Vol. 17(7), pp. 225-241, July, 2023
DOI: 10.5897/JMPR2023.7299
Article Number: C77950470935
ISSN 1996-0875

http://www.academicjournals.org/JMPR

Journal of Medicinal Plants Research

Full Length Research Paper

Pre-sowing treatments to improve seed germination and seedling growth of *Commiphora swynnertonii* (Burrt.) and *Synadenium glaucescens* (Pax.)

Madege Richard Raphael[1]*, Babu Saidi[1], Mabiki Faith Philemon[2], Hosea Mtui[1] and Abdul Kudra[1]

[1]Department of Crop Science and Horticulture, Kididimo, Morogoro, Tanzania.
[2]Department of Chemistry and Physics, Sokoine University of Agriculture, Kididimo, Morogoro, Tanzania.

Received 1 March, 2023; Accepted 12 April, 2023

Medicinal and pesticidal plant propagation is hampered by poor seed germination due to seed dormancy. This study aimed to enhance seed germination and seedling growth using various pre-sowing treatments. A triplicated two-factor experiment in a Randomized Complete Block design was used. Soaking in water at 25°C for 24 h (T1), soaking in 60°C hot water for 10 min (T2), 10 ppm Potassium nitrate (KNO_3) treatment for 24 h (T3), 20 ppm Potassium nitrate (KNO_3) treatment for 24 h (T4), Treating seeds with Gibberellin (GA_3) solution at 250 ppm (T5), GA_3 Treating seeds with Gibberellin (GA_3) solution at 500 ppm for 72 (T6), Treating seeds with Gibberellin (GA_3) solution at 1000 ppm for 72 h (T7), and seeds without any pre-treatment were sown and used as control (T_o) on seed germination and seedling growth of two MPP species. The ability of a pre-sowing treatment to break seed dormancy was significantly dependent ($p = 0.002$) on the plant species. The effects due to interaction between pre-sowing seed treatment and plant species on seedling growth parameters (height, branches/shoot, leaves/shoot/, leaf area, fresh and dry weight) were significant ($p < 0.05$). These results provide the basis for the sustainable use of MPPs through propagation and conservation.

Key words: Medicinal-pesticidal plants, seed dormancy, pre-treatment, germination.

INTRODUCTION

From ancient times, the inhabitants of the Earth have been using plants and plant-based products for different purposes (Bargali et al., 2003; Padalia et al., 2017; Vibhuti and Bargali, 2022). Close to 80% of the global population in low- and middle-income countries uses traditional medicines from plant products (Padalia et al., 2017). Forests/Protected areas/Agricultural lands are the important repositories of terrestrial biodiversity and play a key role in influencing socio-ecological and cultural attributes of human societies for their living being (Hermann, 2006; Parihaar et al., 2015; Karki et al., 2017; Awasthi et al., 2022; Bargali et al., 2022). In developing countries, a large number of people depend on products derived from plants for curing human and livestock ailments. In the beginning, these were the main source of the folk or ethnomedicine (Bargali et al., 2003). During the last few decades, there has been an increasing interest in the study of medicinal plants and their traditional use in

*Corresponding author. E-mail: richmadege@sua.ac.tz.

different parts of the world (Pande et al., 2016; Hanazaki et al., 2000). In African agriculture and medical health care, plants provide medicine and pest control resources for millions of people. Hence, harvesting of Medicinal and Pesticidal Plants (MPP) is widespread, exerting pressure on MPP natural populations. As a result, there is a reduced contribution of these plants to the income and the well-being of traders and consumers. Loss of MPP biodiversity is alarming as the majority are being pushed to extinction due to overharvesting and habitat destruction (Aftab and Hakeem, 2021; Ceballos et al., 2017; Dirzo and Raven, 2003). Nearly 20% of their wild resources have already been nearly exhausted with the increasing human population and plant consumption (Dirzo and Raven, 2003).

Among MPPs that are being rapidly pushed to extinction are *Commiphora swynnertonii* (Burrt) and *Synadenium glaucescens* (Pax). These plant species have medicinal and pesticidal attributes making them useful as medicine for humans and livestock as well as a pesticide for crop protection (Credo et al., 2022; Mary et al., 2022; Matendo et al., 2019; Nyigo et al., 2015a). Currently, the exploitation and indiscriminate collection of such MPPs is at its peak globally as the world is shifting to eating safe organically produced food (Chi et al., 2017; Moyo et al., 2015; van Wyk and Prinsloo, 2018). However, in developing countries, the problem is more severe because the majority in the rural areas depend on herbal drugs for their primary healthcare as well as use botanical pesticides to control different pests that attack crops in the field and storage (Kamanula et al., 2011).

In Tanzania, there is a commercial trade of wild-harvested medicinal plants predominantly practiced by women and youths (Mpelangwa et al., 2022). Unfortunately, the raw materials for herbal medicine and pesticides are harvested directly from their natural environment subjecting them to continuous genetic erosion. A field survey in Mufindi and Njombe districts revealed the disappearance of the *S. glaucescens* in the wild (Mabiki, 2013). Another field survey in Manyara region revealed that there is over-exploitation of *C. swynertonii* in Simanjiro district due to mining, overgrazing, urbanization, and other agricultural activities (George, 2013). This raises a demand for innovative strategies for the conservation of such highly endangered medicinal and pesticidal plant resources. To date, several conservation measures have been recommended including both *in situ* and *ex-situ* conservation, botanical gene banking and reforestation programs (Chen et al., 2016a, b; Chi et al., 2017; Knowler and Bradshaw, 2007; van Andel et al., 2015). All these proposed strategies have not been successful for various reasons one of which are the problems related to seed quality (Sharma and Sharma, 2017).

Seed germination and early seedling growth are considered the most critical phases for the establishment of any species (Pratap and Sharma, 2010; Vibhuti et al., 2015) in which seed quality plays an important role (Pande et al., 2016). The key constraint to germination of MPPs is that they possess seed dormancy and seed inhibitors responsible reduced seed quality (Patade et al., 2020; Topacoglu et al., 2020). These associated seed inhibitors also are known to decrease the viability (Ganesh et al., 2022; Sharma and Sharma, 2017). In this case seed pre-treatment before sowing through various techniques can offer a significant contribution towards improved seed germination, uniform seedling growth and enhancing optimum field establishment (Güleryüz et al., 2021). The objective of study was to improve seed germination and seedling growth by treating with specific chemical under very specific regimes.

MATERIALS AND METHODS

Collection of seeds and plant growth regulators

Seeds of *C. swynnertonii* were harvested from Mererani ward in Simanjiro District of Manyara Region (3° 34.5′ S, 37° 0′ E at 1 009 m a.s.l) (Figure 1). The seeds of *S. glaucescens* were obtained from the Department of Food Technology, Nutrition and Consumer Sciences premises at Sokoine University of Agriculture, Morogoro, Tanzania (6° 85′ S, 37° 65′ E at 556 m a.s.l). Gibberellic acid (GA_3), Potassium nitrate (KNO_3) and Sodium hypochlorite (NaOCl) were purchased from Jakovic General Supplies Ltd, Morogoro, Tanzania.

Experimentation

Fruits of *C. swynnertonii* and *S. glaucescens* were harvested and air dried under shade for three days after which the seeds were extracted using standard protocols (Shalabi and Otaif, 2022). Prior to seed pre-treatments, the seeds were surface sterilized by immersing them in 2% sodium hypochlorite solution for 2 min and then rinsed in sterile distilled water. Ten surface sterilized seeds were subjected to each of the following pre-treatments; soaking in water at 25°C for 24 h (T1), soaking in 60°C hot water for 10 min (T2), 10 ppm Potassium nitrate (KNO_3) treatment for 24 h (T3), 20 ppm Potassium nitrate (KNO_3) treatment for 24 h (T4), Treating seeds with Gibberellin (GA_3) solution at 250 ppm (T5), GA_3 Treating seeds with Gibberellin (GA_3) solution at 500 ppm for 72 (T6), Treating seeds with Gibberellin (GA_3) solution at 1000 ppm for 72 h (T7), and Seeds without any pre-treatment were sown and used as control (T_o). Ten seeds were sown in each of 4 L plastic pots (4-L), filled with steam-sterilized forest soil, farmyard manure and rice husks at a ratio of 4:2:1. Seeds were sown approximately at 1.0 cm deep. The pots were placed in the screen house and watered after every two days. Pots were inspected for weeds and removed when seen. The experiment was arranged in RCBD with four replications.

Data collection

Data were collected according to the method described by Sharma and others (2009) with some modifications. The seeds in the pots were observed daily for seedling emergence and the number of days taken to seedling emergence was recorded. The total number of seedlings emerged in each treatment was recorded daily. Seedlings' survival was recorded at the time of transplanting. The seed germination percentage and seedling survival percentage

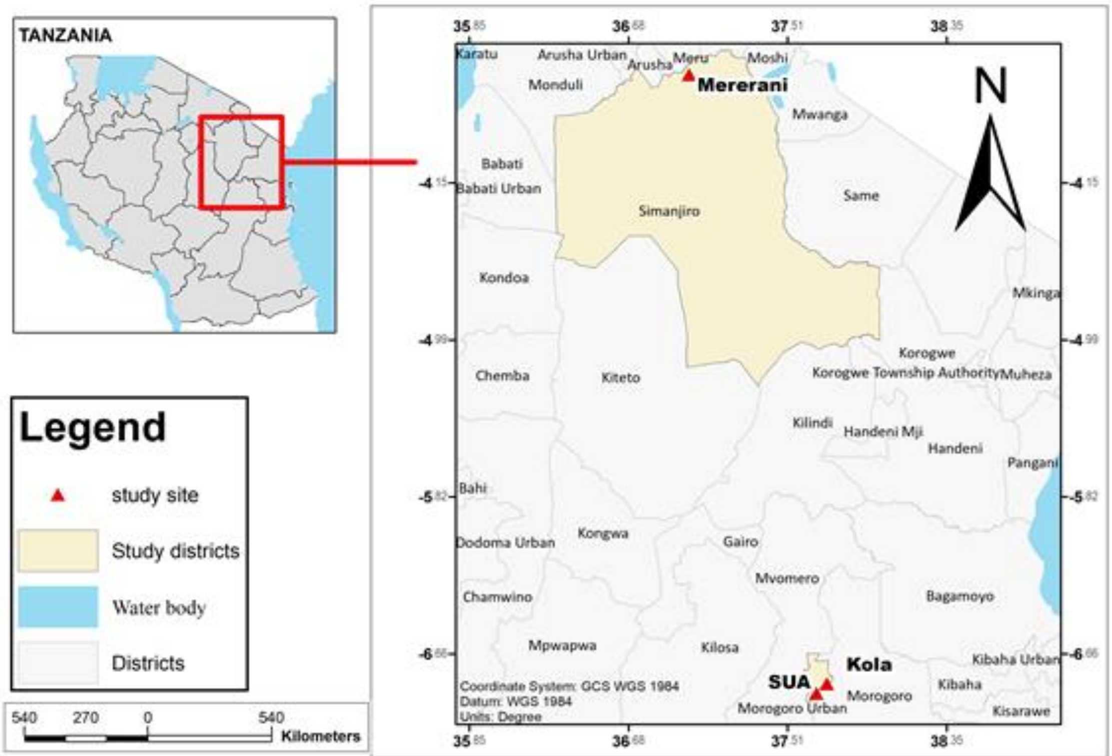


Figure 1. Map of Tanzania showing location of Mererani, a source of *C. swynnertonii.*
Source: Authors

were computed as follows:

$$\text{Germination (\%)} = \frac{\text{number of seedlings emerged}}{\text{number of seeds sown}} \text{ x } 100 \quad (1)$$

$$\text{Seedling survival (\%)} = \frac{\text{number of seedlings survived}}{\text{number of seedling emerged}} \text{ x } 100 \quad (2)$$

Data analysis

Before analysis the data were checked for normality and later square-root transformation was done for the number of days taken to seedling emergence, germination percentage and seedling survival. All data were subjected to analysis of variance using GenStat software 15th Edition (VSN International Ltd. UK). Treatment means were separated by Tukey's HSD (honestly significant difference) test at $p \leq 0.05$.

