

## MICROPROPAGATION OF FIVE ENDEMIC, RARE AND/OR ENDANGERED NARCISSUS SPECIES FROM THE IBERIAN PENINSULA (SPAIN AND PORTUGAL)

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The genus *Narcissus* has several endemic, rare and/or threatened species in the Iberian Peninsula and North Africa. *In vitro* propagation is a useful tool for threatened plants conservation used in *ex situ* strategies. Thus, the aim of this work was to study the propagation *in vitro* of bulb scale explants of five endemic, rare and/or endangered *Narcissus* species from the Iberian Peninsula, treated with different PGR combinations. Initiation was achieved in half-strength Murashige and Skoog (MS) basal salts and vitamins, 10 g/L sucrose, 500 mg/L casein hydrolysate, 2 mg/L adenine, 10 mg/L glutathione and 5.5 g/L plant agar. In the multiplication phase, the highest bulblet proliferation was obtained in MS medium supplemented with 30 g/L sucrose and the combination of 10  $\mu$ M 6-Benzylaminopurine (BAP) + 5  $\mu$ M  $\alpha$ -Naphthaleneacetic acid (NAA) in *N. alcaracensis*, *N. eugeniae* and *N. hedraeanthus*; 20  $\mu$ M BAP + 5  $\mu$ M NAA in *N. jonquilla* and *N. yepesii*. The highest rooting was obtained with 5  $\mu$ M NAA + 1  $\mu$ M Indole-3-butyric acid (IBA) for all species (>75%) and more than 80% of the produced bulblets were successfully acclimatized.

**Key words:** bulb scales, conservation, endangered plants, micropropagation, *Narcissus*, plant growth regulators

### INTRODUCTION

*Narcissus* cultivars are very popular for gardening in parks, public spaces, home gardens, as cut flowers or potted flowers, and they also display interesting pharmaceutical applications (Hanks, 2002). In addition, rare *Narcissus* wild taxa are in high demand, and have come out in several sites all over the world (The Daffodil Society, 2019). Several wild species of this genus are also endemic to restricted territories and threatened in the Iberian

Peninsula, according to the International Union for the Conservation of Nature (<https://www.iucnred-list.org/>) and national (Bañares et al., 2010) or regional (DOCM, 1998) checklists. Although micropropagation of *Narcissus* cultivars has been quite extensively studied (Hussey, 1982; Squires et al., 1991; Chow et al., 1992; Harvey and Selby, 1997; Langen-Gerrits and de Klerk, 1999; Sage et al., 1999; Sochacki and Orlikowska, 2005; de Klerk, 2012; Malik and Bach, 2016, 2017), information on micropropagation of wild species is rather

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limited. Successful *in vitro* production has been achieved for *N. bulbocodium* (Santos et al., 1998), *N. triandrus* (Santos and Salema, 2000), *N. asturiensis* (Santos et al., 2002) and *N. tazetta* (Rahimi Khonakdari et al., 2020). The *in vitro* culture of *N. longispathus* Pugsley, *N. nevadensis* Pugsley and *N. tortifolius* Fdez. Casas. has also been conducted in genebanks (Bañares et al., 2010). However, there are more than 20 rare, endemic and threatened *Narcissus* species listed in the Iberian Peninsula (Spain and Portugal) as well as in North Africa where any information regarding their micropropagation is still lacking. As micropropagation is a useful tool for plant conservation biology that can be applied both in *ex situ* and *in situ* strategies (González-Benito and Martín, 2011), the present study, for the first time, focused on development of micropropagation procedures for five of these *Narcissus* species from the Iberian Peninsula: *N. alcaracensis* S. Ríos, D. Rivera, Alcaraz & Obón; *N. eugeniae* Fdez. Casas, *N. hedraeanthus* (Webb & Heldr.) Colmeiro, *N. jonquilla* L. and *N. yepesii* S. Ríos, D. Rivera, Alcaraz & Obón.

