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Risk Analysis of Sengon (*Falcataria moluccana* Miq.) Seedling Production Using Fault Tree Method

Analisis Risiko Produksi Bibit Sengon (Falcataria moluccana Miq.) Menggunakan Metode Fault Tree

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ABSTRACT

This research analyzed the sengon (*Falcataria moluccana* Miq.) seedling production risk and factors associated with the risks at the Research and Development Center for Forest Plant Seed Technology (BPPTPTH) Bogor. The data collection included interviews using questionnaires with 11 purposely selected respondents. This research employed the Fault Tree Analysis (FTA), a descriptive qualitative method, to analyze the seedling production risks. The results revealed two groups of risks, namely field and management production risks, that stemmed from eight primary roots. These eight primary roots included long seed storage time, far distance between the nursery and the researcher's office, lack of safety facilities, lack of employee skills, lack of employee appreciation, high frequency of employee absences for personal reasons, changes in seasons that cause changes in planting schedules, and changes in budget allocation. In addition to these eight main factors, leaf aphids and fungi attacks, including tumor rust (*karat puru*), could also increase seedling production risks.

INTISARI

Penelitian ini bertujuan untuk menganalisis risiko produksi bibit tanaman sengon (Falcataria moluccana Miq.) dan faktor-faktor yang menyebabkan kegagalannya di Balai Penelitian dan Pengembangan Teknologi Perbenihan Tanaman Hutan (BPPTPTH) Bogor. Pengumpulan data dilakukan melalui wawancara menggunakan kuesioner terhadap 11 responden yang dipilih secara purposive. Fault Tree Analysis (FTA) yang merupakan metode deskriptif kualitatif diterapkan untuk menganalisis resiko produksi benih. Hasil analisis menunjukkan bahwa terdapat dua jenis resiko, yakni resiko produksi di lapangan dan resiko manajemen produksi. Dua jenis resiko tersebut berakar dari delapan penyebab dasar yakni waktu penyimpanan benih yang terlalu lama, jarak persemaian yang jauh dari dari kantor peneliti, kurangnya fasilitas safety, kurangnya keahlian karyawan, kurangnya penghargaan kepada karyawan, tingginya frekuensi absen karyawan untuk kepentingan pribadi, adanya perubahan musim yang menyebabkan perubahan tata waktu penanaman, dan adanya perubahan anggaran pada proposal kegiatan. Selain delapan faktor utama tersebut, serangan hama kutu daun dan jamur termasuk karat puru juga dapat meningkatkan resiko produksi bibit.

Introduction

Indonesia hosts one of the most extensive forests globally, with plantation and natural forests producing approximately 43.19 million m^3 of logs (KLHK 2017). Acacia (31.13 million m^3), Dipterocapaceae (5.19 million m^3), and Sengon (3.83 million m^3) become the primary products. Java Island contributes about 5.15 million m^3 or 10.49 percent of national log production, of which 4.65 million m^3 consists of sengon, teak, mixed hardwoods, and mahogany (BPS 2018). Among these types of wood, sengon (*Falcataria moluccana* Miq) becomes widely cultivated due to its rapid growth, harvestability at approximately five years, and ability to adapt to various soil types (Setiadi et al. 2014).

Sengon possesses various advantages, making it a highly preferred wood species by the community (Putra et al. 2018). The stomata of this plant capture nitrogen from the air, converting it into ammonia, which is beneficial for plant growth. Therefore, it is suitable for reforestation programs, rehabilitation of critical lands (Aprilia 2011), and urban greening projects (Mukhlison 2013). Sengom has excellent prospects for increasing the household income of rural communities. Combining sengon with turmeric in agroforestry systems reduces fertilizer costs in turmeric production (Purnomo et al. 2018). Sengon leaves could become the raw materials for organic fertilizers (Supriyadi et al. 2015). Sengon is also suitable for fuel pellets. The fuel pellets made of sengon and coconut shells could have enhanced energy properties, including increased carbon content and calorific value and reduced pollutant levels, such as N and S (Hasna et al. 2019). Sawdust waste could become biofuel and solid fuel (Yuliati et al. 2022). Among all parts, the stem or wood has the highest economic value, particularly for wood panels and carpentry, such as for building materials, household tools, and fruit packaging. engon has a relatively long fiber than other species, resulting in tear-resistant paper (Supriyadi et al. 2015).

