg/L BA produced 6.40 shoots per explant, whereas in C. wilsonii, the combination of MS with 0.5 mg/L TDZ and 0.1 mg/L NAA resulted in 34 shoots per explant, representing one of the highest proliferation rates among the protocols evaluated.

For C. wilsonii, ½ MS supplemented with 0.5 mg/L IBA was identified as the optimal treatment for root induction. Hyperhydricity was observed at higher TDZ concentrations, indicating the need to optimize phytohormone levels during micropropagation. Silicon supplementation reduced the severity of these physiological disorders.

In C. melanocarpus, the combination of BA, IBA, and GA_3 in either MS or QL medium resulted in 8.83 shoots per explant. During the rooting stage, ½ MS supplemented with 0.5 mg/L IBA produced an average of 4.03 roots per shoot.

Overall, these findings indicate that TDZ has a high proliferative potential in Cotoneaster; however, excessive TDZ concentrations may increase the risk of hyperhydricity, highlighting the importance of optimizing cytokinin levels for efficient and physiologically stable micropropagation.

3.3. Micropropagation in the Genus Photinia

For Photinia × fraseri, both MS and WPM media demonstrated effective regeneration responses. The combination of WPM supplemented with kinetin and IBA produced 5.75 shoots per explant from nodal explants. In contrast, ¼ MS supplemented with 0.6 mg/L NAA resulted in 100% rooting and an average of 6.5 roots per shoot.

The effectiveness of WPM in Photinia species may be attributed to its mineral composition, which is generally more compatible with the physiological requirements of woody plants. At the rooting stage, the use of diluted MS medium enhanced root differentiation and development.

3.4. Micropropagation of Cotinus coggygria

For Cotinus coggygria, MS medium produced a stronger regenerative response than the other culture media evaluated. The combination of MS supplemented with 1.0 mg/L BA and 0.1 mg/L IBA resulted in 96% regeneration and 4.6 shoots per explant. Particular attention has been given to the meta-methoxytopolin cytokinins MemT and MemTR. These cytokinins supported shoot proliferation rates of 10.4–10.7 shoots per explant in C. coggygria ‘Royal Purple’. During the rooting stage, 10 µM IBA resulted in 100% rooting and was associated with minimal basal callus formation. These findings indicate that next-generation cytokinins such as MemT and MemTR may represent promising alternatives to conventional BA for improving shoot proliferation.

3.5. Micropropagation in the Genus Viburnum

Species of Viburnum frequently exhibited high regeneration efficiency on WPM medium. In V. dentatum, supplementation of WPM with either 40 µM BA or 8 µM TDZ resulted in regeneration rates of 70–90%. For V. odoratissimum, WPM supplemented with 0.5 µM BA and 14 µM GA_3 supported high shoot proliferation. In V. opulus ‘Roseum’, WPM supplemented with 2.0 mg/L 6-BA and 0.15 mg/L IBA produced a multiplication coefficient of 7.17. During the rooting stage, ½ MS supplemented with IBA and activated charcoal resulted in an 86.7% rooting rate.

In the rare endemic species Viburnum treleasei, WPM supplemented with 1.1 µM BA was used during the multiplication stage, whereas WPM containing 1.3 µM NAA was applied for root induction. In this case, the principal value of the micropropagation system is determined not by achieving maximum multiplication rates but by its potential to conserve valuable genetic resources of a rare and geographically restricted species.

4. Discussion

4.1. Species-Specific Responses to Culture Media

The comparative analysis revealed a clear ecological and physiological distinction between MS and WPM culture media. Owing to its relatively high concentration of mineral salts, MS medium supported strong regenerative responses in Berberis, Cotoneaster, and Cotinus species. However, a high mineral load is not necessarily optimal for all woody plants. The mineral composition of WPM, which was specifically formulated for woody plant culture, may explain its superior performance in Viburnum and certain Berberis species. Therefore, rather than applying the concept of "MS as a universal medium," culture-medium selection should account for the interactions among species, genotype, explant type, and phytohormonal treatment.