## MATERIAL AND METHODS

Mother plants were selected from the *Narcissus* collection based in the Botanical Garden Torretes (Ibi, Spain) and bulbs (collected in April-May) were used as a source of explants. The bulbs were washed in tap water with commercial soap (Domestos, London, UK) containing sodium hypochlorite at 4.5 g 100 g<sup>-1</sup>. Next, the bulbs were placed in a hot-water treatment consisting in 60 min immersion at 54°C, followed by immersion in 7% (w/v) Ca(ClO)<sub>2</sub>. Then, uniform explants (about 3-5 mm width and 5-10 mm length) were prepared adapting the twin-scale approach by bulb dissection in pieces containing about 2 mm of the bottom plate. These scales were transferred onto initiation medium IN1 containing full-strength MS, 30 g/L sucrose, 500 mg/L casein hydrolysate, 2 mg/Ladenine, 10 mg/L glutathione and 5.5 g/L plant agar (Duchefa, The Netherlands) or the same composition plus 2 g/L activated charcoal (AC) for the initiation medium IN2. Culture conditions during the initiation stage were as follows: temperature 24±1°C in dark for 10 days. Then, the explants were placed for 30 days under a 16-hours photoperiod of red-blue light (intensity of 42 μmol m<sup>-2</sup>s<sup>-1</sup>) using T8 Gro-lux tubes (Sylvania Lamps, Germany) at 24°C. In both

initiation media, bulb-scale explants were put in 25 × 150 mm culture tubes with polypropylene caps (Auxilab S.L., San Ginés, Spain). Three replicates consisting of 20 explants each were placed under cultivation for the initiation phase during 40 days in total. After this period, contaminated (either by fungi, bacteria or both) or dead explants were discarded and those explants showing signs of growth (bulblet formation) were considered initiated under *in vitro* conditions, counted, and selected for further experiments. Initiated cultures, either in IN1 or IN2, were further transferred into multiplication medium containing full-strength MS, 30 g/L sucrose, 5.5 g/L plant agar and 5 μM BAP + 5 μM NAA for 60 days under the same photoperiod and light intensity as mentioned above. Six passages of cultivation of 60 days each were done in order to obtain a stock of bulblets *in vitro* prior to development of the multiplication experiments. Finally, all bulblets obtained as stock were cultured during 30 days in full-strength MS, 30 g/L sucrose, 5.5 g/L plant agar (without plant growth regulators, PGRs) in order to stabilize the PGRs content of the plants to be employed in multiplication trials. For multiplication experiments, four combinations of PGRs using 6-Benzylaminopurine (BAP), α-Naphthaleneacetic acid (NAA) and Indole-3-butyric acid (IBA) were tested. To assess the bulblet production during the multiplication phase the following combinations were used: PGRs-free medium (M1) and mixtures containing 5 μM BAP + 5 μM NAA (M2), 10 μM BAP + 5 μM NAA (M3) and 20 μM BAP + 5 μM NAA (M4). For multiplication, three replicates consisting of 20 explants each were placed under cultivation in the same photoperiod conditions as those explained for initiation. Newly formed bulblets per explant were recorded after 60 days of cultivation on multiplication medium to perform the rooting trials. For rooting experiments, four rooting media composed of MS basal salts and vitamins, 30 g/L sucrose, 5.5 g/L plant agar, and four combinations of PGRs were employed. The PGR combinations were as follows: a growth regulator-free medium (R1), 5 μM NAA (R2), 5 μM NAA + 1 μM Indole-3-butyric acid, IBA (R3) and 5 μM NAA + 1 μM indole-3-acetic acid, IAA (R4). As performed in multiplication phase, the rooting experiments were carried out at 24±1°C in a growth chamber under a 16-hours photoperiod of red-blue light (intensity of 42 μmol m<sup>-2</sup>s<sup>-1</sup>) using T8 Gro-lux tubes (Sylvania Lamps, Germany). Rooting evaluation was visually scored after 30 and 60 days of cultivation on each