RESULTS AND DISCUSSION

Seed germination

The findings in Figure 2A indicate that under the same pre-treatment, the germination percent of *C. swynnertonii* and *S. glaucescens* did not differ significantly (p = 0.672). This implies that the two plants had more or less the same viability potentials. The two plants are different in their ecological adaptability but they are both characterized of having long seed dormancy and traditionally propagated vegetatively via cuttings or air layering (Baskin and Baskin, 2020; Lal and Kasera, 2014). Currently, findings regarding germination of *C. swynnertonii* and *S. glaucescens* could not be traced easily in the literature but comparison with other related tree seeds shows that these findings are comparable to numerous recent studies (Baskin and Baskin, 2020; Cabello et al., 2019; Han et al., 2018).

Significant differences (p = 0.007) were observed in the effects of the different seed pre-treatment applied to enhance germination of *C. swynnertonii* and *S. glaucescens* seeds (Figure 2B). It was realized that seeds that were soaked in water at 25°C for 24 h had more than 10% higher seed germination than the untreated control. All other pre-treatments did not differ significantly or caused significantly lower germination percentage than the untreated seeds. These findings are not in agreement with previous studies on breaking seed dormancy of other tree seeds which have reported that the use of GA_3 and KNO_3 greatly improved germination percent of many tree seeds (Iralu and Upadhaya, 2018; Kheloufi et al., 2018; Tiwari et al., 2018). Reason for this disparity could not be established

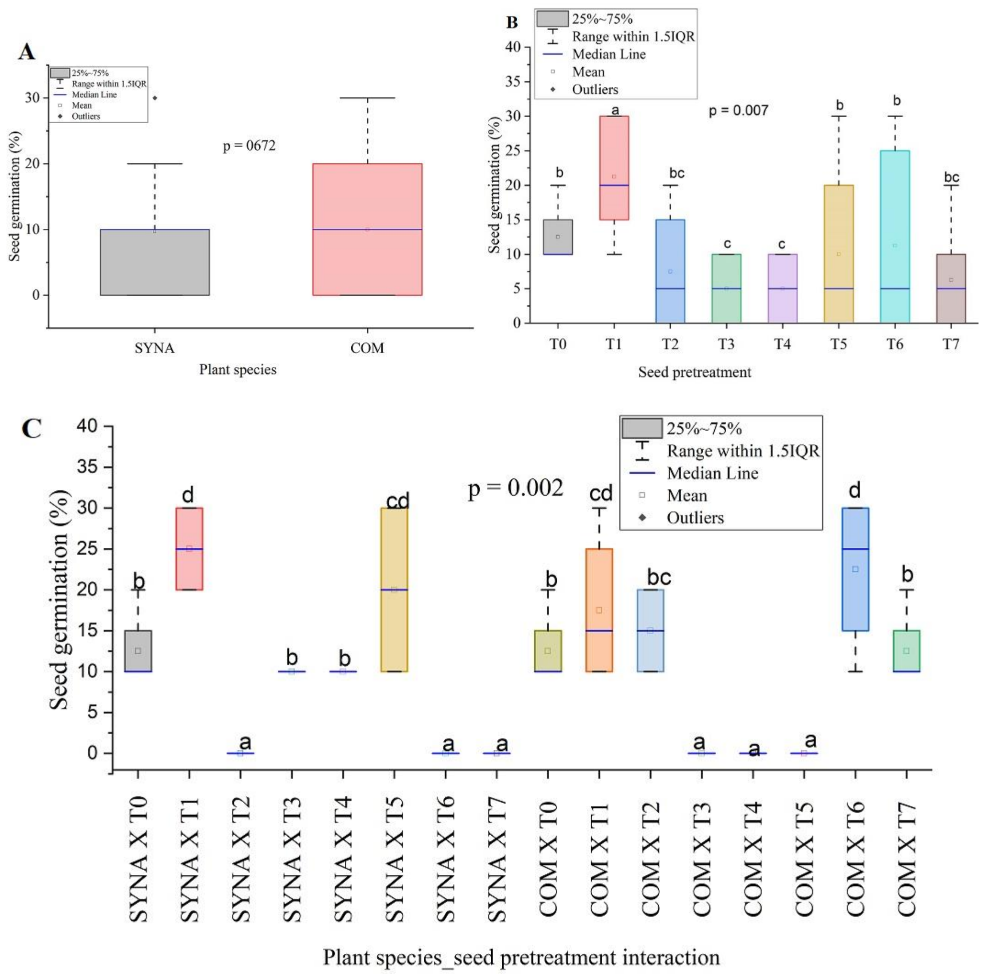


Figure 1. Effects to plant species (A), seed pre-treatment (B), and the interactions of A and B (C) on seed germination. COM and SYNA = *C. swynnertonii* and *S. glaucescens*, respectively. T1 = Soaking in water at 25°C for 24 h, T2 = soaking in 60°C hot water for 10 min, T3 = 10ppm Potassium nitrate (KNO_3) treatment for 24 hrs, T4 = 20 ppm Potassium nitrate (KNO_3) treatment for 24hrs T5 = Treating seeds with Gibberellin (GA_3) solution at 250 ppm, GA_3, T6 = Treating seeds with Gibberellin (GA_3) solution at 500 ppm for 72, T7 = Treating seeds with Gibberellin (GA_3) solution at 1000 ppm for 72 h and T_0 = distilled water treatment used as control. Means with the same letters are not significantly different at $p < 0.05$.
Source: Authors

but the findings suggest that soaking in water at 25°C was enough to soften the tester and germinate.

However, the findings in Figure 2C show that, the ability of a particular pre-treatment to break seed dormancy was significantly dependent on the plant species. The result demonstrates that seeds of *S. glaucescens* which were treated by soaking in water at 25°C for 24 h attained a 25% germination the same as the seeds of *C. swynnertonii* which were treated with. These results are comparable to previous findings although of different plant species (Iralu and Upadhaya, 2018; Kheloufi et al., 2018; Labbafi et al., 2018; Tiwari et al., 2018). Seeds of both *C. swynnertonii* and *S. glaucescens* which were not pre-treated (T0) at all attained a 10% germination percent whereas *S. glaucescens* seeds treated with T2, T6, and T6 and the seeds of *C. swynnertonii* treated with T3, T4 and, T5 did not germinate. These results suggest that these treatments possibly strengthened the seed dormancy of the seed embryo or it could not survive post treatments.

Days to seedling emergence

The results in Figure 3A show that, after seed sowing, the days to seedling emergence did not vary significantly (p = 0.0741) between plant species. Since they were all planted at the same seeding depth, these results suggest that the seeds of the two plant species might have similar intrinsic factors like seed dormancy factors

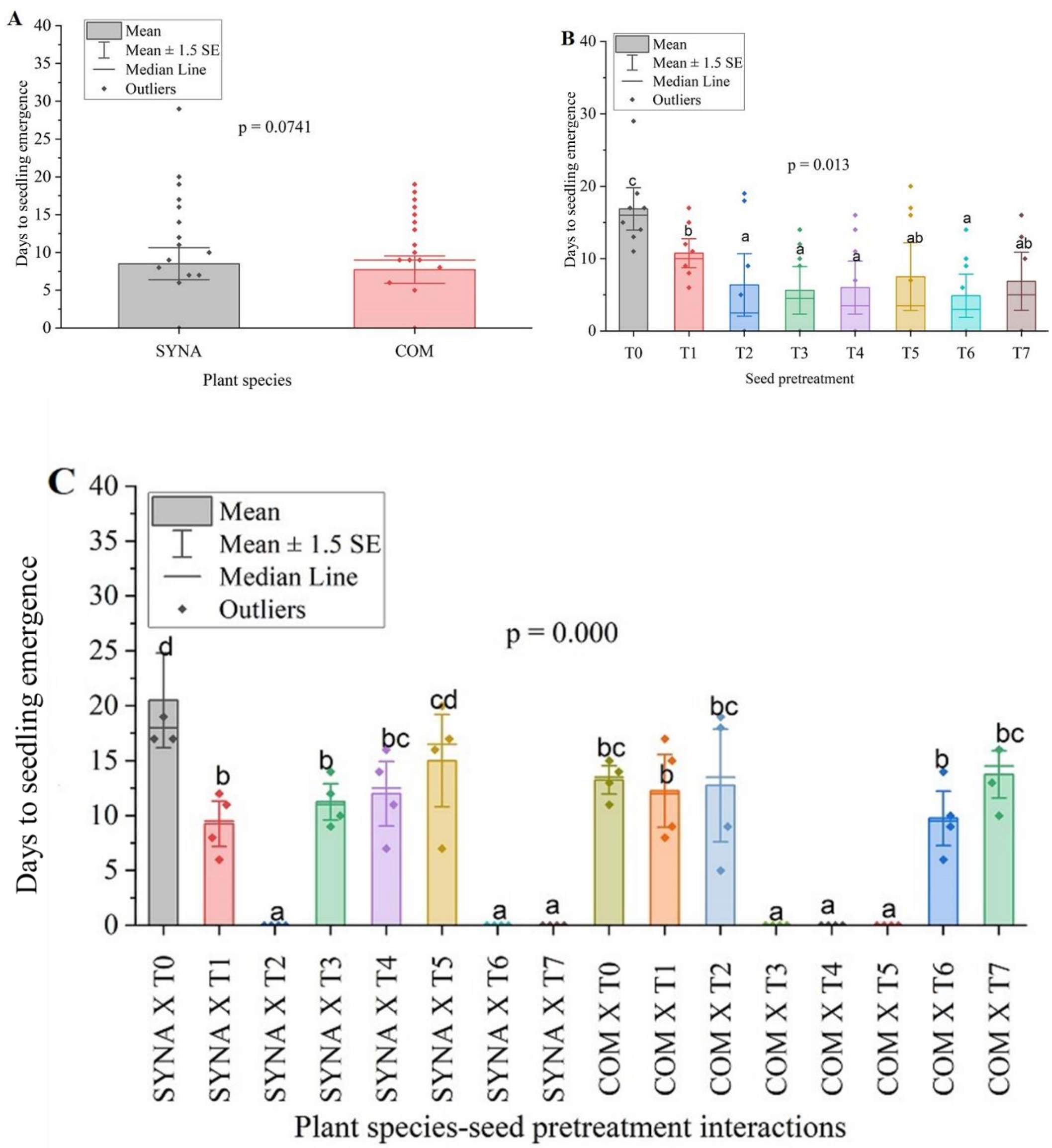


Figure 2. Effects to plant species (A), seed pre-treatment (B), and the interactions of A and B (C) on days to seedling emergence after sowing. COM and SYNA = *C. swynnertonii* and *S. glaucescens*, respectively. T1 = Soaking in water at 25°C for 24 h, T2 = soaking in 60°C hot water for 10 min, T3 = 10 ppm Potassium nitrate (KNO_3) treatment for 24 h, T4 = 20 ppm Potassium nitrate (KNO3) treatment for 24hrs, T5 = Treating seeds with Gibberellin (GA_3) solution at 250 ppm, GA_3, T6 = Treating seeds with Gibberellin (GA_3) solution at 500 ppm for 72, T7 = Treating seeds with Gibberellin (GA_3) solution at 1000 ppm for 72 h and T_0 = distilled water treatment used as control. Means with the same letters are not significantly different at $p < 0.05$.
Source: Authors

(Lamichhane et al., 2018). Figure 3B presents the findings that there was a significant difference (p = 0.0013) between pre-treatment conditions to which the seeds from the two plant species were subjected. Seeds treated with T2, T3, T4, T5, T6 and T7 emerged between 3 and 7days after sowing. However, seeds pre-treated using T5 (6 days) and T7 (7 days) had an emergence rate that was not different from seeds pre-treated using T1 (8 days). The longest time (17 days) was spent by seeds that were not pre-treated suggesting that all pre-treatment procedures had the added advantage of shortening the seedling emergence time.

