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Development of palm pool brondonal pick up tools to increase time efficiency by VDI 2221 method

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ABSTRACT
KUD aims to improve the welfare of its members through the harvesting process in Lubuk Kembang Sari, Riau. The current issue is that the collection of loose palm fruit is still conducted manually, requiring workers to bend or squat. A manual tool was previously introduced; however, the design of its scooping part is less than optimal, causing the loose fruits to be thrown upwards rather than backward into the container. The purpose of this study is to develop a loose fruit collection tool based on existing designs to improve time efficiency. The development of this palm loose fruit collection tool uses the Verein Deutscher Ingenieure (VDI) 2221 method, starting with an analysis of the shortcomings of the existing tool and identifying the farmers' desires and needs regarding specifications for a new loose fruit collection tool. The results of this study produced an innovative loose fruit collection tool capable of more efficient fruit harvesting. A comparison of collection times between manual harvesting and the new tool showed a 28% reduction in time. Further comparisons between the old and new tools indicated that the new tool could accelerate the collection process by up to 54%. User satisfaction tests showed that the new tool is easy to operate, fully automated, and provides significant improvements in operational efficiency.

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1. INTRODUCTION

The majority of residents in Riau Province rely on employment in oil palm plantations for their livelihood. The province's geographical and environmental conditions, including soil texture, are highly conducive to oil palm cultivation, supporting the extensive development of these plantations. Riau Province holds the largest area of oil palm plantations in Indonesia, spanning 3.38 million hectares, or 20.68% of the country's total plantation area, which is distributed across 26 provinces [1]. To support the numerous farmers, village cooperatives were established. Specifically, in Lubuk Kembang Sari Village, Ukui District, Pelalawan Regency, the KUD "BINA SEJAHTERA" cooperative was founded on April 1, 1990, with the aim of enhancing the welfare of local oil palm farmers. To boost plantation productivity, the cooperative offers resources such as fertilizer, agricultural tools, and facilitates the harvesting and marketing processes [2].

Pardaamean [3] proposed cultivation techniques are discussed that enhance competitiveness by optimizing plantation and factory management. The book serves as a guide for industry stakeholders in adopting practices that promote sustainability in palm oil agribusiness—a critical factor for ensuring profitability in the current challenging market landscape. A crucial component of successful palm oil production lies in effective harvesting practices. One sign that the fresh fruit bunch (FFB) is ready for harvesting is the presence of oil palm loose fruits (LF) on the ground. In order to maximize the oil content during processing, these fruits must be gathered together. LF are also present when the bunch falls to the ground during the cutting operation [4]. Harvesting fresh fruit bunches (FFB) is part of the harvesting activities on oil palm plantations since the company makes money from the sale of palm kernels and palm oil. By being mindful of the proper harvesting method and timing, palm oil can be produced as efficiently as possible [5]. During FFB cutting, palm oil fruitlets may detach from the bunches, necessitating manual collection from the ground. The initial step in collecting these loose palm oil seeds requires positioning the body by bending or squatting. The fallen palm oil pulp is then carefully collected by hand, piece by piece. For workers gathering the loose fruits, the oil palm loose fruit picker provides excellent productivity and efficiency. In addition to being affordable, these equipment may be used in any field surveillance situation without gathering undesired items like leaves, twigs, etc., which lowers the chance of a reduced oil extraction rate (OER) [6].