Wood production, including sengon, encounters various production risks. Uncontrolled risks include climate, weather, pests, and diseases, which need better management (Supriadi et al. 2020), while controllable risks include those arising from input and management aspects, such as expertise. The yield fluctuation over a specific period could result from uncontrolled risks. Between 2014 and 2018, the Sengon wood production in Indonesia fluctuated (BPS 2014, 2015, 2016, 2017, 2018). In the second quarter of 2014, the production decreased by around 35%, while in the third quarter increased by about 102%, followed by a 41% decrease in the fourth quarter. In 2015, the production experienced stagnation at the production level of 2,583,976 m^3. In 2016 and 2017, the production increased to 2,556,979 m^3 and 3,808,864 m^3, respectively.

The availability of high-quality seedlings becomes a crucial input in sengon cultivation. Typically, commercial sengon seedlings originate from seeds. The seedlings are ready to be planted in the field at four to five months, with a height of 60 to 100 cm (Krisnawati et al. 2011). Planting sengon on marginal land uses 2 x 3 m spacing or around 1,667 seedlings per ha (Achmad et al. 2012). The size of marginal lands in Indonesia reached about 14.01 million hectares in 2017 (Ministry of Environment and Forestry 2017), creating a substantial demand for sengon seedlings.

Good ready-to-plant seedlings exhibit sturdy stems, upright growth, healthy shoots, porous media, and strong roots that firmly anchor in the medium (Kurniaty & Danu 2012). In addition, healthy sengon seedlings should have no signs of pest and disease infestation on leaves, stems, branches, or roots and have a fresh appearance with no color changes on these plant parts (Naemah & Susilawati 2015). Through *Balai Penelitian dan Pengembangan Teknologi Perbenihan Tanaman Hutan* (BPPTPTH) Bogor, the government conducts research and develops sengon seedling propagation technologies to support the production of quality sengon seedlings. However, seedling production also encounters controllable and uncontrollable risks, leading to seedling damage or production failures. Moreover, the source of seeds also significantly affects the germination rate, growth, and height of the stem (Mashudi et al. 2019). The germination rate of seeds becomes crucial in highcapacity sengon seedling production (Sudomo 2012).

Disease outbreaks in the nursery become challenges in seedling production (Achmad et al. 2012). Damping-off is a common disease characterized by rotting roots' upper part hypocotyl, resulting in wilting, falling, and eventual death. Moreover, the aluminum (Al) content in the soil affected the growth of seedlings (Salim et al. 2021). Previous research suggested that sengon seedling production's primary issue was related to failure (Hakim et al. 2009; Siregar et al. 2021). Therefore, research in risk analysis is imperative to design measures that minimize failures and improve seedling production.

This research assessed the risks associated with sengon seedling production in BPPTPTH Bogor using the Fault Tree Analysis (FTA) method. FTA is a method to analyze risks using various modeling techniques and analyses, such as calculating the probability of failure (Ruijters & Stoelinga 2015). FTA could also assess the effects of failure combinations (Kabir et al. 2015) and production error analysis (Hanif et al. 2015). The FTA development was initially to identify failures within various technology systems in industry, such as transportation and energy. Over time, other research fields, including agriculture, have also employed this method (Chen et al. 2017; Gallardo et al. 2022). This research contributes to improving the seedling production system in BPPTPTH Bogor to support critical land rehabilitation and community forest development.

Methods

This research took place at the BPPTPTH in Bogor. It employed qualitative and quantitative analyses, following the methods of Nugroho et al. (2012) and Satriyo & Puspitasari (2017), to assess the risk in sengon seedling production. The data collection included interviews using questionnaires with 11 purposely selected respondents consisting of researchers and field technicians participating in seedling production activities at BPPTTPH Bogor. The interview results were quantified (in the number of votes or responses) for each fault factor to determine the fault tree. Qualitative analysis included an overview of the research location, sources of risks, and alternative risk management. Quantitative analysis used TopEvent FTA 2017 software to identify the most influential causes of production failure based on the Risk Priority Number (RPN) (Putra et al. 2015).

The FTA used a top-down approach, starting from general to more specific events. It started with determining the primary or top event and then assigning symbols to the fault tree or FTA, which become scores for quantitative analysis. Connecting each element to the primary or top event resulted in the fault tree from the top event to lower levels and up to the basic events. This fault tree became the basis for analyzing events leading to production failure, eliminating these events, and preparing improvement plans to prevent future failure (Nugroho et al. 2012). The analysis of production risk factors used the minimal cut set method to generate combinations of selected basic events and eliminate similar ones to construct the FTA of sengon seedling production. The discussion focused on the risks and determinant factors associated with seedling production.

