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Production Potentials of Quality Tree Seeds from Orchards and Plantations in Tanzania

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Abstract

The availability of large quantities and high-quality planting materials is essential for the sustainability of tree planting and quality forest products. Since 1950, many countries in Africa have established several seed sources of genetically improved tree species. However, there is insufficient information on production potential, both in terms of quality and quantity of tree seeds from the established orchards and plantations, particularly in Tanzania. We assessed and compared seed production potential and germination capacity of four young (8–14 years) and mature (15–48 years) stands of plantations and seed orchards of Tectona grandis and Pinus patula located in different agro-climatic areas of Tanzania. Each seed source, 16 plots measuring 100 m 100 m, were randomly selected. Each plot, seeds were collected from 30 trees bearing seeds and possessing good characteristics. Results showed that matured stands of T. grandis and patula produced significantly heavier seeds with yields of 51.4 kg ha^{-1} and 926.1 kg ha^{-1}, respectively, compared to young stands, which produced 28.3 kg ha^{-1} and 782.6 kg ha^{-1}, respectively. The weight of seeds in orchards was significantly lighter (17.2 kg ha^{-1}) than in plantations (62.5 kg ha^{-1}) for P. patola. In contrast, for T. grandis, the weight of seeds in orchards was heavier (911.8 kg ha^{-1}) than in plantations (796.9 kg ha^{-1}). Seeds from P. patula and T. grandis orchards had significantly higher quality, with germination capacities of 64.5% and 25%, respectively, compared to seeds from plantations, with germination capacities of 51% and 23.2%, respectively. Trees in seed orchards perform better than those in plantations due to superior genetics, controlled breeding, optimal spacing, intensive management, and optimized growing conditions. Germination capacity of P. patula and T. grandis seeds collected from young seed orchards and plantation seed sources was significantly higher than that of mature seed orchards and plantation seed sources.

Keywords: *Tectona grandis, Pinus patula, tree seed sources, seed quality*

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Introduction

A sustainable supply of high-quality tree seeds is vital to the success of tree planting initiatives in general (Kindt et al., 2006). Using genetically improved seeds in forestry can enhance both the productivity and quality of tree seed sources, leading to more sustainable and resilient forests (Roychoudhury et al., 2016). Quality tree seeds refer to seeds of high purity and germination capacity with the essential genetic, physical, and physiological information (Nyoka et al., 2015). The genetic quality of tree seed is determined by the quality of the seed source and the way seeds were collected, processed, and stored (Kindt et al., 2006). Both *Tectona grandis* and *Pinus patula* are shade-intolerant species, with light intensity serving as a critical environmental factor for optimal growth and seed production (Pandey & Brown, 2000). Seed genetic quality is influenced by maternal factors such as maternal age and the maternal environment (Cendán et al., 2013). However, research by Mukassabi et al. (2012) suggests that tree senescence does not reduce fecundity.

Tree height and stem diameter might be important charactertics that indicate trees with better genetic quality (Pramono et al., 2011). Seeds should be collected from a source with high genetic quality planting material in sufficient quantities (Breed et al., 2012). Seeds with high genetic quality produce plants with desirable genetic traits such as resistance to pests and diseases and adaptation to changing climatic conditions (Graudal et al., 2014). Seeds collected from only a few mother trees result in producing a stand of trees of insufficient quantity of seeds and a narrow genetic basis that undermines the vitality and resilience of restoration (Dedefo et al., 2017).

Seed is a progeny/offspring used for propagation purposes. A seed source is a tree stand, inside and outside of forest areas that are managed to produce qualified seeds, it is a source of seed for planting (Mbora et al., 2009). Tree seeds might be obtained from various sources such as seed orchards, plantations, natural forests, farmlands, and vegetative propagules (Mbora et al., 2009). A seed orchard is an isolated, higher-quality plantation intended to reduce pollination from inferior trees that grow outside the orchard

(White et al., 2007). The main purpose of establishing a seed orchard is to mass-produce genetically superior seeds that are easily accessible and collectable. Plantations are forests that have been established by planting or direct sowing, usually with the production of timber. Plantation seed sources are divided into two: a) plantations with unknown origin, which are raised from plants with unknown origin and without documentation, and b) provenance plantations, which are raised from plants with known and documented origin from a broad genetic base (Mbora et al., 2009). The quality and productivity of forest plantations and woodlots will be enhanced by using improved germplasm and appropriate silvicultural practices (Chamshama & Nshubemuki, 2011). A study by the Forest Plantation Working Group in Tanzania revealed genetically improved seeds for the main forest plantation and woodlot in Tanzania (Forestry Development Trust, 2017).

