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Research Paper

Optimization of Supply Superior Oil Palm Seeds Using Artificial Pollination to Support Sustainable Palm Plantations

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Abstract
Seeds as planting material play an important role in agricultural development. The length of seed germination is an obstacle to meeting the high demand for oil palm seeds. This research determines the effect of pollen variety and dosage on the production of superior oil palm seeds. The study used a factorial Randomized Block Design (RAK) with two factors, namely pollen source (V1: Yangambi; V2: PPKS 540) and pollen dose (gr) (D1: 0.25; D2: 0.12; D3: 0.06; D4: 0.04; and D5: talk/blank (control). There were 10 treatment combinations (V1D1, V1D2, V1D3, V1D4, V1D5, V2D1, V2D2, V2D3, V2D4 and V2D5) so that there were 30 experimental units (oil palm trees); if they are significantly different, a further 5% DMRT test (Duncan Multiple Range Test) is carried out. The parameters observed were the number of seeds (grains), number of good and rejected seeds (grains), bunch weight (kg), and seed germination. The results showed that the Yangambi variety produced superior oil palm seeds. The V1D4 treatment showed the best results with the highest number of good seeds produced (2,302 seeds/bundle. The best results were 2,302 items. Treatments V2D2, V2D3, and V2D4 showed the best viability with the same results (81.65%. The treatments did not significantly affect bunch weight.

Keywords *dose, germination, reject, seed, variety*

INTRODUCTION

Indonesia is the largest palm oil-producing country in the world. Oil palm land in Indonesia will reach 16.38 million ha (2022) (Figure 1), with production of 46.89 million tons of CPO (crude palm oil) or vegetable oil (4.2 tons/ha/year) contributing to the country's foreign exchange of up to IDR 525 trillion in 2021 (Wahid, 2010). The advantages of the palm oil agroindustry in Indonesia are supported by the agroecosystem, innovation, and technology, as well as the population that supports the availability workforce (Yousefi et al., 2021). The increase in the number of oil palms supported by the availability of superior plant materials has made Indonesia the largest producer of palm oil in the world (Ministry of Agriculture, 2020).

Seeds are the determinants of success in an oil palm plantation business. The synergy between the management of superior plant materials and technical cultural treatment will provide optimal production results. Through good and correct management of oil palm plant materials, production certainty can be guaranteed. Through technical culture treatment according to standards, all plant material potential can be obtained. To support efforts to manage plant materials properly and correctly, complete information is required regarding the characteristics of plant materials and strategies for managing them.

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Figure 1. Indonesia's oil palm area

PPKS Medan has the largest market share in Indonesia as a distributor of superior palm oil seeds, up to 31.50%. Demand for Medan PPKS oil palm seeds in 2020-2022 is dominated by smallholder plantations, followed by large private and government plantations (Figure 2). The demand for seeds continues to increase but is not accompanied by the availability of productive palm oil, which is an obstacle to meeting the demand for palm seeds.

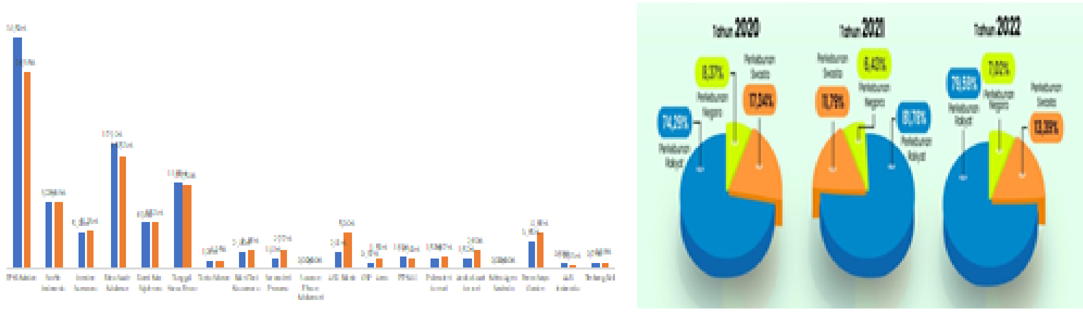

Figure 2. Market share of superior seed distribution in Indonesia 2020-2022 (A. Superior seed distributor; B. Demand for superior seed based on plantation ownership)

One way to guarantee the development of oil palm in Indonesia is to guarantee the availability of superior quality seeds. The national need for seeds is 131-163 million seeds per year, and there is a need for 200 KKS grains per hectare of planting area. Increasing germination power will have a significant effect on the number of sprouts produced. If you look at the national seed distribution data until 2023, it is 122,662,920 seeds; therefore, there is still a shortage of around 41 million seeds (Table 1. The increase in oil palm area was positively correlated with the number of sales of oil palm seeds at the national level in the previous year.

