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Time-Motion Study of Date Palm Traditional Climbing Method and Using Climbing Machine

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DATE palm tree crown operations activities in Egypt are traditionally performed by date palm owners relying on human labor These methods classified as difficult and has a high risk in terms of work safety and musculoskeletal disorders (MSD). This study aims to study the traditional climbing methods besides a comparison of comfort levels with the climbing machine. Both subjective and objective tests are conducted. Subjective tests are based on operator subjectivity complaints as seen by Nordic Body Map (NBM), whilst objective tests are based on Range of Motion (ROM), Rapid Entire Body Assessment (REBA), and also Motion-Time Study (MTS) which done to indicate specific engineering parameters that evaluate targeted climbing methods. (NBM) score was 86 which considered as high degree of risk, most of (ROM) measurements were in the alert zone, (REBA) assessment score ranged between 6 and 12 which considered as medium to very high risk. Work Study (MTS) illustrated in a sequence flowchart and indicated that traditional climbing and coming down time was higher than mechanical method by 21 and 87 seconds when using mechanical forward speed of 20 and 30 cm/sec respectively. Also mechanical savings in time and increase in output when using speed of 30 cm/sec were 39.37% and 65.74 % respectively. Finally, all tests results indicate that employing a portable date palm climbing device reduces the operator's risk than traditional climbing does, improves and develop the climbing process or ergonomics, and achieve the advantages of mechanizing operations implementation.

Keywords: Motion-Time Study; ROM; NBM; REBA; Ergonomics; Climbing machine; Machine learning; K-means clustering.

1. Introduction

Egyptian date palm production is 18 % of the world and 24% of Arab country date palm production with more than 16 million date palm tree. Date palm tree height up to 35 meters high. (SIS, 2023).

The height of Date palm tree affects how it is served; low date palm tree can be served by hand while the taller one must be served by climbing it. Climbing Date palm tree traditionally carries high risk, especially date palm tree which are climbed to a height more than 10 meters. The job of climbing Date palm is in the category of heavy work and high risk because it can be a risk of muscle injuries and even falls. Traditional harvesting practices may lead to issues with worker health and safety. (Dhafir et al., 2024).

Therefore a date palm climbing machines have been designed that can climb palm tree with or without workers to climb, for the convenience of the users, it can be operated by non-expert climbers.

The use of a date palm climbing machine has been proven to facilitate operators in date palm serving, In addition, it outperforms traditional climbing in terms of performance testing and worker safety.

Therefore, in order to ascertain the postural load and ergonomic concerns related to date palm climbing, as well as the danger of Musculoskeletal Disorder (MSD) and operator fatigue, it is important to examine the motion and posture of the operator during the traditional operation. (Harcombe et al., 2014).

Anthropometric data is critically significant when utilized as a foundational reference for the design of

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tools, equipment, and operational procedures. A notable methodology for identifying issues associated with Musculoskeletal Disorders (MSD) is the Nordic Body Map (NBM). Utilizing the NBM enables the identification of muscular regions that report discomfort, which may vary from minimal discomfort (slight pain) to severe pain levels (Setyanto et al., 2015). The employed NBM consists of a questionnaire that incorporates 28 elements pertaining to body part complaints, categorized into four levels of discomfort (no pain, mild, moderate, and severe). Subsequently, the subjective perceptions of the operator were examined to ascertain which body regions reported the highest incidence of MSD complaints in connection with activities involving the climbing of date palm trees.

The Nordic Body Map (NBM) serves as a methodological instrument for the collection of complaints pertaining to Musculoskeletal Disorders (MSD) (Sofyan and Amir, 2019). Nonetheless, it is imperative to note that NBM cannot be employed as a definitive clinical diagnosis, as it is inherently subjective and relies predominantly on the individual's perception rather than established health diagnostic criteria (Suriyatmini, 2010).

(Nasir et al. 2015) elucidated that the initial stage of the process entails the identification of the specific anatomical regions of the workforce that frequently experience complaints. This stage employs the Nordic Body Map questionnaire, which is disseminated among employees during each operational shift. Through the utilization of the Nordic Body Map, various complaints that are commonly reported by operators can be ascertained. The outcomes derived from the Nordic Body Map are documented according to the severity of the complaints, as presented in table 1. Degree of risk and improvement can be decided from table 2.

Table 1. High Request Nordic Body Map.