The success of plantation forests, its growth, and yield depend not only on the site quality but also are strongly controlled by the genetic makeup of the planting materials (Wellendorf & Kaosa-ard, 1988). According to Nair et al. (1996), seed source is one of the important factors that can affect plantation forest productivity. The use of improved seed is essential in improving plant growth, stem quality, and other characteristics of the plantation. It has been estimated that by using such improved seed, the growth and/or volume production gain of the plantation is increased by 525%, depending on types of seed source and planting site (Wellendorf & Kaosa-ard, 1988).

Since 1950, Tanzania has established several seed sources of genetically improved seeds, including *T. grandis* and *P. patula*. However, the seed supply does not meet the demand due to an increase in the establishment of large forest plantations by the government, private investors, and small-scale farmers (Ngaga, 2011). The country has an ambition to expand the establishment of additional seed sources, but there is limited information on the production potential of existing seed sources. In Tanzania, *T. grandis* and *P. patula* are the most valuable commercial tree species. However, there is limited documented information on seed production potential under various seed sources. This study aims to assess and compare the quantity of tree seed production from seed orchards and plantation seed sources. Specifically, the study therefore seeks to a) assess the *T. grandis* and *P. patula* seeds production under different seed sources and b) analyze the germination capacity of *T. grandis* and *P. patula* seeds produced from different seed sources. This information will enable the policy makers, planners, researchers, and tree growers to select a functionally appropriate production system for the sustainability of planting material as well as enhance the availability of high-quality seeds, drive growth in the forestry sector, and enable Tanzania to fully realize its potential in teak and pine production, and the country can attract more investments, ensure the use of superior seeds, and boost yields and productivity. This would benefit the economy, employment, and environmental conservation.

Methods

Research design and data collection In this study, four seed sources located in various agro-climatic areas of Tanzania were selected (Figure 1). This study employed a stratified random sampling design whereby the selected two tree seed sources were stratified according to the tree seed sources, tree species, and stand ages. The tree seed sources were categorized into seed orchards and plantations. Each seed source was further stratified into two species, *P. patula* and *T. grandis*, which are the most cultivated tree species in commercial monoculture forest plantations in Tanzania. The two species were further stratified according to age, as young and mature stands. Therefore, a total of eight stands were selected, as shown in Table 1. For each seed source, 16 plots measuring 100 m × 100 m (1 ha) were randomly established. Plantations should be a minimum of one hectare to ensure possibilities of collecting from 30×100 seed trees (Mbora et al., 2009). The selected size of the plot was to ensure the availability of 30–40 tree bearing seeds (Lillesø et al., 2011)