Previously, this issue was addressed through the design of a palm oil fruit picker tool in a thesis titled Design and Performance Test of a Palm Oil Palm Fruit Picker Tool by Davon Istighfarrahman., a student at Bogor Agricultural University [7]. The project involved the same research object and successfully developed a tool for collecting palm oil pulp. This tool demonstrated an advantage in time efficiency, reducing the average collection time to 65.30 seconds for 30 palm oil seeds spread across a 200 cm diameter around the base of oil palm trees. However, several challenges were identified during its implementation, including limited capacity, inappropriate tool dimensions, the absence of a cover leading to frequent fruit spillage, and manual operation. These issues underscore the need for further improvements. Several previous studies have been conducted that design a tool enhanced the income of oil palm farmers by improving work performance. A loose fruit-collecting machine and a roller-type oil palm loose fruit picker in Malaysia are examined, and their benefits and drawbacks are spoken about. Through the effective gathering of loose fruit, these two machine types have the potential to significantly boost industrial output [8]. The oil palm industry relies on efficient methods to collect loose fruit, which is essential for minimizing post-harvest losses and maximizing yield. The ERBRON-C machine was developed to improve the efficiency of loose fruit collection, but its ergonomic impact on operators requires further study. Research using anthropometric data and the REBA method found that operator postures during ERBRON-C use posed low to moderate ergonomic risk, with REBA scores ranging from 2 to 5. These findings emphasize the need for ongoing ergonomic evaluations to optimize the machine's safety and functionality [9]. However, the design did not account for ergonomic considerations [2]. Similarly, the previous study created a tool designed to collect loose fruit and deposit it into a container. Despite its potential, the tool faced several challenges during application, such as inefficiencies in the gutter mechanism, which hindered the proper trajectory of loose grains into the container—sometimes causing the fruit to be thrown upwards instead of backward into the shelter. Additionally, carrying the tool over long distances proved cumbersome. Another designed of a loose fruit collection tool was able to reduce collection time and labor requirements, however, the tool remained manual in operation [10].

The present research aims to refine the palm fruit picking tool by building upon the existing design and incorporating feedback from farmers to better meet their needs. This development process employs the systematic VDI 2221 method (Verein Deutscher Ingenieure 2221), a design framework that emphasizes user comfort, practicality, and ease of use [8–9]. The VDI 2221 method, a widely used engineering guideline in Germany, enhances the efficiency and organization of the product design process [8-10]. This study seeks to improve the development process by implementing a more integrated approach, making it more responsive to requirements at various project stages [12].

2. METHODS

The focus of this research is the development of a palm fruit harvesting tool following the Verein Deutscher Ingenieure (VDI) 2221 method. This study was conducted in Lubuk Kembang Sari Village, Ukui

District, Pelalawan Regency, Riau Province, and involves analyzing both existing palm oil harvesting tools and farmer preferences regarding these tools. Data collected includes time measurements for harvesting, anthropometric data, and user requirements to determine the specifications for the tool's development [9-10].

Preliminary and research questionnaires were conducted to gather relevant data. The preliminary questionnaire aimed to identify issues in the process of collecting oil palm fruit and assess the condition of existing equipment. Meanwhile, the research questionnaire focused on determining necessary improvements and aligning them with the specifications of a newly designed palm oil fruit collection tool. Additionally, the research questionnaire included a satisfaction survey for the developed tool, utilizing a Likert scale. The preliminary questionnaire was distributed to five farmers and employed an open-ended format, allowing respondents to provide unrestricted answers. The collection process time using existing tools was measured to establish a baseline for comparison with the redesigned tools. This test involved operating the tool on a tree plate with a 200 cm radius, where 30 pieces of oil palm fruit were randomly distributed. The experiment was conducted with five repetitions to ensure reliability. The height of the newly designed tool was customized based on the anthropometric data of farmers, with the overall height calculated at the 50th percentile. The width of the hand was used to design side handles for easier transportation, calculated using the 95th percentile of anthropometric data. The tool's function and structure are outlined using black box and transparent box models, as described in [14]. The black box model illustrates the stages of input, function, and output processes. Subsequently, the black box model is expanded into more detailed functions through the transparent box model. The selection of alternative materials for the tool was based on interviews with KUD leaders and farmers. From the identified alternatives, the most suitable material was chosen through questionnaires distributed to five respondents, including the KUD leader and four farmers. The results were analyzed using the Simple Additive Weighting (SAW) method and the selected material was used for the manufacturing process of the palm oil harvesting tool. The final phase of the VDI 2221 method involved the detailed design stage, which included preparing a Bill of Materials (BOM). The BOM serves as a comprehensive list for producing the palm oil harvesting tool. The picking time refers to the duration needed to complete one cycle of palm oil harvesting. Collection time is measured to assess the improvement in harvest yield when using tools compared to manual hand collection [2]. The calculation of collection time is based on a tool capacity of 10 kg, with each palm oil stalk weighing 10 g, resulting in 1,000 stalks per 10 kg.

