Effect of rooting media and IBA treatment on rooting response of South African dune spinach (*Tetragonia decumbens*): an underutilized edible halophyte

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Abstract

Tetragonia decumbens **is a neglected wild vegetable in South Africa. The dearth of literature on its propagation and cultivation methods has led to its underutilization. This prompted an investigation on the vegetative propagation of *T. decumbens* as influenced by rooting media and indole-3-butyric acid (IBA) treatment to formulate a viable propagation protocol for potential growers of the species. Nodal stem cuttings of *T. decumbens* were obtained from a selected plant population growing along the coast at the Granger Bay campus of the Cape peninsula University of Technology, South Africa. Stem cuttings of about ±15 cm long with a stem thickness of approximately 8 mm were treated with different concentrations of a commercial growth regulator Dynaroot™ (containing 0.1% IBA for 1 softwood, 0.3% for 2 semi-hardwood and 0.8% for 3 hardwood) and planted into four different rooting media: sand (S), sand:peat (SP) (1:1), perlite:peat (PP) (1:1) and peat:perlite:vermiculite (PPV) (1:1:1). The results indicated significant growth differences in various rooting media, whereas the IBA treatment and its interaction with rooting media were only significant in rooting percentage and height. Cuttings placed in sand and peat (1:1) mix without IBA treatment had the best results in variables assessed. This study showed that dune spinach does not require additional growth regulators for root initiation and multiplication. This could be a cost-saving option for potential urban growers of the species, who may want to exploit this plant for diet diversity and as a source of nutritional substitute for spinach and lettuce.**

Keywords: wild vegetable, nodal stem cuttings, vegetative propagation, functional food

INTRODUCTION

Globally, the agricultural industry feeds more than 7 billion people, and alarmingly by 2050, that number will exceed 8 billion (Molotoks et al., 2021). The global demand for food production has never been greater, particularly in developing countries where the population is expected to grow by 90%, implying that food insecurity will become a bigger issue (Gidamis and Chove, 2009; Ogunniyi et al., 2020). To meet the increased food demand, crop production should increase by 70 to 100% by 2050, according to the World Development Report (World Bank, 2007). However, poor agro ecological conditions and the scarcity of freshwater have severely impacted the yield of essential crops such as wheat, rice and maize around the world including South Africa, making it extremely difficult to meet the required target (Acquaah, 2007; Corwin, 2021). Furthermore, poor agro ecological conditions such as soil salinity are anticipated to pose a major problem in many regions in the future due to climate change (Sogoni et al., 2021). Recent attempts to adapt to these climatic conditions include the use of wild salt-tolerant plants (halophytes) with significant economic values such as leafy vegetables, feed crops and pharmaceutical precursors (Debez et al., 2010; Ventura and Sagi, 2013). This resulted in an increased interest in the crop production development of edible halophytes in combating the challenges of food and nutrient deficiency around the world (Jacobsen et al., 2013; Kashyap et al., 2021).

In South Africa, edible halophytes are still neglected and considered important mainly

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in the light of safeguarding biodiversity and are only valued in rural parts of the country during times of famine (Ben Hamed and Custódio, 2019). Nevertheless, Afolayan and Jimoh (2009) reported that these neglected vegetables can contribute to diets by adding both micronutrients and bioactive compounds, and could help eradicate nutrient deficiencies and reduce food insecurity at the household level. Furthermore, given the increasing global climate change and severe conditions that exist around the world, the use of native halophytes for food production in South Africa could be a climate change adaptation strategy (Bartels and Sunkar, 2005; Glenn et al., 1999). Concurrently, it has been stated that South Africa is on the verge of physical water scarcity by 2040, and that the recent drought has directly harmed the country's agricultural sector (Bischoff-Mattson et al., 2020). As a result, it is critical to cultivate crops adapted to harsh conditions to address the challenges of nutrient deficiency, saline soils, and water scarcity (Panta et al., 2014).