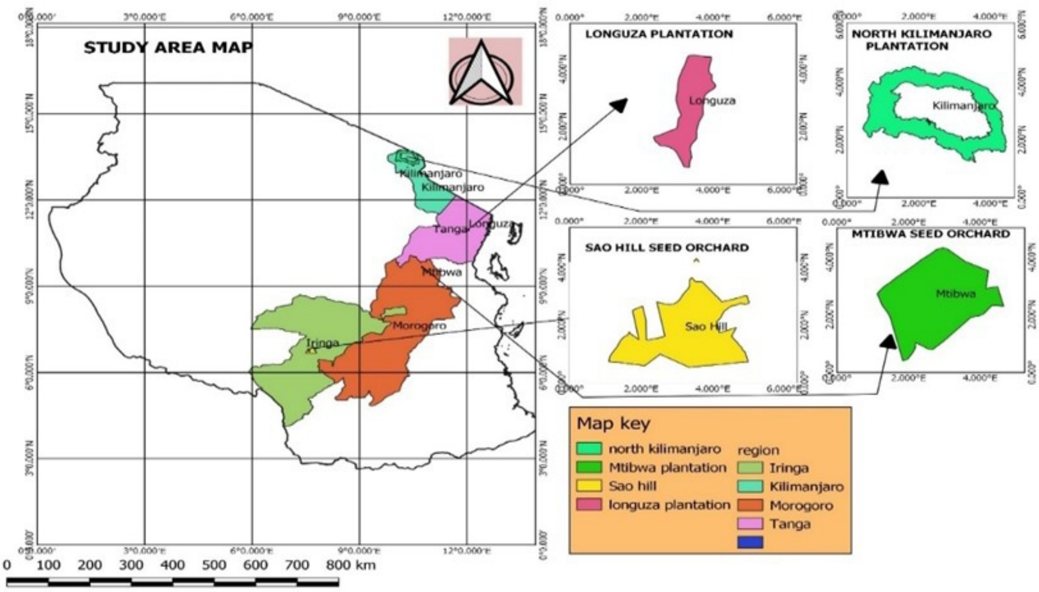

Figure 1 Showing four seed sources located in various agro-climatic areas of Tanzania.

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Table 1 Characteristics of the selected seed sources in the study area

Seed source name	Saohill seed orchard		Mtibwa seed orchard		North Kilimanjaro forest plantation		Longuza forest plantation	
Location/District	Mufindi		Mvomero		Rombo		Muheza	
Species grown	*Pinus patula*		*Tectona grandis*		*Pinus patula*		*Tectona grandis*	
Age status	Young	Mature	Young	Mature	Young	Mature	Young	Mature
Area covered (ha)	8	25	8	15	14	18	8	48
Age (years)	2007	1997	2008	2011	1994	1974	2009	2013
Forest operations	Weeding	Weeding	Weeding, thinning, fertilization	Weeding, thinning, fertilization	Weeding, thinning, pruning	Weeding, thinning, pruning	Weeding, thinning, pruning	Weeding, thinning, pruning
Altitude (m asl)	1,400–1,700	1,400–1,700	457	457	2,000–2,300	2,000–2,300	180	180
Annual rainfall	751–2,010	751–2,010	1,205	1,205	800	800	1,548	1,548
Temperature	15 ºC–25 ºC	15 ºC–25 ºC	28 ºC–33 ºC	28 ºC–33 ºC	15 ºC	15 ºC	15 ºC–20 ºC	15 ºC–20 ºC
Soil type	Moderately acidic, well drained	Moderately acidic, well drained	Alluvial and fertile	Alluvial and fertile	Moderately deep sand clay loam	Moderately deep sand clay loam	Volcanic, porous and free drainage	Volcanic, porous and free drainage
Actual stand density (N/ha)	820	812	532	540	304	209	570	170
Standard stand density (N/ha)	250	100	250	150	150	150	250	100
Sees production/Cone	116	124			132	156		

and a seed lot with seeds of good quality genetic diversity needed for health and to improve the resilience of future generations of trees (Boshier et al., 2014).

On each plot, at least 30 trees with superior character and good performance, such as above-average tree height and stem diameter, straight stem, long clear bole, uniform crown, without heavy branches or double stems, free of pests and disease, and a mature tree that can produce ample quantities of seeds, were randomly selected (Pramono et al., 2011). Mature fruits of *T. grandis* and cones of *P. patula* were collected following standard procedures described in ICRAF (2009). The spacing of at least 10–14 m from each other was maintained to control pollination between closely related individual trees (inbreeding) (Mbora & Lillesø, 2007). Seeds were collected through climbing the tree by two tree climber's experts from the Tanzania Forest Service Agency-Tree Seed Production Station (TFS-TSPS) between November 2022 and January 2023 (*T. grandis*), June and December 2022 (*P. patula*). Climbers use a pole with an S-shape hook and a sharp blade at the end to remove mature and ripe *P. patula* cones and drop them down in the plastic sheet, while for *T. grandis* climbers climb, and shake the tree vigorously to allow mature and ripe teak fruit to drop down in the plastic sheets, whereas all the immature and unripe were removed during seed extraction. Sisal gunny bags and sacks were used to store the collected seeds, and records of seed source, altitude, temperature, and annual rainfall of seed source location were taken, whereas a label was placed inside and outside the seed bag with basic information; species name (botanical and local name), type of seed source, date of collection, and seed lot number. Collecting seeds directly from the tree allows for the selection of mature seeds, with higher germination rates and better seed quality, being uncontaminated by soil, moisture, or soil-borne microorganisms, and becoming free from pests and disease, but also collecting seeds from various parts of the tree crown and different trees in the population can contribute to a broad genetic base (Mulawarman et al., 2003).