4.2. Role of Cytokinins in Regeneration

BA/BAP emerged as the most broadly applicable cytokinin among the species evaluated. However, the highest proliferation rates were not consistently associated with BA. TDZ produced a particularly high proliferation rate of 34 shoots per explant in Cotoneaster wilsonii. At the same time, excessive TDZ concentrations may increase the incidence of hyperhydricity, potentially compromising the physiological quality of regenerated shoots.

In Cotinus coggygria, the meta-methoxytopolin cytokinins MemT and MemTR enabled proliferation rates of 10.4–10.7 shoots per explant. Thus, cytokinin selection depends not only on concentration but also on the chemical nature of the regulator and the species-specific physiological response of the plant.

4.3. Rooting Strategies

Across the protocols evaluated, the use of diluted MS or WPM media during the rooting stage was common. In particular, ½ MS and ¼ MS media enhanced root differentiation and development. IBA emerged as the most broadly effective auxin, whereas NAA demonstrated high effectiveness in certain Photinia and Viburnum species. The incorporation of activated charcoal may also improve root system development in species such as Viburnum opulus. In addition, short-term pulse treatments with IBA may represent an effective strategy for enhancing rooting efficiency.

4.4. Acclimatization

High regeneration efficiency under in vitro conditions does not necessarily translate into high plant survival after transfer to ex vitro conditions. Micropropagated plants require time to develop functional leaf cuticles, regulate stomatal activity, and adapt their water relations to the substantially different ex vitro environment. Therefore, the overall effectiveness of a micropropagation protocol should be evaluated not solely on the basis of shoots per explant but by considering rooting, acclimatization, and survival rates collectively.

For example, although 100% shoot proliferation was reported for B. asiatica, post-acclimatization survival was 65%. In contrast, C. wilsonii achieved a survival rate of 98%. This difference demonstrates that the assessment of a micropropagation protocol should extend beyond the laboratory regeneration stage and encompass the successful establishment of regenerated plants under ex vitro conditions.

Table 1. In vitro micropropagation efficiency of ornamental and medicinal plants: culture media, phytohormones, and key constraints

Taxon	Most effective culture medium and growth regulators	Highest regeneration/multiplication response	Rooting response	Key constraint
Berberis asiatica	MS + BA + IAA/NAA	100% shoot regeneration	70%	Survival during acclimatization
Berberis	WPM + TDZ	26.5 shoots/callus	55.6%	Limited

aristata				availability of seed and explant material
Berberis chitria	WPM + BA + NAA	22.89 shoots/explant	100%	Shoot necrosis
Cotoneaster horizontalis	MS + BA	6.40 shoots/explant	30%	Low rooting efficiency
Cotoneaster wilsonii	MS + TDZ + NAA	34.0 shoots/explant	100%	Hyperhydricity
Cotoneaster melanocarpus	MS + BA + IBA + GA_3	8.83 shoots/explant	4.03 roots/shoot	Need to optimize regeneration efficiency
Photinia × fraseri	WPM + kinetin + IBA	5.75–5.90 shoots/explant	100%	Limited rooting under conventional conditions
Cotinus coggygria	MS + MemT/MemTR	10.4–10.7 shoots/explant	100%	Genotype-dependent regenerative response
Viburnum dentatum	WPM + BA/TDZ	90% regeneration	>65%	Optimization of regeneration conditions
Viburnum opulus	WPM + 6-BA + IBA	7.17-fold multiplication coefficient	86.7%	Initially slow shoot proliferation
Viburnum odoratissimum	WPM + BA + GA_3	High proliferation	82%	Need to optimize rooting efficiency
Viburnum treleasei	WPM + BA	Effective regeneration	WPM + NAA	Conservation priority due to its rare endemic status

5. Major Constraints and Strategies for Their Mitigation

The major constraints identified in in vitro micropropagation were classified into five principal groups:

Contamination and endophytic microorganisms. Particularly for explants collected under field conditions, sterilization protocols need to be carefully optimized to minimize microbial contamination while maintaining explant viability.

Shoot necrosis. In Berberis chitria, supplementation with casein hydrolysate and GA_3 helped reduce the incidence of shoot necrosis.

Hyperhydricity. This physiological disorder was particularly evident in Cotoneaster wilsonii at high TDZ concentrations. Silicon supplementation helped reduce the severity of hyperhydricity.