Tetragonia decumbens Mill. also known as dune spinach or duinespinasie (Afrikaans) is an underutilized indigenous edible halophyte of South Africa. Reports on the edibility of this species have shown that the leaves and soft stem can be used like green spinach, eaten raw in green salads, or cooked with other vegetables (Rusch, 2016; Van Wyk and Gericke, 2017). However, as of today, there are no studies that have been conducted on seed germination and vegetative propagation of this species (Sogoni et al., 2021). This has contributed immensely on its underutilisation and consumption among South African households. Considering the economic potential of the species as a leafy vegetable, a propagation protocol could support the commercial cultivation of the species in urban areas. This study was therefore undertaken to assess the effect of rooting media and indole-3-butyric acid (IBA) treatment on rooting response of *T. decumbens* stem cuttings to formulate a viable propagation protocol for potential growers of the species.

MATERIALS AND METHODS

Experimental location

The experiment was conducted in the research greenhouse of the Department of Horticultural Sciences at the Cape Peninsula University of Technology, Bellville campus, Cape Town, South Africa, located at 33°55’56”S, 18°38’25”E. The experiment was carried out over a period of two months from June to August 2021. The research greenhouse was equipped with overhead automatic spray nozzles for precise intermittent spraying, a heating bed and environmental control with temperatures set to range from 21 to 26°C during the day and 12-18°C at night. The average humidity was maintained at 60-70% during the experimental period.

Plant preparation and treatments

Cuttings of *T. decumbens* were harvested from a selected plant population growing along the coast at the Cape Peninsula University of Technology, Granger Bay campus located at 33°53’58.2”S, 18°24’41.4”E. Only cuttings taken using homogeneous methods, i.e., stem cuttings with about two-thirds of leaves removed, ±15 cm long with a stem thickness of approximately 8 mm were used for the experiment. The cuttings were then rinsed in 0.1% Sporekil™ for precaution against fungal infection, thereafter, were dipped in different concentrations of commercial rooting hormone Dynaroot™ (containing 0.1% IBA for 1 softwood, 0.3% for 2 semi-hardwood and 0.8% for 3 hardwood) for two seconds. Stem cuttings with no hormone treatment served as controls. A total of 11 cuttings were allocated per treatment and replicated three times The cuttings were immediately planted into four different rooting media: sand (S), sand and peat (SP) (1:1), perlite and peat (PP) (1:1) and peat, perlite and vermiculite (PPV) (1:1:1) arranged in a completely randomized design on a specialized propagation bed with heating cables/rod underneath at 26°C. The cuttings were then irrigated by an intermittent sprayer at 18 s per 40-min intervals.

Data collection and statistical analysis

Data collection included rooting percentage, root length, number of roots, number of leaves and plant height after 60 days. All percentage data were subject to angular transformation (arcsin $\sqrt{X}$ and SE number data to square root transformation before analysis (Mukhtar, 2019). The experimental data were analysed using one and two-way analyses of variance (ANOVA), and Fisher's least significant difference was used to compare means at P≤0.05 level of significance between treatments. All calculations were done on the computer software program, STATISTICA version 13.5.0.17.

RESULTS

Rooting percentage (%)

The rooting media in which the nodal stem cuttings were planted significantly affected the rooting percentage at P≤0.05 (Table 1). The highest rooting percentage (84.2%) was recorded on cuttings planted in SP followed by S at 76.8%. These percentages were significantly higher than the percentages recorded in PP (66.3%) and PPV (57.5%) respectively. Conversely, the rooting hormone had no significant effect on rooting percentage although Dynaroot 2 produced the highest rooting (75.4%), which did not differ significantly from that obtained with Dynaroot 1(72.6%), 3 (66.8%) and the control (69.8%) (Table 2). The interaction of rooting media and hormone treatment also had a significant effect on rooting percentage (Table 3). S/D/1 (84.7%), S/D/2 (84.1%), S/D/3 (82.6%), SP/D/0 (87.9), SP/D/1 (82.4%) and SP/D/2 (84.5%) had significantly higher rooting percentages compared to S/D/0 (55.5%), PPV/D/3 (36.3%), PPV/D/2 (69.4%), PPV/D/1 (60.5%) and PP/D/0 (72.3%) respectively (Table 3).

Table 1. Effect of rooting media on rooting percentage, root length, number of roots, and number of leaves and plant height of *Tetragonia decumbens* stem cuttings.