Seed pre-sowing treatments and germination The seed sample for the experiment was drawn from seed-lot storage by using Riffle Sample Divider to avoid biases, and enough samples were repacked and labeled prior to information being available for further procedure. The experiment was laid out in the TFS-TSPS Laboratory using a complete randomized block design (CRBD) with four (4) replications. Each *P. patula* replicate contained 100 seeds (International Seed Testing Association, 2009), making a total of 400 seeds, while each *T. grandis* replicate contained 25 seeds, making a total of 100 seeds. Standard procedures for germinating the seeds were adopted. Teak seeds were pre-treated by soaking the seeds in cold water, changing the water daily for three days, and drying them for two days (International Seed Testing Association, 2009). For pine seeds, pre-treatment is optional, but germination was improved by soaking in cold water for 1–8 days or in hydrogen peroxide for 1–4 days (Nigro et al., 2008).

Sand was sterilized by the oven-dry method at 180 °C for 2 hours prior to seed sowing (Sinegani & Hosseinpur, 2010). To maintain adequate moisture for germination and seedling growth, sawn seeds were watered once a day (in the morning) using a watering spray bottle, and each replicate/germination tray received 200 ml of distilled water for three weeks (24 days for *P. patula*) and six weeks (43 days for *T. grandis*). Under controlled temperature (25–30 °C) (International Seed Testing Association, 2009), all the seed that emerged on the sand surface showing at least 10 mm of their cotyledons and hypocotyls were regarded as viable (International Seed Testing Association, 2009). Seed germination capacity in terms of percentage was evaluated by counting and recording germinated seeds at an interval of 2 days until no further germination took place (Likoswe et al., 2008). There was no more germination after three weeks (24 days for *P. patula*) and six weeks (43 days for *T. grandis*) (Billah et al., 2015). A seed is regarded to be germinated if there is a visible radicle emergence (Tian et al., 2014).

High-quality, fresh drupe seeds, mature and dark brown, free from defects, were collected from teak plantations aged 8, 15, 25, and 48 years. Seed vigor reflects health, viability, and germination potential under varying conditions. For *P. patula*, the mean daily germination was 13 seeds, with a peak value of 44 seeds, while for *T. grandis*, the mean was 3 seeds, with a peak value of 8 seeds. The peak value is the maximum

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seeds germinated in a day divided by the total seeds tested, and mean daily germination is the total seeds germinated divided by test days. The average seed moisture content was 10.7% for *P. patula* and 10.9% for *T. grandis*. Seed purity was 99.9% and 99.7%, with viability rates of 92% and 89%, respectively, for the two species.

Data analysis Data were summarized in Microsoft Excel software version 2016 Seed production (seed yield) per hectare was calculated using the Equation *[1]* developed by Banerjee et al. (2001), whereas germination capacity was calculated using the Equation *[2]* developed by (Mwendwa et al., 2020).

$$SY = ASP \times PNT \quad [1]$$

$$GP = GS/TSS \ \ 100\% \quad [2]$$

Note: SY = seed yield, ASP = average seed produced per tree, PNT = potential number of trees collected per hectare, GP = germination percentage (%), GS = germinated seeds, and TSS = total seed sown.

Analysis of variance (ANOVA) was performed to determine if seed yield and seed germination capacity were different among seed sources age classes. All analyses were performed in IBM Statistical Package for Social Sciences (SPSS) Version 23.0. Armonk, NY: IBM Corp.

Results

Tree seed production in orchard and plantation seed sources The results revealed that the amount of *P. patula* seeds produced in the plantations (62.5 kg ha^{-1}) was statistically higher when compared to seed orchards (17.2 kg ha^{-1}) (Figure 2a). On the contrary, the amount of *T. grandis* seeds produced from seed orchards (911.8 kg ha^{-1}) was statistically higher than from plantations (796.9 kg ha^{-1}) (Figure 2b). The results indicated further that the amount of *P. patula* and *T. grandis* seeds (both plantation and orchard) was statistically higher in mature stands than young ones (Table 2). Furthermore, the results indicated that mean height was observed to be higher in mature-aged plantations (26.5 m : 26.1 m) compared to mature-aged seed orchards (20.7 m : 19.7 m) for *P. patula* and *T. grandis*, respectively, whereas mean diameter at breast height (dbh) was observed to be higher in mature aged plantations (32.1 cm : 27.7 cm) compared to mature-aged seed orchards (24.7 cm : 24.6 cm) for *P. patula* and *T. grandis,* respectively.