rooting medium according to the methodology described for *Lapiedra martinezii* Lag. in Juan-Vicedo et al. (2019): 0 = no roots; 1 = roots <0.5 cm; 2 = 1-2 roots  $\geq$  1 cm or any number of roots 0.5-1 cm long; 3 = 3 or more roots  $\geq$  1 cm. After rooting experiments, rooted bulblets showing calibers around 5 mm width and 5–10 mm length, as well as roots longer than 1 cm were selected for acclimatization experiments. These bulblets were previously subjected to cold exposure of 10°C, at 42  $\mu\text{mol m}^{-2}\text{s}^{-1}$ , for 30 days in order to break dormancy. Then, bulblets were transferred to *ex vitro* conditions by planting rooted bulblets in an autoclaved (30 minutes at 121°C) soil mixture of peat moss and vermiculite (5:4 ratio) (Batlle, Molins de Rei, Spain) for 60 days during a double-phase experiment. In the first phase (acclimatization), pots were placed in a growth chamber with light and humidity control at a constant temperature of 24 $\pm$ 1°C, 100% relative humidity (RH), and a 16-hours photoperiod using red-blue light (T8 Gro-lux tubes, Sylvania Lamps, Germany, with photosynthetically active radiation of 42  $\mu\text{mol m}^{-2}\text{s}^{-1}$ ) during 30 days. In the second phase (hardening), the RH was decreased to 70% and light intensity was increased up to 80  $\mu\text{mol m}^{-2}\text{s}^{-1}$  for 30 days. At the end of the experiment, the pots were placed

in shade in outdoor conditions for 40 days and the survival was recorded. All experiments (initiation, multiplication, rooting and acclimatization) were performed using three replicates of 20 explants each and means as well as standard errors were calculated in order to perform statistical tests. A summary of the experiments is presented in Table 1: all set experiments were done by triplicate. For the data analyses, one-way analyses of variance (ANOVA) were conducted and significant differences between means were obtained with the Tukey's honestly significant difference (HSD) test at the 5% level. All data were analyzed using the Infostat 2008 package (Di Rienzo et al., 2008). Percentages of rooting and acclimatization were previously arcsine square root transformed whereas the bulblet formation was analyzed without any transformation.

## RESULTS AND DISCUSSION

Initiation of bulb-scale explants was more successful in initiation media not containing AC (IN1) for all species tested (Table 2). The use of AC on plant *in vitro* cultures has been related to its role in

TABLE 1. Summary of the experiments performed for bulb-scale micropropagation of *N. alcaracensis*, *N. eugeniae*, *N. hedraeanthus*, *N. jonquilla* and *N. yepesii*.

Stage	Explant (number)	Media	Culture conditions	Culture period (days)
Initiation <i>in vitro</i>	100-183	IN1, IN2	<b>Temperature:</b> 24 $\pm$ 1°C <b>Light:</b> dark for (10 days) and 16-hours photoperiod of 42 $\mu\text{mol m}^{-2}\text{s}^{-1}$ (30 days)	40
Multiplication <i>in vitro</i>	60 (3 replicates of 20)	M1, M2, M3, M4	<b>Temperature:</b> 24 $\pm$ 1°C <b>Light:</b> 16-hours photoperiod of 42 $\mu\text{mol m}^{-2}\text{s}^{-1}$	30
Rooting <i>in vitro</i>	60 (3 replicates of 20)	R1, R2, R3, R4	<b>Temperature:</b> 24 $\pm$ 1°C <b>Light:</b> 16-hours photoperiod of 42 $\mu\text{mol m}^{-2}\text{s}^{-1}$	60
Cold exposure	60 (3 replicates of 20)	R1, R2, R3, R4	<b>Temperature:</b> 10°C <b>Light:</b> 16-hours photoperiod of 42 $\mu\text{mol m}^{-2}\text{s}^{-1}$	30
Acclimatization <i>ex vitro</i> I	60 (3 replicates of 20)	Peat moss: vermiculite (5:4)	<b>Temperature:</b> 24 $\pm$ 1°C <b>Relative Humidity:</b> 100% <b>Light:</b> 16-hours photoperiod of 42 $\mu\text{mol m}^{-2}\text{s}^{-1}$	30
Acclimatization <i>ex vitro</i> II (Hardening)	60 (3 replicates of 20)	Peat moss: vermiculite (5:4)	<b>Temperature:</b> 24 $\pm$ 1°C <b>Relative Humidity:</b> 70% <b>Light:</b> 16-hours photoperiod of 80 $\mu\text{mol m}^{-2}\text{s}^{-1}$	30