Treatment	Rooting (%)	Root length (cm)	Number of roots (*n*)	Number of leaves (*n*)	Height (cm)
Sand	76.8±3.8a	6.21±0.92a	2.66±0.31b	18.05±1.70bc	18.45±1.6ab
Sand:peat (1:1)	84.2±1.6a	7.76±0.86a	3.75±0.45a	20.18±1.88b	19.69±1.38a
Peat:perlite (1:1)	66.3±2b	5.93±0.94ab	1.52±0.20c	13.45±1.71c	14.33±1.62bc
Peat:perlite:vermiculite (1:1:1)	57.5±4.2b	3.62±0.66c	2.41±0.36bc	8.14±1.21a	12.43±1.50c
F-value	14.1*	4*	7.2*	10.5*	5*

Values (mean ± SE) followed by dissimilar letters in each column are significantly different at P≤0.05 (*).

Table 2. Effect of rooting hormone on stem cuttings of *Tetragonia decumbens*.

Treatment	Rooting (%)	Root length (cm)	Number of roots (*n*)	Number of leaves (*n*)	Height (cm)
No rooting hormone (C)	69.8±4a	6.52±0.88a	2.80±0.44a	16.50±2.a	16.64±1.45a
Dynaroot 1	72.6±3.4a	6.99±1.07a	2.89±0.34a	14.86±1.69a	17.68±1.66a
Dynaroot 2	75.4±3.1a	4.72±0.71a	2.39±0.33a	14.16±1.65a	16.26±1.50a
Dynaroot 3	66.8±5.9a	5.30±0.77a	2.27±0.33a	14.30±1.78a	14.33±1.71a
F-value	0.75ns	1.5ns	0.7ns	0.4ns	0.8ns

Values (mean ± SE) followed by similar letters in each column are not significantly different as calculated by Fisher's least significant difference. D: Dynaroot.

Root length (cm)

The root length was significantly (P≤0.05) reduced by the media PPV to 3.62 cm. Longer root length was recorded in SP at 7.76 cm, but this was not significantly different from S (6.21 cm) and PP (5.93 cm) respectively (Table 1). The rooting hormone and its interaction with rooting media had no significant effect on root length (Tables 2 and 3), although PP/D/1 produced a root length of 7.59 cm, which did not differ significantly from 3.05 cm obtained in

PPV/D/3.

Table 3. Effect of rooting media and hormone on rooting percentage, root length, number of roots, and number of leaves and plant height of *Tetragonia decumbens* stem cuttings.

Treatment	Rooting (%)	Root length (cm)	Number of roots (*n*)	Number of leaves (*n*)	Height (cm)
S/D/0	55.5±0.6e	4.68±1.52bc	2.45±0.74bcde	12.73±3.72bcd	12.64±3.68cd
S/D/1	84.7±3.2a	9.41±2.48ab	3.55±0.71abc	24.45±3.23a	24.82±2.69a
S/D/2	84.1±1.5a	5.22±1.41bc	2.18±0.48bcde	17.82±3.23abc	17.82±2.72abc
S/D/3	82.6±1.7a	5.55±1.64bc	2.45±0.5bcde	17.18±2.89abc	18.55±2.88abc
SP/D/0	87.9±3a	10.32±2.06a	4.64±1.34a	22.91±4.96a	18.73±2.88abc
SP/D/1	82.4±0.5ab	7.23±1.88abc	3.18±0.64abc	15.82±2.96abc	18.82±3abc
SP/D/2	84.5±2.7a	6.00±1.38abc	3.09±0.78abc	18.82±3.73ab	18.77±2.92abc
SP/D/3	81.9±5.1ab	7.50±1.43abc	4.09±0.74ab	23.18±3.17a	22.45±2.47ab
PP/D/0	72.3±5.4bc	6.91±1.63abc	1.36±0.31de	19.18±4ab	18.55±2.98abc
PP/D/1	62.9±0.6cde	7.59±2.74abc	1.73±0.47cde	10.55±2.92bcd	13.55±3.34c
PP/D/2	63.5±5cde	4.14±1.56c	1.36±0.41de	10.36±3.03bcd	13.64±3.34c
PP/D/3	66.4±2.8cd	5.09±1.36bc	1.64±0.45cde	13.73±3.42bcd	11.59±3.361cd
PPV/D/0	63.5±5.5cde	4.18±1.32c	2.73±0.57abc	11.18±2.32bcd	16.64±1.76abc
PPV/D/1	60.5±3de	3.73±1c	3.09±0.79abc	8.64±2.56de	13.55±3.4c
PPV/D/2	69.4±2.9cd	3.52±1.4c	2.91±0.8abc	9.64±2.5cde	14.82±3.12bc
PPV/D/3	36.3±5.2f	3.05±1.62c	0.91±0.51e	3.09±1.77e	4.73±2.45d
F-value	10.7*	0.7 ns	1.1 ns	1.9 ns	2.2 *