Low rooting efficiency. Root induction can be improved through the use of diluted MS/WPM media supplemented with IBA or NAA and, in some cases, activated charcoal.

Mortality during acclimatization. Successful establishment during the transition to ex vitro conditions depends strongly on substrate composition, humidity, light intensity, and gradual acclimatization procedures.

6. Conservation and Practical Significance of In Vitro Micropropagation

The results of the comparative analysis indicate that micropropagation has broader significance than simply providing an efficient plant propagation technology. For rare species such as Berberis aristata, Cotoneaster wilsonii, and Viburnum treleasei, in vitro collections may reduce the pressure on natural populations by providing an alternative source of propagative material.

A study of Berberis asiatica reported that in vitro-derived plants contained higher levels of berberine and palmatine than naturally growing plants and exhibited enhanced antioxidant and antimutagenic activities. This finding provides an important basis for integrating micropropagation with pharmaceutical and biotechnological applications.

Thus, in vitro micropropagation can be strategically applied in three major areas:

ex situ conservation of rare and threatened genotypes;

large-scale production of standardized planting material;

production of biomass enriched in biologically active compounds.

7. Conclusions

The comparative analysis demonstrated that the efficiency of in vitro micropropagation in Berberis, Cotoneaster, Photinia, Cotinus, and Viburnum species is strongly dependent on species-specific combinations of culture media and plant growth regulators.

MS medium represented a broadly applicable and effective basal medium for Berberis, Cotoneaster, and Cotinus, whereas WPM demonstrated superior performance in woody Viburnum species and certain Berberis taxa. BA/BAP was identified as the most broadly applicable cytokinin, while TDZ showed high proliferation potential in Cotoneaster species and MemT/MemTR demonstrated particularly promising performance in Cotinus coggygria.

The highest shoot proliferation rate was recorded in Cotoneaster wilsonii, reaching 34 shoots per explant. High proliferation was also observed in Berberis chitria (22.89 shoots/explant), Cotinus coggygria (10.4–10.7 shoots/explant), and Viburnum opulus ‘Roseum’ (7.17-fold multiplication coefficient).

During the rooting stage, IBA emerged as the most broadly effective auxin, although NAA also demonstrated high efficiency in certain Photinia and Viburnum species. Diluted MS/WPM media, activated charcoal, and short-term auxin treatments represent promising strategies for enhancing root differentiation and development.

Overall, a high regeneration rate should not be considered the sole criterion for evaluating the efficiency of a micropropagation protocol. An optimal protocol should integrate shoot proliferation, rooting, acclimatization, and ex vitro survival into a single evaluation framework. This approach is particularly important for rare and medicinal woody species because it can facilitate the conservation of genetic resources, expand the production of planting material, and reduce anthropogenic pressure on natural populations.

8. Practical Recommendations

Future studies should move beyond the “one medium–one protocol” approach and develop optimization systems tailored to individual genotypes and explant types.

The following research directions are particularly promising:

- comparative evaluation of gradient concentrations of MS and WPM media;
- testing combinations of BA, TDZ, kinetin, and next-generation cytokinins;
- relating IBA/NAA ratios to quantitative and qualitative parameters of root development;

- application of silicon and other mineral supplements to reduce hyperhydricity;
- standardization of substrate composition and moisture regimes during acclimatization;
- establishment of in vitro gene banks and cryopreservation systems for rare species;
- assessment of the genetic stability of micropropagated plants using molecular markers.

In vitro micropropagation should not be regarded merely as a conventional vegetative propagation technique for woody shrubs. Rather, it should be considered an integrated biotechnological platform that connects plant propagation, conservation, biomass production, and the long-term preservation of valuable genetic resources.