Media: IN1 (full-strength MS, 30 g/L sucrose, 500 mg/L casein hydrolysate, 2 mg/L adenine, 10 mg/L glutathione and 5.5 g/L plant agar), IN2 (IN1 plus 2 g/L AC), M1 (growth regulators free), M2 (5  $\mu\text{M}$  BAP + 5  $\mu\text{M}$  NAA), M3 (10  $\mu\text{M}$  BAP + 5  $\mu\text{M}$  NAA), M4 (20  $\mu\text{M}$  BAP + 5  $\mu\text{M}$  NAA), R1 (growth regulators free), R2 (5  $\mu\text{M}$  NAA), R3 (5  $\mu\text{M}$  NAA + 1  $\mu\text{M}$  IBA) and R4 (5  $\mu\text{M}$  NAA + 1  $\mu\text{M}$  IAA).

TABLE 2. Effect of two initiation media on the initiation success of bulb-scale explants of *N. alcaracensis*, *N. eugeniae*, *N. hedraeanthus*, *N. jonquilla* and *N. yepesii*. Results are expressed as the number of explants cultured, contaminated (either by bacteria, fungi or both), dead and recovered/healthy explants that restored growth within 40 days of culture.

Species	Treatment	Cultured explants	Contaminated explants	Dead explants	Recovered/Healthy explants
<i>N. alcaracensis</i>	IN1	119	75	27	17
	IN2	100	80	15	5
<i>N. eugeniae</i>	IN1	158	63	67	28
	IN2	161	69	74	18
<i>N. hedraeanthus</i>	IN1	183	73	63	47
	IN2	180	75	78	27
<i>N. jonquilla</i>	IN1	161	80	47	34
	IN2	158	89	58	11
<i>N. yepesii</i>	IN1	107	52	43	12
	IN2	105	51	47	7

Treatments: IN1 (full-strength MS, 30 g/L sucrose, 500 mg/L casein hydrolysate, 2 mg/L adenine, 10 mg/L glutathione and 5.5 g/L plant agar), IN2 (IN1 plus 2 g/L AC).

adsorption of substances (e.g., phenolics and their oxidates, inhibitory compounds) that can be harmful for the new tissues formed *in vitro* (Thomas, 2008). In bulbous plants' multiplication *in vitro*, AC was related to a higher bulb size in *Lilium* sp. (Bachetta et al., 2003) and improved shoot regeneration in *L. longiflorum* explants (Nhut et al., 2001). AC also promoted bulblet production both in already initiated cultures of *N. tazetta* (Steinitz and Yahel, 1982) and in *N. tazetta* "Chinensis" (Abdel-Rahman et al., 2017). However, other compounds that can be adsorbed by AC are organic supplements and growth regulators (Thomas, 2008). Due to the importance of these compounds to restore the plant growth at the initiation of the *in vitro* cultures (Langen-Gerrits and de Klerk, 1999; Iliev et al., 2010), it seems reasonable to think that AC could sometimes impede the intake of these substances and, in turn, give lower response at the initiation stage as reported here. In fact, AC in culture medium was also related to a decrease in bulblet differentiation in *Lilium* (Takayama and Misawa, 1980) and in initiation success also in *L. martinezii* (Juan-Vicedo et al., 2019). After the cultures had been initiated, multiplication experiments were performed. It is usually reported that reduced NAA concentrations in comparison to BAP promote *in vitro* bulblet proliferation in geophytes

