**EXOGENOUS SPERMINE APPLICATION ENHANCES ROOTING OF SEMI-HARDWOOD AND HARDWOOD CUTTINGS OF TWO *ROSA* SPECIES**

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**Abstract**

Polyamines have been demonstrated to play an important role in adventitious root formation and development in plants. In the present investigation, the effects of exogenous spermine (Spm) application on adventitious rooting of semi-hardwood and hardwood cuttings of *Rosa* *damascena* Mill. (Damask rose) and *Rosa moschata* J.Herrm. (Musk rose) were determined. Cuttings were soaked in aqueous solution of four concentrations of Spm (1, 2, 3, and 4 mM, along with control) plus 200 mg l­-1 IBA in each treatment for 24hr and then were placed in a mixture of topsoil:sand:leaf mold (1:1:1 v/v) as rooting media in greenhouse benches. Results showed that the highest percentage of rooting (91.5%), root number (2.58), root length (8.64 cm) and root fresh and dry weights (0.31 g and 0.055 g, respectively) were obtained for Damask rose hardwood cuttings at 2 mM Spm. However, concentrations more than 3 mM showed negative effects on most parameters. In Musk rose, the maximum percentage of rooting (66.25%) and the highest root number (1.91) were observed after application of 3 mM Spm for hardwood and semi-hardwood cuttings, respectively. These results demonstrated that Spm could promote rooting of cuttings of these two *Rosa* species. However, between two species and two types of cutting woods, Damask rose and hardwood cuttings showed better results, especially at 2 to 3 mM Spm.

**Key words:** *Rosa* *damascena* Mill. (Damask rose); *Rosa moschata* J.Herrm. (Musk rose); Polyamines (PAs); Rooting of cuttings

**INTRODUCTION**

The genus *Rosa* contains over 130 recognized species (Anderson 2007) and millions of rose bushes are planted in garden or pots and billions of rose cut flowers are sold annually over the world (Khosh-Khui and Teixeira da Silva 2006). Damask rose (*R*. *damascene*) is one of the most important medicinal, aromatic, and ornamental plants which is cultivated for its essential oil and medicinal properties in many areas of the world, such as Bulgaria, Turkey, India, and Iran (Yousefi et al. 2009). For the perfume industry, Damask rose is the most important species for the production of attar of rose, made by distilling volatile oils from the flowers. It is also used widely in the manufacture of rose water, a flavoring agent (Kiani et al. 2008). Musk rose, another important species, is native to North Africa and the area from southern Europe to western Asia (Frederick et al. 2002) and has been cultivated in Iran as a garden plant and also for extracting its water. Consequently, these two species in addition ornamental aspects have valuable medicinal properties and their clonal propagation is very important.

Roses are woody shrubs and their cultivars are propagated by seed, stem cutting, grafting, budding, cutting–graft (stenting), cutting–budding, root grafting and tissue culture (Nazari et al. 2009). Due to variability in progeny and difficulty in seed germination, most elite genotypes of roses are exclusively asexually propagated by bud-grafting or from softwood or semi-hardwood cuttings (Hartmann et al. 2002, Anderson 2007). Therefore, in order to preserve the ornamental and medicinal properties of *Rosa* species, such as Damask rose and Musk rose, it is important to find suitable materials and methods to enhance the rooting of their cuttings.

Root development is under the control of hormonal, metabolic, and environmental cues and it involve not only the five classical plant hormones, but also other growth regulators, such as PAs (Cou´ee et al. 2004). Whereas auxins seem to be universal inducers of adventitious roots, other factors are also involved and they may become limiting factor under specific conditions. Thus, inhibitors, rooting cofactors, auxin antagonists, and nutrients have been shown to modulate root formation (Friedman et al. 1982, Shyr and Kao 1985). PAs, are low molecular mass polycations that are found in all living organisms (Martin-Tanguy 2001). They are generally considered to be growth regulators and in higher plants, they have been implicated in a range of developmental processes (Cou´ee et al. 2004). Large literatures indicated that PAs play an important role in primary, lateral and adventitious root development (Cou´ee et al. 2004, Altamura et al. 1991, Biondi et al. 1990, Gaspar et al. 1997, Kevers et al. 1997) and showed that the auxin-induced root formation was accompanied by increasing levels of PAs.

