International Journal of Forestry Research

WILEY

RESEARCH ARTICLE OPEN ACCESS

Assessment of Profitability of *Tectona grandis* and *Pinus patula* Seeds Production From Selected Forest Plantations in Tanzania

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Received: 31 December 2024 | **Revised:** 15 July 2025 | **Accepted:** 29 September 2025

Academic Editor: Poorani Gurumallesh

Keywords: costs of production | foreign investors | local investors | tree seed industry | tree seed sources

ABSTRACT

Levels of profitability and production expenses are crucial decision-making tools in any organization. This study was undertaken to assess the profitability of *T. grandis* and *P. patula* seeds production in selected forest plantations seed sources in Tanzania. It focused on analyzing the costs, benefits, and profits associated with the production of *T. grandis* and *P. patula* seeds from the selected plantation sources. Data were collected using key informant interviews, researcher's direct field observations, and literature review. The collected information was analyzed using the SPSS (Version 23.0) and Microsoft Excel computer programs. Cost−benefit analysis (CBA) was performed to assess profitability, in which the net present value (NPV), cost−benefit ratio (CBR), and internal rate of return (IRR) were the criteria used for assessing profitability. Findings indicate that *T. grandis* seed production is a profitable project with an NPV of TZS 3,225,502/ha, CBR of 7.78%, and IRR of 1.28, despite having higher production costs than *P. patula* seeds. The production of *P. patula* seeds was observed to be unprofitable with negative NPV, CBR, and IRR of TZS −3,689,000/ha, −24.65%, and 0.14, respectively. It was evident that weeding was the most costly activity in the production of both *T. grandis* and *P. patula* seeds. On the other hand, Longuza Forest Plantation was observed to be the most suitable area for producing *T. grandis* seeds. However, appropriate price decisions and cost control measures are important aspects for ensuring sustainability and maximizing profitability of *T. grandis* and *P. patula* seed industry.

1 | Introduction

Tectona grandis is one of the commercially important hardwood species that produces quality timber having good specific gravity, strength, and durability [1]. *Pinus patula,* on the other hand, is an essential commercial plantation species in Sub-Saharan Africa [2]. Being among the most important commercial tree species, its production is therefore vital. However, the supply of wood in Tanzania is unable to meet demands, and it is reported that by 2025, the demand for industrial wood will be about 3.7 million m^3, while the existing plantations will only be able to supply about 1.1 million m^3 [3]. The problem of tree seed sourcing is becoming more acute due to the increased demand for seeds to meet the current massive global commitments to forest plantation (FP) establishment and other tree planting initiatives [4]. In Tanzania, few seed sources of genetically improved seeds exist in addition to inadequate use of vegetative propagules [5]. Furthermore, the supply of local tree seeds is insufficient, where only 18.3 tons of seeds are produced annually, while the demand is about 40 tons [6]. The insignificant investment in the tree seed industry from both formal

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and informal sectors has diminished the insurance of increased tree seed production, improved seed quality, and forest productivity in general [7]. Both formal and informal sectors have limited information concerning the production costs of *T. grandis* and *P. patula* tree seeds and profitability, hence hindering the engagement in the tree seed industry.

The success of any forest company will largely depend on the profit realized and the return on investment accrued. According to Sholichah et al. [8], profitability is a reflection of the company's success or failure because it shows the company's capacity to generate returns on investment based on its resources against a variant investment. Profitability is the relationship between profits achieved by the firm and the investment activities contributing to profit generation. Therefore, cost control measures are important and need to be used in various firms to control and reduce costs in order to maximize the firm's profit [9]. Regardless of the type of organization, cost data can considerably aid decision-making in many different ways [10]. Having this information enables an organization to identify which cost objects are being harmful to the business and then apply corrective measures on the flow of costs of those objects, thus increasing the probability of earning high total profits [11]. Lack of cost data for different silvicultural activities in FPs' seed sources has created an environment of relative uncertainties among investors, projects, and tree farmers, Gomez and Reiche [12]. Insufficient tree seed production cost information, such as seedling raising costs, tree seed sources establishment and management costs, and tree seed collection, processing, storage, and packaging costs tend to inhibit stakeholders and local and foreign investors from engaging in the tree seeds industry. Investor's engagement will qualify the provision of capital, technology transfer, employment, access to foreign markets, and attracting other investors in the seed production sector (Pfeferman and Madarasy1990). Therefore, this study aimed to gather and provide information on the production costs and the profitability of *T. grandis* and *P. patula* seeds production in selected FP seed sources in Tanzania. Specifically, the study attempted to first analyze the costs and benefits associated with the production of *T. grandis* and *P. patula* seeds to determine the profitability in the production of *T. grandis* and *P. patula* seeds. Findings from this aimed to assist both the government and the private sector in formulating policies, laws and regulations, as well as in planning and decision-making processes for the tree seed industry to attract local and foreign investors, hence ensuring a sustainable supply of tree seeds in Tanzania.

1.1 | Study Limitations

i. Limited accessibility to skilled tree climbers and scarcity of appropriate climbing equipment.

ii. Difficulty terrain causing limited accessibility to seed source compartments, particularly during the rainy season.

iii. Insufficient funding availability and time constraint for undertaking a longitudinal study

1.2 | Research Questions

1. How profitable is the production of *Tectona grandis* and *Pinus patula* tree seeds in selected FPs in Tanzania?
2. What are the key cost components and revenue drivers affecting the profitability of tree seed production for these two species?

1.3 | Research Hypothesis

1. H_{01}: There is no significant difference in the production costs between *T. grandis* and *P. patula* seed production in selected FPs in Tanzania.
2. H_{02}: There is no significant difference in the profitability of *T. grandis* and *P. patula* seed production in selected FPs in Tanzania.
3. H_{11}: There is a significant difference in the production costs between *T. grandis* and *P. patula* seed production in selected FPs in Tanzania.
4. H_{12}: There is a significant difference in the profitability of *T. grandis* and *P. patula* seed production in selected FPs in Tanzania.

2 | Materials and Methods

2.1 | Descriptions of the Study Areas

In this study, four FP seed sources (Figure 1) were selected. The selection of these study sites was based on the availability of potential seed sources.

The four selected study sites have different characteristics, including geographical location, altitude, amount of rainfall received per year, and temperature, as summarized in Table 1.

2.2 | Research Design

The research employed a cross-sectional, purposeful, and analytic sampling design. The selected four FPs' seed sources were due to the availability of *T. grandis* and *P. patula* compartments with information on tree seed sources, seedling production costs, and establishment and management costs (planting, weeding, pruning, thinning, seed collection, processing, and packaging).