Results and Discussion

Profile of Respondents

The respondents consisted of researchers and technicians at BPPTTPH Bogor. The researchers had working experience between three and 25 years, while the technicians were between four and 26 years old (Table 1). The interviews suggested two root causes

Table 1. Profile of Respondents

No.	Position	Total	TotalWork Experience (Year)
1.	Principal Researcher	2	25
2.	Associate Researcher	2	22-25
3.	Young Researcher	2	3-14
4.	Advanced Research Technician and Executive Engineer	1	26
5.	Research Technician and Executive Engineer	3	4-22
6.	Supervisory Research Technician and Executive Engineer	1	14
	Total	11	

leading to seedling production risks at BPPTPTH Bogor. These two root causes had connections to eight branches, consisting of several basic events. The first root cause was the disruption in the seedling production process, consisting of five branches (low-quality seeds, inadequate research equipment, hindrance in the nursery operation, poor working environment conditions, and low employee productivity). The second root cause was poor management of seedling production, consisting of three branches (sub-optimal casual workers' performance, ineffective fieldwork execution, and unexecuted research proposals).

Fault Tree Analysis

The FTA was processed manually and using Top Event FTA 2017 software when basic events became too complex. The production risks and the influencing factors associated with sengon seedling production at BPPTPTH Bogor are as follows.

Disruptions During Production

Low-quality Seeds

The risk of low-quality seeds stemmed from unstandardized seed quality, prolonged storage, and inconsistent sources of seeds with the requirements (Figure 1). Unstandardized seed quality could exhibit traces of diseases, such as fungi infections, and physical defects, such as abnormal size or incomplete parts (Sukarman et al. 2012: Naemah & Susilawati 2015). Sengon seeds could last up to 3 years. However, prolonged seed storage could deteriorate their quality, indicated by low germination rate (Priadi & Hartati 2015). The BPPTPTH Bogor acquired sengon seeds for seedling production through the government procurement process from Cianjur, Papua, and Kediri. The BPPTPTH Bogor set the seed source requirements for each procurement proposal. However, BPPTPTH Bogor received the seeds from other sources, such as Papua or Kediri, due to the unavailability of seeds from Cianjur. The competition for sengon seeds increased due to the multiple health benefits of the seeds, including preventing hypertension and reducing cholesterol levels and uric acid.

Inadequate Research Equipment

The BPPTPTH had limited laboratory and field research equipment, some out of function, because of insufficient maintenance and excessive usage. Laboratory research equipment included measurement tools, containers, storage space, and calibration tools (maintained annually). Field research required sterilization, sowing, seedling transplanting, seedbeds, and watering equipment. Damage occurred in sterilization and watering equipment. Some types of required research equipment were unavailable (Figure 2).