Free PAs such as putrescine (Put), spermidine (Spd), and Spm and also macromolecule-bound PAs are reported to be present in root systems (Cou´ee et al. 2004). It has been reported that during poplar shoots rooting, an early increase in Put level occurred, that was accompanied by a transient increase in IAA (Gaspar et al. 1997). The same studies have shown that inhibitors of the Put biosynthesis, such as DFMO (α-difluoromethylornithine) and DFMA (α-difluoromethylarginine) applied prior to or at the beginning of the inductive phase inhibited rooting (Hausman et al. 1994) and exogenously applied Put prior to or at the beginning of the inductive phase stimulated rooting (Hausman et al. 1995).

Bartolini et al. (2009) investigated the variations of free PAs in rooting of *Vitis* rootstock. After cold treatment of the shoots at 2°C free-PAs levels were increased and therefore percentage of rooting was enhanced. They concluded that an increase in the endogenous Put and Spm could be correlated with primordia formation time. On the contrary, Spd did not appear to be correlated to the rooting process. Also, some studies have shown that the combinations of Put and IBA in both *in vitro* and *in vivo* conditions can increase percentage of rooting in some cultivars of *Olea* *europaea* L. (Rugini et al. 1992, Ozkayaet and Celik 1994). Naija et al. (2009) reported that interaction between PAs and auxins could control rooting of apple rootstock MM106 shoots.

Recently, Wu et al. (2010) demonstrated that exogenous PAs applications could improve mycorrhizal development of citrus seedlings, possibly due to changes of leaf and root sugar content. In addition, Wu et al. (2011) showed that exogenous PAs could stimulate both root morphology and colonization with arbuscular mycorrhizal fungus (AMF). They concluded that root morphological improvement of mycorrhizal seedlings by PAs was related to root phosphorous level and would result in an increment of growth performance. Also, ectomycorrhizal fungi were shown to promote root growth of Scots pine through the potential involvement of the diamine cadaverine (Cou´ee et al. 2004, Niemi et al. 2002).

Cano Castillo and Casas Martinez (2008) investigated the PAs pattern during *in vitro* rooting of *Tamarix* *boveana* and *Helianthemum* *marminorense*. They concluded that PAs seems to be important not only during the inductive phase of rooting but also during root morphogenesis. Tan and Newton (2005) showed that Put, Spd, and Spm at 0.001 mM by increasing root cell division improve rooting frequency and promote root elongation in regenerated Virginia pine (*Pinus* *virginiana* Mill.) plantlets through tissue culture. Put, Spd, and Spm at 0.01–1 mM decreased rooting frequency and reduced root elongation. Hausman et al. (1994) reported that polyamine application promoted root formation in micro-shoots of hazelnut (*Corylus* *avellana* L.). Also, two studies reported that shoot formation in Torenia stem segments (Tanimoto et al. 1994) and popula leaf segments (Kim et al. 1993) was promoted by Spd.

Faivre-Rampant et al. (2000) reported that rooting of wild-type tobacco (*Nicotiana* *tabacum* cv. Xanthi) shoots raised *in vitro* was promoted by PAs in the absence of any other growth regulator and was inhibited by two inhibitors of PAs metabolism. Also, they concluded that the auxin insensitive and recalcitrant to rooting rac mutant shoots did not respond to the same treatments. Results showed that in the basal part of the mutant stems however, the accumulation of free and conjugated Put as well as the transient increase in biosynthetic enzyme activities was delayed compared to the wild-type.

In this research, the influence of different concentrations of Spm on rooting of semi-hardwood and hardwood cuttings of Damask rose and Musk rose was investigated. However, the aim of this study was to clarify the interaction between *Rosa* species, type of wood cutting and different concentrations of Spm.

**MATERIALS AND METHODS**

***Greenhouse conditions***

This experiment was carried out in a greenhouse, located in Shiraz at Bajgah region of Iran. The greenhouse equipment for climatic control was set to produce day and night temperatures of 25±2 °C and 20±2 °C, respectively.