(Hussey, 1982; Seabrook, 1990; Santos et al., 1998; Langen-Gerrits and de Klerk, 1999; Santos et al., 2002; Freytag et al., 2017; Juan-Vicedo et al., 2019; Rahimi Khonakdari et al., 2020), as revealed in this study. However, determination of the specific concentration of these PGRs in culture media is crucial for successful micropropagation of the target species (de Klerk, 2012; Freytag et al., 2017). Among the four combinations of PGRs used for multiplication in the present work, the best response was obtained in M3 (10  $\mu$ M BAP + 5  $\mu$ M NAA) that showed significantly higher bulblet induction in *N. alcaracensis* ( $4.35 \pm 0.59$ ), *N. eugeniae* ( $5.95 \pm 0.60$ ) and *N. hedraeanthus* ( $9.00 \pm 0.72$ ). Also, M4 (20  $\mu$ M BAP + 5  $\mu$ M NAA) promoted the highest bulblet formation in *N. jonquilla* ( $7.40 \pm 1.19$ ) and *N. yepesii* ( $4.05 \pm 0.69$ ) (Table 3). The combinations M1 (growth regulators free) and M2 (5  $\mu$ M BAP + 5  $\mu$ M NAA) yielded much lower than M3 and M4 in all studied species. Taking into account each species' multiplication yield, the highest bulblet proliferation was obtained in *N. hedraeanthus* (9 bulblets per explant). This is in agreement with the yield obtained by Santos et al. (1998) for the closely related species *N. bulbocodium* L. (*Narcissus* L. Section *Bulbocodium* DC). *N. jonquilla* performed a lower response (7.40 bulblets per explant). To the best of our knowledge, this is the first report

TABLE 3. Effect of four combinations of growth regulators on bulb-scale explant multiplication of *N. alcaracensis*, *N. eugeniae*, *N. hedraeanthus*, *N. jonquilla* and *N. yepesii*. Mean values per species within a column followed by different letters represent significant differences between treatments according to Tukey's HSD test ( $P < 0.05$ ).

Species	Treatment	Number of bulblets
<i>N. alcaracensis</i>	M1	0.65±0.49c
	M2	1.00±0.46c
	M3	4.35±0.59a
	M4	2.65±0.67b
<i>N. eugeniae</i>	M1	0.70±0.0.47c
	M2	2.15±0.37b
	M3	5.95±0.60a
	M4	2.05±0.69b
<i>N. hedraeanthus</i>	M1	0.60±0.50d
	M2	1.15±0.37c
	M3	9.00±0.72a
	M4	4.00±0.65b
<i>N. jonquilla</i>	M1	1.90±0.79d
	M2	3.75±1.02c
	M3	5.95±0.51b
	M4	7.40±1.19a
<i>N. yepesii</i>	M1	1.10±0.31c
	M2	1.55±0.76bc
	M3	2.05±0.69b
	M4	4.05±0.69a

Treatments: M1 (growth regulators free), M2 (5  $\mu\text{M}$  BAP + 5  $\mu\text{M}$  NAA), M3 (10  $\mu\text{M}$  BAP + 5  $\mu\text{M}$  NAA) and M4 (20  $\mu\text{M}$  BAP + 5  $\mu\text{M}$  NAA).

concerning micropropagation of wild jonquils (*Narcissus* L. Section Jonquillae DC). Chow et al. (1992) found an increase in bulblet proliferation from shoot cultures in *N. jonquilla* after transference of shoot clumps from 3% to 9% sucrose. However, there was no information on direct bulblet formation from bulb explants using PGRs and therefore we cannot establish whether multiplication performance is in accordance with other species of the Section. In any case, the yield obtained in this study is still high taking into account the results of the five studied *Narcissus* species. In contrast, *N. eugeniae*, *N. yepesii* and *N. alcaracensis* gave the lowest yield (4.05–5.95 bulblets per explant). These results may suggest that the range of combinations of PGRs used in this study might be not optimal for bulb multiplication in these taxa. However, Santos et al. (2002) also obtained similar optimal micropropagation