These findings are not far from previous reports which have demonstrated that Potassium nitrate (KNO_3) can break seed dormancy, promote seed germination and enhance growth uniformity in a variety of plant species (Cabello et al., 2019; Lal and Kasera, 2014). Similarly, previous studies have demonstrated that GA3 can break seed dormancy and promote germination by activating hydrolyzing enzymes within the seeds to increase carbohydrate hydrolysis for rapid energy metabolism and promote seedling elongation (Tiwari et al., 2018; Wang et al., 2021). Exposure of dormant seeds to different regimes of hydration and temperature has been reported to upregulate or downregulate seed germination (Baskin and Baskin, 2020; Guo et al., 2020; Lamichhane et al., 2018). In this study, soaking seeds in warm and hot water has demonstrated the ability to break seed dormancy and promote seedling growth toward emergence. However, the influence of these pretreatments on breaking seed dormancy and promoting seedling growth is said to be dependent on plant species suggesting there is usually an interaction between seed pre-treatment and inherent plant species attributes (Kheloufi et al., 2018). In this study, the findings in Figure 3C confirm the previous studies in that, the effects of the different seed pre-treatments were significantly dependent on plant species. In this result the same pre-treatment T2, no seed germination could be realized for *S. glaucescens* while germination coupled with seedling emergence within 7 days after sowing was realized for *C. swynnertonii.*

Seedling growth

Shoot height

Although *C. swynnertonii* and *S. glaucescens* did not show differences in seed germination and seedling emergence, the two species showed significant differences (p = 0.014) in seedling shoot height. This can be linked to their inherent differences in their capacity to mobilize growth factors like water, light, and mineral nutrients (Montaño-Arias et al., 2021). Like other plants within the genus *Commiphora*, *C. swynnertonii* is characterized by small trees or shrubs with short, thorny branches while *S. glaucescens* is a shrub or small tree with fleshy stems and branches with leaves spirally arranged, crowded near the ends of branches (Mihale et al., 2018). Application of the different pre-sowing treatments significantly impacted seedling shoot height. The longest (25 cm) seedling shoot height was attained for seedlings from seeds that were pre-treated with 10 ppm.

Potassium nitrate (KNO_3) treatment for 24 h (T3) (Figure 4B). Treating seeds with Gibberellin (GA_3) solution at 250 ppm caused the shortest seedling shoot height of 6 cm while seeds pre-treated with T6 and T7 did not germinate. These results are similar to the previous studies which reported that pre-sowing treatment with lower KNO_3 improved the seedling height significantly although the reduction in the plant height was observed under the higher concentration of KNO_3 (Dev et al., 2020). However, the influence of these pre-sowing treatments on seedling shoot height was significantly dependent on plant species (Figure 4C). The longest seedling shoot height (43 cm) was observed on seedlings of *C. swynnertonii* whose seeds were pre-treated with T3 and the longest seedling shoot height of 15 cm was observed on seedlings of *S. glaucescens.* Such differences between plant species in growth responses to pre-sowing seed treatment have been reported by many workers (Dev et al., 2020; Montaño-Arias et al., 2021; Yang et al., 2020). Pre-sowing treatments with T6 and T7 did not break the seed dormancy of both *S. glaucescens* and *C. swynnertonii* while T5 and T2 pre-treatments did not break the seed dormancy of *S. glaucescens* and *C. swynnertonii*, respectively. Reasons for this difference could not be established in this study. However, previously, studies have reported the variable effect of GA_3 and KNO_3 on germination and growth traits of various plant species (Iralu and Upadhaya, 2018; Kheloufi et al., 2018; Raji and Siril, 2018; Wang et al., 2021; Yang et al., 2020).

Shoot branching

The increase in seedling shoot height happened together with the development of shoot branches. There were significant differences between plant species in the number of branches per shoot (Figure 5A). In this regard, *C. swynnertonii* produced about four (4) branches per shoot which were significantly higher than the one branch per shoot produced by *S. glaucescens.* These differences can be linked to their differences in their branching nature whereby *C. swynnertonii* is naturally a shrub with multiple thorny branches while *S. glaucescens* develops an herbaceous stem with few thick branches consisting of many broad leaves (Mihale et al., 2018). These interspecies differences in branching have implications for their resilience to harsh climates. Among the two plant species, *C. swynnertonii* showed rapid branching, and the leaves are reduced into thorns. This is an adaptation to low moisture tropical climate (Ziter et al., 2019) which is a typical climate of Simanjiro, in Manyara region, Tanzania where its natural habitat is found. The seedling shoot branching pattern was also influenced by the pre-sowing seed treatment whereby the highest branching (6 branches per shoot) was attained by the seedlings whose seeds were pre-treated using 10 ppm Potassium nitrate (KNO_3) for 24 h (Figure 5B). The lowest number of branches per shoot was achieved in seedlings developing from seeds that were pre-treated with Gibberellin (GA_3) solution at 250 ppm. The ability of KNO_3 to promote the growth and development of tree species has been reported by many previous workers (Dev et al., 2020; Yang et al., 2020). In this regard, the seedlings of *C. swynnertonii* which were from seeds that were previously treated with 10 ppm Potassium nitrate (KNO_3) for 24 h developed an average of nine branches per shoot which was the highest of all other treatment combinations.

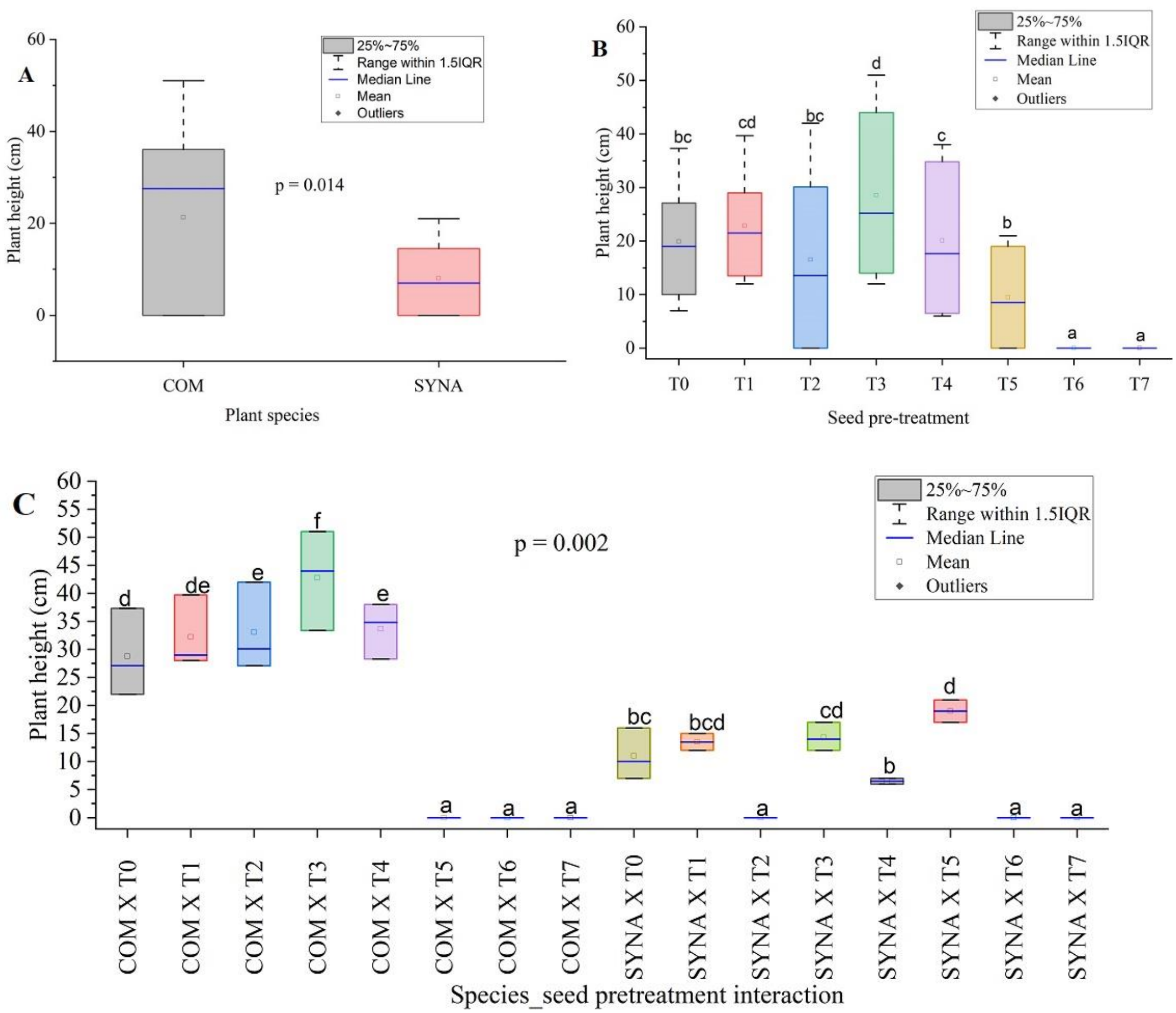


Figure 3. Effects to plant species (A), seed pre-treatment (B), and the interactions of A and B (C) on seedling shoot height. COM and SYNA = *C. swynnertonii* and *S. glaucescens*, respectively. T1 = Soaking in water at 25°C for 24 h, T2 = soaking in 60°C hot water for 10 min, T3 = 10 ppm Potassium nitrate (KNO_3) treatment for 24 h, T4 = 20 ppm Potassium nitrate (KNO_3) treatment for 24 h T5 = Treating seeds with Gibberellin (GA_3) solution at 250 ppm, GA_3, T6 = Treating seeds with Gibberellin (GA_3) solution at 500 ppm for 72, T7 = Treating seeds with Gibberellin (GA_3) solution at 1000 ppm for 72 h and T_0 = distilled water treatment used as control. Means with the same letters are not significantly different at p < 0.05.
Source: Authors

Leaf number and leaf area

The findings show that there was a significant difference between plant species in the number of leaves (p = 0.0010) (Figure 6A) as well as the leaf area (p = 0.007) (Figure 6B). While *C. swynnertonii* produced about 50 leaves, *S. glaucescens* produced less than ten leaves within the same growth period. On the contrary, despite having the least number of leaves, *S. glaucescens* had the largest leaf area of about 35 cm^2 compared to 5 cm^2 of more than 50 leaves of *C. swynnertonii.* The differences could be related to their natural adaptation whereby *C. swynnertonii.* As an adaptation to semi-arid climate, *C. swynnertonii* has small leaves that are developed and the stem is thorny to reduce excessive transpiration while *S. glaucescens* is broad-leaved and is adapted to humid climates (Ziter et al., 2019).