Values (mean ± SE) followed by dissimilar letters in each column are significantly different at P≤0.05 (*), ns=not significant.
S: sand, SP: sand and peat, PP: peat and perlite, PPV: peat, perlite and vermiculite, D: Dynaroot, 0: control.

Number of roots (*n*)

The rooting media significantly increased (P≤0.05) the mean number of roots per cutting in SP (3.75) and S (2.66) compared to PP (1.52) and PPV (2.41) which had lower numbers of roots (Table 1). The rooting hormone and its interaction with rooting media had no significant effect on the number of roots although SP/D/0 recorded the highest number (4.64) of roots in all treatments (Tables 2 and 3).

Number of leaves (*n*)

Although most media had higher numbers of leaves, PPV (8.14) significantly reduced the number of leaves in cuttings. The SP media recorded the highest number of leaves (20.18); this was significantly higher than PP (13.45) and PPV (8.14) except S (Table 1). The rooting hormone and its interaction with rooting media had no significance on the number of leaves (Tables 2 and 3).

Plant height (cm)

Rooting media had a significant influence on plant height. The SP treatment recorded the highest mean value of height at (19.69 cm) and was significantly higher (P≤0.05) than PPV (12.43 cm) and PP (14.33 cm) except S (18.45 cm) (Table 1). Rooting hormone had no significant effect on plant height (Table 2) but its interaction with rooting media was significant (Table 3). S/D/1 (24.82), SP/D/3 (22.45), SP/D/2 (18.77) and SP/D/0 (18.73) had a significantly higher mean of plant height, which was similar to S/D/3 (18.55) and S/D/2 (17.82) but significantly higher than PP/D/3 (11.59).

DISCUSSION

Propagation media is considered as one of the most significant factors affecting root initiation in cuttings (Jaleta and Sulaiman, 2019), and this experiment has provided evidence of its significance on root initiation of the nodal stem cutting of dune spinach. The application of growth regulators for root initiation of dune spinach is optional, as cuttings treated with media only rooted better than those treated with growth regulators. These findings substantiate those of Akinyele (2010) on *Bucholzia coriacea* stem cuttings, Mukhtar (2019) on juvenile stem cuttings of *B. aegyptiaca* and Jiang et al. (2016) on nodal stem cuttings of *Silene coronaria,* where cuttings planted in propagation media without hormone treatment showed improved results on tested variables.

The highest cutting survival, rooting rate, number of roots, length of roots and number of leaves were achieved on Sand and Peat mix followed by Sand. Root development was significantly lower in peat, perlite, and vermiculite mix. Several interacting factors within a growth medium such as oxygen, water and nutrient availability are known to affect the rooting success of cuttings (Bhardwaj, 2014; Rajkumar et al., 2017). Insufficient of one or more of these beneficial factors leads to lower or reduced rooting percentage (Mehri et al., 2013). The rooting success of *T. decumbens* stem cuttings utilizing sand and peat could be ascribed to the positive interaction of aeration and water-holding capacity, as compared to the combination of peat, vermiculite, and perlite. These results are in agreement with the findings of Kontoh (2016) on *Voacanga africana* stem cuttings and Dvin et al. (2011) on apple hardwood cuttings (MM1111), where the authors reported high rooting success in sand and peat mixture than sand, fibre or peat moss alone. Akakpo et al. (2014) also reported that a well-aerated media increases respiration at the base of the cuttings and thus promoting root initiation. Poor rooting performance in peat, vermiculite and perlite mix might be caused by poor aeration since both peat and vermiculite have high water retention capacity. This led to delayed rooting and decaying of cuttings. This concur with the statement made by Schmitz et al. (2013), where the authors indicated that an increase in moisture content within a media reduces the oxygen diffusion efficiency in the root zone, thus resulting to delay rooting and decay.