***Plant materials and treatments***

Semi-hardwood and hardwood cuttings of Damask rose and Musk rose with four nodes and 4–5 mm diameter for semi-hardwoods and 7-8 mm diameter for hardwoods, at dormant stage, were collected from field-grown stock plants in College of Agriculture of Shiraz University and then were disinfected with fungicide. The latitude and longitude of Shiraz is 29° 36' 54" N and 52° 32' 17" E and its altitude is about 1600 meters.

The presence of auxins is essential for rooting (Hartmann et al. 2002, Sun and Bussuk 1991) and PAs are known as ancillary compounds that modify main hormone effects on rooting and root formation. They may serve as secondary messengers for rooting. It seems that polyamine enhancement of rooting occurs only in the presence of auxin (Hartmann et al. 2002). However, according to many studies that found soaking method is more effective for rooting of woody cuttings (Hartmann et al. 2002, Kweon and Sun 1997), the bases of cuttings were inserted in an aqueous solution of IBA at 200 mg l­-1 in combination with four concentrations of Spm (1, 2, 3 and 4 mM) along with control for 24hr. Cuttings were placed in a mixture of topsoil:sand:leaf mold (1:1:1 v/v) as rooting media in greenhouse benches under intermittent mist.

***Statistical analysis***

The statistical design was arranged as a factorial in a completely randomized design with three factors including cutting types (semi-hardwood and hardwood), Spm concentrations (0, 1, 2, 3 and 4 mM) and *Rosa* species (Damask rose and Musk rose) with four replications. The percentage of rooting; number, length, fresh and dry weights of roots; length, fresh and dry weights of shoots and also leaflet number were measured. Collected data were statistically analyzed and means were compared using Duncan’s new multiple range test (DNMRT) at 5% level of probability using SPSS program.

**RESULTS**

***Percentage of rooting***

The highest percentage of rooting (91.5%) was obtained in Damask rose hardwood cuttings at 2 mM Spm (Table 1), whereas the lowest percentage of rooting (0%) was recorded forMusk rose hardwood (at 0 mM Spm) and semi-hardwood (at 0 and 1mM Spm) cuttings. Also, Musk rose hardwood cuttings at 1 mM showed the lowest percentage of rooting (33%) among rooted cuttings. The interaction between three factors on percentage of rooting was not significant. However, Musk rose and semi-hardwood cuttings had less percentage of rooting between two species and two cutting types (Table 1).

***Root number and length***

Among rooted cuttings the highest (2.58) and the lowest (1.06) root number was observed for Damask rose hardwood cuttings (at 2 mM Spm) and Musk rose hardwood cuttings (at 1 mM), respectively (Table 1). However, Musk rose hardwood (at 0 mM Spm) and semi-hardwood (at 0 and 1mM Spm) cuttings had the lowest root number (0) among all cuttings. The highest concentration (4 mM) of Spm in two species and two cutting types led to decrease in root number. The results indicated that interaction between three factors on mean root length was significant. Taller roots (with an average of 8.64 cm) were noted for Damask rose hardwood cuttings at 2 mM Spm. Minimum average roots length of rooted cuttings (1.73) was for Musk rose semi-hardwood cuttings at 2 mM Spm.

***Root fresh and dry weights***

Interaction between three factors on root dry weight was significant. However, fresh weight was not significantly affected. The highest root fresh and dry weights (0.31 g and 0.055 g, respectively) were observed for Musk rose hardwood cuttings at 2 mM Spm and Musk rose semi-hardwood cuttings at 3 mM Spm, respectively. The lowest root fresh and dry weights (0 %) was recorded for Musk rose hardwood (at 0 mM Spm) and semi-hardwood (at 0 and 1mM Spm) cuttings. Among cuttings with root system, hardwood cuttings of Damask rose at 0 mM Spm had the lowest mean root fresh (0.03) and dry (0.01) weights (Table 1).