The goal of this research is to create a tool that enhances efficiency in collecting loose palm fruits [9,12] while also prioritizing a systematic and organized design process. This approach includes developing a framework that structures design steps sequentially to ensure reliability, consistency, and foster innovation [16].

3. RESULTS AND DISCUSSION

3.1 *Planning and Explanation of Tasks*

The planning and task description stages are essential steps that outline the primary issues to address in product development[9–10]. Challenges associated with current tools for collecting loose palm oil fruits serve as the foundation for identifying potential improvements. Proposed enhancements to these existing tools are summarized in Table 1.

Table 1. Suggestions for improving the palm oil harvester picking tool

No	Current condition	Proposed Improvements
1	Still use the tool by moving it forward and backward to insert the palm oil loose	This tool is made by adding a DC motor to ensure consistency in inserting palm oil loose fruit
2	In the trajectory of the fruit being thrown into the container, sometimes the oil palm fruit leaves are thrown upwards instead of back into the container	Put a cover on the top of the picker so that the loose fruit doesn't get thrown up
3	Previous tools could only be moved by pulling and pushing	The tool can be moved by lifting it
4	The process of collecting palm oil loose fruit is still done manually	The tool working system is easy to operate so that it can be used directly by all farmers

No	Current condition	Proposed Improvements
5	Don't know the details of the tool components	Provide price analysis of tool components

3.2 *Product Design Concept*

3.2.1 Anthropometric Data

Anthropometric data is essential for supporting the product design process [14–15].

a. Calculations indicate an overall tool height of 90.2 cm.
b. Calculations specify a handle width of 10.23 cm.

3.2.2 Determine Alternative tool Development Components

The selected alternative materials will be used in the construction of palm oil harvesting tools. The determination of materials for each component is as follows:

a. For the motor component, the highest score was V1 (Dynamo), with scores of 13, 12, 15, 15, and 19 from respondents 1 through 5, respectively. Thus, the dynamo was chosen as the motor component for the palm oil harvester.
b. For the tool covering component, the highest score was V1 (Plate proportion), with scores of 22, 21, 18, 19, and 14 from respondents 1 through 5. Therefore, the plate proportion was selected as the covering component for the palm oil harvesting tool.

3.3. Form Design

The preliminary design concept for a more automated and efficient palm oil harvesting tool was developed based on an analysis of farmers' needs and suggested improvements. This new product design emphasizes dimensions such as aesthetics, functionality, and symbolism [14,16]. During the conceptualization phase, the design challenge is divided into several critical parameters [19]. The design incorporates both incremental and radical innovation, taking into account how technological advancements and evolving meanings affect user-centered design approaches [20]. The tool's operation system is user-friendly, allowing it to be used by all farmers. Ergonomic strategies and health interventions are integrated to enhance working conditions and boost productivity [21]. The tool is designed for operation in a standing position, with anthropometric data applied to improve user comfort and efficiency [22]. An illustration of the initial design for this palm oil harvesting tool is provided in Figure 1.