2.3 | Sampling and Data Collection

In each of the four FPs' seed sources, the plantation staff was chosen using a purposeful random sampling design to provide the necessary information, including various expenses related to the *T. grandis* and *P. patula* seedlings production and establishment and management costs of the seed sources. Data were collected using field observations, key informants' interviews, focus group discussion, and various literature reviews. Key informant interviews were conducted with the personnel responsible for the nursery activities, silviculture officers, and plantation managers. Other information on seed sources establishment and management, seed collection, processing and seed packaging costs, as well as the seed selling prices for *T. grandis* and *P. patula,* was collected from literature review. Production costs included seedling production and seed source establishment and management costs, while the management costs were categorized into planting, weeding, pruning, thinning, seed collection, processing, and packaging. All the necessary costs and revenue data were collected from each of the four selected study sites. Some information was obtained from various reports of TFS

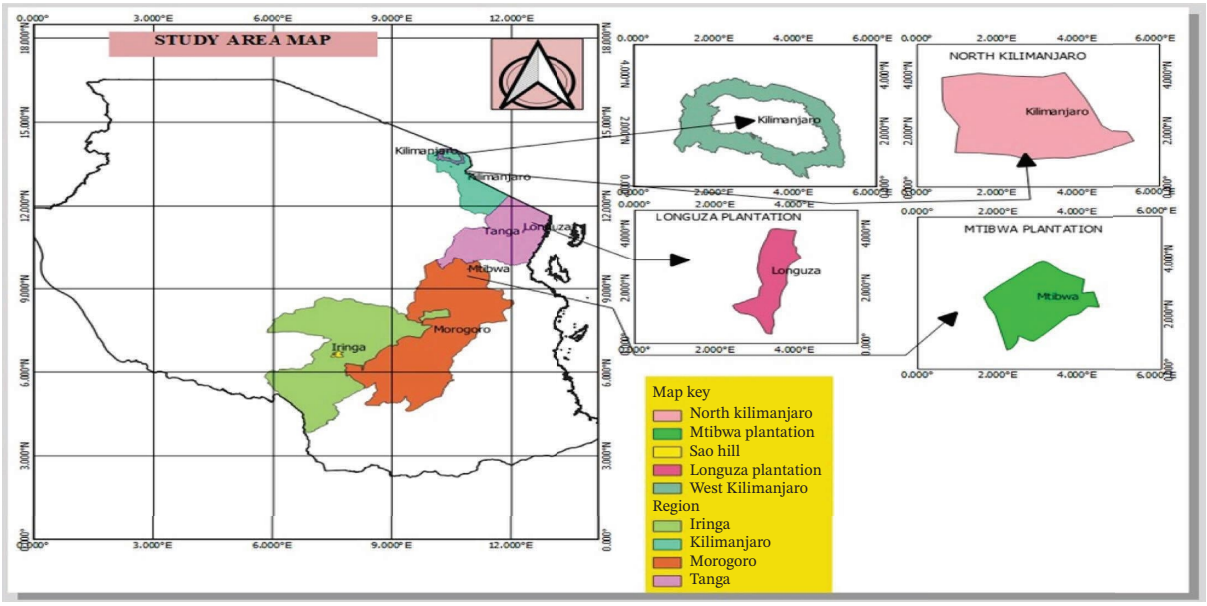


FIGURE 1 | Distribution of four government forest plantations in Tanzania.

plantation managers. The Tree Seeds Production Station catalog and Government Notes No. 59 of 2022 were reviewed to obtain various information including the government prices used for selling various seeds. The amount of *T. grandis* and *P. patula* seeds production per hectare was collected from all four FP seed sources. To obtain the total revenue from each plantation, the amount of *T. grandis* and *P. patula* seeds produced in kilograms per hectare (kg/ha) was then multiplied by the existing selling or market prices (Table 2).

2.4 | Data Analysis

In this study, data were analyzed using SPSS and Excel statistical computer programs. To estimate the profits and assess the viability of the investment, the cost−benefit analysis (CBA) technique was used. In addition, the discounted cash flow analysis was then adopted to show the profitability of *T. grandis* and *P. patula* seeds production in the four FPs' seed sources. In the analysis, the net present value (PV) (NPV), cost−benefit ratio (CBR) and internal rate of return (IRR) were used as criteria to establish the profitability or viability of the business.

According to the World Bank [13] and Gittinger [14], who provide official guidelines for forestry economics, the NPV, IRR, and CBR are standard methods for appraising agricultural and forestry investments. These indicators form the backbone of project evaluation in World Bank−supported initiatives and are widely regarded as the most reliable tools for determining the economic viability of forestry investments [15]. The forestry project evaluation guide insisted that the indicators NPV, IRR, and CBR should be used together in forest investment appraisal to ensure decisions are based on full economic analysis.

NPV, IRR, and CBR are robust indicators for identifying economically viable forestry investments, particularly in contexts where ecosystem services and long-term benefits are significant [16]. Global agencies and national governments actively promote the use of these financial tools in project appraisals to enhance transparency and ensure consistency. They are widely adopted in evaluating forestry, agroforestry, and seed system investments, given the long-time horizons and uncertain returns associated with such projects. As noted by the FAO [15], NPV, IRR, and CBR are essential tools for assessing both the profitability and

TABLE 1 | Study area description.

District	Plantation/station	Altitude (m.a.s.l)	Mean annual rainfall (mm)	Mean annual temperature (°C)	Spacing (m)	Silvicultural practices conducted
Siha	West Kilimanjaro	1562–3125	658	15°C	3 × 3	Weeding
Mvomero	Mtibwa	457	1205	28°C–33°C	6 × 6	Weeding, thinning, and fertilization
Rombo	North Kilimanjaro	1800–2250	900	17°C	3 × 3	Weeding
Muheza	Longuza	180	1548	15°C–20°C	5 × 5	Weeding, thinning, and pruning

TABLE 2 | Tree seeds production per hectare in plantation seed sources.