Degree of Pain	Score	Degree of Pain	Score
No pain	1	Pain	3
Rather pain	2	Very Pain	4

Table 2. Total score Nordic Body Map.

Score	Individual Sum score	Degree of Risk	Improvement
1	28 – 49	Low	Doesn't need improvement
2	50 – 70	Medium	Maybe need improvement
3	71 – 91	High	Need Improvement
4	92 - 112	Very High	Need Improvement as soon as Possible

Range of Motion (ROM) denotes the angular displacement achievable at the joints of a typical human being across all anatomical segments. An increase in the extent of motion angles executed corresponds to heightened effort and an amplified risk of injury. Consequently, the operational interval data pertaining to each component was scrutinized by categorizing it into four distinct zones: namely, the comfort zone, safe zone, alert zone, and dangerous zone (Openshaw, 2006) and (Harcombe et al., 2014).

The professional environment ought to be conducive to user comfort and should be capable of accommodating their diverse requirements to the greatest extent feasible. Products developed for the workplace that take this principle into account can result in enhanced employee productivity alongside a diminished likelihood of injuries and illnesses. The human anatomy possesses an inherent range of motion (ROM); engaging in movements that fall within the appropriate ROM fosters improved blood circulation and flexibility, potentially yielding increased comfort and productivity. Notwithstanding the necessity to encourage movement, it is imperative for users to minimize repetitive motions and avoid certain extremes in their ROM over extended durations. By taking into account both ROM and repetitive motion, it becomes possible to engineer products that function within optimal parameters, thereby assisting in the reduction of fatigue and the incidence of musculoskeletal disorders.

There exist four distinct zones that an individual may encounter; Zone 0 (Green Zone) and Zone 1 (Yellow Zone) are the preferred zones for the majority of movements, exerting minimal stress on the musculature and articulations. Zone 2 (Red Zone) represents a more extreme positioning for the extremities, imposing a greater degree of strain on the musculature and articulations. Ultimately, Zone 3 (Beyond Red Zone) encompasses the most extreme positions for the extremities and should be eschewed whenever feasible, particularly during heavy lifting or repetitive activities; motion within these parameters imposes increased stress on the musculature and tendons, potentially leading to the emergence of musculoskeletal disorders. Figure 1 illustrates the range of motion (ROM) for prevalent joint movements. Table 3 delineates the numerical values corresponding to each zone.

In instances where repetitive tasks are deemed essential, the reduction of continuous movements can significantly mitigate the likelihood of sustaining injuries. There exists no definitive quantification concerning the minimum number of daily repetitions. The variables influencing repetitive tasks encompass the individual's muscular strength, the magnitude of force necessary, and the nature of the task itself. Furthermore, the diminution of the force required to execute a task will concomitantly reduce the risk of discomfort and the onset of musculoskeletal disorders.

Due to the repetitive characteristics of occupational tasks, it is imperative to ascertain the extent, frequency, and ergonomic posture with which an individual reaches for an object. Predominantly, the majority of tasks should be executed within Zones 0 and 1, as previously delineated.

Cumulative trauma disorders (CTDs) may manifest across various bodily positions. CTDs are injuries arising from repetitive motions, excessive stresses, and specific actions. The following considerations are proposed to mitigate the likelihood of these injuries; eliminate tasks necessitating rapid, highly repetitive arm movements or those that enforce sustained static postures, remain vigilant regarding pressure points where the wrist, forearm, or other bodily regions come into contact with an edge or hard surface of an object, minimize shoulder flexion and abduction, reduce the retention of weighted objects in the hands, lessen or eradicate forceful applications of significant peak exertions, and ultimately, mandate that workers engage in frequent rest periods (Openshaw, 2006) and (Harcombe et al., 2014).