***Shoot Length and leaflet number***

Interaction between all factors had a significant effect on the average shoot length per cuttings. However, Musk rose hardwood (at 0 mM Spm) and semi-hardwood (at 0 and 1mM Spm) cuttings produced no shoot and therefore had the lowest shoot length and leaflet number (Table 1). Cuttings ofDamask rosehad the shortest shoots among rooted cuttings. The longest shoots (with an average of 24.53 cm) were found inMusk rose hardwood cuttings at 4 mM Spm. Also, the comparison between three factors indicated that leaflet number significantly was affected by species, cutting types and Spm concentrations. Semi-hardwood cuttings of Damask rose had the lowest average of leaflets number (3.18) among rooted cuttings when they received the control treatment (Table 1). The average number of leaflets per cuttings increased with increase in Spm concentration. It ranged from 3.18 to 16.58 but significantly the maximum leaflet number (16.58) was recorded for Musk rose hardwoods when the cuttings were treated with 3 mM Spm.

***Shoot fresh and dry weights***

Shoot fresh and dray weights were significantly affected with interaction between three factors. Among rooted cuttings, the highest mean shoot fresh weight (5.85 g) and the lowest mean shoot fresh weight (1.65 g) was recorded for Damask rose hardwood cuttings (at 2 mM Spm) and Semi-hardwood cuttings of Musk rose (at 4 mM Spm), respectively. Hardwood cuttings of Damask rose (at 2 mM Spm) showed the highest (1.40 g) sooth dry weight. The minimum shoot dry weight was recorded for semi-hardwood cuttings of Musk rose. However, Musk rose hardwood (at 0 mM Spm) and semi-hardwood (at 0 and 1mM Spm) cuttings had no shoot and thus had no shoot fresh and dry weights (Table 1).

Rooting and shoot growth of cuttings are depicted in the figures 1 to 4.

**DISCUSSION**

Many previous studies showed that PAs are involved in many plant developmental processes such as cell division, embryogenesis, reproductive organ development, root growth, tuberization, floral initiation and development, fruit development, and the other growth aspects (Kaur-Sawhney et al. 2003). Mode of action of PAs has not been perfectly characterized yet. However several researches demonstrated that besides biophysical effects on membranes and nucleic acids, PAs interact with protein kinases and transcription factors and are thus involved in signal transduction pathways (Cou´ee et al. 2004). They also are considered important in cell division because they stimulate DNA synthesis and their biosynthetic enzyme activity and PAs levels increase before DNA replication (Liu et al. 1998). They largely bound in cells to RNA and DNA (Coffino 2001) and have been shown to modulate gene expression and to act as signal mediators (Hiraga et al. 2000).

Percentage of rooting is considered as one of the most important factors for rooting evaluation. Results of this study indicated that hardwood cuttings of Damask rose showed acceptable results, especially in percentage of rooting (Table 1). It may also be due to the more carbohydrate reservation that find in these types of cuttings and could boost the effect of Spm. Results presented here are in agreement with the results of Hajian and Khosh-Khui (2000) who reported that hardwood cuttings of Damask rose showed better rooting in comparison with the semi-hardwood cuttings. However, Sun and Bassuk (1991) showed that Spm had no effect on rooting or budbreak of ‘Royalty’ rose cuttings.

We found that in Damask rose, Spm had significant effect on root number (P<0.05) compared to the control. Almost, similar results have been reported by Shyr and Kao (1985) who reported that Spd and Spm effectively increased the number of roots per cutting in mungbeen. Furthermore, studies in a number of plant species have shown that depletion of polyamine pools leads to root growth inhibition. It has been reported that in *Phaseolus* *vulgaris*, depletion of Put, Spd, and Spm levels leads to decrease of root length (Cou´ee et al. 2004). Similarly, in this research we observed that 2 and 3 mM Spm led to root enlargement and these concentrations showed significant differences compared to the control. In another study, Lee (1997) showed that exogenously-added Put in concentrations varying from 0.01 to 1 mM enhanced elongation in excised rice roots under *in* *vitro* conditions at 25 ◦C.