SN	Plantation name	Species name	Average seeds produced kg/ha
1.	North Kilimanjaro	*Pinus patula*	27.1
2.	West Kilimanjaro	*Pinus patula*	24.1
3.	Mtibwa	*Tectona grandis*	793.4
4.	Longuza	*Tectona grandis*	993.8

sustainability of investments in the forestry and natural resource sectors. The average net values were calculated for the period between 10 and 18 years for *P. patula* and 10 and 20 years for *T. grandis.* This is because, based on the technical order No.1 of 2021, the age for prolific seeds production for both *P. patula* and *T. grandis* is 10 years, while the rotation age is 18 and 20 years, respectively. The costs and benefits flow over the specified period of time were discounted to their PVs. The discounted costs were then subtracted from discounted benefits (Equation (1)) to calculate the NPV as specified by Fernando [17]. The IRR was calculated using Equation (2), following the method outlined by Gittinger [14], which identifies the discount rate that equates the PV of benefits and costs, resulting in a NPV of zero. Similarly, the CBR was estimated using Equation (3), as described by Boardman et al. [18], by dividing the total PV of benefits by the total PV of costs to assess the economic viability of the investment. NPV, CBR, and IRR results can then be used as a guide for decision-making in the investment or business [19].

The selection of a 5% discount rate in the investment analysis of *Tectona grandis* and *Pinus patula* seed production aligns with established guidelines for evaluating long-term forestry and environmental projects. The Asian Development Bank [20], World Bank−affiliated research [21], and Tanzania's Ministry of Finance and Economic Planning [22] all recommend a 3%−5% social discount rate for forest and environmental investments. This approach ensures accurate valuation and supports informed decision-making for sustainable forest management.

The NPVs, CBR, and IRR were calculated by using the following formulas:

$$\text{NPV} = \sum\left(\frac{R_n}{(1+i)^n}\right) - \sum\left(\frac{R_n}{(1+i)^n}\right), \tag{1}$$

where NPV = NPV, $\sum$ = sum of all values in parentheses, Rn = revenue in year n, Cn = costs in year n, n = year in which cash flow occurs, and i = interest rate (5% has been used for calculations).

$$\text{CBR} = \frac{\text{total present value of benefit}}{\text{total present value of costs}}. \tag{2}$$

The internal rate of return can be calculated as

$$0 = \sum \frac{\text{net cash flow}_t}{(1+r)^t}, \tag{3}$$

where net cash flow = revenue − cost in year *ttt*. R = IRR (what you are solving for) and t = year (1, 2, 3...n). This formula finds the rate r where the NPV = 0.

3 | Results

3.1 | Production Costs for *Pinus Patula* and *Tectona Grandis* Seeds

Among the important cost elements in the production of *P. patula* seeds are seedling raising, land preparation, planting, weeding, pruning, thinning, seed collection, seed processing, packaging, and administrative costs. Findings from this study indicate that a total cost of TZS 6,630,591/ = was used to produce *P. patula* seeds per hectare for the entire 18 years of rotation age. Weeding activities had the highest cost, averaging to about TZS 2,325,000/ = , equivalent to 35% of the total costs of producing *P. patula* seeds per hectare for the entire 18 years of rotation age. Administrative and protection costs contributed about 6.617.2% and 8.11.2% of the total production costs, respectively (Table 3). Planting has the lowest cost, contributing to about 3.5% of the total costs of producing *P. patula* seeds (Table 3).

For *T. grandis* seeds, the total production costs were TZS 9,428,816.36/ = per hectare for the entire 20 years of rotation age. Like in the production costs for *P. patula,* weeding activity was ranked the highest cost element contributing to TZS 4,526,031/ =, equivalent to 48% of the total production costs (Table 4). Administration and protection contributed to about 14.6% and 8.2% of the total costs, respectively. Seedling raising costs make the lowest costs of 2.9% of the total costs of producing *T. grandis* seeds, as indicated in Table 4.

3.2 | The NPV, CBR, and IRR for *Pinus patula* Seeds Production

Findings show that production of *P. patula* seeds per hectare had a negative NPV of TZS −3,689,000/ = and the CBR of 0.14, which is averaged to be 0.008/= (Table 5), as well as the IRR of −24.65%. This involves calculating the PV of each year's net cash flow (benefits minus costs) using different discount rates until the total NPV becomes zero. A higher IRR indicates a more profitable investment.

On the other hand, the production of *Tectona grandis* seeds per hectare had a positive NPV of TZS 3,225,502/ = and the CBR of 25.54, which is averaged to be 1.28 (Table 6), as well as an internal rate of return of 7.78%. This involves calculating the PV of each year's net cash flow (benefits minus costs) using different discount rates until the total NPV becomes zero. A higher IRR indicates a more profitable investment.

3.3 | Seeds Production Costs in the Four Selected Forest Plantations

The results from this study show that the production of *P. patula* seeds in North Kilimanjaro FP had the highest production costs averaging to about TZS 6,896,000/ = per hectare, while West Kilimanjaro FP had the average production cost of TZS 6,365,183/ = per hectare (Table 7). For the production of *T. grandis* seeds, Longuza FP had the highest production costs averaging to about TZS 10,954,477/ = per hectare for the entire 20 years of rotation age, and at Mtibwa FP, the total production costs averaged to about TZS 7,903,156/= (Table 7).

As indicated in the Methodology section, the calculation of the total production costs for both *T. grandis* and *P. patula* seeds per hectare was based on the various cost elements, including

TABLE 3 | Various costs of producing *Pinus patula* seeds per hectare.

Year	Land prep	Seedlings	Planting	Protection	Thinning	Admin	Seed collection	Weeding	Total costs
1	732,800	278,000	400,000	70,000	0	258,817.8	0	780,000	2,519,617.8
2	0	0	0	60,000	0	58,817.8	0	690,000	808,817.8
3	0	0	0	50,000	0	58,817.8	0	456,031	564,848.4
4	0	0	0	40,000	0	58,817.8	0	300,000	398,817.8
5	0	0	0	40,000	200,000	58,817.8	0	250,000	548,817.8
6	0	0	0	30,000	0	58,817.8	0	250,000	338,817.8
7	0	0	0	30,000	0	58,817.8	0	200,000	288,817.8
8	0	0	0	30,000	0	58,817.8	0	200,000	288,817.8
9	0	0	0	20,000	200,000	58,817.8	0	200,000	478,817.8
10	0	0	0	20,000	0	58,817.8	0	150,000	228,817.8
11	0	0	0	10,000	0	58,817.8	0	150,000	218,817.8
12	0	0	0	10,000	0	58,817.8	0	100,000	168,817.8
13	0	0	0	10,000	0	58,817.8	0	100,000	168,817.8
14	0	0	0	50,000	0	58,817.8	0	100,000	208,817.8
15	0	0	0	50,000	213,215.20	58,817.8	0	100,000	422,033.0
16	0	0	0	50,000	0	58,817.8	0	100,000	208,817.8
17	0	0	0	50,000	0	58,817.8	0	100,000	208,817.8
18	0	0	0	50,000	0	58,817.8	0	100,000	208,817.8
19	0	0	0	50,000	0	58,817.8	0.00	100,000	208,817.8
20	0	0	0	50,000		58,817.8	732,415.60	100,000	941,233.4
Costs/activity	732,800	278,000	400,000	770,000	613,215.20	1,376,355.00	732,416	4,526,031	9,428,816.40

seedling raising, establishment and management, seeds collection, processing, packaging and administrative costs.