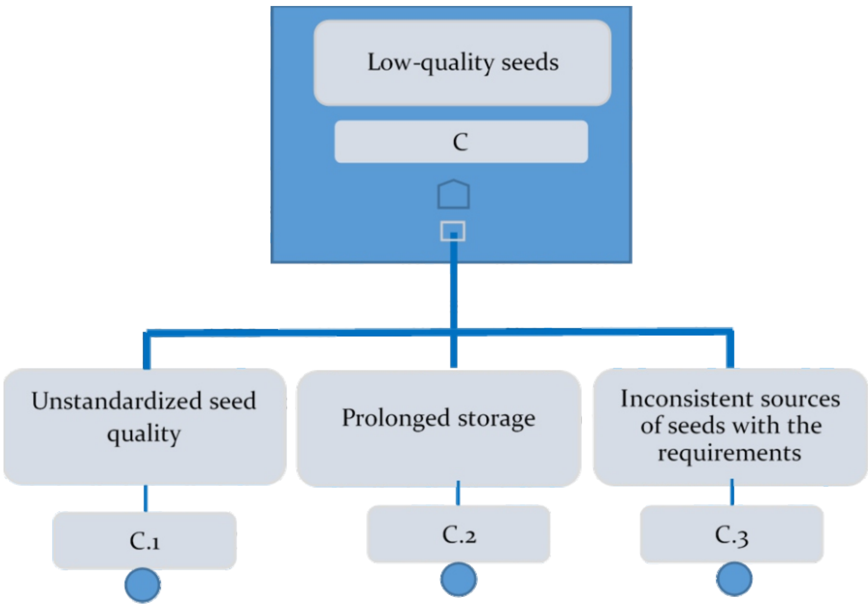

Figure 1. Factors causing the low-quality seed

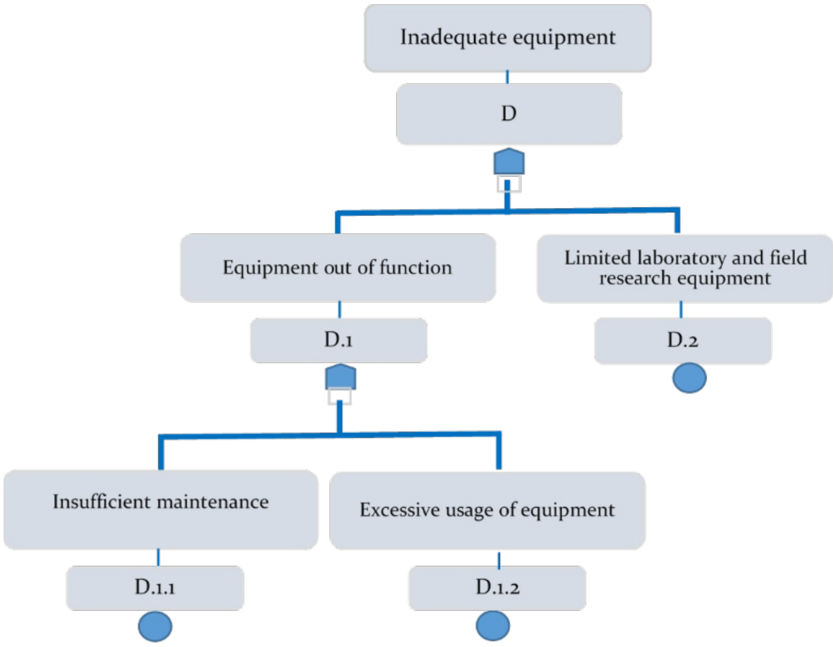

Figure 2. Factors causing the inadequate equipment

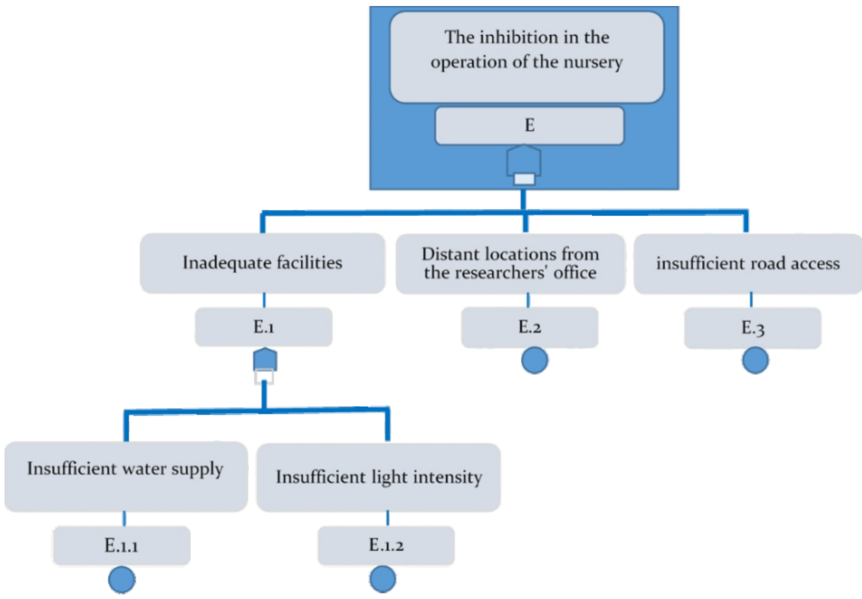

Figure 3. Factors causing the inhibition in the operation of the nursery

Hindrance in the Nursery Operation

Inadequate facilities, distant locations from the researchers' office, or insufficient road access were obstacles to nursery operations (Figure 3). The nursery facilities needed improvement due to insufficient water supply and light intensity. Tefaa et al. (2015) suggested that the ideal watering frequency was twice daily. Sengon seedlings with sufficient water exhibited taller plants, larger stems, broader leaf surface area, and longer roots. The required light intensity of the sowing beds was 75-80%, adjusted using shading nets. However, weaned seedlings in polybags needed more sunlight without shading nets for optimal growth (Prakasa et al. 2020). The distance between the research office and the nursery was approximately 5-7 km, connected by narrow roads that transversed residential areas.