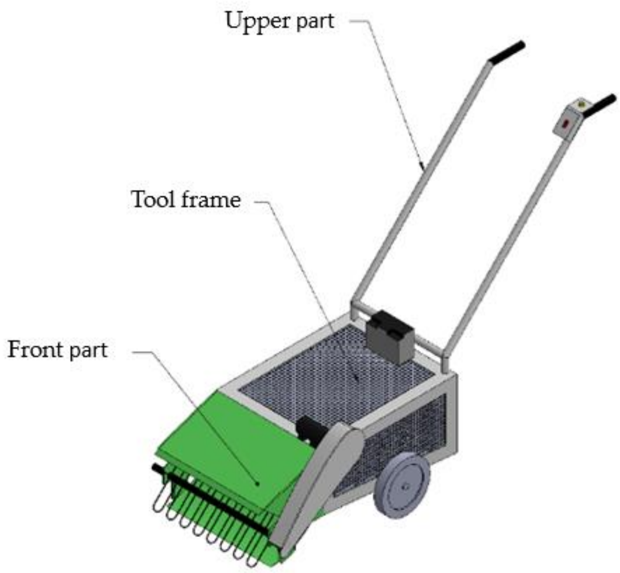

Figure 1. Initial design of oil palm fruit harvesting tool

The application of passive exoskeletons as ergonomic tools in material handling tasks can alleviate physical strain and enhance worker efficiency in industrial settings [23]. The illustration above depicts the initial design of a palm oil harvester, optimized for ergonomic suitability [24]. To assess the design's effectiveness, methods such as usability testing, user surveys, and performance analysis are employed, ensuring the design aligns with user requirements [25]. Ergonomic design principles should take a holistic approach, addressing both physical and psychological factors. Integrating these aspects into product design helps to minimize injury risks and enrich the user experience [17]. The use of anthropometric data fosters an inclusive design, enhancing user comfort, safety, and satisfaction, which can accelerate product development and reduce the need for revisions [18].

The palm oil fruit harvesting tool is composed of three primary components, including a DC motor. Detailed specifications of each component are as follows:

a. Tool Frame . Constructed from angle iron with a thickness of 4 mm, the frame is reinforced with additional purchased components, such as wheels and a DC motor, providing the durability needed to support palm oil stalks. The overall frame dimensions are 41 cm in length, 40 cm in width, and 33 cm in height.
b. Front Component. Made with iron plates and steel brackets, the front section is designed to be lightweight yet strong and stable. It measures 20 cm in length, 42 cm in width, and 35 cm in height.
c. Top Part. Serving as the control handle, the top part is designed ergonomically to ensure user comfort during operation. Its dimensions are 67 cm in length, 32 cm in width, and 91 cm in height.
d. Drive Components. This includes a DC motor and battery, where the motor converts electrical energy into mechanical power to drive the rotor's rotation. The motor operates on a 12V electrical input and achieves speeds up to 15,000 rpm, adjustable via a current control device to a range of 6,000 rpm to 48,000 rpm. DC motors are typically suited for lighter loads, sourced from battery power.

3.4. Detailed Design in Detail

The VDI 2221 methodology, a systematic approach to product development and engineering design, has been implemented in the design process of the equipment [26]. The final phase in the VDI 2221 method is the detailed design stage [18]. During this phase, a Bill of Materials (BOM) is prepared [27]. The BOM serves as a comprehensive list for manufacturing the palm oil harvesting equipment. The BOM for the palm oil harvesting tool is presented in Figure 2.

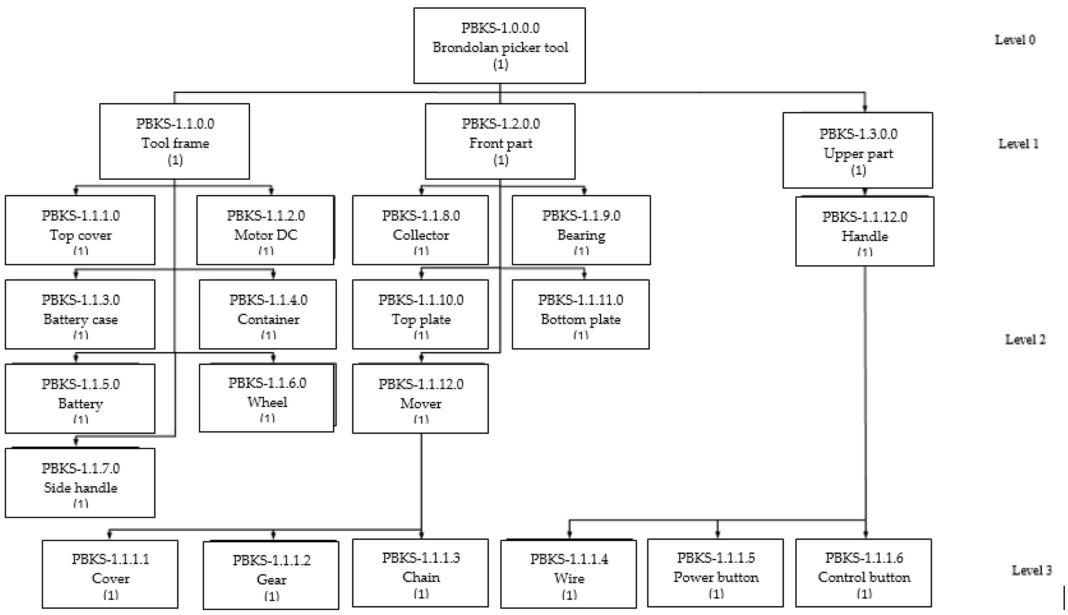

Figure 2. Bill of Material

3.5. Tool Testing

Tool testing is the process of evaluating and assessing a tool or device to ensure that it functions according to its design objectives, meets the specified requirements, and delivers optimal performance. This testing is conducted to identify any shortcomings, ensure reliability, and improve the efficiency of the tool before it is widely used or mass-produced [28].