3.4 | The NPV, CBR, and IRR in the Four FP Seed Sources

The results from this study indicated that the NPV, CBR, and IRR for the two FPs, North Kilimanjaro and West Kilimanjaro, were as follows: the NPVs were −3,847,531 and −3,569,202, respectively; the CBRs were 0.14 and 0.13; and the IRRs were −4.3% and −4.5%, respectively. These results refer to the two FP seed sources involved in the production of *Pinus patula* seeds, as indicated in Table 8. On the other hand, the study results indicated that the NPV, CBR, and IRR for the two FPs, Longuza and Mtibwa, were as follows: the NPVs were 3,225,502 and 1,056,192, respectively; the CBRs were 1.29 and 1.22; and the IRRs were 7.8% and 6.9%, respectively. These results refer to the two FP seed sources involved in the production of *Tectona grandis* seeds, as indicated in Table 8.

The potential total revenue was estimated by multiplying the amount of seeds produced (kg/ha) and the prices. Based on the market survey and key informant interviews with managers and other experts, the existing market prices, which were then used in this study, were TZS. 20,000/ = and 55,000/ = per kg for *T. grandis* and *P. patula*, respectively. Findings show that both North Kilimanjaro and West Kilimanjaro FPs had almost the same negative NPV of TZS −3,847,531 and −3,569,202 (Table 8); the same negative IRR of −4.3% and −4.5%, respectively; and they also had a figure of less than one for CBR of 0.14 and 0.13, respectively (Table 8).

3.5 | Sensitivity Analysis

The production of *Pinus patula* seeds is not financially viable at any discount rate. At a 5% discount rate, it shows a negative NPV of TZS –3,689,000, a CBR of 0.14, and a negative IRR (approximately −24.7%), meaning the project returns significantly less than it costs to implement, as indicated in Table 9. The production of *Tectona grandis seeds* is financially viable at a 5% discount rate, with a positive NPV of TZS 3,225,502/ =, a CBR of 1.28, and an IRR of approximately 7.8%, indicating profitability. However, it becomes unprofitable at higher discount rates (10% and 15%), where NPV turns negative and CBR drops below 1, reducing its financial appeal.

4 | Discussion

4.1 | Production Costs for *Tectona grandis* and *Pinus patula* Seeds

The cost of tree seed production refers to all expenses incurred throughout the process of seedling raising, land preparation, weeding, thinning, pruning, seed collection, processing, and storing tree seeds. According to Mbuya et al. [23], tree seed production involves both direct and indirect costs, with significant variation depending on species, site accessibility, and the scale of production. Mishra et al. [24] emphasized that understanding the structure of production costs is essential for improving economic efficiency, determining profitability, and formulating pricing strategies, especially in agricultural and forestry production systems. Our present study has identified

TABLE 4 | Various costs of producing *Tectona grandis* seeds per hectare.

Year	Land prep	Seedlings	Planting	Protection	Pruning	Thinning	Administrative	Seed collection	Weeding	Total costs
1	740,400	330,520	230,000	30,000	0	0	165,143.8	0	250,000	1,746,063.8
2	0	0	0	25,000	0	0	57,254.4	0	225,000	307,254.4
3	0	0	0	20,000	10,000	0	57,254.4	0	200,000	287,254.4
4	0	0	0	15,000	15,000	0	57,254.4	0	200,000	287,254.4
5	0	0	0	10,000	10,000	200,000	57,254.4	0	175,000	452,254.4
6	0	0	0	10,000	5000	0	57,254.4	0	150,000	222,254.4
7	0	0	0	10,000	5000	0	57,254.4	0	150,000	222,254.4
8	0	0	0	10,000	5000	0	57,254.4	0	150,000	222,254.4
9	0	0	0	5000	5000	200,000	57,254.4	0	100,000	367,254.4
10	0	0	0	5000	5000	0	57,254.4	0	100,000	167,254.4
11	0	0	0	5000	5000	0	57,254.4	0	100,000	167,254.4
12	0	0	0	5000	5000	0	57,254.4	0	75,000	142,254.4
13	0	0	0	5000	5000	0	57,254.4	0	75,000	142,254.4
14	0	0	0	5000	5000	0	57,254.4	0	75,000	142,254.4
15	0	0	0	5000	5000	243,534.8	57,254.4	0	75,000	385,789.2
16	0	0	0	30,000	50,000	0	57,254.4	0	75,000	212,254.4
17	0	0	0	30,000	50,000	0	57,254.4		75,000	212,254.4
18	0	0	0	30,000	50,000		57,254.4	732,667.3	75,000	944,921.7
Cost/activity	740,400	330,520	230,000	255,000	235,000	643,535	1,138,468.9	732,667	2,325,000	6,630,591.0

TABLE 5 | Net present value, cost–benefit ratio, and internal rate of return for *Pinus patula* seed production.

Year	Cost	Revenue	Net cash flow	Discounted revenue	Discounted cost	Discounted net CF	Net present value (NPV)	Cost–benefit ratio (CBR)
1	368,366.2	0	−36.8366	0	350,824.9	−35,0824.92	−350,825	0
2	368,366.2	0	−36,8366	0	684,943.9	−33,4118.97	−684,944	0
3	368,366.2	0	−36,8366	0	1,003,152	−31,8208.54	−100,3152	0
4	368,366.2	0	−36,8366	0	1,306,208	−30,3055.76	−13,06,208	0
5	368,366.2	0	−36,,8366	0	1,594,833	−28,8624.53	−15,94,833	0
6	368,366.2	0	−368366	0	1,869,713	−274880.51	−18,69,713	0
7	368,366.2	0	−36,8366	0	2,131,504	−26,1790.96	−21,31,504	0
8	368,366.2	0	−36,8366	0	2,380,829	−24,9324.72	−23,80,829	0
9	368,366.2	0	−36,8366	0	2,618,281	−23,7452.12	−26,18,281	0
10	368,366.2	0	−36,8366	0	2,844,426	−22,6144.87	−28,44,426	0
11	368,366.2	0	−36,8366	0	3,059,802	−21,5376.07	−30,59,802	0
12	368,366.2	0	−36,8366	0	3,264,922	−20,5120.07	−32,64,922	0
13	368,366.2	0	−368,366	0	3,460,274	−19,5352.44	−34,60,274	0
14	368,366.2	0	−36,8366	0	3,646,324	−18,6049.95	−36,46,324	0
15	368,366.2	0	−36,8366	0	3,823,515	−17,7190.42	−38,23,515	0
16	368,366.2	0	−36,8366	0	3,992,268	−16,8752.79	−39,92,268	0
17	368,366.2	0	−36,8366	0	4,152,985	−16,0716.94	−41,52,985	0
18	368,366.2	1,485,000	1,116,634	617,048.2	4,306,048	463,984.42	−36,89,000	0.14
0	6,630,591	1,485,000	1,116,634	617,048.2	4,306,048	−3,689,000.2	−3,689,000	0.14