References

1. Бикметова К. Р., Смирнова Ю. С. Исследование эффективности различных способов стерилизации эксплантов скумпии кожевенной (Cotinus coggygria) в условиях микроклонального размножения //Рисоводство. – 2021. – №. 1 (50). – С. 49-52.
2. Rovină E. A. et al. In vitro regeneration capacity of the ornamental varieties related to the cultural media. – 2010.
3. Shi, K., Zheng, C.X., 2015. *Liquid culture system of rapid propagation of Cotinus coggygria 'Royal Purple'.* Journal of Plant Physiology 51, 553–558.
4. Ilczuk, A., Jacygrad, E., 2016. *The effect of IBA on anatomical changes and antioxidant enzyme activity during the in vitro rooting of smoke tree (Cotinus coggygria Scop.).* Scientia Horticulturae 210, 268–276.
5. Jacygrad, E., Ilczuk, A., Mikos, M., Jagiełło-Kubiec, K., 2012. *Effect of medium type and plant growth regulators on the in vitro shoot proliferation of Cotinus coggygria Scop. 'Royal Purple'.* Acta Scientiarum Polonorum, Hortorum Cultus 11, 143–151.
6. Pacholczak, A., Petelewicz, P., Jagiełło-Kubiec, K., Ilczuk, A., 2015b. *Physiological aspects in propagation of smoke tree (Cotinus coggygria Scop.) 'Royal Purple' by stem cuttings.* Acta Scientiarum Polonorum, Hortorum Cultus 14, 145–157.
7. Podwyszyńska, M., Węgrzynowicz-Lesiak, E., Doležal, K., Krekule, J., Strnad, M., Saniewski, M., 2012. *New cytokinins – meta-methoxytopolins in micropropagation of Cotinus coggygria Scop. 'Royal Purple'.* Propagation of Ornamental Plants 12, 220–228.
8. Podwyszyńska, M., Wojtania, A., Rojek, A., Kowalczyk, J., 2000. *Micropropagation of smoke tree.* Proc. Polish Conf. "New Technology in Nursery Production", Poznań-Kórnik, Poland, 8–9.09.2000, pp. 92–95.
9. Dai W. et al. Plant regeneration from in vitro leaf tissues of Viburnum dentatum L //Plant Cell, Tissue and Organ Culture (PCTOC). – 2011. – Т. 104. – №. 2. – С. 257-262.
10. Nobre J., Santos C., Romano A. Micropropagation of the Mediterranean species Viburnum tinus //Plant cell, tissue and organ culture. – 2000. – Т. 60. – №. 1. – С. 75-78.
11. Schoene G., Yeager T. Micropropagation of sweet viburnum (Viburnum odoratissimum) //Plant Cell, Tissue and Organ Culture. – 2005. – Т. 83. – №. 3. – С. 271-277.
12. Ibañez M. A., Martin C., Pérez C. Alternative statistical analyses for micropropagation: a practical case of proliferation and rooting phases in Viburnum opulus //In Vitro Cellular & Developmental Biology-Plant. – 2003. – Т. 39. – №. 5. – С. 429-436.
13. Şeker Karatoprak G., İlgün S. Viburnum opulus L //Novel Drug Targets with Traditional Herbal Medicines: Scientific and Clinical Evidence. – Cham : Springer International Publishing, 2022. – С. 569-583.

14. Llorente B. E., Larraburu E. E. In vitro propagation of fraser photinia using Azospirillum-mediated root development //Protocols for micropropagation of selected economically-important horticultural plants. – Totowa, NJ : Humana Press, 2012. – С. 245-258.
15. Ramírez-Malagón R. et al. Micropropagation for fraser photinia (Photinia× fraseri) //Plant cell, tissue and organ culture. – 1997. – Т. 48. – №. 3. – С. 219-222.
16. AL-Mizory L. S. M., Hassan A. M. In Vitro Multiplication of Photinia (Photinia X Fraseri) Usingdifferent Culture Media //Science Journal of University of Zakho. – 2014. – Т. 2. – №. 2. – С. 310-322.
17. Bisht A. et al. In vitro propagation and antioxidant potential of Berberis asiatica from Western Himalaya //Plant Biosystems-an International Journal Dealing with All Aspects of Plant Biology. – 2022. – Т. 156. – №. 2. – С. 490-496.
18. Brijwal L., Pandey A., Tamta S. In vitro propagation of the endangered species Berberis aristata DC. via leaf-derived callus //In Vitro Cellular & Developmental Biology-Plant. – 2015. – Т. 51. – №. 6. – С. 637-647.
19. Pandey A., Brijwal L., Tamta S. In vitro propagation and phytochemical assessment of Berberis chitria: an important medicinal shrub of Kumaun Himalaya, India //J Med Plant Res. – 2013. – Т. 7. – №. 15. – С. 930-937.