The results demonstrate that pre-sowing seed treatments had significant (p = 0.022) effects on the number of leaves per shoot and the leaf area (Figure 7A). Similarly, the same treatments had significant (p = 0.000) effects on the leaf area (Figure 7B). Treating the seeds with 10 ppm Potassium nitrate (KNO_3) treatment for 24 h resulted in an increase of 15 more leaves per shoot compared to 19 leaves per shoot in seedlings from untreated seeds. The number of leaves per shoot in seedlings arising from seeds pre-treated by soaking in water at 25°C for 24 h and with 20ppm Potassium nitrate

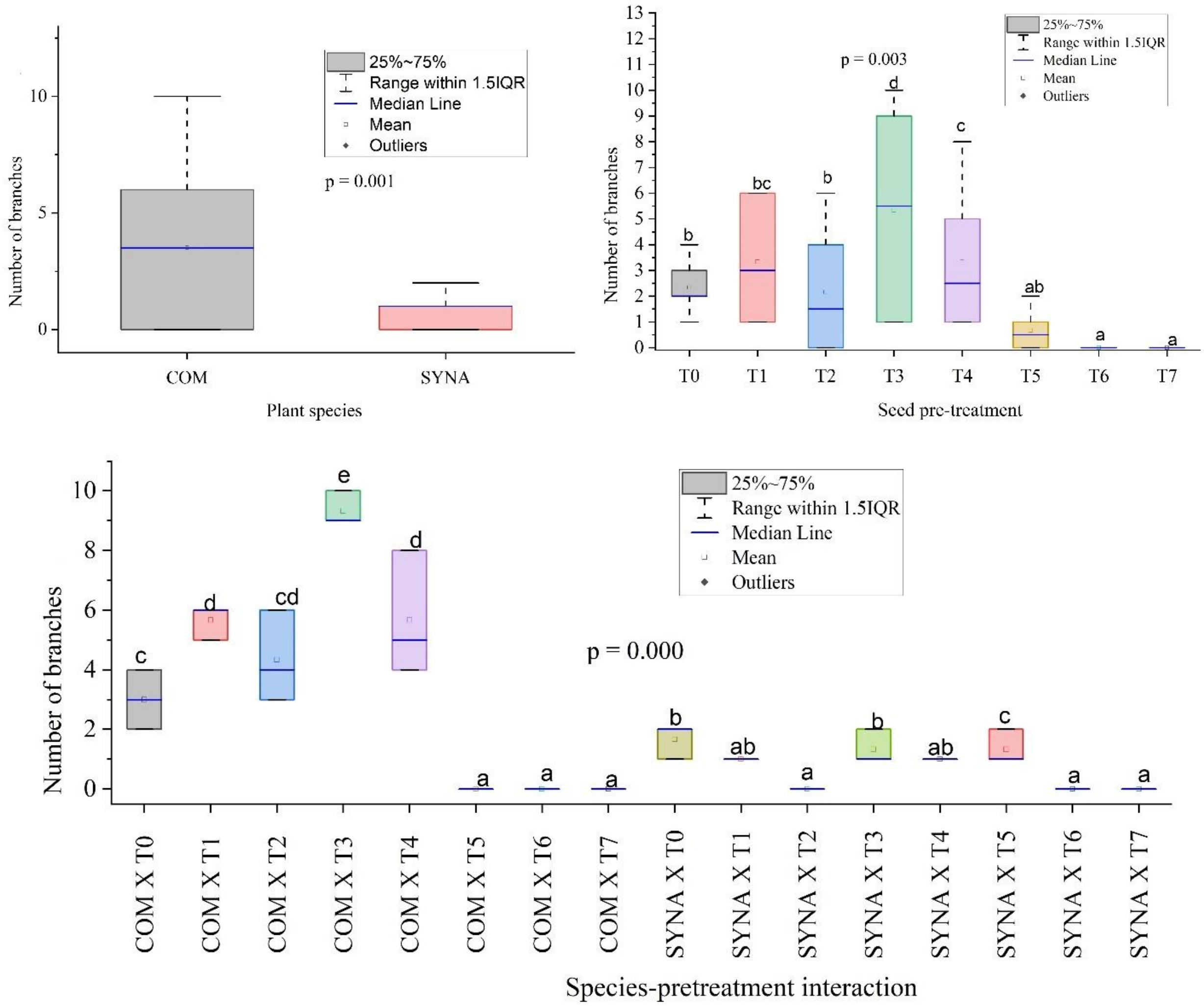


Figure 4. Effects to plant species (A), seed pre-treatment (B), and the interactions of A and B (C) on seedling shoot branching. COM and SYNA = *C. swynnertonii* and *S. glaucescens*, respectively. T1 = Soaking in water at 25°C for 24 h, T2 = soaking in 60°C hot water for 10 min, T3 = 10 ppm Potassium nitrate (KNO_3) treatment for 24 hrs, T4 = 20 ppm Potassium nitrate (KNO_3) treatment for 24 h, T5 = Treating seeds with Gibberellin (GA_3) solution at 250 ppm, GA_3, T6 = Treating seeds with Gibberellin (GA_3) solution at 500 ppm for 72, T7 = Treating seeds with Gibberellin (GA_3) solution at 1000ppm for 72 h and T_0 = distilled water treatment used as control. Means with the same letters are not significantly different at $p < 0.05$.
Source: Authors

(KNO_3) for 24 h was higher than the number of leaves per shoot in untreated control by 5 and 7, respectively. Seeds that were pre-treated by soaking in 60°C hot water for 10 min and application of Gibberellin (GA_3) solution at 250 ppm gave rise to seedlings with several leaves per shoot that was smaller than the untreated control (Figure 7A). Treatments with zero number of leaves per shoot are for seeds that did not germinate at all. The influence of KNO_3 on seedling leaf numbers outweighed all other treatments. Although the mechanism by which KNO_3 improves seed germination and subsequently plant growth is still unknown, previous studies have explained that KNO_3 may affect supplying nitrogen required for plant growth (Duermeyer et al., 2018; Shim et al., 2008) and the composition of abscisic acid and GA_3 required for seed germination and vegetative growth (Antonia et al., 2018). The findings are also in agreement with previous studies that the effects of KNO_3 on seed germination and seedling growth were dependent on the concentration of the extracts (Alabi et al., 2019; Dev et al., 2020; Ziter et al., 2019).

Significant variations between pre-sowing seed treatments were also observed in the seedling leaf area (Figure 7B) suggesting that the effects were dependent on treatment type, concentration, and mode of application. The highest average leaf area was recorded on seedlings arising from seeds that were pre-treated

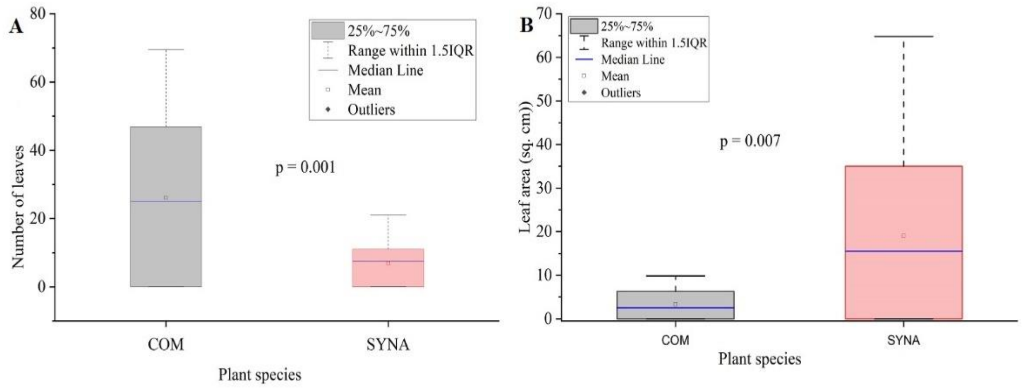


Figure 5. Effects to plant species (A), Seed pre-treatment (B), and the interactions of A and B (C) on seedling shoot branching. COM and SYNA = *C. swynnertonii* and *S. glaucescens*, respectively.
Source: Authors

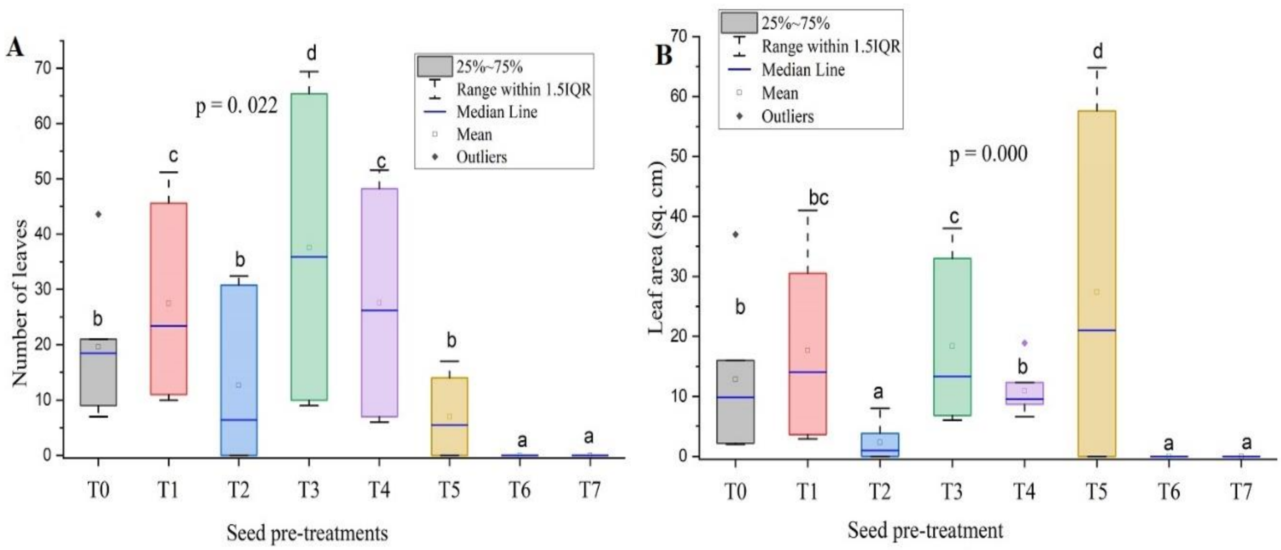


Figure 7. Effects of pre-sowing seed treatments on seedling leaf number and leaf area. T1 = Soaking in water at 25°C for 24 hours, T2 = soaking in 60°C hot water for 10 minutes, T3 = 10ppm Potassium nitrate (KNO3) treatment for 24 hrs, T4 = 20ppm Potassium nitrate (KNO3) treatment for 24hrs, T5 = Treating seeds with Gibberellin (GA_3) solution at 250 ppm, GA_3, T6 = Treating seeds with Gibberellin (GA_3) solution at 500 ppm for 72, T7 = Treating seeds with Gibberellin (GA_3) solution at 1000ppm for 72 hrs and T_0 = distilled water treatment used as control. Means with the same letters are not significantly different at $p < 0.05$.
Source: Authors

with T5 followed by T3 and T1. Here, the effect of T1 was not significantly different from the T0 which is the untreated control while the leaf area in seedlings from seeds pre-treated with T2 was by far below the control. The observations show that treatments that resulted in the greatest increase in seedling leaf number were not the same as those resulting in the greatest increase in seedling leaf area. This could be due to the observed variation in leaf area between species in Figure 7B where seedlings of *C. swynnertonii* had leaf area that is significantly less than the leaf area of the seedlings of *S. glaucescens* while opposing results were observed for their leaf numbers.