Seeds germination capacity The results indicated that the germination capacity of seeds from *P. patula* and *T. grandis* orchards was 64.5% and 25.1% compared to 51.0% and 23.2% in plantations, respectively (Figure 3a, Figure 3b). In both seed sources, the germination capacity of *P. patula* and *T. grandis* seeds from young stands was significantly higher than those from mature stands (Table 3).

Discussion

Seed production in orchard and plantation seed sources The present study observed that the amount of *P. patula* seeds was higher in plantations than in seed orchards sources. Gunaga and Vasudeva (2005) conducted a study on tree seed production in orchards and plantations, emphasizing the critical role of silvicultural practices in enhancing seed yields. Their findings highlighted the importance of practices such as manuring, fertilizing, soil working, and applying growth hormones to improve tree seed production. This might be due to adequate management practices such as thinning conducted in plantations but not in orchards. Thinning reduces competition, increases great availability of light, water, and nutrients and hence seeds yield (González-Ochoa et al., 2004). The number of stems in *P. patula* plantations was substantially lower than in the orchards (Table 1), which reduced competition and low stand density, respectively. This observation agreed with the study, which revealed that management practices on seed stands and orchards have been postulated to increase seed yield (Moreno-Fernández et al., 2013). This suggestion concurs with the study by Smith et al. (1997) which pointed out that

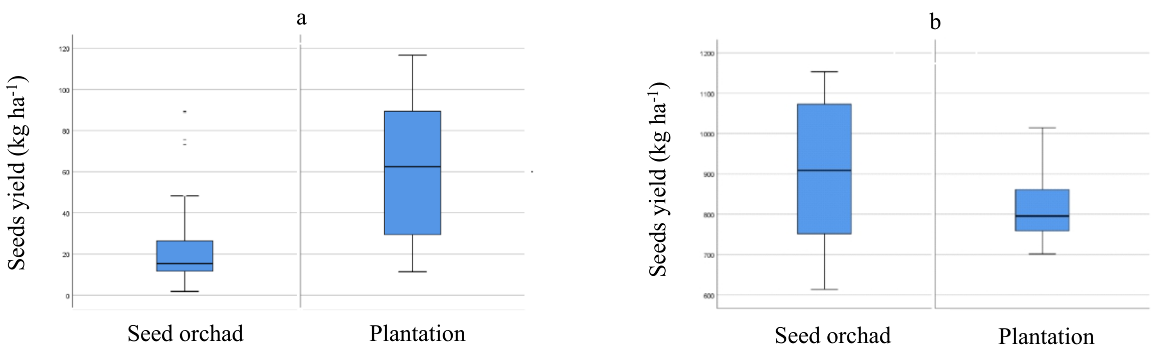

Figure 2 Production of *Pinus patula* seeds (a), *Tectona grandis* seeds (b).

Table 2 Production of *Pinus patula* and *Tectona grandis* seeds in young and matured stands

Tree species	Seed yield in orchard (kg ha^{-1})						Seed yield in Plantation (kg ha^{-1})					
	Young	Mature	*N*	Std.	*F.*	*p*-value	Young	Mature	*N*	Std.	*F.*	*p*-value
Pinus patula	13.1	21.3	120	6.1	23,125	0	43.5	81.5	120	11.8	27,977	0
Tectona grandis	790.4	1,033.2	120	77.6	23,125	0	774.8	819	120	68.0	27,977	0

Young stands (>15 years); Mature stands (<15 years)