The success of industrial development and the need for land expansion cannot be separated from the availability of supporting factors, namely the availability of superior seeds from crossing the female flowers of the Dura tree (D) with the pollen of the male flowers of the Pisifera tree (P), which is based on systematic and sustainable breeding activities. Artificial pollination can be designed in such a way that is in accordance with breeding science so that the origin of the seeds can be clearly identified, which is one of the requirements for superior seeds. Effective artificial pollination is influenced by the origin of the pollen from the parent tree and the pollen dose and storage time. Therefore, it is necessary to optimize the supply of superior oil palm seeds to support sustainable oil palm plantations.

Table 1. Distribution of Indonesian oil palm seeds for the 2009-2023 period

No	Produsen	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
1	PPKS Medan	35145000	29978342	35.116.993	40260941	27760070	23461269	26925350	20.020.993	22425895	24.306.025	16900675	31.149.218	33497510	35857970	39.847715
2	Socfin Indonesia	24644000	32000000	36.388.905	47484.703	30050369	31895824	22408538	16.258.646	13595486	13.671.395	5590038	7.880.356	5804358	11288168	9.188301
3	London Sumatra	7578000	20000000	27.091.627	28026.742	19695407	6963605	10689916	7.846.847	10540645	11.201.197	5058267	5.418.125	5362748	7195199	7.884563
4	Bina Sawit Makmur	5628000	10000000	11.460.788	11352.204	9168266	6204695	10056136	7.599.528	6359621	6.688.592	4099530	11.388.255	16202175	20454012	19.477000
5	Dami Mas Sejahtera	13470000	20000000	10.486.075	16615.978	18414355	14802189	6012988	4.029.904	10499388	11.808.262	4670286	4.325.407	6748448	6559025	7.669213
6	Tunggal Yunus Estate	6600000	15000000	13.081.000	16641.444	11966795	6769058	10568856	9.775.605	6306447	7.408.808	6186699	9.337.508	12606128	16047196	16.887562
7	Tania Selatan	2000000	6000000	2.505.000	1629.490	2490564	1102770	1119942	2.165.156	1304295	808.689	780997	1.248.884	1336848	1521699	1.757688
8	Bakti Tani Nusantara	3400000	16000000	2.409.882	1950.770	3040542	2313886	1834529	1.166.342	1115200	3.288.996	1459652	2.482.686	2600538	3383178	1.319361
9	Sarana Inti Pratama	-	-	5.545.088	1288.276	2411850	3537252	3295231	2.905.245	2048768	2.288.289	1116352	1.379.788	1499046	3519987	2.489670
10	Sasaran Ehsan Mekarsari	-	-	-	780.000	3547348	775370	380300	90.000	-	6.150	41450	40.530	16300	-	165030
11	ASD-Bakrie	-	-	-	-	-	-	-	1.196.687	1515194	2.125.608	1524318	1.282.880	2555427	6151429	3.706456
13	PPPN IV	-	-	-	-	-	-	-	989.676	316028	770.289	618895	690.551	1026167	2210599	1.270247
12	GSP - Asian	-	-	-	-	-	-	-	880.305	662956	1.086.677	455219	881.084	1917985	1706366	2.260062
14	Palma Inti Lestari	-	-	-	-	-	-	-	381.500	1595522	1.146.675	1021790	1.484.880	1691725	890634	1.506084
15	Anda Sawit Lestari	-	-	-	-	-	-	-	1.588.150	1648185	1.882.956	1041459	2.011.992	1620176	287074	479862
16	Mitra Agro Semindo	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
17	Panca Surya Garden	-	-	-	-	-	-	-	-	-	-	77960	4.688.116	4096091	6126189	4.541709
18	AAR Indonesia	-	-	-	-	-	-	-	-	-	-	-	541.458	911654	500228	375745
19	Timbang Deli	-	-	-	-	-	-	-	-	-	-	-	466.881	841612	1279626	1.865862
	Nasional	102460000	148978342	144.080.378	170081.528	118511508	101826918	98297781	77.289.506	82298864	87.841.989	50808574	87.042.681	106332991	116980570	122.862180

LITERATURE REVIEW

Techniques for Artificial Pollination in Oil Palm Production

In oil palm cultivation, synthetic pollination has been considered a viable alternative to natural pollination, especially when natural pollinators are scarce or unfavorable weather exist. Research conducted by Yabani et al. (2023) and Joshua et al. (2021) indicated that effective control of artificial pollination can significantly improve fruit set and overall crop yield. The findings of these studies highlight the importance of timing, as early morning pollination at lower temperatures yields the best results due to higher pollen viability. This study emphasizes the importance of fresh pollen in achieving optimal pollination outcomes. This suggests that using fresh pollen produces better bunch weights than (Pathan et al. 2020).