These differences in seedling leaf number and leaf area are more clearly evident in Figure 8A to B. Here, the result shows that the effect of pre-sowing seed treatment on seedling leaf numbers and leaf area was only dependent on the pre-treatment type, concentration, and mode of application but also dependent on plant species. Seedlings arising from seeds of *C. swynnertonii*

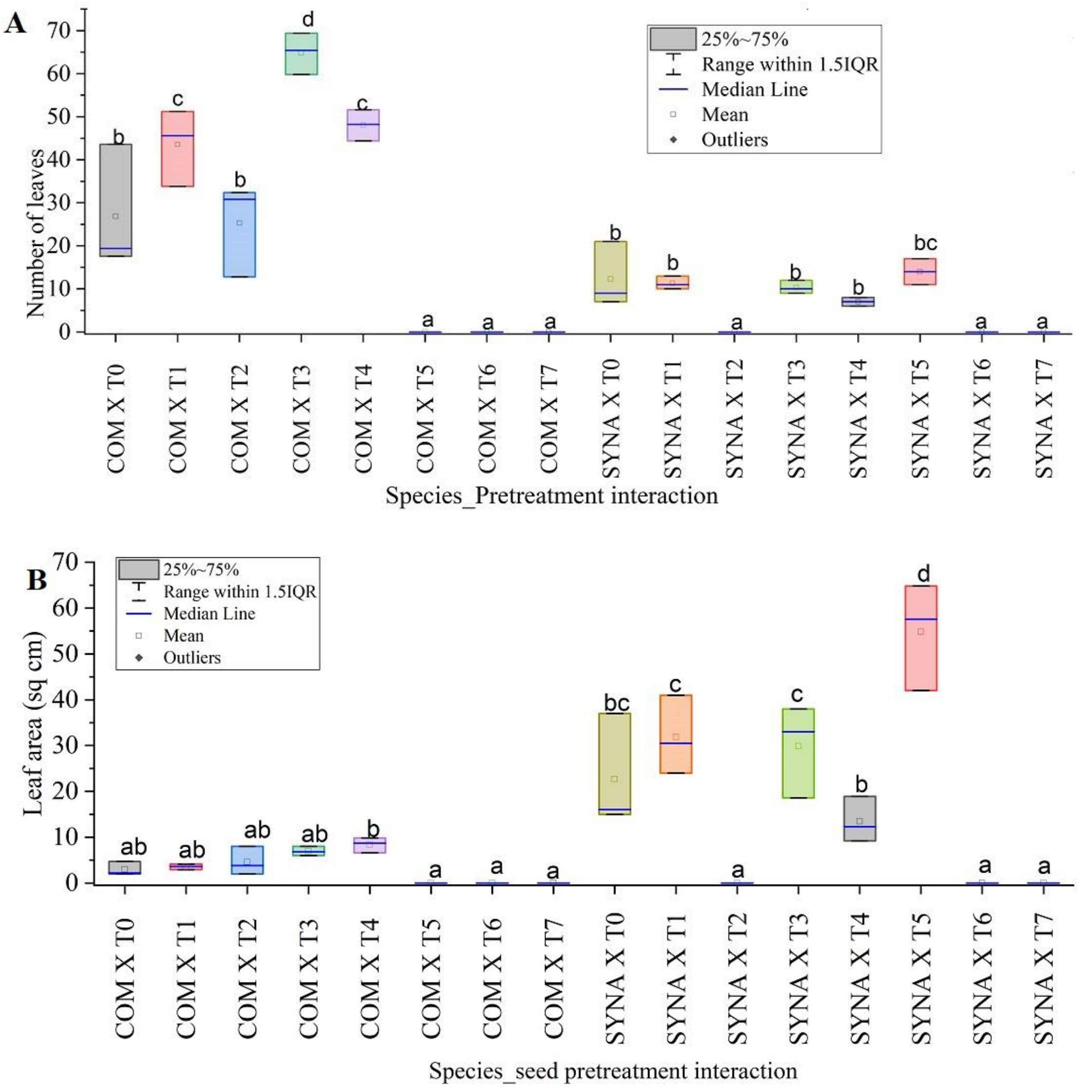


Figure 6. Effects of plant species and seed pre-treatment interactions on seedling leaf numbers and leaf area. COM and SYNA = *C. swynnertonii* and *S. glaucescens,* respectively. T1 = Soaking in water at 25°C for 24 hours, T2 = soaking in 60°C hot water for 10 minutes, T3 = 10ppm Potassium nitrate (KNO_3) treatment for 24 h, T4 = 20 ppm Potassium nitrate (KNO_3) treatment for 24 h T5 = Treating seeds with Gibberellin (GA_3) solution at 250 ppm, GA_3, T6 = Treating seeds with Gibberellin (GA_3) solution at 500 ppm for 72, T7 = Treating seeds with Gibberellin (GA_3) solution at 1000 ppm for 72 h and T_0 = distilled water treatment used as control. Means with the same letters are not significantly different at $p < 0.05$.
Source: Authors

whose pre-sowing treatment was T3 had the highest (65) leaves per shoot followed by 46, 45, and 30 leaves per shoot for seeds pre-treated with T4, T1, and T2, respectively (Figure 8A). The seedling leaf numbers in all these treatments were by far higher than the same in the seedlings arising from untreated seeds of *C. swynnertonii.* However, the seedling leaf numbers observed in seedlings from seeds of *S. glaucescens* pre-treated with the same treatments were not different from leaf numbers recorded on seedlings arising from untreated seeds of the same plant species (Figure 8A). Inter-species variation in response to similar seed treatment has been recorded by many workers in different plant species (Duermeyer et al., 2018; Lara et al., 2014; Wang et al., 2021; Yang et al., 2020).

Similar to the findings in Figure 8A, findings in Figure 8B show that the effects of pre-sowing seed treatments on seedling leaf area were significantly dependent on the plant species to which the treatment is applied. All germinated seedlings from seeds of *S. glaucescens* had leaf areas significantly higher than the leaf areas of the seedling from untreated seeds of the same plant species. At the same time, all germinated seeds of *C. swynnertonii* gave rise to seedlings whose leaf area was not different

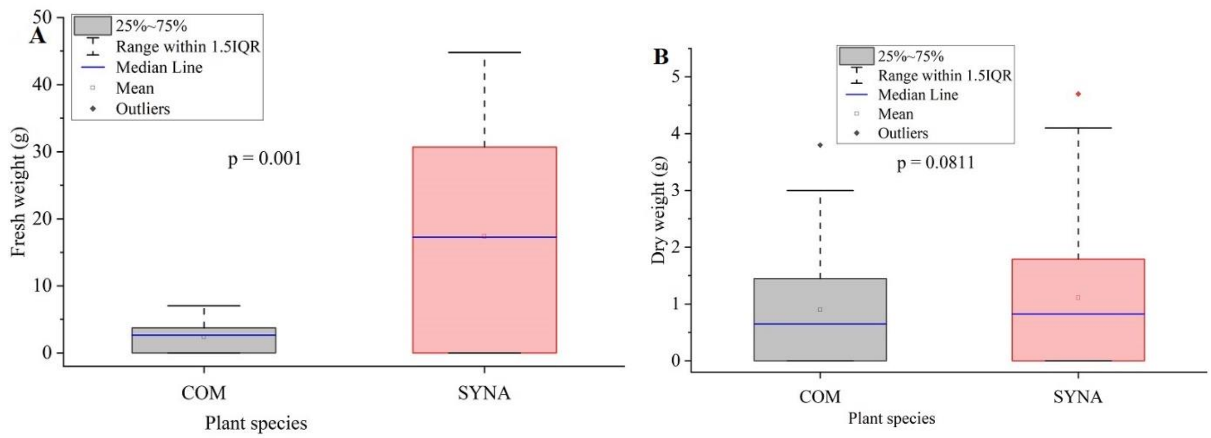


Figure 7. Effects to plant species (A), seed pre-treatment (B) and the interactions of A and B (C) on seedling Fresh and Dry weight. COM and SYNA = *C. swynnertonii* and *S. glaucescens* respectively.
Source: Authors

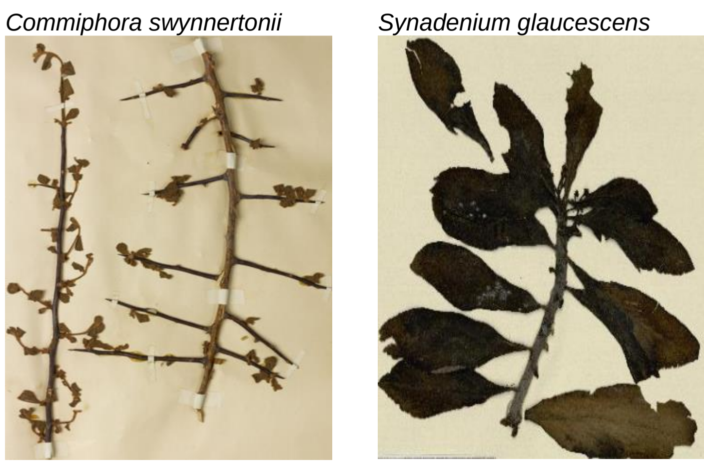


Figure 8. Herbarium specimens showing vegetative morphological features of *C. swynnertonii and S. glaucescens*. (*Qwarse et al., 2018*)
Source: Authors

from seedlings from untreated seeds of the same plant, *C. swynnertonii*. The highest leaf area of 65 cm^2 was recorded on seedlings from seeds of *S. glaucescens* followed by 35, 30, 15 and 12 cm^2 were which were treated with T3, T1, T0 and T4, respectively for seedlings from seeds of the same plant.

The results show that different plant species responded differently to different seed pre-treatments suggesting that their genetic differences in adapting to environmental condition could be linked to these observations. *C. swynnertonii* is semi aridic plant that develops numerous leaflets of small size reduced into thorns to minimize water losses through transpiration (Lal and Kasera, 2014; Soromessa, 2013). *S. glaucescens* grows well in subhumid climates hence it develops few broad and thick evergreen leaves to maximize photosynthetic plant productivity (Carter, 1987; Nyigo et al., 2015b).