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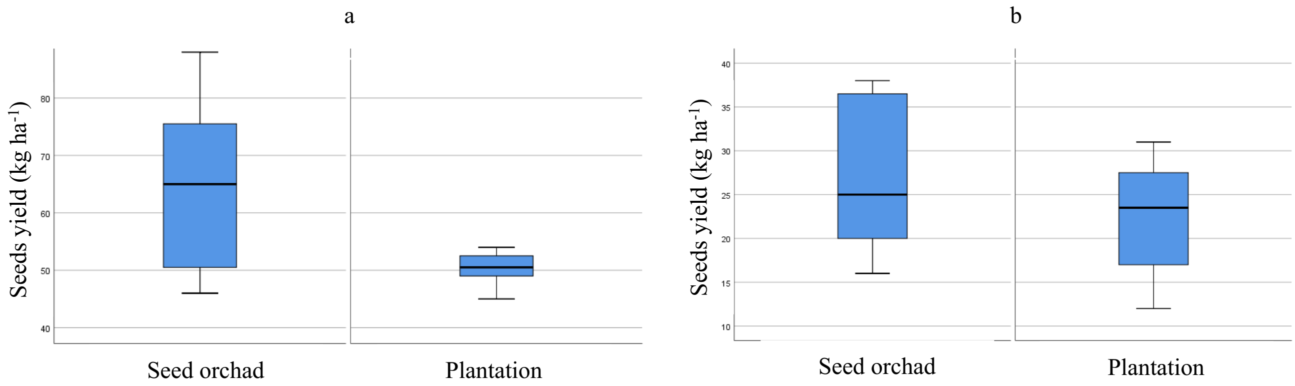

Figure 3 Germination capacity of *Pinus patula* seeds (a), *Tectona grandis* seeds (b).

Table 3 Germination capacity of seeds from young and matured seeds stands

Tree species	Germination capacity in orchards						Gemination capacity in plantation					
	Young	Mature	*N*	Std.	*F*.	*p*-value	Young	Mature	*N*	Std.	*F*.	*p*-value
Pinus patula	73.00	57.8	16	9.7	4.331	0	57.3	45.1	16	5.7	4.33	0
Tectona grandis	30.08	20.1	16	4.7	4.331	0	26.1	20.3	16	3.6	4.33	0

Young stands (>15 years); Mature stands (<15 years)

Table 4 Mean tree height and diameter in orchards and plantation

Tree species	Height and diameter in orchards				Height and diameter in plantation			
	Mean height (m)		Mean diameter (cm)		Mean height (m)		Mean diameter (cm)	
	Young	Mature	Young	Mature	Young	Mature	Young	Mature
Pinus patula	15.2	20.7	18.8	24.7	22.8	26.5	19.5	32.1
Tectona grandis	15.1	19.7	15.5	24.6	20.1	26.1	26.1	27.7

Young stands (>15 years); Mature stands (<15 years)

silvicultural practiced might favor individual tree productivity, which is similarly inversely related to stand density. These remarks agree with the study, which highlighted that stand density not only affects tree growth but also influences cone production and the amount of stored seeds in the canopy (Moreno-Fernández et al., 2013). The observation was also supported by the study, which pointed out that thinning results in greater availability of light, water, and nutrients to the remaining trees, which facilitates cone production (González-Ochoa et al., 2003). Inadequate management practices, such as weeding and thinning, were not conducted in seed orchards due to unavailability of fund, which resulted into lower seed production. This observation agreed with the study by Woodruff et al. (2002), which reported that restricted tree growth and cone production in a dense stand density is presumably caused by severe intraspecific competition that suppresses tree growth and seeds production.

Average seeds production per cone of *P. patula* was 132 seeds/cone (Table 1). Other studies on *P. patula* seed yield demonstrated that seed production per cone in South Africa has been reported to be as high as 140 seeds/cone (Hagedorn, 2001), whereas in Mexico it is about 125 seeds/cone (Valera & Kageyama,1991). According to Dieters (1996), Australia reported to have an average of 55 seeds/cone whereas in Kenya, a study by Angaine (2020) reported a productivity of 38 seeds/cone. Therefore, appropriate management practices favor generous *P. patula* seed production in plantation seed sources rather than in seed orchards.

The present study further observed that a substantial number of *T. grandis* seeds were produced in seed orchards sources than in plantation seed sources. The results of this study are not exceptional compared to other studies on the same topics. It was reported that the productivity from teak seed orchards in Nigeria has been reported to be as high as 734 kg ha^{-1} (Egenti, 1981). In Honduras, it averaged about 880 kg ha^{-1} (Chable, 1967), while in Thailand it is about 70 kg ha^{-1} (Meekaew, 1992). In Kenya, a study by Nicodemus (2007) reported a productivity of 18 kg ha^{-1}. According to Ramachandra et al. (2001), the Karnataka seed orchard in India is reported to have an average of 30–50 kg ha^{-1}.