Many other researches showed the critical role of PAs in root growth. Scholten (1998) showed that application of Put was accompanied by positive effect on length, weight and percentage of rooting in Acacia. Chang-en et al. (1994) showed that different kinds and ratios of exogenous phytohormones would change metabolism of the endogenous PAs, thus influence the morphogenesis and adventitious root formation in *Cucumis* *melon*. Cristofori et al. (2010) reported that young cuttings collected from *Corylus* *avellana* L. ‘Tonda Gentile Romana’ in early September rooted poorly when treated with IBA alone, but showed the best rooting (similar 80%) after the application of a combination of 1000 ppm IBA and 1600 ppm Put.

Modifications of endogenous levels of PAs by exogenous treatment can have drastic effects on root development and subsequent architecture. These effects may be related to the involvement of PAs in the control of cell division and differentiation, which plays an important role in the root apex and during lateral and adventitious root formation (Cou´ee et al. 2004). Biondi and Bagni (1989) reported that PAs may be involved in the rooting process of *Prunus* *avium*, probably in the stages of active cell division. They concluded that intracellular Put and Spd levels were increased before root protrusion and led to maximum primordium development. Furthermore, Spd synthesis showed a peak in the basal portions (the site of root formation) of shoots. Also, inhibition of Put and Spd biosynthesis showed adverse effects on rooting.

Furthermore, PAs have been shown to interact with phytohormones (Alabadi et al. 1996 Tonon et al. 2001). For example, the exogenously applied auxin (IBA and NAA) may act on polyamine synthase and IAA oxidase activity at the gene level or through enzyme regulation. Also, PAs can be the precursors of several hundred alkaloids (Martin-Tanguy 2001) that some of which can be associated with root development. Other studies suggested that the relationship between polyamine and gibberellin actions may also potentially be responsible for modifications of root development. In the acaulis5 mutant of Arabidopsis, which is mutated in a gene encoding a Spm synthase, transcript levels of gibberellin-related genes are affected (Hanzawa et al. 2000).

Results of present investigation showed that shoot growth (shoot length and leaflet number) in both cutting types of Damask rose and Musk rosewas increased after Spm application compared to the control (Table 1). Similarly, Terakado-Tonooka and Fujihara (2008) found that the application of Spd or Spm promoted shoot growth of soybeans (*Glycine* *max*). It has been confirmed that PAs are present in chloroplasts, thylakoid membranes, photosystem II membranes, and the light-harvesting complex (Kotzabasis et al. 1993). Aziz (2003) observed that exogenous Spd induces an increase in soluble sugar content of both leaves and inflorescences of *Vitis* *vinifera*. It was concluded that the increase of soluble sugar in leaf due to PAs was related to the maintenance of photosynthetic activity by PAs. Also, Reggiani et al. (1989) found that Put biosynthesis in the shoot has an important role in shoot elongation (p.p. 1-14).

Our findings indicated that Spm application in all factors compared to the control stimulated root and shoot growth of Damask rose. However, for cuttings of Musk rose most factors such as percentage of rooting, root number and root length were not affected after using different concentrations of Spm (Table 1). These results confirming that the rooting ability of cuttings in rose is influenced by genotype as reported for other woody species such as olive (Wiesman and Lavee 1995). Rugini et al. (1993) reported that the effects of PAs on rooting were completely depended on the plant species. They investigated the effect of Put treatment on several difficult-to-root fruit tree species and demonstrated that Put increased the rooting of apple (M9 rootstock, clone P3) and olive, but did not affect chestnut, almond, jojoba and apricot rooting.

**CONCLUSION**

In summary, findings of this study showed the significant effects of Spm on some parameters of rooting for Damask rose and Musk rosecuttings. According to results we found that Damask rose cuttings after exposing to Spm showed the best characteristics of rooting in comparison with Musk rose cuttings. Moreover, hardwood cuttings generated the strongest root system. Additionally, results indicated that the best rooting was occurred after applying 2-3 mM Spm to cuttings. However, modification of root morphology depends on PAs types. It has been shown that Spd and Spm treatments had positive correlations with primary root growth of *Pringlea* *antiscorbutica*, whereas Put level showed neutral or negative effects (Hummel et al. 2002). Therefore, future studies should be directed to evaluate the influence of the other types of PAs such as Put and Spd on rooting of *Rosa* species.