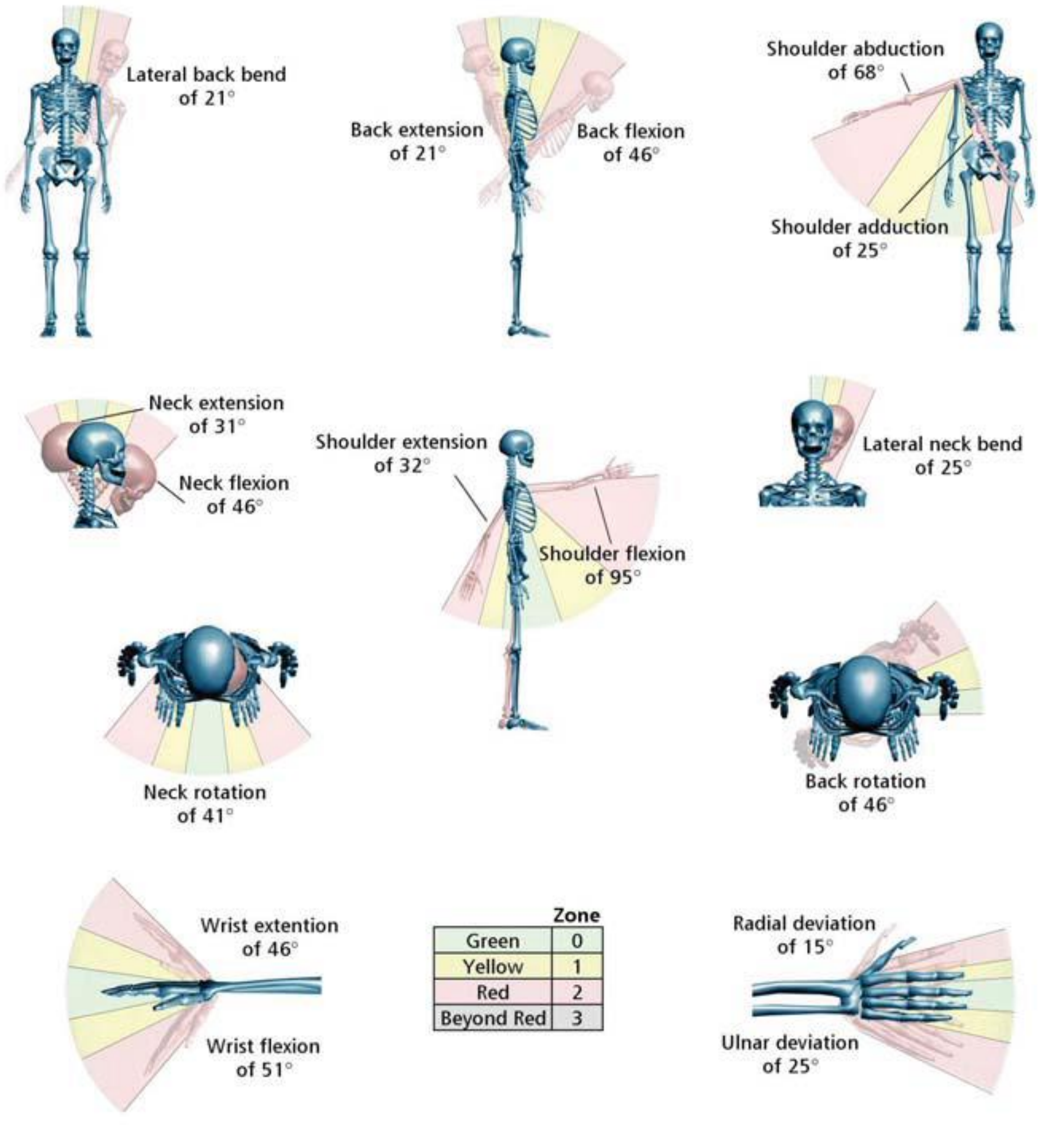


Fig. 1. Various ranges of motion for different joints.

Table 3. Range of Motion numerical values.

	Movement	Range of Motion Zones (degrees) 0	1	2	3
Wrist	Flexion	0 – 10	11 – 25	26 – 50	51+
	Extension	0 – 9	10 – 23	24 – 45	46+
	Radial Deviation	0 – 3	4 – 7	8 – 14	15+
	Ulnar Deviation	0 – 5	6 – 12	13 – 24	25+
Shoulder	Flexion	0 – 19	20 – 47	48 – 94	95+
	Extension	0 – 6	7 – 15	16 – 31	32+
	Adduction	0 – 5	6 – 12	13 – 24	25+
	Abduction	0 – 13	14 – 34	35 – 67	68+
Back	Flexion	0 – 10	11 – 25	26 – 45	46+
	Extension	0 – 5	6 – 10	11 – 20	21+
	Rotational	0 – 10	11 – 25	26 – 45	46+
	Lateral Bend	0 – 5	6 – 10	11 – 20	21+
Neck	Flexion	0 – 9	10 – 22	23 – 45	46+
	Extension	0 – 6	7 – 15	16 – 30	31+
	Rotational	0 – 8	9 – 20	21 – 40	41+
	Lateral Bend	0 – 5	6 – 12	13 – 24	25+