a. Measurement of palm oil harvest time.

A comparison of collection times is shown in Table 2.

Table 2. Comparison of picking times for 10 kg of palm oil loose fruit

No	Time to collect 30 palm oil bunches			Time to collect 10 kg of oil palm fruit		
	Manual picking time (second)	Long tool collection time (second)	New equipment collection time (second)	Manual picking time (second)	Long tool collection time (second)	New equipment collection time (second)
1	40,00	71,00	32,66	22,22	39,44	18,14
2	37,51	63,15	28,00	20,84	35,08	15,56
3	51,36	59,80	30,21	28,53	33,22	16,78
4	43,00	67,31	31,67	23,89	37,39	17,59
5	35,78	65,24	27,24	19,88	36,24	15,13
Average	33,53	65,30	29,96	23,07	36,28	16,64

The average time to manually pick 10 kg of palm oil fruit is 23.07 seconds, with variations across the five trials. The time ranges from 19.88 seconds to 28.53 seconds.This method represents the baseline for comparison, as it relies entirely on human labor and effort.The long tool collection method requires more time than manual picking, with an average of 36.28 seconds. This method ranges from 33.22 seconds to 39.44 seconds across trials.The use of a long tool appears to be more time-consuming than manual picking, possibly due to its size, weight, or the need for more effort from the user.The new equipment significantly reduces the time required to collect 10 kg of loose fruit. The average time is 16.64 seconds, ranging from 15.13 seconds to 18.14 seconds. The new equipment provides substantial time savings, with the most significant improvement seen in the collection of loose fruit. It reduces the time required by more than half compared to the long tool method (54% improvement), making it a highly efficient solution for harvesting palm oil.These improvements indicate that the new equipment can increase productivity by reducing the amount of time spent per harvest, allowing workers to collect more fruit in less time.The variation in times across the different methods is relatively low for the new equipment, suggesting that it provides consistent performance. The long tool and manual methods show more variation, possibly due to differences in user effort or tool handling.Table 2 illustrates that the new equipment offers a significant improvement in harvesting efficiency for palm oil, reducing the time required for fruit collection by over 50%. This suggests that the new tool not only improves productivity but also offers greater consistency, making it a valuable asset for workers in the palm oil industry.

b. Cost Used

Production cost analysis involves identifying, calculating, and evaluating the expenses associated with manufacturing palm oil harvesting tools [3]. The production of this harvesting tool was conducted independently in Lubuk Kembang Sari Village, Ukui, Pelalawan, Riau. These costs include expenditures for raw materials and labor. A detailed list of tools used in constructing the palm oil harvester is provided in Table 3.

Table 3. Details of component and material costs

No	Item Name	Amount	Unit	Unit (price)	Total price(rp)
Raw material costs					
1	Angle iron 40 x 40 mm	4	Meters	20.000	80.000
2	Iron plate 2 mm	1	Piece	294.000	294.000
3	Iron begel 2 mm	1	Piece	44.000	44.000

No	Item Name	Amount	Unit	Unit (price)	Total price(rp)
4	Besi begel	1	Piece	40.500	40.500
5	Galvanized pipe	1	Piece	26.100	26.100
6	DC motors	1	Piece	210.000	210.000
7	Wheel	2	Pieces	85.000	16.000
8	Bearing	2	Pieces	3.500	7.000
9	Chain	1	Piece	21.000	21.000
10	Cable 1 m	1	Piece	42.000	42.000
11	Power button	1	Piece	45.000	45.000
12	Current control button	1	Piece	23.000	23.000
13	Handgrib	1	Pair	30.000	30.000
Service fees					
14	One person welding service	7	Day	50.000	350.000
		Amount			1.228.600