yields in the closely related species *N. asturiensis* (Jord.) Pugsley, which could indicate that wild species belonging to the *Narcissus* Section Pseudonarcissi DC (trumpet daffodils) might have lower bulblet production *in vitro* in comparison to other members of the genus. However, further research would be desirable to check whether there exists a different multiplication performance depending on the taxonomical group where they belong and in turn, to optimize the bulblet proliferation *in vitro*. It is generally accepted that bulbs do not need rooting treatments (Langen-Gerrits and de Klerk, 1999) as they can spontaneously achieve high rooting percentages in multiplication medium (Juan-Vicedo et al., 2019). In *Narcissus* bulblets, rooting treatment is normally necessary to achieve higher sprouting rates in micropropagated bulbs after transference to *ex vitro* conditions (de Klerk, 2012) and, therefore, to ensure a successful micropropagation protocol. In our experiments, variable percentages of root induction were obtained in all tested combinations of PGRs (including the controls, R1) for the five species studied during the 30-days rooting period. When the cultivation period was extended up to 60 days all these percentages significantly increased and the rooting medium R3 containing 5  $\mu\text{M}$  NAA + 1  $\mu\text{M}$  IBA performed the best response (2–3 roots showing about 1 cm length) in the five studied species (Table 4). Finally, acclimatization success was higher than 80% for all rooted bulblets (Table 4). In this work, a satisfactory specific method of micropropagation for five endemic, rare and/or threatened *Narcissus* was described for the first time. These results provide relevant information for the conservation of these species *ex situ*. In addition, given the great importance of *Narcissus* species in the galanthamine production (Hanks, 2002; Rahimi Khonakdari et al., 2020) we expect that the results presented in this work could be helpful for further studies on alkaloid biosynthesis using *in vitro* systems.

#### AUTHORS' CONTRIBUTION

JJV performed the experiments, analysis and interpretation of data, as well as drafted the manuscript. AP helped in the work design and in manuscript drafting. SR carried out the field work and developed the idea and JLCM participated in the experiment designing and manuscript drafting. The authors declare that there is no conflict of interest.



TABLE 4. Effect of four combinations of growth regulators and two periods of culture on rooting of regenerated bulblets as well as acclimatization success of rooted bulblets for *N. alcaracensis*, *N. eugeniae*, *N. hedraeanthus*, *N. jonquilla* and *N. yepesii*. Mean values per species within a column followed by different letters represent significant differences between treatments according to Tukey's HSD test ( $P < 0.05$ ).

Species	Treatment	Rooting (% at 4 weeks)	Rooting score (4 weeks)	Rooting (% at 8 weeks)	Rooting score (8 weeks)	Acclimatization (%)
<i>N. alcaracensis</i>	R1	30.25d	0.09	62.75c	1.88	90a
	R2	42.50c	1.3	79.00b	2.37	95a
	R3	74.75a	2.25	92.37a	2.77	100a
	R4	51.75b	1.5	79.00b	26.07	90a
<i>N. eugeniae</i>	R1	37.00c	1.1	58.00b	1.74	80a
	R2	38.25c	1.15	61.75bc	1.85	80a
	R3	78.50a	2.35	93.50a	2.8	95a
<i>N. hedraeanthus</i>	R4	59.50b	1.8	64.75b	1.94	90a
	R1	35.5c	1.06	40.25b	1.2	95a
	R2	48.25a	1.5	65.00b	1.95	100a
	R3	47.75a	1.4	94.25a	2.8	95a
<i>N. jonquilla</i>	R4	40.00b	1.2	57.25c	1.7	90a
	R1	33.75b	1.0	57.75c	1.73	80a
	R2	37.75b	1.13	63.75b	1.9	80a
	R3	44.75a	1.34	81.00a	2.43	80a
<i>N. yepesii</i>	R4	36.50b	1.09	54.25c	1.63	80a
	R1	25.00d	0.75	47.50c	1.4	90a
	R2	33.25c	1.0	38.50d	1.15	85a
	R3	59.75a	1.8	75.50a	2.26	95a
	R4	48.00b	1.44	64.75b	1.94	95a

Treatments: R1 (growth regulators free), R2 (5  $\mu$ M NAA), R3 (5  $\mu$ M NAA + 1 $\mu$ M IBA) and R4 (5  $\mu$ M NAA + 1 $\mu$ M IAA).