that weeding constitutes the highest expense in the production of *P. patula* seeds per hectare. Weeding is a labor-intensive and frequent activity, especially in the first few years after planting. This observation aligns with the findings from a study by George and Brennan [25], which indicated that weed control costs can significantly impact silvicultural costs. Muriuki et al. [26] noted that weeding constituted the most substantial recurrent cost in the management of tree seed stands, often surpassing other silvicultural operations such as thinning and pruning.

This, therefore, forces the managers in all the plantations to invest highly on this activity in order to maintain the expected quality and quantity. According to Goswami and Challa [27], weeding expenses represented a substantial portion, accounting for about 31% of the total costs associated with plantation establishment and management in a study conducted in India. Similarly, a study by Kiwuso et al. [28] on tropical tree seed systems in Uganda found that the major cost components in tree seed production are labor for weeding, which accounts for over 30% of the total cost, depending on species and ecological conditions. This observation aligns with ICRAF [29], which states that weeding accounts for the highest proportion of the labor budget in tree seed production, particularly during the first 2−3 years, due to the need to maintain weed-free conditions for optimal seedling development. Weeds interference hinders the growth of young plants in the plantation, thereby prolonging the time required for these trees to reach maturity. The expenses associated with weed control in plantation development encompass not only direct financial costs, yield losses, or downgrades and reductions in quality but also the broader impact on seeds pricing. Effective weed control is an avenue through which tree growth, seed production, and ultimately profitability are enhanced [30]. Kindt et al. [31] affirm that inadequate weeding compromises seed production both in terms of quantity and genetic quality, as stressed or shaded trees may not flower adequately or synchronize with others in the stand. These findings align with the results of a study conducted by Fox et al. [32], indicating that modern plantation management has prioritized increasing forest productivity through tree improvement and effective weed control.

Compared to site establishment, maintenance, and management (such as weeding and pruning), seed collection and processing generally require less intensive labor and fewer inputs. Especially when seed-producing trees are already mature and accessible, collection is often seasonal and short-term, reducing ongoing labor costs. This observation agrees with Kindt et al. [31], who explained that, in contrast to the high costs of establishing and managing seed stands or orchards, the actual collection and basic processing of seed often represents a relatively small share of total production costs. According to Lillesø et al. [33], when seeds are sourced from existing natural forests or FPs, collection costs are minimal compared to the cost of establishing and maintaining formal seed orchards. Similar results were reported by FAO [34], which insisted that seed collection and processing tend to be less expensive than orchard maintenance or nursery production, particularly when carried out at a small scale using locally available methods and materials. Seed collection was much cheap because various tree seed collection techniques ranging from simple collection from the ground to climbing of trees or the use of expensive sophisticated equipment could be used. Collection from the ground is easy and less labor and equipment intensive as well as less time-consuming requiring less skills and minimal costs [35], while the collection from higher branches that involves climbing needs additional equipment such as long-handled pruners or saws, and it is also time consuming, which directly has an impact on the associated costs [35]. The study by Köhl et al. [36] provides a general conclusion that in forest seed systems, the major cost drivers are land preparation and management, not collection or processing, which tend to require limited resources.

Thinning expenses also represented a substantial portion of the total costs of producing *T. grandis* seeds. Thus, thinning results in wider spacing, which activates greater availability of light, water, and nutrients to the remaining trees. In this study, both *T. grandis* stands have wider spacing with a significant amount of seed production, which suggests that wider spacing in *T. grandis* stands allows a significant amount of sunlight and reduces intraspecific competition that stimulates tree growth and seed production [37]. Weeding was found to be the highest expenditure in the production of *T. grandis* and *P. patula* seeds per hectare.

4.2 | The NPVs for *Tectona grandis* and *Pinus patula* Seeds' Production

NPV quantifies the total value of a project by discounting all future cash flows to present terms, allowing decision-makers to compare benefits and costs over time. NPV is the most reliable criterion for project evaluation because it directly measures the net social gain in monetary terms from undertaking a project [18]. A project yields a positive NPV, CBR > 1, and IRR > discount rate when the PV of benefits outweighs the costs. This generally happens when the revenues are high or occur earlier, costs are minimized, the discount rate is low, and the investment has long-lasting and high returns. A project is considered economically justified if its NPV is positive, which implies the PV of benefits exceeds the PV of costs, even when discounted to reflect time preferences [18].

The production of *T. grandis* seeds, on the other hand, showed a positive NPV value. This might be attributed to the moderate prices charged for the species. Unlike *P. patula*, it is evident that *T. grandis* is a highly valued tree species, probably that is why it has a higher market price compared to *P. patula*. According to Yescombe [38], a higher NPV is primarily the result of a larger initial investment size. This could be explained by the fact that using improved seeds during establishment led to more seeds being produced, which might increase revenue generated relative to costs of production. According to Helfert [39], the size of the NPV is prospectively affected by the greater initial investment costs. The greater initial investment costs are expected to affect the NPV, boost production, and perhaps cause a revenue explosion.

The production of *P. patula* revealed a negative NPV value using an interest rate of 5%, implying that *P. patula* trees yield fewer seeds, of inferior quality, and at a lower selling price, which results in a negative NPV. This lower yield when multiplied with lower price charged resulted in less revenue generated from the local *Pinus patula* seeds. With the highest production costs exceeding the revenue generated, no profit is expected to be made, and the firm could suffer significant losses [40]. Moreover, if the selling price is lower than it should be, a company could be at risk

TABLE 6 | Net present value, cost–benefit ratio, and internal rate of return for *Tectona grandis* seed production.