**ACKNOWLEDGMENT**

The authors gratefully thank engineer Hojat Hashemi (Department of Crop Production and Plant Breeding, Shiraz University, Iran) for assistance with statistical analyses and engineer Farhad Nikbakht (Department of Horticultural Science, Shiraz University, Iran) for assistance during this experiment.

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Table 1

The effect of interaction between species, wood type and spermine concentrations on measured parameters.

|  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | Damask rose | | | | | | | | | | Species |
|  | Hardwood Semi-hardwood | | | | | | | | | |  |
|  | Spermine (mM) | | | | | | | | | |  |
| 4 | 3 | 2 | 1 | 0 |  | 4 | 3 | 2 | 1 | 0 |  |
| 74.5abc | 83ab | 49.5cde | 49.5cde | 41.25de |  | 83ab | 74.5abc | 91.5a | 66.25abcd | 41.25de | Rooting percent (%) |
| 1.85bcdef | 2.24abc | 1.58cdefg | 1.56cdefg | 1.5fg |  | 1.82bcdef | 2.41ab | 2.58a | 2.17abcd | 1.3efg | Root number |
| 4.15fg | 7.19c | 7.61bc | 4.20fg | 2.65hi |  | 5.93d | 8.43ab | 8.64a | 5.91d | 3.80fg | Root length (cm) |
| 0.11bcd | 0.15abcd | 0.1bcd | 0.09cd | 0.08cd |  | 0.15abcd | 0.17abc | 0.12bcd | 0.08cd | 0.03cd | Root fresh weight (g) |
| 0.039cd | 0.041bcd | 0.051a | 0.037cd | 0.040bcd |  | 0.053a | 0.049ab | 0.033d | 0.046abc | 0.01e | Root dry weight (g) |
| 12.46fg | 12.68f | 11.23g | 7.06h | 7.92h |  | 11.88fg | 11.68fg | 12.37fg | 11.73fg | 7.87h | Shoot length (cm) |
| 3.33d | 4.97b | 3.26d | 3de | 2.84de |  | 3.91c | 4.10c | 5.85a | 4.08c | 2.94de | Shoot fresh weight (g) |
| 0.81d | 1.15b | 0.81d | 0.72de | 0.74de |  | 0.98c | 1.03c | 1.40a | 0.94c | 0.69de | Shoot dry weight (g) |
| 8.68e | 7.92e | 4.55g | 3.70gh | 3.18h |  | 6.18f | 6.47f | 5.87f | 6.33f | 3.55gh | Leaflet number |

Table 1 (Continued)

|  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | Musk rose | | | | | | | | | | Species |
|  | Hardwood Semi-hardwood | | | | | | | | | |  |
|  | Spermine (mM) | | | | | | | | | |  |
| 4 | 3 | 2 | 1 | 0 |  | 4 | 3 | 2 | 1 | 0 |  |
| 49.5cde | 57.75bcde | 41.25de | 0f | 0f |  | 49.5cde | 66.25abcd | 41.25de | 33e | 0f | Rooting percent (%) |
| 1.49defg | 1.91abcde | 1.69cdefg | 0h | 0h |  | 1.39efg | 1.59cdefg | 1.48defg | 1.06g | 0h | Root number |
| 3.35gh | 4.07fg | 1.73i | 0j | 0j |  | 4.63ef | 5.21de | 4.3efg | 2.56hi | 0j | Root length (cm) |
| 0.13bcd | 0.26ab | 0.09cd | 0d | 0d |  | 0.13bcd | 0.17abc | 0.31a | 0.08cd | 0d | Root fresh weight (g) |
| 0.031d | 0.055a | 0.036d | 0f | 0f |  | 0.037cd | 0.038cd | 0.037cd | 0.042bcd | 0f | Root dry weight (g) |
| 16.8d | 18.19c | 22.09b | 0i | 0i |  | 24.53a | 23.75a | 14.40e | 15.16e | 0i | Shoot length (cm) |
| 1.65f | 1.94f | 1.95f | 0g | 0g |  | 2.58e | 2.63e | 2.9de | 2.96de | 0g | Shoot fresh weight (g) |
| 0.41g | 0.51fg | 0.47g | 0h | 0h |  | 0.61ef | 0.62ef | 0.72de | 0.72de | 0h | Shoot dry weight (g) |
| 12.53bc | 10.92d | 16.07a | 0i | 0i |  | 13.22b | 16.58a | 12.05c | 8.17e | 0i | Leaflet number |

In each row means with the same letter(s) are not significantly different at 5% level of probability using DNMRT.