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## REFERENCES

- BACCHETTA L, REMOTTI PC, BERNARDINI C, and SACCARDO F. 2003. Adventitious shoot regeneration from leaf explants and stem nodes of *Lilium*. *Plant Cell Tissue Organ Culture* 74: 37–44.
- BAÑARES Á, BLANCA G, GÜEMES J, MORENO JC, and ORTIZ S. 2010. *Atlas y Libro Rojo de la Flora Vasculare Amenazada de España*. Dirección General de Medio Natural y Política Forestal (Ministerio de Medio Ambiente, y Medio Rural y Marino)-Sociedad Española de Biología de la Conservación de Plantas, Madrid.
- DE KLERK GJ. 2012. Micropropagation of bulbous crops: technology and present state. *Floriculture and Ornamental Biotechnology* 6: 1–8.

- DI RIENZO JA, CASANOVES F, BALZARINI MG, GONZALEZ L, TABLADA M, and ROBLEDO CW. 2008. InfoStat, versión 2008, Grupo InfoStat, FCA, Universidad Nacional de Córdoba, Argentina.
- DOCM. 1998. Decreto 33/1998, de 05-05-98, por el que se crea el Catálogo Regional de Especies Amenazadas de Castilla-La Mancha (DOCM, 15 de mayo de 1998). <https://derechoanimal.info/sites/default/files/legacy-files/bbdd/Documentos/636.pdf>. Accessed 15 April 2019
- FREYTAG C, PABAR SA, DEMETER Z, SIMON Á, RESETÁR A, MOLNÁR A, SRAMKÓ G, and MÁTHÉ. 2017. Production and characterization of tissue cultures of four *Crocus* species from the Carpathian Basin. *Acta Biologica Cracoviensis Series Botanica* 59(2): 31–39. DOI: [10.1515/abcsb-2017-0009](https://doi.org/10.1515/abcsb-2017-0009)
- GONZÁLEZ-BENITO ME, and MARTIN C. 2011. *In vitro* preservation of Spanish biodiversity. *In Vitro Cellular and Developmental Biology – Plant* 47: 46–54.
- HANKS GR. 2002. *Narcissus and Daffodil: The Genus Narcissus*. CRC Press, London.
- HARVEY BMR, and SELBY C. 1997. Micropropagation of *Narcissus* (daffodils). In: Bajaj (ed.), *Biotechnology in Agriculture and Forestry* vol. 40 *High-Tech and Micropropagation VI*, 225–251. Springer-Verlag Berlin, Heidelberg.
- HUSSEY G. 1982. *In vitro* propagation of *Narcissus*. *Annals of Botany* 49: 707–719.
- ILIEV I, GAJDOSOVÁ A, LIBIAKOVA G, and JAIN SH. 2010. Plant micropropagation. In: Davey and Anthony [ed.], *Plant Cell Culture*, 1–20. John Wiley & Sons Ltd, Chichester, West Sussex.
- JUAN-VICEDO J, PAVLOV A, RÍOS S, and CASAS JL. 2019. *In vitro* culture and micropropagation of the Baetic-Moroccan endemic plant *Lapiedra martinezii* Lag. (Amaryllidaceae). *In Vitro Cellular and Developmental Biology – Plant* 55(6): 725–732. <https://doi.org/10.1007/s11627-019-10031-5>
- LANGEN-GERRITS MM, and DE KLERK GJ. 1999. Micropropagation of flower bulbs: *Lily* and *Narcissus*. *Methods in Molecular Biology* 111: 141–147. DOI: [10.1385/1-59259-583-9:141](https://doi.org/10.1385/1-59259-583-9:141)
- MALIK M, and BACH A. 2016. Morphogenetic pathways from *Narcissus* L. 'Carlton' *in vitro* cultures of PC stage flower bud explants according to cytokinin and auxin ratios. *Acta Scientiarum Polonorum Hortorum Cultus* 15(1): 101–111.
- MALIK M, and BACH A. 2017. High-yielding repetitive somatic embryogenesis in cultures of *Narcissus* L. 'Carlton'. *Acta Scientiarum Polonorum Hortorum Cultus* 16(2): 107–112.