Year	Cost (TZS)	Revenue (TZS)	Net cash flow (TZS)	Discounted cost (TZS)	Discounted revenue (TZS)	Discounted NCF (TZS)	Net present value (NPV) (TZS)	Cost–benefit ratio
1	1,632,449	0	−1,632,449	1,632,449	0	−1,632,449	−1632,449	0
2	534,196	0	−326,529	110,980	0	−310,980	−310,980	0
3	534,196	0	−281,529	155,355	0	−255,355	−255,355	0
4	534,196	0	−281,529	143,195	0	−243,195	−243,195	0
5	421,529	0	−421,529	230,065	0	−330,065	−330,065	0
6	281,529	0	−281,529	210,066	0	−220,066	−210,066	0
7	281,529	0	−281,529	200,062	0	−210,062	−200,062	0
8	281,529	0	−281,529	190,535	0	−200,535	−190,535	0
9	281,529	0	−281,529	181,462	0	−190,462	−181,462	0
10	534,196	0	−361,529	121,053	0	−232,053	−221,053	0
11	281,529	0	−281,529	162,891	0	−172,891	−162,891	0
12	281,529	0	−281,529	155,134	0	−164,134	−155,134	0
13	281,529	0	−281,529	147,747	0	−157,747	−147,747	0
14	534,196	0	−361,529	178,867	0	−192,867	−178,867	0
15	281,529	0	−281,529	133,950	0	−143,950	−133,950	0
16	381,529	0	−281,529	127,571	0	−136,571	−127,571	0
17	281,529	0	−281,529	121,496	0	−129,496	−121,496	0
18	281,529	0	−281,529	115,710	0	−123,710	−115,710	0
19	534,196	0	−534,196	121,970	0	−223,970	−221,970	0
20	972,843.4	19,860,000	19,082,269	193,216	7,859,276	7,551,502	7,551,502	25.54
0	9,428,816	19,860,000	19,082,269	4,633,774	7,859,276	7,551,502	7,551,502	25.54

for charges of predatory pricing practices as a strategy to attract customers by using low selling prices. Another study by Raju and Zhang [41] revealed that pricing strategies can have a huge impact on profits in the business or project. Therefore, clarifying how pricing impacts profits helps to emphasize how crucial it is to set the right price.

When costs are high and revenues are delayed or minimal, such as in low-production forest seed, the PV of benefits can easily fall below total costs, resulting in a negative NPV, a low IRR, and a CBR below 1. This scenario is particularly common in forestry-related projects where benefits accrue far in the future and capital outlays are required upfront. According to Price [42], forest investments with long gestation periods, low production rates, and moderate discount rates frequently yield negative NPVs, even when the environmental benefits are significant. These projects become financially unattractive, not necessarily due to inefficiency, but because the timing of returns significantly reduces their PV. The study by Zhuang et al. [20] further emphasizes that projects with concentrated end-cycle revenues are especially vulnerable to higher or moderate discount rates, and when production is low, the NPV can turn negative despite potentially high nominal returns. This highlights the critical need for careful financial planning and possibly concessional financing when evaluating long-term forestry and conservation investments. If seed yield is low or market prices decline, projected revenues may fall short, rendering the investment unattractive. Uncertainty in tree seedling production rates, limited market access, and depressed prices significantly reduce the NPV and IRR of plantation investments [43].

TABLE 7 | *Tectona grandis* and *Pinus patula* seeds production costs in four forest plantation seed sources.

Plantation name	Specie name	Present value cost	Percentages (%)
West Kilimanjaro	*Pinus patula*	6,365,183.00	48.00
North Kilimanjaro	*Pinus patula*	6,896,000.00	52.00
			100.00
Mtibwa	*Tectona grandis*	7,903,156.00	41.91
Longuza	*Tectona grandis*	10,954,477.00	58.09
Total cost			100.00

TABLE 8 | The net present value (NPV), cost−benefit ratio, and internal rate of return in the four forest plantation seed sources.

Metric	North Kilimanjaro FP	West Kilimanjaro FP	Longuza FP	Mtibwa FP
Total costs (TZS)	6,896,000	6,365,183	10,954,477	7,903,156
Discounted cost (TZS)	4,466,865	4,120,121	4,633,774	4,922,207
Seed yield (kg/ha)	27.1	24.1	993	793
Price per kg (TZS)	55,000	55,000	20,000	20,000
Total revenue (TZS)	1,490,500	1,325,500	19,860,000	15,860,000
Discounted revenue (TZS)	619,334	550,919	7,859,778	5,978,399
Net present value (NPV)	−3,847,531	−3,569,202	3,225,502	1,056,192
Cost–benefit ratio (CBR)	0.139	0.134	1.286	1.215
Internal rate of return (IRR)	−4.3%	−4.5%	7.8	6.9

In the current study, the production of *T. grandis* seeds not only has higher costs of production compared to that of *P. patula* but also the amount of *T. grandis* seeds produced per hectare is much higher. With the high yield obtained per hectare, it is therefore possible to achieve a positive NPV, a CBR greater than 1, and an IRR higher than the discount rate, when the PV of benefits exceeds the costs, unlike the values observed for *Pinus patula* trees, which have a lower yield per hectare.

4.3 | The IRR for *Tectona grandis* and *Pinus patula* Seeds Production

The IRR is the discount rate that makes the NPV of a project equal to zero. It reflects the expected annual return generated by an investment over its life. This observation agrees with Gittinger [14], who states that IRR is the rate of discount that equates the PV of benefits with the PV of costs, indicating the profitability of a project or investment over time. Similarly, Boardman et al. [18] state that IRR helps in evaluating and comparing investment projects, especially in capital budgeting decisions where ranking by expected return is crucial. It is a critical indicator for assessing the financial viability of investments, with a positive IRR exceeding the discount rate signaling profitability, while a negative IRR indicates financial loss and failure to recover the initial investment. In the production of *P. patula* seed, an IRR of −24.65% reveals severe underperformance and value loss, primarily driven by low seed prices that depress revenue and prevent cost recovery. This negative value of the IRR could be as well due to the high production costs, which are not proportional to the potential revenues generated. The production costs for *P. patula* seeds are therefore higher than their respective revenues. When the project yields a negative internal rate of return, it means the project costs more to pursue than the revenue generated [44]. When seed prices are set administratively or kept artificially low, they often fail to reflect actual production costs, leading to negative cash flows and poor financial outcomes such as negative NPV and IRR [45]. The study by Nyoka et al. [46] emphasizes that tree seed pricing must account for full production and quality control costs to ensure sustainability, warning that underpricing drives producers into losses and discourages long-term participation. Supporting this, Mbora et al. [47] found that in Kenya, seed enterprises experienced IRRs between −12% and −28% due to low prices and erratic demand, while Rao et al. [48] reported similar patterns in India, where community nurseries failed to recover seedling costs through market pricing, resulting in negative or negligible IRRs. These studies collectively confirm that unrealistic pricing structures are a central cause of poor financial performance in tree seed enterprises.