Poor Working Environment Conditions

Uncomfortable workplaces, inadequate safety facilities, less synergy among employees, and uneasy relationships between employees and surrounding communities resulted in poor working conditions (Figure 4). The nursery had basic facilities, such as toilets, rest areas, and dining rooms, but they needed to meet cleanliness and completeness standards. The BPPTPTH Bogor office had no fire extinguishers (APAR) and exhaust fans. Fire extinguishers should be available in the building, placed according to procedures, and underwent regular inspections. Exhaust fans were needed to maintain room temperature (prevent stuffiness) and stabilize the oxygen supply in the workspaces. Less harmonious relationships among employees and between employees and the surrounding community were predominant in workplaces. Efforts to create synergies, such as team-building activities, family days, or celebrations of national/religious holidays, could lead to better work productivity. Disputes with the local community resulted from the mismatches between planting patterns or the layout of sengon required by the institution with those planted by the community. The working environment conditions could influence employees' performance. However, safety and health aspects received scant attention in forest management activities in Indonesia (Yovi 2019). Providing basic facilities for field workers, such as first aid equipment (P3K), clean toilets, rest areas, places of worship, dining rooms, and pantries, could stimulate their working performance.

Low Employee Productivity

Internal (lack of skills, lack of rewards, and workplace accidents) and external (accidents outside the workplace, personal problems affecting work, and employees frequently being absent for sudden reasons) factors could influence employees' productivity (Figure 5). The BPPTPTH Bogor often assigned tasks that did not match employee skills. Inexperienced casual workers were assigned tasks such as selecting healthy/sick seedlings or measuring physical/chemical parameters with specific equipment. The government gave rewards only during significant events in the form of certificates/badges