Shoot fresh and dry weight

Seedlings of *C. swynnertonii and S. glaucescens* accumulated fresh weight differently (p = 0.001) but the dry weight of the two plant species did not differ significantly (p = 0.0811) (Figure 9A and B). The latter accumulated five times more fresh weight than the former. The differences in fresh weight between the two species could be linked to their botanical attributes of the two species. *C. swynnertonii* being an aridic plant, it is a woody shrub with leaves reduced into thorns while *S. glaucescens* is an herbaceous plant characterized by thick stems and broad leaves (Figure 10). Seedlings of the two plant species did not differ in terms of the total dry matter accumulation over the growing period after emergence suggesting that the two plant species had similar photosynthetic efficiency where the

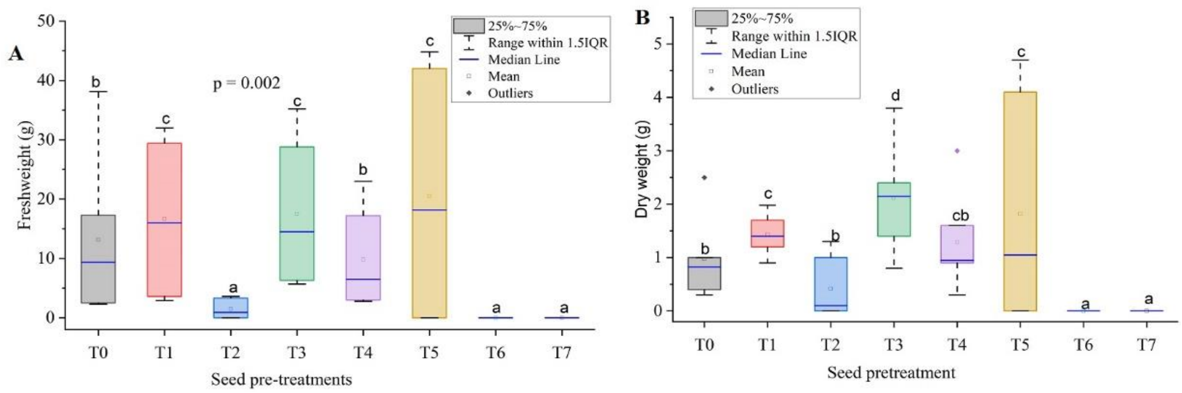


Figure 9. Effects of pre-sowing seed treatments on seedling Fresh and Dry weight. COM and SYNA = *C. swynnertonii* and *S. glaucescens*, respectively T1 = Soaking in water at 25°C for 24 h, T2 = soaking in 60°C hot water for 10 min, T3 = 10 ppm Potassium nitrate (KNO_3) treatment for 24 h, T4 = 20 ppm Potassium nitrate (KNO_3) treatment for 24 h, T5 = Treating seeds with Gibberellin (GA_3) solution at 250 ppm, GA_3, T6 = Treating seeds with Gibberellin (GA_3) solution at 500 ppm for 72, T7 = Treating seeds with Gibberellin (GA_3) solution at 1000 ppm for 72 h and T_0 = distilled water treatment used as control. Means with the same letters are not significantly different at $p < 0.05$.
Source: Authors

photosynthetic power of *C. swynnertonii* could be on the leaf numbers while the photosynthetic power in *S. glaucescens* could be on the large leaf area hence both possibly had more or less the same amount of chlorophyll content as well as the stomatal pores for gaseous exchange (Andersen et al., 2010; Chaves et al., 2002; Wei et al., 2021). Another possibility is that the woody plants accumulate more carbon in their woody tissues than herbaceous plants, therefore, despite the small leaf area, *C. swynnertonii* could be adapted photosynthetically to accumulate carbon faster than *S. glaucescens* (Hallik et al., 2012; Knapp et al., 2014; Nadal and Flexas, 2019).

The different pre-sowing seed treatments showed significantly different effects on seedlings fresh and dry weight (Figure 11) implying that, the treatments had effects on the photosynthetic activity of the seedlings. In terms of seedling fresh weight, T2 treatment was inferior to the control. Seedlings from seeds under T4 treatment had fresh weight which was statistically the same as the fresh weight of seedlings from the control treatment. The other three treatments, T1, T3, and T5 resulted in 17.02, 17.53, and 17.99 g seedling fresh weights which were significantly greater than the control fresh weight (10.01 g) and their effects did not vary significantly (Figure 11). In terms of seedling dry weight, T3 treatment was associated with the highest weight of 2.12 g followed by 1.51, 1.42, and 1.33 g dry weight linked to T1, T5, and T4 treatments in that order. From these findings, it can be learned that treatment concentration, form, and application method played a key role in the ability of seedlings to accumulate photosynthates in their tissues similar to the findings by Hikosaka et al. (1998). It has been established that, compared to the control seeds, there is a significant increase in seed germination and growth of seedlings due application of different concentrations of GA3 and KNO_3 (Dev et al., 2020).

The different pre-sowing treatments influenced seedling fresh and dry weight differently depending on plant species (Figure 12A and B). The fresh weight of seedlings *C. swynnertonii* whose seeds were subjected to T3 treatments accumulated a fresh biomass yield that was two times more than the untreated seeds. With the rest of the treatments applied to seeds of *C. swynnertonii*, there was no improvement of fresh biomass yield to untreated seeds. Significant improvement in fresh biomass was achieved with all pre-sowing treatments (except T4) applied to *S. glaucescens* seeds. The highest fresh biomass of 44.08 g was accumulated in seedlings of *S. glaucescens* under T5 treatment. Compared to the untreated seeds, significant improvement in dry matter accumulation in seedlings of both *C. swynnertonii* and *S. glaucescens. S. glaucescens* seeds that were subjected to T5 pre-treatment resulted to seedlings with dry matter accumulation that was four times higher than dry matter accumulated in seedlings from untreated seeds. This implies that treating seeds with Gibberellin (GA_3) solution at 250 ppm did not only break seed dormancy but also the growth promotor simulated rapid seedling growth leading to increased photosynthetic efficiency in line with Hikosaka et al. (1998). The same treatment which gave such a great response to *S. glaucescens* seedlings, was applied to *C. swynnertonii* seeds and they did not germinate. But with this plant species, the seeds pre-treated with T3 resulted in seedlings with dry matter accumulation which was five times higher than the untreated seeds. Therefore, for this plant, pre-sowing seeds treatment using 10 ppm Potassium nitrate (KNO_3) treatment for 24 h gave the best improvement in terms of breaking seed dormancy as well as promoting early seedling growth, a prerequisite for the successful

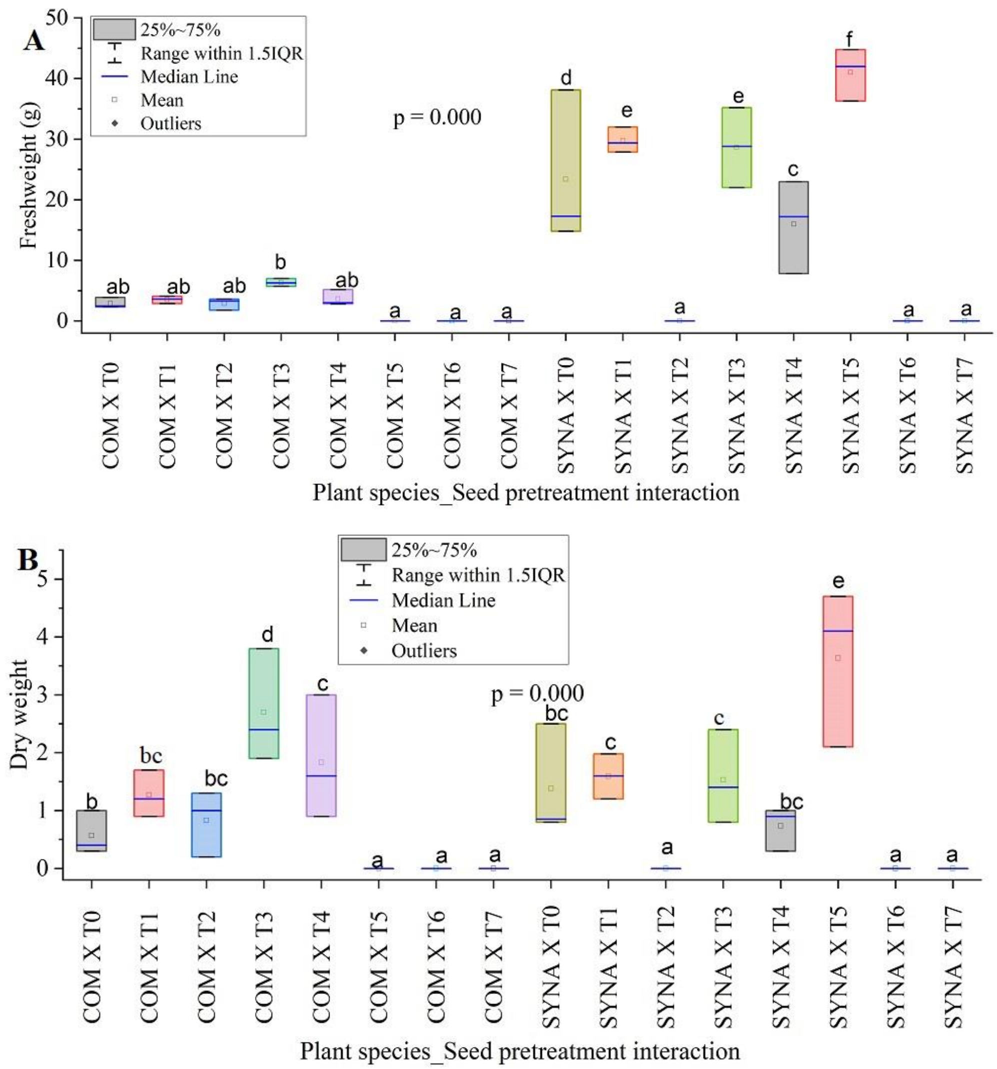


Figure 10. Effects of plant species and Seed pre-treatment interactions on seedling Fresh and Dry weight. COM and SYNA = *C. swynnertonii* and *S. glaucescens* respectively. T1 = Soaking in water at 25°C for 24 h, T2 = soaking in 60°C hot water for 10 min, T3 = 10 ppm Potassium nitrate (KNO_3) treatment for 24 h, T4 = 20 ppm Potassium nitrate (KNO_3) treatment for 24 h T5 = Treating seeds with Gibberellin (GA_3) solution at 250 ppm, GA_3, T6 = Treating seeds with Gibberellin (GA_3) solution at 500 ppm for 72, T7 = Treating seeds with Gibberellin (GA_3) solution at 1000 ppm for 72 h and T_0 = distilled water treatment used as control. Means with the same letters are not significantly different at $p < 0.05$.
Source: Authors

establishment of any crop stand. The differences observed agree with the previous findings that, different species respond differently to different pre-sowing seed treatments (Ruttanaruangboworn et al., 2017; Maneesha, 2019; Zavariyan et al., 2015).

Seedling growth parameters' relationship

A significant relationship was observed between seedling plant height and a number of branched per shoot (r = 0.88), number of leaves per shoot (r = 0.9), and seedling dry weight (r = 0.59) (Table 1). This implies that an increase in seedling height, an increased number of nodes with active axillary buds from which branched are born, and the increase in the number of branches were significantly related to a number of leaves per shoot (r = 0.95). The fact that leaves are the main photosynthetic machinery of plants could be explaining why plant height was also significantly correlated with seedling dry matter content. In this study, correlation analysis established that the seedling dry matter content was significantly

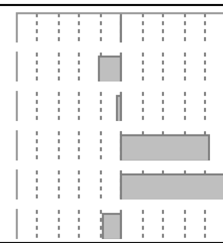
Table 1. Correlation analysis of seedling growth parameters.