The REBA methodology critically evaluates occupational hazards concerning the overall postural alignment of workers. The REBA approaches are systematically divided into two distinct categories. The initial category comprises the neck, torso, and lower extremities (Score A). The subsequent category encompasses the upper arm, forearm, and wrist, which collectively constitute (Score B). The assessment of the REBA score's initial segment is contingent upon the subject's exertion in lifting weights, while the evaluation of the latter segment is based on the subject's ability to maneuver the weight with relative ease (Muhammad D, 2021) The two segments are subsequently synthesized through the REBA tabulation into a tertiary segment. The outcomes from the tertiary segment of the REBA score are integrated with the operational activity factor of the workers. The REBA score assessment employs uniform motion interval data for each work element during the Range of Motion (ROM) analysis phase. The REBA methodological worksheet, along with the assessment protocol, is illustrated in Figure 2. (Dhafir et al., 2024)

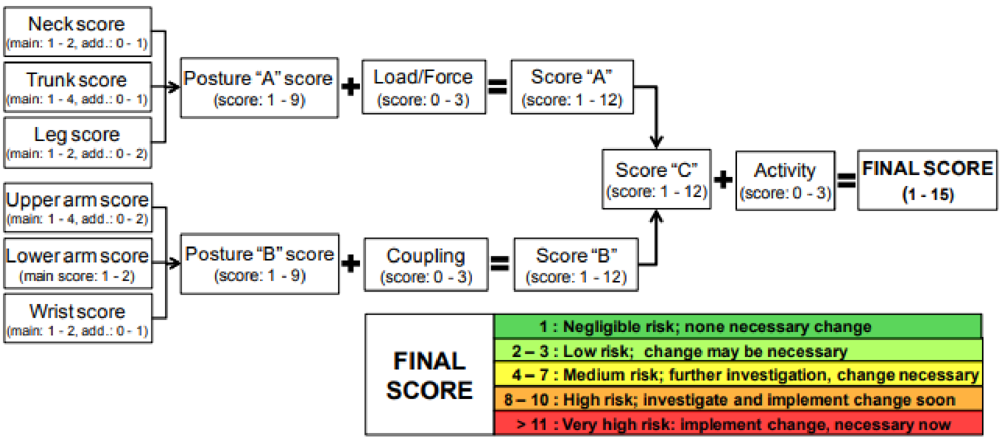


Fig. 2. REBA work procedure assessment chart.

(Barnes 1980) articulated that motion and time study constitutes a systematic examination of work systems with the objectives of (1) formulating the optimal system and methodology, typically the one associated with minimal expenditure. (2) Standardizing the aforementioned system and methodology. (3) Assessing the duration necessitated by a competent and adequately trained individual operating at a regular pace to execute a specific task or operation. (4) Facilitating the training of the worker in the optimal methodology. As evidenced by this definition, the two principal components are (A) motion study or methods design aimed at identifying the preferred approach to executing work. (B) Time study or work measurement dedicated to establishing the standard duration required to accomplish a particular task. Although elemental data, motion-time data, and work sampling are extensively employed for the formulation of time standards, it is arguably the case that the most prevalent technique for measuring work is the stop-watch time study.

(Muhammad D, 2021) referenced the work of (Barnes 1980), who articulated that motion study constitutes a specialized domain within ergonomic research, frequently employed to devise an efficient methodology, procedural framework, or operational approach, minimizing exertion to achieve maximal outcomes. Consequently, motion study can also be construed as a design of work methodologies.

(Furthermore, Syuaib 2015) conducted a comprehensive investigation into the motion and posture of manual oil palm harvesters. The findings derived from the posture evaluation utilizing the Rapid Upper Limb Assessment (RULA) methodology indicated that the occupational practices extend beyond the established safe thresholds. Concurrently, simulations of work motion yielded procedural methodologies that are capable of mitigating unsafe postures and preventing musculoskeletal disorders (MSD). (Yadaf et al. 2010) executed an empirical analysis of strength parameters pertinent to the design of manually operated agricultural machinery. The data concerning these strength parameters proved to be extremely beneficial in the formulation of equipment that ensures operator comfort, safety, and operational efficiency. Furthermore, (Toren 2001) explored the muscle activity and range of motion associated with back rotation during the operation of a tractor in a seated posture. The outcomes revealed no statistically significant variance attributable to the direction of back rotation executed. Consequently, the posture characterized by a twisted back while operating the tractor is hypothesized to represent a contributing factor to the incidence of low back pain.