The production of *T. grandis* seed with an IRR of 7.78% above the 5% discount rate indicates that the tree seed production is financially viable, generating returns that exceed the cost of capital [14]. This IRR aligns with findings from a related study by Katani et al. [49], who reported a 7.5% IRR in indigenous tree seed systems in Tanzania, and Kindu et al. [50], who observed 12.2% in community-based operations in Ethiopia, whereas Moges et al. [51] found even higher IRRs for *Acacia* and *Eucalyptus* seed

TABLE 9 | Sensitivity analysis for *Tectona grandis* and *Pinus patula* at various discount rates.

Specie name	Discount rate	Discounted revenue (TZS)	Discounted cost (UGX)	Net present value (NPV)	Cost–benefit ratio (CBR)	Interpretation
Pinus patula	5%	617,048.17	4,306,048.00	−3,689,000.	0.14	✗ Not viable
Pinus patula	10%	281,103.47	3,045,996.00	−2,764,893	0.09	✗ Worse
Pinus patula	15%	158,984.57	2,204,195.00	−2,045,210	0.07	✗ Still unviable
Tectona grandis	5%	7,859,276	4,633,774	3,225,502	1.28	✓ Profitable
Tectona grandis	10%	3,047,070	4,633,774	−1,586,704	0.66	✗ Not profitable
Tectona grandis	15%	1,225,498	4,633,774	−3,408,276	0.26	✗ Unviable

production (14.5% and 16.8%) respectively, suggesting that profitability can vary with species and market dynamics. Despite being on the lower end, the 7.78% IRR remains within the viable range for the sector, particularly when considering the ecological benefits of seed production. However, Bozzano et al. [52] caution that profitability is sensitive to factors such as market access and production capacity, and that low IRRs are often linked to inefficiencies and inadequate support systems. They also argue that even below the commercial threshold IRRs may be acceptable in projects with long-term environmental value. To strengthen profitability and ensure sustainability, strategic interventions such as subsidies, training, and appropriate seed sources management are essential, especially in systems lacking economies of scale. Overall, the 7.78% IRR reflects a solid foundation for future investment, improvement, and potential scaling of tree seed production. The production of *T. grandis* seeds resulted in a positive IRR. These findings indicate that the *T. grandis* seeds production project is ionically viable.

4.4 | The CBR for *Tectona grandis* and *Pinus patula* Seeds Production

CBR provides a simple metric (benefits divided by costs) for comparing multiple small projects or when the budget is limited. The CBR remains one of the most used indicators in agriculture and forestry project planning due to its clarity in expressing returns per unit of investment [14]. CBR is particularly helpful for evaluating small-scale environmental and forestry investments, where the NPV may be modest but the returns relative to costs are high. CBR provides a comparative figure, typically with values greater than 1.0, indicating viability, and is especially useful when resources are limited or when multiple projects are competing for funding. High-yield agricultural and forestry projects with strong market demand often generate high CBRs above 1.0, even when returns are delayed [14]. According to Sinden and Thampapillai [53], although the CBR is less robust than NPV when used in isolation, it remains an excellent tool for comparing the efficiency of investment per dollar spent. The CBR above 1.0 reinforces this by demonstrating that each shilling invested yields more than one shilling in return. The study by Nas [54] emphasizes the importance of applying financial indicators such as CBR, NPV, and IRR to prevent financially unsound public investments.

The seed production for *T. grandis* shows a CBR of 1.28, indicating that the project is financially feasible and potentially scalable in similar agroecological contexts, whereas the seed production for *P. patula* shows a CBR of 0.14, suggesting that the investment destroys the value. In the latter case, the PV of costs exceeds the benefits, and the CBR falls below the cost of capital, signaling underperformance. The study by Köhlin et al. [16] notes that many tree planting programs underperform due to long gestation periods, poor market access, and underestimation of recurring costs. According to Köhl et al. [36], seed production from *Pinus patula* is typically uneconomical under extensive management due to its low reproductive output, which undermines profitability indicators including CBR, NPV, and IRR. Similarly, Turnbull [55] observes that many coniferous species, including *Pinus patula*, produce irregular and low seed yields, particularly in unmanaged stands, making commercial seed production difficult to plan and sustain. This observation agrees with the study by FAO [34], which highlighted that in several developing countries, conifer seed production is not financially viable unless seed yields are artificially enhanced or supported through public funding. According to Köhlin et al. [16], many tree planting and seed production programs underperform due to long gestation periods, poor market access, and recurring operational costs that are often underestimated. Similarly, FAO [34] also notes that in several developing countries, conifer seed production is not financially sustainable unless supported through public funding or yield enhancement interventions.

As noted by Emtage and Suh [56], many small-scale forestry and seed production projects exhibit wide variations in financial viability depending on management intensity, species, and market conditions, with lower CBRs often linked to weak institutional support and poorly developed value chains. Similarly, Lillesø et al. [33] emphasize that effective tree seed supply systems must be both biologically and economically viable, and when seed pricing fails to reflect actual production costs, projects often report CBRs well below 1.0. These findings highlight the importance of accurate cost and benefit forecasting in determining the financial attractiveness of seed ventures. Therefore, a CBR of 1.28 signals strong investment potential, while a 0.14 ratio necessitates a critical review of cost structures, production models, and market price dynamics.

4.5 | Seeds Production Costs, NPV, CBR, and IRR in the Four Forest Plantation Seed Sources

The minor differences in the establishment and management costs of *P. patula* in North and West Kilimanjaro FP could be attributed to similar climatic conditions, cultural and silvicultural practices, as well as the use of the Taungya system through intercropping with food crops by nearby farming communities. A study conducted in Ghana by Kollert and Kleine [57] revealed that forest management through intercropping with food crops is considered a cost-reducing management intervention. The high costs of seed production in Longuza FP compared to Mtibwa FP might be due to the presence of continuous moisture of the Longuza seed stand as a result of 6 months of rainfall of 1548 mm per year starting from March to May and then September to November as indicated in Table 1. This high amount of rainfall for such a long time tends to activate more regeneration of weeds. These findings are similar to those obtained in the study conducted by Ball et al. [58], which found that the cost of seed production depends on numerous factors such as cost of labor, intensity of management, and plant spacing. Therefore, the variation of costs in different localities is expected. Costs of seed production in Longuza and Mtibwa FP were higher compared to those of North and West Kilimanjaro FP seed sources stand, and this might be attributed to the presence of continuous moisture in Longuza and Mtibwa FP (1548 − 1217 mm/year), respectively, which might activate trees growth, seed production, as well as weeds growth. This observation agrees with the study by Yaduraju [59], which postulates that an increase in rainfall would increase weed growth and its management costs and increase costs of production as well.