CONCLUSIONS

The present study demonstrated that nodal stem cuttings of dune spinach may be propagated vegetatively for multiplication in sand and peat mixture without the use of growth hormones. This could be a cost-saving option for potential urban growers of the species, who may want to exploit this plant for diet diversity and as a source of nutritional substitute for spinach and lettuce. Furthermore, its creeping nature, glistening leaves and showy flowers also makes it a potential ornamental plant in urban gardens, especially in areas where the soil lack stability.

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Literature cited

Acquaah, G. (2007). Principles of Plant Genetics and Breeding (Oxford: Blackwell publishing), p.101–115.

Afolayan, A.J., and Jimoh, F.O. (2009). Nutritional quality of some wild leafy vegetables in South Africa. Int J Food Sci Nutr *60* (*5*), 424–431 https://doi.org/10.1080/09637480701777928. PubMed

Akakpo, D.B., Amissah, N., Yeboah, J., and Blay, E. (2014). Effect of indole 3-butyric acid and media type on adventitious root formation in sheanut tree (*Vitellaria paradoxa* C. F. Gaertn.). Stem Cuttings. Am. J. Plant Sci. *5* (*3*), 313–318 https://doi.org/10.4236/ajps.2014.53043.

Akinyele, A.O. (2010). Effects of growth hormones, rooting media and leaf size on juvenile stem cuttings of *Buchholzia coriacea* Engler. Ann. For. Res. *53*, 127–133.

Bartels, D., and Sunkar, R. (2005). Drought and salt tolerance in plants. Crit. Rev. Plant Sci. *24* (*1*), 23–58 https://doi.org/10.1080/07352680590910410.

Ben Hamed, K., and Custódio, L. (2019). How could halophytes provide a sustainable alternative to achieve food security in marginal lands? In Ecophysiology, Abiotic Stress Responses and Utilization of Halophytes, M. Hasanuzzaman, and K.Ö.M. Nahar, eds. (Singapore: Springer), p.259–270 https://doi.org/10.1007/978-981-13-3762-8_12.

Bhardwaj, R.L. (2014). Effect of growing media on seed germination and seedling growth of papaya cv. 'Red lady'".

Afr. J. Plant Sci. *8* (*4*), 178–184 https://doi.org/10.5897/AJPS11.265.

Bischoff-Mattson, Z., Maree, G., Vogel, C., Lynch, A., Olivier, D., and Terblanche, D. (2020). Shape of a water crisis: practitioner perspectives on urban water scarcity and 'Day Zero' in South Africa. Water Policy *22* (*2*), 193–210 https://doi.org/10.2166/wp.2020.233.

Corwin, D.L. (2021). Climate change impacts on soil salinity in agricultural areas. Eur. J. Soil Sci. *72* (*2*), 842–862 https://doi.org/10.1111/ejss.13010.

Debez, A., Saadaoui, D., Slama, I., Huchzermeyer, B., and Abdelly, C. (2010). Responses of *Batis maritima* plants challenged with up to two-fold seawater NaCl salinity. J. Plant Nutr. Soil Sci. *173* (*2*), 291–299 https://doi.org/10.1002/jpln.200900222.

Dvin, S., Ganji Moghadam, E., and Kiani, M. (2011). Rooting response of hardwood cuttings of MM111 apple clonal rootstock to indolebutyric acid and rooting media. Asian J. Appl. Sci. *4* (*4*), 453–458 https://doi.org/10.3923/ajaps.2011.453.458.

Gidamis, A.B., and Chove, B.E. (2009). Biotechnology and biosafety: exploring the debate and public perception in developing countries. J. Knowl. Glob. *2*, 45–62.

Glenn, E.P., Brown, J.J., and Blumwald, E. (1999). Salt tolerance and crop potential of halophytes. Crit. Rev. Plant Sci. *18* (*2*), 227–255 https://doi.org/10.1080/07352689991309207.

Jacobsen, S.E., Sørensen, M., Pedersen, S.M., and Weiner, J. (2013). Feeding the world: genetically modified crops versus agricultural biodiversity. Agron. Sustain. Dev. *33* (*4*), 651–662 https://doi.org/10.1007/s13593-013-0138-9.