Models of Optimization in Agricultural Management

To optimize crop yield and improve resource efficiency, agricultural management has extensively used optimization algorithms (Anselmi et al. 2021). Sun et al. (2024) developed an optimization model for controlling the use of fertilizer in oil palm fields. According to the study, applying optimized fertilizers can increase agricultural yield. However, because this model was limited to single-objective optimization, it could not fully account for the complexities of interdependent variables such as seed quality, bunch weight, and pollen viability. This gap in the literature emphasizes the need for a more comprehensive multi-objective optimization technique that can consider several output-influencing elements at the same time.

Data-Driven Methods and Artificial Intelligence in Agriculture

The adoption of machine learning and data-driven approaches has revolutionized agricultural processes by enabling more informed and precise decision-making (Sarker, 2021). Precision agriculture has used approaches like K-means clustering, as investigated by Li et al. (2020), to classify data based on significant attributes, allowing for targeted management operations. By using specialized pollination techniques, oil palm farmers can use clustering to find plant groups that respond to pollination conditions similarly to other conditions and increase crop yield. The application of K means clustering to determine optimal pollination conditions is a significant advancement over traditional heuristic methods, providing a more robust framework for decision making.

Crop Production: Multi-Objective Optimization

The importance of multi-objective optimization in addressing complex decision-making problems in agricultural production is growing. Unlike single-objective models, multi-objective optimization considers multiple objectives simultaneously, such as yield maximization, cost minimization, and quality improvement. Research in this area, as demonstrated by Sundaramoorthi and Dong (2022), shows that multi-objective optimization can produce outcomes that are well-balanced and suitable for various agricultural goals. This paper presents an optimization model that blends a multi-objective optimization framework with K-means clustering findings to improve current knowledge. A dynamic tool for improving oil palm pollination methods is provided by this model.

Sensitivity and Scenario Analysis in Optimization Models

Scenarios analysis is a crucial component of optimization models that allows researchers to assess several solutions under various conditions. Previous studies have shown that scenario analysis can provide important insights into the possible outcomes of different management approaches. Scenario analysis was used in this study to examine the effects of several pollination procedures, such as maximizing high-quality seeds, increasing bunch weight, and minimizing rejected seeds. This work proposes a flexible approach to decision making that can be tailored to specific needs and environmental conditions by varying the weights in the optimization formula (Pathirana et al. 2022).

Research Contribution and Gaps in Current Literature

Despite the progress achieved in agricultural operation optimization, there remains a significant gap in the application of advanced data-driven techniques to multi-objective optimization in the oil palm industry. Most existing studies focused either on the biological aspects of pollination or on specific optimization models, but they did not combine these approaches into a coherent whole. In order to close the current knowledge gap, this study proposes a novel strategy for improving the accuracy of artificial pollination techniques. The proposed strategy uses K-means clustering and a recently developed optimization formula. As a result, it provides a more comprehensive and scalable method of enhancing oil palm productivity, thus satisfying the intellectual and practical demands of modern agriculture (Sharma et al. 2020).

RESEARCH METHOD

The research was conducted at the Marihat Palm Oil Research Center (PPKS) Seed Plantation from August 2023 to January 2024. The altitude of the research location is ±369 meters above sea level (asl), at a position of 02°55' North Latitude and 99°05' East longitude. The study used a factorial Randomized Block Design (RAK) with two factors, namely pollen source (V1:Yangambi;V2:PPKS 540) and pollen dose (gr) (D1:0.25;D2:0.12;D3:0.06;D4:0.04; and D5:talk/blank (control). times so that there were 30 experimental units (oil palm trees); if they are significantly different, a further 5% DMRT test (Duncan Multiple Range Test) is carried out. Observations were made by harvesting the bunches ≥4.5-6 months after pollination. The parameter observed is the number of seeds (grains), number of good and rejected seeds (grains), bunch weight (kg), and seed germination. The research implementation followed the method of Yabani et al. (2024).

Field Preparation and Wrapping of Female Flower Bunches

The parent tree was determined by selecting a tree with female flower clusters. The flower bunches are wrapped using bagging made of terylene/agriveg, 10 days before flower anthesis or the tip of the flower sheath (spatha) is still closed with the sheath broken 25%. All frond spines were cleaned, and the base of the frond that supports the flower was sliced lengthwise. The midrib is pressed down to facilitate easy flower wrapping. The spatha (spatha) covering the flower is removed, and the flower is cleaned of rubbish and remnants of the sheath. Next, the stalks of the female flower clusters are wrapped with cotton that has been sprinkled with insecticide powder to prevent insects from entering from the direction of the bunch stalks. The pollination bag (bagging) that will be used to wrap the flowers is first sprayed with liquid insecticide (to make it sterile from insects). The bagging was covered from the top to the bottom of the bunch stalk and tied with a rubber strap in the middle of the stalk. The bagging is then coated with khalsa wire to anticipate pest attacks.