3.6. Test the satisfaction Level

User perceptions of the reliability and credibility of reviews play a significant role in their satisfaction levels, which ultimately affect purchasing decisions [29]. The results of the satisfaction level survey are displayed in Table 4

Table 4. Results of the new tool satisfaction level questionnaire

Current condition	Likert Scale	Proposed Improvements
Automatic	5	5 means that most respondents agree that the tool is automatic
Citation consistency	4,8	4.8 means that the majority of respondents agree that the tool is consistent in picking up palm oil stalks
Easy to move tools	3,8	3.8 means that most respondents agree that the tool is easy to move
Affordable prices	4,8	4.8 means that most respondents agree that prices are affordable
Easy to operate	5	5 means that most respondents agree that the tool is easy to operate

3.7. Comparison of previous tool designs with existing tools

The tool is equipped with a DC motor with adjustable rotation speed, allowing users to work faster and more efficiently. Moreover, the inclusion of side handles enhances the tool's mobility, particularly in challenging terrains [30]. A comparison of previous tool designs with tools that have actually been developed can be seen in Table 5.

Table 5. Real comparison of previous tools with tools that have been developed

Existing tools(6)	Tools after development
	
Has overall size Length: 120 cm Width: 40 cm Height: 100 cm The baggage capacity that can be held is 8 kg	Has overall size Length: 131 cm Width: 40 cm Height: 91 cm The capacity of loose beans that can be accommodated is 10 kg

Existing tools(6)	Tools after development
There is no cover on the top of the picker so the fruit is thrown out of the container	There is a cover at the top of the picker which functions to prevent palm oil pulp from being thrown out
The collecting part is moved by moving the tool back and forth	The collector section is driven using a DC motor with a power source from a battery whose speed can be adjusted
When carrying a tool, this can only be done by pulling or pushing the tool	There is a side handle that can help move the tool by lifting it

The newly designed tool, with dimensions of 131 cm in length, is intended to provide sufficient capacity to accommodate an additional 2 kg of palm fruit, increasing the total capacity from 8 kg to 10 kg. Unlike the previous model, the new tool features a top cover, which is expected to prevent palm fruit from spilling out, thereby eliminating scattered fruit during use. The tool is equipped with a DC motor with adjustable speed, aligning with respondents' preferences for an automatic tool. Notably, all respondents expressed this preference, as indicated by a score of 5 in the questionnaire. Additionally, the design incorporates side handles to enhance mobility, addressing feedback from respondents who requested a tool that is easier to transport.

4. CONCLUSION

The manual collection of loose palm oil fruits takes an average of 23.07 minutes, whereas using the newly developed tool reduces this time to 16.64 minutes, achieving a 28% time reduction. For loose fruit collection, the old tool required an average of 36.28 minutes, while the new tool only required 16.64 minutes, demonstrating a 54% improvement in efficiency. These findings indicate that the new tool significantly reduces collection time. The new tool can accommodate up to 10 kg of loose palm oil fruits, an improvement from the previous tool's capacity of only 8 kg. This increased capacity reduces the frequency of emptying the container during the harvesting process, thereby enhancing work efficiency.The addition of a top cover to the new tool effectively prevents palm oil fruits from being thrown out of the container during operation, reducing the risk of yield loss. The tool is equipped with a DC motor with adjustable rotation speed, allowing users to work faster and more efficiently. Moreover, the inclusion of side handles enhances the tool's mobility, particularly in challenging terrains. The new tool's design prioritizes user comfort, featuring ergonomic dimensions and automated features that reduce the need for manual labor. This makes the tool more user-friendly and improves overall productivity.

Based on the satisfaction questionnaire results, most respondents gave high scores for aspects such as automation, consistency in collecting fruits, affordability, and ease of operation. These findings demonstrate that the new tool meets the needs and expectations of users. With shorter collection times and automated features, the new tool also has the potential to reduce overall operational costs, making it a more economical solution for harvesting loose palm oil fruits.The newly developed tool provides significant advantages over the previous design in terms of efficiency, ergonomics, and user satisfaction.

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