- MORENO JC. 2008. *Lista Roja 2008 de la flora vascular española*. Dirección General de Medio Natural y Política Forestal (Ministerio de Medio Ambiente, y Medio Rural y Marino, y Sociedad Española de Biología de la Conservación de Plantas), Madrid.
- MURASHIGE T, and SKOOG F. 1962. A revised medium for rapid growth and bio assays with tobacco tissue cultures. *Physiologia Plantarum* 15: 473–497. <https://doi.org/10.1111/j.1399-3054.1962.tb08052.x>
- RAHIMI KHONAKDARI M, REZADOOST H, HEYDARI R, and HOSSEIN MIRJALILI M. 2020. Effect of photoperiod and plant growth regulators on *in vitro* mass bulblet proliferation of *Narcissus tazetta* L. (Amaryllidaceae), a potential source of galantamine. *Plant Cell, Tissue and Organ Culture* 142: 187–199. <https://doi.org/10.1007/s11240-020-01853-y>.
- SAGE DO, LYNN J, and HAMMATT N. 1999. Somatic embryogenesis in *Narcissus pseudonarcissus* cvs Golden Harvest and St. Keverne. *Plant Science* 150: 209–216.
- SANTOS A, FIDALGO F, SANTOS I, and SALEMA R. 2002. *In vitro* bulb formation of *Narcissus asturiensis*, a threatened species of the Amaryllidaceae. *The Journal of Horticultural Science and Biotechnology* 77(2): 149–152. <https://doi.org/10.1080/14620316.2002.11511471>.
- SANTOS I, and SALEMA R. 2000. Promotion by jasmonic acid of bulb formation in shoot cultures of *Narcissus triandrus* L. *Plant Growth Regulation* 30: 133. <https://doi.org/10.1023/A:1006381127884>.
- SANTOS J, SANTOS I, and SALEMA R. 1998. *In vitro* production of bulbs of *Narcissus bulbocodium* flowering in the first season of growth. *Scientia Horticulturae* 76: 205–217. [https://doi.org/10.1016/S0304-4238\(98\)00141-1](https://doi.org/10.1016/S0304-4238(98)00141-1)
- SEABROOK JEA. 1990. *Narcissus* (Daffodil). In: Ammirato PV, Evans DA, Sharp WR, Bajaj PS (eds.), *Handbook of Plant Cell Culture* vol. 5, 577–597. McGraw-Hill, New York.
- SOCHACKI D, and ORLIKOWSKA T. 2005. Factors influencing micropropagation of *Narcissus*. In: Okubo H, Miller WB, Chastagner GA (eds), *Proceedings of the IXth International Symposium on Flower Bulbs – Acta Horticulturae* 673 International Society for Horticultural Science, Leuven, Belgium.
- SQUIRES WM, LANGTON FA, and FENLON JS. 1991. Factors influencing transplantation success of micropropagated *Narcissus* bulblets. *Journal of Horticultural Sciences* 66: 661–671. <https://doi.org/10.1080/00221589.1991.11516197>
- STEINITZ B, and YAHIEL H. 1982. *In vitro* propagation of *Narcissus tazetta*. *HortScience* 17: 333–334.
- TAKAYAMA S, and MISAWA M. 1980. Differentiation in *Lilium* bulb scales grown *in vitro*. Effects of activated charcoal, physiological age of bulbs and sucrose concentration on differentiation and scale leaf formation *in vitro*. *Physiologia Plantarum* 48: 121–125.
- THE DAFFODIL SOCIETY. 2019. Bulb Suppliers. <https://thedaffodilsociety.com/bulb-suppliers/>. Accessed 5 December 2019.
- THOMAS TD. 2008. The role of activated charcoal in plant tissue culture. *Biotechnology Advances* 26(6): 618–631.