(Muhammad D. 2021) articulated that the objective of this investigation is to conduct an analysis of the operational activities associated with pivot-type trailers through an ergonomic lens. The focus of the study encompassed a motion analysis aimed at identifying the safety and ergonomic risks linked to trailer operation, grounded in the natural range of motion index as well as the anthropometric compatibility of the operator. The findings regarding the subjective perceptions of the operators concerning complaints related to discomfort in the most affected anatomical regions while operating the pivot type trailer revealed that 42% of the complaints pertained to the upper limbs, while 33% were associated with the lower limbs. The overarching conclusion indicates that a series of ergonomic interventions are essential to enhance the comfort levels experienced during the operation of this specific type of trailer.

This research aims to study the traditional manual climbing method and compare the comfort levels with the climbing machine through engineering investigation to determine clear and specific values.

2 Material and methods

Data collection in date palm trees was in farm belonged to the Faculty of Agriculture, Cairo University, Egypt. Field data was collected during date palm tree harvesting seasons in August and September 2023. The climbing facilities used in this study were portable climbing rope for date palm climbers as shown in figure 3, trimming & cutting blade, handling ropes and climbing machine as shown in figure 4. Scales, tape measure, protractor, stopwatch, spreadsheet, and a 20 MP digital camera. The date palm tree used is a relatively old tree with average height of 20 meters. Several data processing and analysis software, including computer-aided design (CAD) 2016 software, Excel sheets, and video converter to jpeg.

Fig. 3. Portable rope for date palm climber.

Fig. 4. climbing machine.

2-1 Data Analysis

To avoid multiple labor problems related to scarcity and lack of the necessary experience, skill, and training in addition to the economic aspects, and also to reach the multiple advantages of applying process mechanization, in addition to improving the working conditions and environment (ergonomics). The current study was conducted through engineering investigation to determine clear and specific values that prove the aforementioned goals. So,

the target indicators are:

- Indication of the workers complaints, a questionnaire on health complaints for a sample of palm service workers via (NBM)) test. According to (Nasir et al, 2015)
- (ROM) analysis of a sample of 5 workers, then evaluating the angles obtained. According to (Openshaw, 2006).
- Evaluation using (REBA) model for a sample of 5 workers specialized in date palm climbing with age from 16 to 55 years old. According to (Muhammad D, 2021).
- Functional (motion) and time analysis of the manual operation for a sample of 7 workers with 5 iterations, then comparison with the use of a climbing mechanism. Study and analyze the common and usual traditional manual method and compare it to the proposed mechanized method, through conducting a work study, which is divided into two parts, namely (1) studying motion using photography and video recording, (2) studying time using stop watch and video recording. The operation functionally analyzes and presented in form of a process diagram (flowchart). Through that chart, the time of the steps followed in the method was recorded and analyzed.

The description of data analysis in this study is explained as follows:

Three tests (NBM, ROM, and REBA) were applied to workers with manual method and was compared with automated operations, then the situation was evaluated and the required improvement or change decisions were determined, thus recommending the best way to avoid health problems for operating workers and then improving the work environment (ergonomics).

2-2- Motion and Time Study:

To study the time, the workers were climbed the date palm trees and this climbing process was recorded as video using digital camera. The recorded video was analyzed into frames using Adobe premiere pro 2021. Operations time were calculated by frame analysis and classified into main categories.

2-3- Manual method analysis (video transcribe):

- Manual climbing study and clustering via a type of unsupervised learning (K-means clustering).

Manual climbing investigation and clustering: K-means clustering constitutes a form of unsupervised learning, which is applicable in scenarios involving unlabeled data (i.e., data that lacks specified categories or classifications). The primary objective of this algorithm is to identify clusters within the dataset, with the number of clusters denoted by the variable K. The manual climbing duration data was categorized into three distinct clusters utilizing Python version 3.11.1 and the OriginLab software 2023 (Sayed et al., 2023).