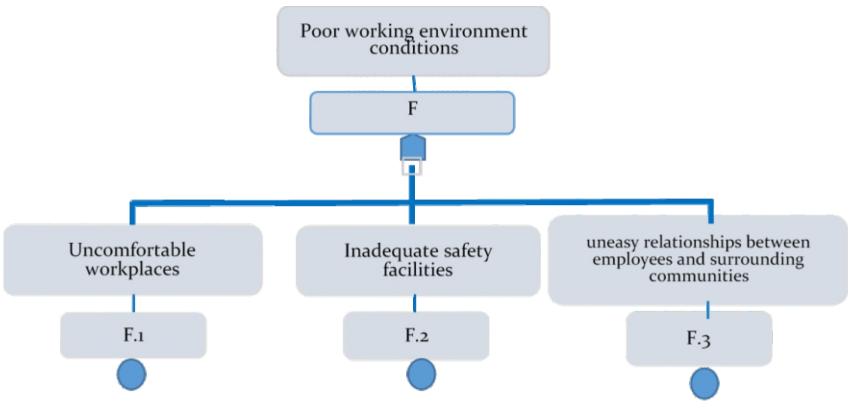

Figure 4. Factors that cause poor working environment conditions

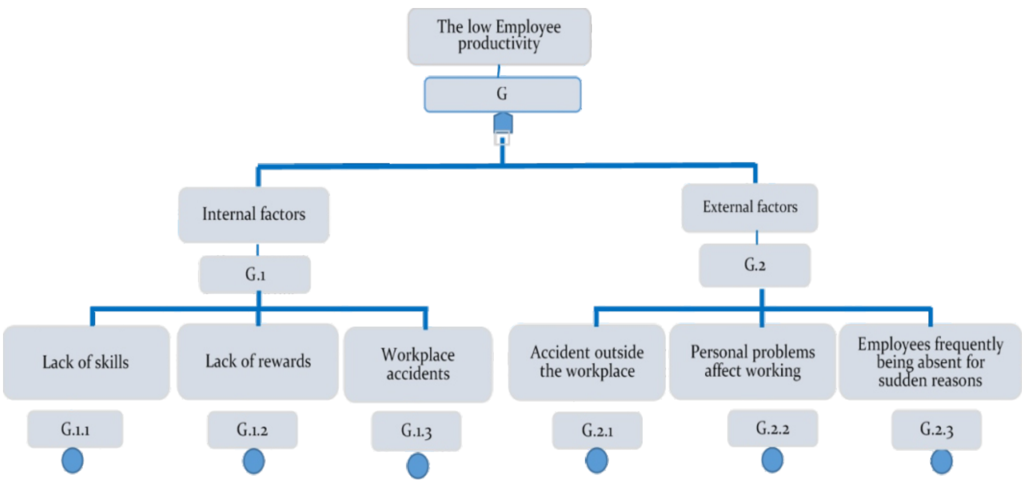

Figure 5. Factors causing the low employee productivity

signed by government institutions. However, employees also expected tangible rewards, such as bonuses or career development opportunities. The government should formulate a performance evaluation accompanied by rewards and punishments mechanisms. Workplace accidents are caused by using sharp tools, stepping on thorns, or falling from heights. Preventive measures included increasing employees' awareness of occupational safety and health (OSH) management systems and providing sufficient personal protective equipment (PPE) comprising safety shoes, helmets, aprons, safety glasses, and gloves. However, some employees also experienced traffic accidents while commuting to or from work. Moreover, personal problems, such as family concerns or issues arising at work, could influence employees' psychological conditions, reduce their focus on executing their tasks, and affect productivity. Frequent, unanticipated absences occurred when employees visited a sick family member or death. Another related issue was punctuality, with some employees resuming office at the beginning or end of working hours, affecting the seedlings' production process, which required continuous attention.

OSH management systems were mandated for businesses/organizations with 100 or more employees, as stipulated by Law No. 1 of 1970. However, workplace safety was a fundamental need for every organization because employees who felt safe and secure in their work contributed positively to output and positively impacted the company's overall performance. Casual workers at BPPTPTH Bogor also required a safe and healthy working environment. Some potential measures included providing PPE and monitoring the health of employees. The ideal condition in line with OSH aspects comprised the safety of workers during their activities and break time. For example, safety induction for new workers or external visitors entailed a proper understanding of response to hazards such as fire, earthquakes, or power outages. Providing all OSH facilities requires high costs, and leadership and commitment are needed to improve these conditions.

Employees' commitment is crucial for the success of any work, and their commitment depends on internal and external factors around them (Ingarianti 2017). Personality, job satisfaction, organizational commitment, and work experience are internal factors. On the other hand, external factors include perceptions of retirement and workplace threats, incentives offered by the organization, expected contributions, promotion opportunities, and rewards.

Poor Management

Sub-optimal Casual Workers' Performance

Casual workers assisted the sengon seedling production in the nursery. However, they earned low daily rates and lacked skills (Figure 6). Their daily wage rates ranged from IDR 50,000 to IDR 75,000, depending on the work performed. Watering the seedlings in the morning and evening according to procedures became one of their tasks. Irregular