Parameter	Plant height (cm)	Branches per shoot	Leaves per shoot	Leaf area (cm^2)	Fresh weight (g)
Branches per shoot	0.88**				
Leaves per shoot	0.90**	0.95**			
Leaf area (cm^2)	0.1605	-0.0238	0.0294		
Fresh weight (g)	0.1143	-0.0608	-0.0013	0.9674**	
Dry weight (g)	0.59*	0.51*	0.58*	0.75**	0.70**

Source: Authors

Table 2. Partial least square analysis for seedling dry weight.

Coefficient	Dry weight (g)
Intercept	0.0000
Plant height (cm)	-0.1954
Branches per shoot (Count)	-0.0381
Leaves per shoot (Count)	0.7668
Leaf Area (cm^2)	0.9131
Fresh weight (g)	-0.1582



Source: Authors

related with number of leaves per shoot, leaf area as well as the seedling fresh weight. These results are not very far from the findings of previous studies which established that growth parameters are good predictors of seedling survival based on ability to accumulate sufficient carbohydrates in their early stages of growth after emergence (Koca and Erekul, 2016; Özalkan et al., 2010; Rathore, 2020).

Apart from the established relationship among growth parameters with an accumulation of dry matter in seedling tissues, the part least square analysis in Table 2 highlights that, of the four growth parameters; plant height, number of branches per shoot, number of leaves per shoot and leaf area, only two last two were better explaining the observed seedling dry matter content. The results suggest that a unit change in a number of leaves per shoot explains a corresponding change in seedling dry weight by more than 76% while a unit change in leaf area would explain a corresponding change in seedling dry matter content by more than 90% (Table 2). Previously, it has been established that the leaf is the most important machine giving the ability of the plants to transfer solar energy to biological energy by means of photosynthesis (Huang et al., 2019). Leaf area and number are functional traits of photosynthetic capacity which are closely related to plants' competitive abilities to survival in hostile natural environments after germination (Huang et al., 2019; Koca and Erekul, 2016; Rathore, 2020).

In conclusion, the study has established that under the same pre-sowing seed treatment, *C. swynnertonii* and *S. glaucescens* attained different germination percent due to the differences in the plant forms because the former is the shrub and the later one is the herbaceous species. The different pre-sowing treatments had different effects breaking seed dormancy for germination, and promoting seedling growth after the emergence of *C. swynnertonii* and *S. glaucescens* seedlings. The growth parameters (plant height, number of branches per shoot, number of leaves per shoot and leaf area were positively correlated with seedling dry matter content. A number of leaves per shoot and leaf area were the best predictor of the seedling dry matter content.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

ACKNOWLEDGEMENT

The authors appreciate the financial support given by the African Academy of Sciences (AAS) through the VASPHAD project to implement this research.

REFERENCES

Aftab T, Hakeem KR (Eds.) (2021). Medicinal and Aromatic Plants. Springer International Publishing. https://doi.org/10.1007/978-3-030-58975-2

Alabi ON, Adikpe OA, Dare AH (2019). Effect of different growing soil media on seed germination and growth of tamarind as influenced by seed dormancy breaking approaches. International Journal of Environmental Sciences and Natural Resources 17(1):21-27. https://doi.org/10.19080/ijesnr.2019.17.555954

Andersen M, Jordhei I, Kiremire B (2010). Anthocyanins with unusual furanose sugar (apiose) from leaves of *Synadenium grantii* (Euphorbiaceae). Phytochemistry 71(13):1558-1563. https://doi.org/10.1016/j.phytochem.2010.05.025

Awasthi P, Bargali K, Bargali SS, Jhariya MK (2022). Structure and functioning of Coriaria nepalensis dominated shrublands in degraded hills of Kumaun Himalaya. I. Dry matter dynamics. Land Degradation and Development 33(9):1474-1494. https://doi.org/10.1002/ldr.4235

Bargali SS, Shrivastava SK, Dixit VK, Bargali K (2003). Some less known ethnomedicinal plants of Jagdalpur District of Chattisgarh State. The Botanica 53:192-197.

Bargali SS, Shahi C, Bargali K, Negi B, Khatri K (2022). Energy and monetary efficiencies at the different altitudinal agroecosystems in central Himalaya, India. Heliyon 8(11):e11500. https://doi.org/10.1016/j.heliyon.2022.e11500

Baskin CC, Baskin JM (2020). Breaking seed dormancy during dry storage: a useful tool or major problem for successful restoration via direct seeding? Plants 9(5):636. https://doi.org/10.3390/plants9050636

Cabello Á, Espinoza N, Espinoza S, Cabrera A, Santelices R (2019). Effect of pre-germinative treatments on nothofagus glauca seed germination and seedling growth. New Zealand Journal of Forestry Science 49. https://doi.org/10.33494/nzjfs492019x34x

Carter S (1987). Taxonomic changes in Synadenium (Euphorbiaceae) from East Africa. In *ZAMBIA.* Mbala District: Mpulungu, Crocodile Island. http://about.jstor.org/terms

Ceballos G, Ehrlich PR, Dirzo R (2017). Biological annihilation via the ongoing sixth mass extinction signaled by vertebrate population losses and declines. Proceedings of the National Academy of Sciences of the United States of America 114(30):E6089–E6096. https://doi.org/10.1073/pnas.1704949114

Chaves MM, Pereira JS, Maroco J, Rodrigues ML, Ricardo CPP, Osório ML, Pinheiro C (2002). How plants cope with water stress in the field? Photosynthesis and growth. Annals of Botany 89(7):907-916.

Chen SL, Yu H, Luo HM, Wu Q, Li CF, Steinmetz A (2016a). Conservation and sustainable use of medicinal plants: problems, progress, and prospects. Chinese Medicine pp. 1-10. https://doi.org/10.1186/s13020-016-0108-7

Chen SL, Yu H, Luo HM, Wu Q, Li CF, Steinmetz A (2016b). Conservation and sustainable use of medicinal plants: Problems, progress, and prospects. In Chinese Medicine (United Kingdom*)* 11(1). BioMed Central Ltd. https://doi.org/10.1186/s13020-016-0108-7

Chi X, Zhang Z, Xu X, Zhang X, Zhao Z, Liu Y, Wang Q, Wang H, Li Y, Yang G, Guo L, Tang Z, Huang L (2017). Threatened medicinal plants in China: Distributions and conservation priorities. Biological Conservation 210:89-95. https://doi.org/10.1016/j.biocon.2017.04.015

Credo D, Mabiki FP, Machumi F, Chacha M, Cornett C, Styrishave B (2022). Anti-Newcastle Disease Virus activity of 3β and 3α Friedelanol Triterpenoids from the leaves of *Synadenium glaucescens* Pax. Tropical Biomedicine 39(2):257-264. https://doi.org/10.47665/tb.39.2.016

Dev R, Dayal D, Sureshkumar M (2020). Gibberellic Acid and Potassium Nitrate Promote Seed Germination and Growth of Grey-leaved Saucer-berry (Cordia Sinensis Lam.) Seedlings. International Journal of Fruit Science *20*(S2):S937-S954. https://doi.org/10.1080/15538362.2020.1774465

Dirzo R, Raven PH (2003). Global state of biodiversity and loss. Annual Review of Environment and Resources 28:137-167. https://doi.org/10.1146/annurev.energy.28.050302.105532

Duermeyer L, Khodapanahi E, Yan D, Krapp A, Rothstein SJ, Nambara E (2018). Regulation of seed dormancy and germination by nitrate. Seed Science Research *28*(3):150-157. https://doi.org/10.1017/S096025851800020X

Ganesh MG, Ramanandam K, Ravindra K, Kalpana M, Salomi SDR (2022). "Effect of bio-agents and growth stimulators on rooting and survival of orthotropic shoots in black pepper (*Piper nigrum* L.)."

George BG (2013). Biological activity of extracts from Commiphora swynnertonii against microbes of veterinary importance in chickens. Thesis of doctor in philosophy, Sokoine University of Agriculture. Morogoro, Tanzania.

Güleryüz G, Kırmızı S, Arslan H, Bayrak M (2021). Effects of pre-treatments in relation to breaking of dormancy of endemic *Hypericum adenotrichum* Spach. seeds. Journal of Applied Research on Medicinal and Aromatic Plants 25:100344. https://doi.org/10.1016/j.jarmap.2021.100344

Guo C, Shen Y, Shi F (2020). Effect of temperature, light, and storage time on the seed germination of pinus bungeana zucc. ex endl.: The role of seed-covering layers and abscisic acid changes. Forests 1(3):300*.* https://doi.org/10.3390/f11030300

Hallik L, Niinemets Ü, Kull O (2012). Photosynthetic acclimation to light in woody and herbaceous species: A comparison of leaf structure, pigment content and chlorophyll fluorescence characteristics measured in the field. Plant Biology 14(1):88-99. https://doi.org/10.1111/j.1438-8677.2011.00472.x

Han AR, Kim HJ, Jung JB, Park PS (2018). Seed germination and initial seedling survival of the subalpine tree species, Picea jezoensis, on different forest floor substrates under elevated temperature. Forest Ecology and Management 429:579-588. https://doi.org/10.1016/j.foreco.2018.07.042

Hanazaki N, Tamashiro JY, Leitao-Filho H, Gegossi A (2000). Diversity of plant uses in two Caicaras communities from the Atlantic forest coast, Brazil. Biological Conservation 9:597-615.

Hermann TM (2006). Indigenous knowledge and management of Araucaria araucana forest in the Chilean Andes: implications for native forest conservation. Biodiversity and Conservation 15:647-662.

Hikosaka K, Hanba YT, Hirose T, Terashima I (1998). Photosynthetic nitrogen-use efficiency in leaves of woody and herbaceous species. Functional Ecology 12(6):896-905. https://doi.org/10.1046/j.1365-2435.1998.00272.x

Huang W, Ratkowsky DA, Hui C, Wang P, Su J, Shi P (2019). Leaf fresh weight versus dry weight: Which is better for describing the scaling relationship between leaf biomass and leaf area for broad-leaved plants? Forests 10(3). https://doi.org/10.3390/f10030256

Iralu V, and Upadhaya, K. (2018). Seed dormancy, germination and seedling characteristics of Elaeocarpus prunifolius Wall. ex Müll. Berol.: a threatened tree species of north-eastern India. *New* Zealand Journal of Forestry Science 48(1). https://doi.org/10.1186/s40490-018-0121-y

Kamanula J, Sileshi GW, Belmain SR, Sola P, Mvumi BM, Nyirenda G KC, Nyirenda SP, Stevenson PC (2011). Farmers' insect pest management practices and pesticidal plant use in the protection of stored maize and beans in Southern Africa. International Journal of Pest Management 57(1):41-49. https://doi.org/10.1080/09670874.2010.522264

Kheloufi A, Mounia ML, Aziz N, Sahnoune M, Boukemiche S, Ababsa B (2018). Breaking seed coat dormancy of six tree species. Reforesta *5*:4-14. https://doi.org/10.21750/R

Knapp AK, Carroll CJW, Fahey TJ (2014). Patterns and controls of terrestrial primary production in a changing world. In Ecology and the Environment pp. 205-246. https://doi.org/10.1007/978-1-4614-7501-9_2

Knowler D, Bradshaw B (2007). Farmers' adoption of conservation agriculture: A review and synthesis of recent research. Food Policy *32*(1):25-48.