Pollination of Female Flower Clusters

Pollination of female flower clusters is an effort to pollinate anthesis of female flower clusters with pollen from compatible male flower clusters, with the aim of ensuring the legitimacy of seeds that are not contaminated with wild pollen. This pollination is carried out when the flower experiences anthesis (minimum flower anthesis of 75%). At that time, most of the stigmas had opened and were yellowish white. This pollination was carried out using pollen mixed with 4 g of pure talcum. Before pollination, bags are sprayed with liquid insecticide to repel (kill) annoying insects, including the oil palm pollinator insect (SPKS) "Elaeidobius kamerunicus". When pollinating, all equipment is sterilized using alcohol to prevent contamination.

Opening the Package

Opening of the package was carried out 15 days after pollination. Opening the package allows the flowers to develop naturally. The package is opened by opening the bagging that covers the bunch and then attaching the bunch identity label.

Harvesting

Harvesting is performed when the bunches are 4.5–6 months old. The way to harvest bunches is to cut the stalk of the bunch. The bunches are then taken to the seed preparation unit (Plant Materials Strategic Business Unit Production Division) for further processing.

FINDINGS AND DISCUSSION

Number of Rejected Seeds

A statistically significant analysis of variance can be followed by further tests (post hoc tests), one of which is the DMRT test. The goal is to identify specific treatment factors or interactions that contribute to significant differences in mean responses. Our research results show that the level of the number of female flowers that are successfully pollinated by pollinators greatly influences the number of seeds produced, considering that the viability of the pollen used is in accordance with the work instructions of the Mother Tree Division, namely >70% viability. Corley and Tinker (2003) stated that there was a negative correlation between the number of bunches and the weight of the bunch. The weight of the bunches increased as the age of the bunch increased, but the number of bunches decreased. The similarity of protein structures and molecules supports evidence that pollen sources do not influence fruit formation (Wang et al,.2018).

Figure 3. Position of fruit spikelets in the bunch

Stalks and spikelets are quite important parts in seed production. The stalk is the part where spikelets are attached and has a fairly large proportion, namely between 20%-50% of the weight of the bunch. Each spikelet part has different characteristics, including size, shape, and number of grains. The top of the bunch is the tapered part, while the bottom of the bunch is the part with the stalk cut. In general, varietal differences between seed bunches did not differ significantly; most were the same size and shape. The top of the bunch has a medium-small spikelet character with a total number of grains ranging from 18 to 26 grains with well-formed grains of 9-12 grains (50%). The middle part of the bunch has a medium-large spikelet character with a total of 28-33 grains with well-formed grains of 22-26 grains (75%). The lower part has characteristic spikelets that are large and wide but short in size. In this section, the total number of grains was between 16 and 22 grains, with the number of well-formed grains of 11-13 grains (50%).

Number of Rejected Seeds

The results of the analysis of variance indicated that pollen source, dose, or the interaction between the two did not have a statistically significant (significant) effect on the number of rejected seeds at the significance level (5%). In other words, the average number of rejected seeds in the present experiment was considered to be not significantly different. Because there is no significant effect, there is no need to perform further DMRT (Duncan Multiple Range Test) tests.α

Bunch Weight

The results of the analysis of variance above also show that pollen source, dose, or interaction between the two did not have a statistically significant (significant) effect on bunch weight at the 5% significance level. In other words, the average bunch weight in this experiment was considered to be not significantly different. Because nothing has a significant effect, there is no need to perform further DMRT (Duncan Multiple Range Test) tests.α)

Viability

A statistically significant analysis of variance can be followed by further tests (post hoc tests), one of which is the DMRT test. The goal of this study was to identify specific treatment factors or interactions that contribute to significant differences in mean responses. The results of thethe result of the DMRT test show that pollen sources are significantly different from each other. V2 has a higher average Viability than V1. The graph in Fig. 1 shows the result of the DMRT test, which shows that the V1D1 interaction is significantly different from the other 7 interactions. V1D1 also had the lowest mean viability of 80.83%. Meanwhile, the other 7 treatment interactions were not significantly different from each other.

CONCLUSIONS

The pollen dosage treatment used for artificial pollination of seed bunches has a significant effect on the number of fruit bunches but is also influenced by the health of the plant and the size of the bunches on each tree. The pollen dose treatment used for artificial pollination of seed bunches significantly affected the number of good seeds produced at the treatment level. The Yangambi variety (V1D4:0.04 grams) with the highest average yield of good seeds was 2,302 specimens, whereas the lowest yield was the PPKS 540 variety (V2D3:0.06 grams) with the highest number of good seeds produced. There were 1,068 sign items. The highest number of good seeds in the V1D3 treatment (0.06 grams) was 3,232 grains, and the lowest was V1D2 (0.12 grams) at 1,050 grains.

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