Jaleta, A., and Sulaiman, M. (2019). A review on the effect of rooting media on rooting and growth of cutting propagated grape (*Vitis vinifera* L.). World J. Agric. Soil Sci. *3* (*4*), 1–8 https://doi.org/10.33552/WJASS.2019.03.000567.

Jiang, L., Dunn, B.L., Wang, Y., and Goad, C.L. (2016). Responses to propagation substrate and rooting hormone products to facilitate asexual propagation of *Silene chalcedonica* and *Silene coronaria.* J. Environ. Hortic. *34* (*3*), 80–83 https://doi.org/10.24266/0738-2898-34.3.80.

Kashyap, S.P., Kumari, N., Mishra, P., Moharana, D.P., and Aamir, M. (2021). Tapping the potential of *Solanum lycopersicum* L. pertaining to salinity tolerance: perspectives and challenges. Genet. Resour. Crop Evol. *68* (*6*), 2207–2233 https://doi.org/10.1007/s10722-021-01174-9.

Kontoh, I.H. (2016). Effect of growth regulators and soil media on the propagation of *Voacanga africana* stem cuttings. Agrofor. Syst. *90* (*3*), 479–488 https://doi.org/10.1007/s10457-015-9870-2.

Mehri, H., Mhanna, K., and Soltane, A. (2013). Root growth of arbequina cuttings as influenced by organic and inorganic substrates under the conditions of Al-Jouf (KSA). Am. J. Plant Physiol. *8* (*2*), 74–83 https://doi.org/10.3923/ajpp.2013.74.83.

Molotoks, A., Smith, P., and Dawson, T.P. (2021). Impacts of land use, population, and climate change on global food security. Food Energy Secur. *10* (*1*), e261 https://doi.org/10.1002/fes3.261.

Mukhtar, R.B. (2019). Effect of rooting media and hormone concentrations on vegetative propagation of *Balanites aegyptiaca.* J. For. Res. *30* (*1*), 73–76 https://doi.org/10.1007/s11676-018-0622-9.

Ogunniyi, A.I., Mavrotas, G., Olagunju, K.O., Fadare, O., and Adedoyin, R. (2020). Governance quality, remittances and their implications for food and nutrition security in Sub-Saharan Africa. World Dev. *127*, 104752 https://doi.org/10.1016/j.worlddev.2019.104752.

Panta, S., Flowers, T., Lane, P., Doyle, R., Haros, G., and Shabala, S. (2014). Halophyte agriculture: success stories. Environ. Exp. Bot. *107*, 71–83 https://doi.org/10.1016/j.envexpbot.2014.05.006.

Rajkumar, R., Gora, J.S., Kumar, R., Singh, A., Kumar, A., and Gajender, G. (2017). Effect of different growing media on the rooting of pomegranate (*Punica granatum* L.) cv. 'Phulearakta' cuttings. J. Appl. Nat. Sci. *9* (*2*), 715–719 https://doi.org/10.31018/jans.v9i2.1263.

Rusch, L. (2016). The Cape Wild Food Garden: a Pilot Cultivation Project (Lyndoch, Stellenbosch: Sustainability Institute).

Schmitz, D., Anlauf, R., and Rehrmann, P. (2013). Effect of air content on the oxygen diffusion coefficient of growing media. Am. J. Plant Sci. *4* (*5*), 955–963 https://doi.org/10.4236/ajps.2013.45118.

Sogoni, A., Jimoh, M., Kambizi, L., and Laubscher, C. (2021). The impact of salt stress on plant growth, mineral composition, and antioxidant activity in *Tetragonia decumbens* Mill.: an underutilized edible halophyte in South Africa. Horticulturae *7* (*6*), 140 https://doi.org/10.3390/horticulturae7060140.

Van Wyk, B.E., and Gericke, N. (2017). People's Plants - a Guide to Useful Plants of Southern Africa, 2nd edn (Pretoria, South Africa: Briza Publications).

Ventura, Y., and Sagi, M. (2013). Halophyte crop cultivation: the case for *Salicornia* and *Sarcocornia.* Environ. Exp. Bot. *92*, 144–153 https://doi.org/10.1016/j.envexpbot.2012.07.010.

World Bank. (2007). World Development Report 2008: Agriculture for Development (Washington, DC).