West and North Kilimanjaro FPs seed sources showed almost the same negative NPV, CBR, and IRR for *P. patula*. The negative NPV, CBR, and IRR might be caused by the lower seed yield and price used. The decision to adopt a certain price level by any firm

will definitely determine its profitability and survival [60]. Price is therefore the essential element in the marketing mix of any firm, business, or institution. The lower quality and quantity of seeds produced in the West and North Kilimanjaro FP could have caused a lower revenue and subsequently a negative NPV and IRR. Further evidence from Köhl et al. [36] indicates that low reproductive output in species such as *Pinus patula* under extensive management systems negatively affects profitability, contributing to poor investment indicators such as low CBR. Therefore, West and North Kilimanjaro FPs are therefore operating at a loss in the seed production business.

Both Mtibwa and Longuza FPs, which are producing *Tectona grandis* seeds, had positive NPV, a CBR greater than 1, and an IRR higher than the discount rate. Longuza FP had a higher NPV and IRR, probably due to the high yield of seed produced per hectare, which averaged to about 993 kg/ha, unlike the Mtibwa FP, which had an average yield of about 793 kg/ha. The difference in yield could have a significant implication for the final NPV and IRR if the operational cost is the same. The IRR for Longuza and Mtibwa FPs exceeds the chosen discount rate of 5%, and thus the investment is considered profitable. For instance, the tree seed production for Longuza FP has an IRR of 7.8% compared to a discount rate of 5%, which implies a positive return margin of 2.8%, making it economically sound. According to Gittinger [14], IRR helps determine whether a project is financially viable by showing the effective yield on invested capital. Boardman et al. [18] explain that IRR offers a direct benchmark for profitability, and projects with IRRs significantly higher than the cost of capital should be prioritized. In the forestry sector, where long-term investments such as seed orchards are common, a high IRR confirms their financial sustainability and justifies initial capital outlays [33]. Brent [61] points out that IRR provides a clear percentage-based metric that allows ranking and comparison of multiple investment options. When IRR is used alongside CBR, they together present a robust and complementary assessment of a project's profitability and investment potential. The positive NPV and IRR values obtained for both Mtibwa and Longuza FPs imply that seeds production projects are viable and profitable.

4.6 | Sensitivity Analysis

The economic viability of tree seed production for *Pinus patula and Tectona grandis* is significantly based on both their revenue-generating capacity and sensitivity to discount rates.

For *Pinus patula*, the results are financially discouraging across all discount rates. At a 5% discount rate, the discounted cost is TZS 4,306,048/ = , while the discounted revenue is only TZS 617,048/ = , resulting in a negative NPV of TZS −3,689,000/ = and a CBR of 0.14. This indicates that for every 1 TZS invested, the project returns only TZS 0.14 in value, which is well below the breakeven threshold of 1. As the discount rate increases to 10% and 15%, the financial performance worsens, with the NPV becoming more negative (TZS − 2.76 million and TZS − 2.04 million, respectively), and CBR dropping to 0.09 and 0.07. These results highlight that the *Pinus patula* seed production is economically unviable, largely due to low seed yield or pricing and high production costs. The project destroys value under all standard evaluation metrics, making it unsuitable for scaling or investment without substantial improvement in productivity or price support.

In contrast, the *Tectona grandis* seed production demonstrates strong economic performance at the baseline 5% discount rate. With discounted revenue of TZS 7,859,276 and a discounted cost of TZS 4,633,774, the project yields a positive NPV of TZS 3,225,502 and a CBR of 1.28, confirming that the investment is profitable and worth replicating in similar ecological and market contexts. However, the sensitivity analysis reveals that this profitability erodes quickly with higher discount rates. At 10%, the NPV drops to TZS −1,586,704 and CBR falls to 0.66, indicating that future benefits are not enough to justify the investment at higher opportunity costs. At 15%, the project becomes deeply unviable, with NPV plunging to TZS −3,408,276 and CBR dropping to 0.26. These findings underline that while the *Tectona grandis* is economically promising, it remains highly sensitive to discount rate assumptions and would benefit from strategies that reduce upfront costs or bring forward revenue generation. Overall, these contrasting cases illustrate the importance of species selection, seed yield, market pricing, and appropriate management practices in determining the financial success of tree seed production ventures.

5 | Conclusions and Recommendations

It is evident that weeding activities constitute the highest costs in the production of both *T. grandis* and *P. patula* seeds. *Pinus patula* seeds production showed a negative NPV, CBR, and IRR, which was triggered by its yield, quality, and price. Both North Kilimanjaro and West Kilimanjaro FPs had negative NPV, CBR, and IRR for *Pinus Patula,* indicating that they are operating at a loss. One may therefore conclude that the production of seeds for *P. Patula* is an unprofitable project not worth to invest. The production of seeds for *T. grandis,* on the other hand, had positive NPV, CBR, and IRR. The positive NPV, CBR, and IRR for *Tectona grandis* seed production in Mtibwa FP imply that, with access to capital and other extension services, investment in the production of *Tectona Grandis* seeds could be a lucrative business. Since weeding contributes significantly to the total production costs, it is crucial to control this activity in order to reduce the total production costs, hence increasing the profitability in the production of both *T. grandis* and *P. patula* seeds. It is important that the determination of the tree seeds price should take into account the seeds' production costs to ensure the sustainability of the tree seeds business in Tanzania, especially for *P. patula* seeds, which have indicated a negative NPV, CBR, and IRR. Proper management of the seed stands should be adopted to stimulate significant quantity and quality of seeds produced, hence profitability. Longuza FP should be the focus for *T. grandis* seeds' production because of its highest productivity and profitability. Future studies should focus on investigating seed production under different climate conditions to understand how variations in temperature, rainfall, and humidity affect seed yield and quality. This will help identify suitable regions and optimal growing conditions for different tree species, ultimately improving productivity and sustainability in seed production.

Funding

No funding was received for this study.

Disclosure

I Fortunate Stephen Senya, declare that this study titled "*Assessment of profitability of Tectona grandis and Pinus patula seed production from selected forest plantations,*" did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The datasets generated and/or analyzed during the study are not publicly available due to institutional restrictions but are available from the corresponding author on reasonable request.

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