It was further revealed that intensive management, including use of improved seeds, was involved during the establishment and management of seed orchards compared to plantations. This report is supported by the study conducted by Sembony (2009), which highlighted that seed orchards and plantations developed in Tanzania with teak have been done mostly using improved seeds from superior seed stands established at Longuza, Mtibwa, and Kihuhwi. It also concurred with the study by Kaviriri et al. (2020), which pointed out that seed orchards are established from known materials with the assumption of high performance for industrial, commercial forestry. Seed orchards, unlike other commercial plantations, are managed differently in terms of wider spacing and rogueing for robust branching to maximize seed production (Loewe-Muñoz et al., 2019).

Empirical evidence from Nyoka et al. (2010) revealed that high tree seed abundance in seed sources will ensure sustainable tree seed sources and reliable seed supply, which is critical for sustainable tree production. It has been estimated that by using such improved seed, the growth and/or volume production gain of the plantation is increased (from base populations) by 5–25%, depending on types of seed source and planting site (Wellendorf & Kaosa-ard, 1988). It was further revealed that seed management practices on seed stands and orchards have been postulated to increase seed yield (Moreno-Fernández et al., 2013). Significant amounts of seeds were produced in seed orchard sources compared to plantation sources as a result of good site quality, the use of improved seeds, and proper management practices.

Seed production in young and mature seed source stands
This study found that more seeds of *P. patula* and *T. grandis* were produced in mature stands (<15 years) compared to young stands (>15 years). The production of more seeds at the mature stand might be due to the fact that seed production in *P. patula* increased with age and this observation is concurred by the study conducted by the Kenya Forest Research Institute (2009), which postulates that the production of viable seeds in *P. patula* starts when trees are 5 years old and is prolific in 8 to 10 years old. The study conducted by Mendoza-Hernández et al. (2018) supports the observation by stating that cones and seeds production in *P. patula* trees is expected to increase with age and intensive management is required to promote cone production. These results agreed with the previous study by Barnes and Mullin (1974), which revealed that in Zimbabwe, *P. patula* stands aged 13 years old produced 45 filled seeds/cone, while in Queensland in Australia, the old stand aged 45 years old produced 55 filled seeds/cone. The seed production in *P. patula* appeared to be influenced by the increased stand age.

This observation agreed with the study conducted by Louppe et al. (2008), which revealed that the production of viable seeds in *T. grandis* starts when trees are 5 years old and is prolific in 810 years old trees. These outcomes might be due to the presence of continuous moisture in the stand as a result of rainfall found in mature stands of Mtibwa seed orchards and Longuza plantation ranging 1,205–1,548 mm year^{-1} (March to May, then Sept to Dec), which enables the leaf to be retained in the tree without shading for a more extended period and activating more photosynthates for the growth of the tree as well as seed production. The mature stands take this moisture presence opportunity and advantage of age to grow and produce more seeds. These results are supported by the study conducted by Krishnamoorthy (2014), which revealed that wood properties of fast-growing teak of 34-year-old trees in the Canal area of India, under moisture conditions did not show any significant variation to those of 50–67-year-old trees from Nilambur, India. It was further revealed that in Mozambique the old teak plantation of 65 years reported that 80% of the trees were flowered (Bila et al., 1999). This increase in *T. grandis* seeds with age might be due to access to more thinning, which reduced the stand density for more photosynthesis, activated insects for more pollination, and provided a wider chance for branch growth and seed production. The seed production in *T. grandis* appeared to be influenced by the increased stand age through the availability of prolonged moisture, which stimulates stand growth.

The study further revealed that mature-aged plantations exhibited greater mean height and diameter at breast height (dbh) compared to seed orchard stands. This aligns with Madoffe and Magembe's (1988) findings of strong dbh performance (19.3–19.8 cm) in Longuza Teak plantations, Tanzania. Katwal et al. (2003) further highlighted that site quality influences both timber production and seed yield.

Site altitude is crucial for *P. patula* seed production, according to the Institute for Commercial Forestry Research (ICFR) conducted in South Africa, showing that shifting stands to higher altitudes (1,450 m) increased filled seeds per cone from 66 to 140 (Hagedorn, 2001). Proper management of seed stands and orchards is vital for improving seed yields per tree or hectare (Nguyen et al., 2019). Significant seed production occurs at altitudes between 2,000 and 2,300 m, while lower rates are seen at 1,700 m in Tanzania. For optimal growth and high-quality *T. grandis* seeds and wood, moisture conditions should range from 1,200 to 2,500 mm of annual rainfall, with a 3–5-month dry season (Keogh, 1987). Research by Indira and Mohandas (2002) showed that 95% of teak pollination occurs with sunlight, while only 45% happens without it, likely due to reduced insect activity on rainy days. These findings emphasize the important role of rainfall and the dry season in *T. grandis* seed productivity.