Koca YO, Erekul O (2016). Changes of Dry Matter, Biomass and Relative Growth Rate with Different Phenological Stages of Corn. Agriculture and Agricultural Science Procedia 10:67-75*.* https://doi.org/10.1016/j.aaspro.2016.09.015

Labbafi M, Mehrafarin A, Badi H, Ghorbani M, Tavakoli M (2018). Improve germination of caper (*Capparis spinosa* L.) seeds by different induction treatments of seed dormancy breaking. Trakia Journal of Science 16(1):70-74. https://doi.org/10.15547/tjs.2018.01.011

Lal H, Kasera PK (2014). Nitrates improved seed germination performance in Commiphora wightii (Guggal), a data deficient medicinal plant from the Indian arid zone. Journal of Plant Development 21 p.

Lamichhane JR, Debaeke P, Steinberg C, You MP, Barbetti MJ, Aubertot JN (2018). Abiotic and biotic factors affecting crop seed germination and seedling emergence: a conceptual framework. In Plant and Soil 432:1-28.

Lara TS, Lira JM S, Rodrigues AC, Rakocevic M, Alvarenga AA (2014). Potassium Nitrate Priming Affects the Activity of Nitrate Reductase and Antioxidant Enzymes in Tomato Germination. Journal of Agricultural Science 6(2):72.

Mabiki F (2013). Bioactivity Potential of extracts from *Synadenium glaucescens* Pax (Euphorbiaceae) Faith Philemon Mabiki for reference only. A thesis submitted in fulfilment of the requirements for the Degree of Doctor of Philosophy of Sokoine University of Agriculture.

Maneesha SR (2019). Effect of calcium nitrate and potassium nitrate priming on seed germination and seedling vigour of papaya (Carica papaya L.). Journal of Horticultural Sciences 14(2):149-154.

Mary OG, Zaituni MS, Faith MP, Lughano KJ, Robinson MH, John OE(2022). Antibacterial effects of single and combined crude extracts of *Synadenium glaucescens and Commiphora swynnertonii.* African Journal of Infectious Diseases 16(2):9-16.

Matendo RE, Nonga HE, Bakari GG, Ndusha NB, Mwatawala MW, Maerere AP (2019). Controlling Tuta absoluta (Meyrick) by Selected Crude Plant Extracts in the Laboratory and in the Screen House. Journal of Agricultural Science and Technology *A* 9:227-239. https://doi.org/10.17265/2161-6256/2019.04.003

Montaño-Arias SA, Zavaleta-Mancera HA, Camargo-Ricalde SL, Grether R (2021). Effect of seed age on germination, seedling survival and growth of Mimosa luisana (Leguminosae). Trees - Structure and Function 35(1):231-239. https://doi.org/10.1007/s00468-020-02031-5

Moyo M, Aremu AO, van Staden J (2015). Medicinal plants: An invaluable, dwindling resource in sub-Saharan Africa. Journal of Ethnopharmacology 174:595-606. https://doi.org/10.1016/j.jep.2015.04.034

Mpelangwa EM, Makindara JR, Sorensen OJ, Kitundu Bengesi KM, Mabiki FP (2022). Effect of changes in business environments on traded medicinal plants products in Tanzania: An explorative study. Heliyon 8(9):e10426. https://doi.org/10.1016/j.heliyon.2022.e10426

Nadal M, Flexas J (2019). Variation in photosynthetic characteristics with growth form in a water-limited scenario: implications for assimilation rates and water use efficiency in crops. Agricultural Water Management 216:457-472. https://doi.org/10.1016/j.agwat.2018.09.024

Nyigo V, Mdegela R, Mabiki F, Malebo H (2015a). Assessment of Dermal Irritation and Acute Toxicity Potential of Extracts from Synadenium glaucescens on Healthy Rabbits, Wistar Albino Rats and Albino Mice. European Journal of Medicinal Plants 10(4):1-11. https://doi.org/10.9734/ejmp/2015/20763

Nyigo V, Mdegela R, Mabiki F, Malebo H (2015b). Assessment of Dermal Irritation and Acute Toxicity Potential of Extracts from Synadenium glaucescens on Healthy Rabbits, Wistar Albino Rats and Albino Mice. European Journal of Medicinal Plants 10(4):1-11. https://doi.org/10.9734/ejmp/2015/20763

Özalkan Ç, Sepetoğlu HT, Daur I, Şen OF (2010). Relationship between some plant growth parameters and grain yield of chickpea (*Cicer arietinum* L.) during different growth stages. Turkish Journal of Field Crops 15(1).

Padalia KIRTIKA, Bargali KIRAN, Bargali S S (2017). Present scenario of agriculture and its allied occupation in a typical hill village of Central Himalaya, India. Indian Journal of Agricultural Sciences 87(1):132-141.

Pande PC, Awasthi P, Bargali K, Bargali SS (2016). Agro-biodiversity of kumaun himalaya, India: a review. Current Agriculture Research Journal 4(1):16.

Parihaar RS, Kiran B, Bargali SS (2015). Status of an indigenous agroforestry system: a case study in Kumaun Himalaya, India. Indian Journal of Agricultural Sciences 85(3):442-447.

Patade VY, Kumar K, Gupta AK, Grover A, Negi PS, Dwivedi SK (2020). Improvement in Seed Germination Through Pre-treatments in Timur (Zanthoxylum armatum DC.): A Plant with High Medicinal, Economical and Ecological Importance. National Academy Science Letters 43(3):295-297. https://doi.org/10.1007/s40009-019-00851-9

Pratap V, Sharma YK (2010). Impact of osmotic stress on seed germination and seedling growth in black gram (*Phaseolus mungo*). Journal of Environmental Biology 31(5):721.

Qwarse M, Mihale MJ, Sempombe J, Mugoyela V, Henry L, Sunghwa F (2018). Ethnobotanical survey of medicinal and pesticidal plants used by agropastoral communities in Mbulu District, Tanzania. Tanzania Journal of Science and Technology 1(1):22-35. https://www.researchgate.net/publication/326771040.

Raji R, Siril EA (2018). Assessment of different pretreatments to breakage dormancy and improve the seed germination in Elaeocarpus serratus L. - an underutilized multipurpose fruit tree from South India. Forest Science and Technology 14(4):160-168. https://doi.org/10.1080/21580103.2018.1507951

Ganesh M, Ramanandam G, Kumar KR, Kalpana M, Suneetha DS (2022). Effect of bio-agents and growth stimulators on rooting and survival of orthotropic shoots in black pepper (*Piper nigrum* L.) The Pharma Innovation Journal 11(8S):569-573.

Rathore V (2020). Correlation Study between Growth Parameters, Yield and Oil Quality of Anethum graveolens Linn. Indian Journal of Pharmaceutical Sciences 82(5):773-780. https://doi.org/10.36468/pharmaceutical-sciences.705

Ruttanaruangboworn A, Chanprasert W, Tobunluepop P, Onwimol D (2017). Effect of seed priming with different concentrations of potassium nitrate on the pattern of seed imbibition and germination of rice (*Oryza sativa* L.). Journal of Integrative Agriculture 16(3):605-613. https://doi.org/10.1016/S2095-3119(16)61441-7

Shalabi LF, Otaif FS (2022). Commiphora Jacq (Burseraceae) in Saudi Arabia, Botanical, Phytochemical and Ethnobotanical Notes. Ecologies 3(2):38-57. https://doi.org/10.3390/ecologies3020005

Sharma RK, Sharma S (2017). Seed longevity, germination and seedling vigour of Rheum australe D. Don: A step towards conservation and cultivation. Journal of Applied Research on Medicinal and Aromatic Plants 5:47-52. https://doi.org/10.1016/j.jarmap.2016.10.004

Sharma NK, Ahirwar D, Jhade D, Gupta S (2009). Medicinal and phamacological potential of nigella sativa: a review. Ethnobotanical Leaflets (7):11.

Shim SI, Moon JC, Jang CS, Raymer P, Kim W (2008). Effect of potassium nitrate priming on seed germination of seashore paspalum. HortScience 43(7):2259-2262.

Soromessa T (2013). Ecological phytogeography a case study of Commiphora species. Science*,* Technology and Arts Research Journal *2*(3):93-104.

Tiwari RKS, Chandra KK, Dubey S (2018). Techniques for Breaking Seed Dormancy and its Efficacy on Seed Germination of Six Important Medicinal Plant Species. International Journal of Agriculture, Environment and Biotechnology 11(2):293-301. https://doi.org/10.30954/0974-1712.04.2018.10

Topacoglu O, Sevik H, Guney K, Unal C, Akkuzu E, Sivacioglu A (2020). Effect of rooting hormones on the rooting capability of *Ficus benjamina* L. cuttings. *Šumarski list* 140(1-2):39-44.

van Andel TR, Croft S, van Loon EE, Quiroz D, Towns AM, Raes N (2015). Prioritizing West African medicinal plants for conservation and sustainable extraction studies based on market surveys and species distribution models. Biological Conservation 181:173-181. https://doi.org/10.1016/j.biocon.2014.11.015

van Wyk AS, Prinsloo G (2018). Medicinal plant harvesting, sustainability and cultivation in South Africa. Biological Conservation 227:335-342.

Vibhuti BK, Bargali SS (2022). Changing pattern of plant species utilization in relation to altitude and their relative prevalence in homegardens of Kumaun Himalaya. India Natural Resource for Human Health 2(2):253-264. https://doi.org/10.53365/nrfhh/144792

Vibhuti CS, Kiran B, Bargali SS (2015). Seed germination and seedling growth parameters of rice (*Oryza sativa* L.) varieties as affected by salt and water stress. Indian Journal of Agricultural Sciences 85:102-108.

Wang M, Chen J, Zhang X, Li S, Zhang T, Li W, Lin L (2021). Gibberellin A3 induces polyaerial shoot formation and increases the propagation rate in Paris polyphylla rhizomes. Industrial Crops and Products 167:113511*.* https://doi.org/10.1016/j.indcrop.2021.113511

Wei N, Mutie FM, Mwachala G, Grace OM, Hu GW, Wang QF (2021). Euphorbiambuinzauensis, a new succulent species in Kenya from the Synadenium group in Euphorbiasect. Monadenium (*Euphorbiaceae*). PhytoKeys 183:21. https://doi.org/10.3897/phytokeys.183.70285
Yang LE, Peng DL, Li ZM, Huang L, Yang J, Sun H (2020). Cold stratification, temperature, light, GA3, and KNO3 effects on seed germination of *Primula beesiana* from Yunnan, China. Plant Diversity *42*(3):168-173. https://doi.org/10.1016/j.pld.2020.01.003
Zavariyan AM, Rad MY, Asghari M (2015). Effect of seed priming by potassium nitrate on germination and biochemical indices in *Silybum marianum* L. under salinity stress. International Journal of Life Sciences 9(1):23-28.
Ziter CD, Pedersen EJ, Kucharik CJ, Turner MG (2019). Scale-dependent interactions between tree canopy cover and impervious surfaces reduce daytime urban heat during summer. Proceedings of the National Academy of Sciences of the United States of America 116(15):7575-7580. https://doi.org/10.1073/pnas.1817561116