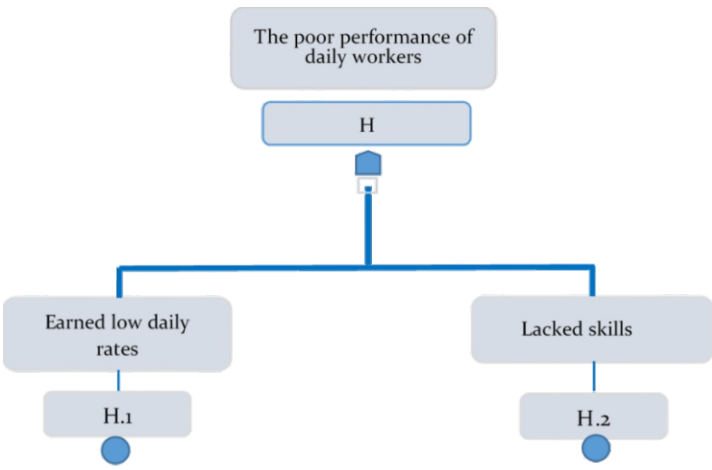

Figure 6. Factors causing the poor performance of daily workers

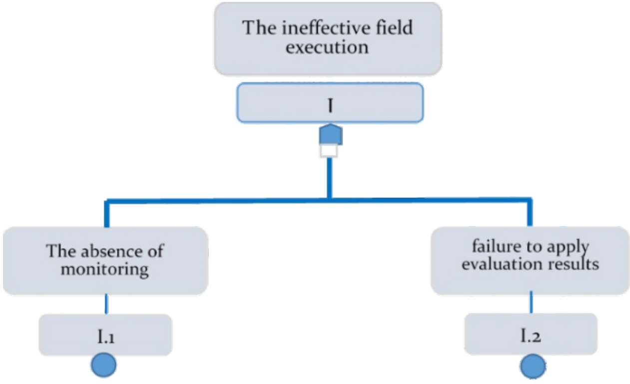

Figure 7. Factors causing the ineffective field execution

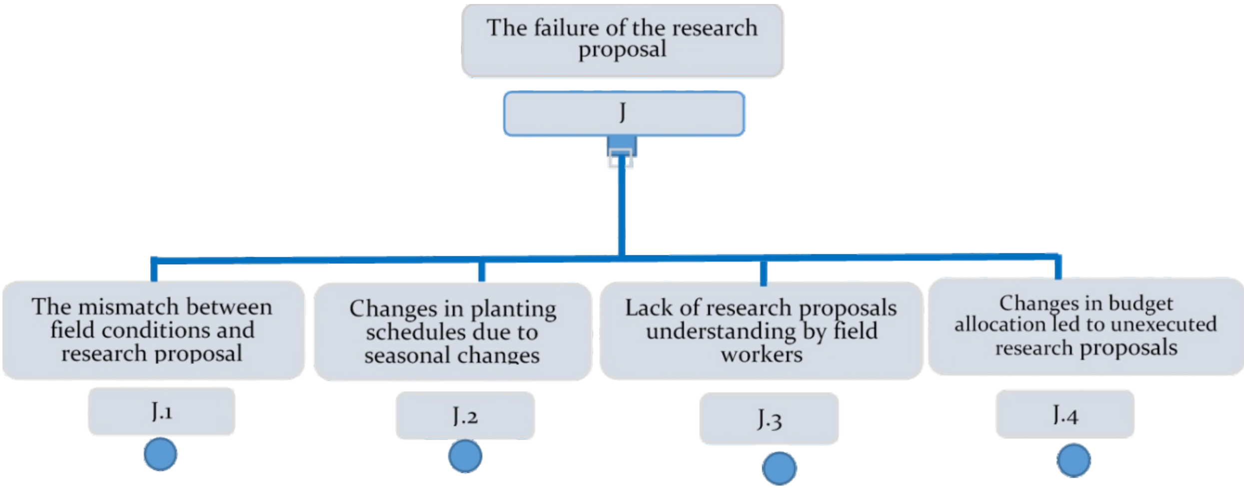

Figure 8. Factors causing the failure of the research proposal

intervals and inappropriate amounts of water could affect the growth. Anggraini et al. (2015) revealed that the volume and interval of watering influenced the physiological behavior and growth of black locust seedlings. The performance of casual workers could improve with training and regular supervision.

Ineffective Fieldwork Execution

The absence of monitoring and failure to apply evaluation results had led to ineffective fieldwork execution (Figure 7). The BPPTPTH nursery conducted monitoring every three to five days, depending on the growth phase.

Unexecuted Research Proposals

The mismatch between field conditions and research proposal, changes in planting schedules due to seasonal changes, lack of research proposals understanding by field workers, and changes in budget allocation led to unexecuted research proposals (Figure 8). Sometimes, the seed availability could not meet the quantity of seed specified in the proposal. Consequently, the research implementation deviated from the plan. Changes in the planting schedule typically occur twice a year at the beginning of the rainy season. For example, the planting schedule might change due to unprepared or immature seedlings. The solution was to provide seedlings according to the planned schedule or maintain reserves to anticipate any damage. The BPPTPTH usually discussed research proposals before conducting research in the field. However, there might be minor misunderstandings about details not included, such as the precise timing of activities. Changes in government funding affected the budget allocation in BPPTPTH, leading to minor adjustments in the research proposal and the field research, although the objectives remain unchanged. Changes in the budget allocation might occur from one to five times in five years.