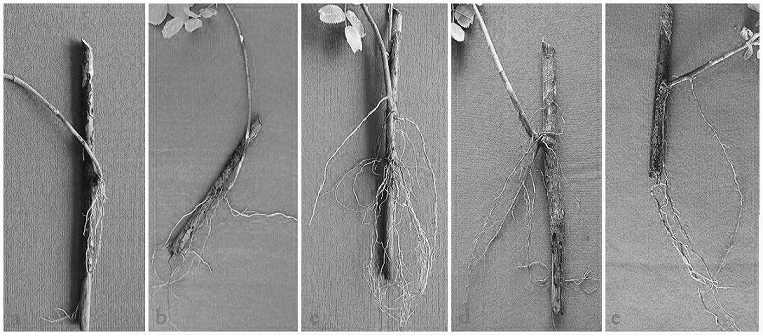


Figure 1. Influence of exogenous spermine application on rooting of hardwood cuttings of Damask rose. (a) 0 mM spermine, (b) 1 mM spermine, (c) 2 mM spermine, (d) 3 mM and (e) 4 mM spermine.

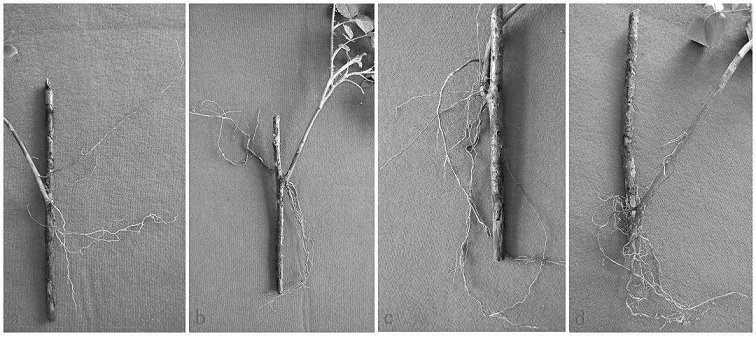


Figure 2. Influence of exogenous spermine application on rooting of semi-hardwood cuttings of Damask rose. (a) 1 mM spermine, (b) 2 mM spermine, (c) 3 mM spermine and (d) 4 mM spermine.

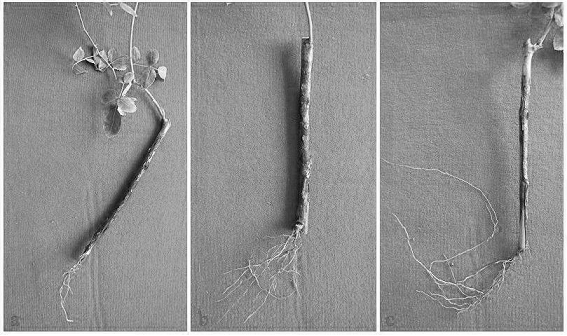


Figure 3. Influence of exogenous spermine application on rooting of hardwood cuttings of Musk rose. (a) 1 mM spermine, (b) 2 mM spermine, (c) 3 mM spermine.

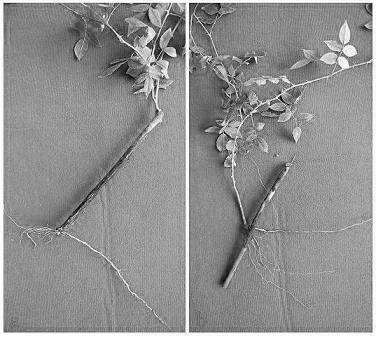


Figure 4. Influence of exogenous spermine application on rooting of semi-hardwood cuttings of Musk rose. (a) 2 mM spermine and (b) 3 mM spermine.