Seed germination in mature and young orchard and plantation seed sources The present study further recognized that the germination capacity of *P. patula* and *T. grandis* seeds collected from seed orchards sources was significantly higher than that of plantation seed sources. This might be due to the high quality of seeds produced in the seed orchard sources. This observation supported by the study of Graudal et al. (2014), which highlighted that seeds with high genetic quality (seed orchards) have high germination capacity and produce plants with desirable genetic traits such as fast growth, pest tolerance/resistance, good tree performance, and high-quality tree products. It was further revealed that seed orchard seeds produce faster, even germination in the nursery, and more uniform seedling crops (Wennström et al., 2001). The present study further observed that germination capacity of *P. patula* and *T. grandis* seeds collected from young seed orchards and plantation seed sources was significantly higher than that of mature seed orchards and plantation seed sources. This observation agreed with the study by Gutterman (2000), which pointed out that the stand age of the mother plant has a significant influence on seed germination capacity. This observation concurred with the study from Ghana by Fredrick et al. (2016), which insisted that germination rate was not different between 10 years (47.33%) and 15 years (45.33%) maternal stands, but both were significantly (p-value < 0.01) higher than 20 years old (34.22%) maternal stands. It means that germination rate was observed to be higher in young (10 years) to middle-aged (15) trees and falls drastically as the stands grow older (age 20). Lyngdoh et al. (2014) postulate that the importance of the age of mother stands from which seeds are collected for germination, which is an essential factor influencing plantation development. It was further detailed that seed source, the age of the mother stand from which seeds are collected, as well as the prevailing site conditions the mother stand dwells in, are very influential when it comes to seed germination (Mao et al., 2014).

As trees age, their declining leaf growth and photosynthetic rates may reduce viable seed production (Mencuccini et al., 2005). Older seeds typically show decreased germination energy and capacity, with higher rates of abnormalities or non-germination (Bewley & Black, 1994). Teak seeds have low and sporadic germination rates (30–50%) over a prolonged period (10–50 days) (Kumaravelu, 1993), performing better in moist areas (30–50%) compared to dry areas (5–10%) (Palanisamy, 2014). In contrast, *P. patula* seeds exhibit higher germination rates (75–85%) and shorter germination periods (7–14 days) (Wormald, 1975), with environmental factors like higher temperatures significantly influencing seed release and germination (Núñez & Calvo, 2000). Teak's low germination rates are due to its thick seed coat and hard, woody endocarp, which hinder water absorption and gas exchange, and immature embryos reduce the number of viable seeds capable of germination (Venkatesan et al., 2023).

Conclusion

A significant amount of *T. grandis* seeds were produced in seed orchards compared to plantation seed sources. Good site quality was found in the seed orchard with an adequate amount of moisture conditions that might enabled the availability of sunlight, which favors *T. grandis* growth and seed production. A weighty amount of *P. patula* seeds was higher in plantations than in seed orchards sources. Adequate management practices such as weeding and thinning conducted in plantation sources might lead to a reduction of competition, and low stand density looks to be a vital factor for the attainment of profuse *P. patula* seeds in plantation sources. Both *T. grandis* and *P. patula* seed production seemed to be influenced by the increase in stand age since more seeds of T. *grandis* and *P. patula* were produced in mature stands compared to young stands. Germination is an important trait that determines the quality of seeds. The germination capacity of seeds from orchards was significantly higher than that of those from plantations, and the germination capacity of seeds from young sources was significantly higher than that of those from mature seed sources.

Recommendation

Appropriate silvicultural management should be maintained during the establishment and management of seed orchards and plantation seed source stands. Proper analysis of moisture conditions (1,200–2,500 mm) for *T. grandis* should be undertaken prior to the establishment of commercial seed sources. Seeds to be used for the establishment of forest woodlots and plantations in Tanzania should be collected from seed orchards sources for sustainable quality and significant quantity of forest productivity.

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Conflict of interests

All authors declare that they have no conflict of interest regarding the content and publication of this paper.

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