Table 2. Factors causing risk of failed sengon seedling production in BPPTPTH Bogor

No.	Event Code	Event	Total Vote
1.	C.2	Prolonged seed storage	6
2.	E.2	Distance from research office to nursery	7
3.	F.2	Inadequate safety facilities	6
4.	H.1.1	Lack of employee skill	6
5.	H.1.2	Lack of rewards or recognition for employees	7
6.	H.2.3	Frequent unscheduled absences	8
7.	J.2	Changes in planting schedules due to seasonal changes	10
8.	J.4	Changes in the budget allocation	10

Risk of Sengon Seed Production

The interviews resulted in 27 basic events, of which eight had a frequency equal to or greater than six. These eight events were the main factors causing the risk of failed seedling production at BPPTPTH Bogor (Table 2).

Risk of Pests and Diseases

The respondents also mentioned other factors associated with risk in sengon seedling production, such as attacks by leaf aphids and fungi, including *tumor rust (karat puru).* The disease attacks could occur in the sowbed, nursery, and field (Busyairi 2013).

1. Leaf Aphids
   Leaf aphids or woolly aphids (*Ferrisia virgata*) attacked sengon leaves (Figure 9). A thick, white waxy layer covered their body, and they attacked by sucking the sap from shoots and young leaves. Subsequently, the plant turned white due to the waxy layer covering the entire shoot and leaves. Sengon plants infested with leaf aphids withered, and their leaves eventually fell off (Aprilia 2011). These aphids attacked during the rainy season.

2. Fungi
   Infection by *Uromycladium tepperianum*, which caused rust disease, could occur on all parts, including shoots, branches, twigs, leaves, stems, flowers, and seeds, at various stages of growth, both in young and mature plants on the field. Stems became the most susceptible to rust disease for the juveniles in the nursery. Ganoderma could attack sengon seedlings (Herliyana et al. 2012) and cause rotting stems, leading to death. Sterilizing the growing medium could prevent fungi infestation. Fungi could spread faster during the rainy season and develop more rapidly in shaded areas than in those with direct sunlight (Corryanti & Novitasari 2015).

3. *Karat puru* or Rust Disease
   Karat puru, or rust disease, attacked sengon seedlings in the nursery (Figure 10) caused by wind, temperature, and humidity (Suharti 2019; Djam'an et al. 2018). Karat puru could spread rapidly and affect the entire plant (Syarifuddin et al. 2021) and was highly detrimental to sengon seedling producers (Azzahro et al. 2020). Spraying fungicide prepared with 200 grams of neem leaves per two liters of water reduced the

Figure 9. *Aphids (Ferissia virgata) (Nuraeni et al. 2016)*

Figure 10. Rust disease attacked *young sengon plants*
(Source: Corryanti & Novitasari 2015)

intensity of the disease. In addition, karat puru could spread through insects (Triyogo & Widiyastuti 2012), necessitating insecticide treatment.

Prevention plans to avoid failure in providing high-quality sengon seedlings include optimizing nursery conditions. Seedlings with growing leaves needed a controlled environment to prevent fungi or insect attacks. Untreated fungi-attacked plants might develop rust disease in all parts of the plants, causing wilting and death. This research revealed that two factors influenced the failure of sengon seedling production: disruptions during the production process and management aspects. Good sowing practices, consistent planting and caring for seedlings according to procedures, and preventing and treating pest and disease attacks could minimize the failure. Improvements in the management aspect included the workers' commitments, regular supervision, infrastructures, and OSH facilities. However, several factors were uncontrollable, such as changes in seasons/weather and the scarcity of seed due to changing demand trends for other purposes. Moreover, unused marginal lands remained significantly extensive and needed rehabilitation. Sengon became one of the species suitable for regreening those marginal lands. Therefore, efforts to provide high-quality sengon seedlings should continue through research and commercial production by the broader community.

Conclusion

In conclusion, the BPPTPTH Bogor encountered two root causes of sengon seedling production. The first was the disruption in the seedling production process, and the second needed good management, which stemmed from eight branches and 27 basic events. The disruption in the seedling production process consisted of five branches (low-quality seeds, inadequate research equipment, hindrance in the nursery operation, poor working environment conditions, and low employee productivity). The management of seedling production consisted of three branches (sub-optimal casual workers' performance, ineffective fieldwork execution, and unexecuted research proposals). The most influential factors were changes in the planting schedule due to seasons, adjustments in budget allocations, and frequent absenteeism of employees. External factors also contributed to the risks, such as leaf aphids, fungi attacks, and rust disease outbreaks. Addressing those root causes could reduce the failure risk in sengon seedling production at BPPTPTH Bogor.

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