Data extraction: The participants involved in this investigation comprised seasoned Date palm tree cultivators, specifically five adult laborers who routinely engage in Date palm tree climbing activities, possessing a minimum of five years of relevant experience. The initial phase of the research encompassed field observations along with the gathering of both primary and secondary data. Field observations entailed the examination of traditional Date palm climbing methods, which involved direct ascension of the trees. The data acquired included anthropometric measurements of the operators as well as the characteristics of the Date palm trees themselves. Subsequently, data collection was conducted during the climbing procedures, which comprised both traditional climbing techniques and the utilization of a Date palm climbing apparatus. The assessment was performed by five male participants, with each individual executing three iterations of the task. Data was captured through video recordings during the climbing activities, encompassing both traditional methods and machine-assisted climbing, utilizing a digital camera for documentation. Data acquired from the operational documentation of both the date palm climbing machinery and traditional climbing methods served as the primary source of empirical evidence. In addition, the assessment of the operator's anthropometric characteristics encompassed twelve distinct body dimension parameters.

- The evaluation of the operator's anthropometric data and body mass index (BMI) was conducted in accordance with the World Health Organization (WHO) standards.

The calculation of Body Mass Index (BMI) is achieved by analyzing an individual's height and weight measurements. As per the criteria established by WHO, BMI classifications are delineated as severely underweight (BMI < 18.5), normal weight (BMI 18.5-24.9), overweight (BMI 25-29.9), and obese (BMI ≥ 30). To facilitate the computation of Body Mass Index (BMI), participants were instructed to accurately measure their height and weight. The formula for BMI is defined as body mass in kilograms divided by the square of height in meters (kg/m^2), resulting in categorization into four distinct classifications.

- The assessment of the operator's subjective experience was facilitated through a questionnaire derived from the Normative Body Model (NBM).

This questionnaire was administered to the research participants while they engaged in the activity of climbing date palm trees. The NBM questionnaire encompasses subjective grievances that the operators express during the performance of their occupational tasks.

- Measurement of joint angles and indicate (ROM), determine the range of movement of the head, trunk, wrist, and extremities (legs and hands).
- Indicate specific scenes, head angles and body joints, postural analysis (REBA) test and evaluate (Score) for both manual and automated method.
- Functional analysis of the climbing operating cycle steps (Motion Study).
- Operation times measurement (Time Study) of the climbing operating cycle steps which included effective time, necessary ineffective time, and wasted (unnecessary ineffective) time.
- Indicate the percentage of operating step time (%) out of total sequence time.
- Determine time utilization factor for effective process (harvesting process).
- $ATT = AET + AIT + AWT$ ....……………………….. Equation no. 1.

Where:
ATT: Average Total Actual Time (sec).
AET: Average effective time (sec).
AIT: Average Ineffective but Necessary Time (sec).
AWT: Average Wasted Time (ineffective and unnecessary) (sec).

- $SP = \frac{ST}{ATT} * 100$ …………………….. Equation no. 2.

Where:
SP: Percentage of operating step time (%).
ST: Average effective time (sec).
ATT: Average Total Actual Time (sec).

In addition to filming the entire process, a stopwatch was used to record the total time as well as the times of the actual operations steps, and comparing these times with the time recorded through the video, to calculate time utilization factor for the effective process (harvesting process).

$TUF = \frac{HAT}{HTT}$ …………………….. Equation no. 3.

Where:
TUF: Time Utilization Factor.
HAT: Harvesting Actual Time (sec).
HTT: Harvesting Theoretical Time (sec).

2-4- Mechanical method analysis:

The target indicators of the time analysis are:

- Value of time (min - max - average) for the whole operation and each step.
- Indicate the time of climbing and descending with three different machine forward speeds (10, 20, and 30 cm/s), then comparing with the times for the manual method.
- Indicate the percentage of operating step time (%) out of total sequence time.
- Comparison between manual and automatic capacity and performance rate.

$AC = RAT * 60 = \frac{60}{ATT}$. …………………….. Equation no. 4.

Where:
AC: Actual Capacity (palm/hour).
RAT: Reciprocal of Actual Time (palm/minute).
ATT: Average Total Actual Time (minute/palm).

$PR = AC * SP$. ……………….. Equation no. 5.

Where:
PR: Performance rate (palm/day).
AC: Actual Capacity (palm/hour).
Shift Period (hours/day).

The results of an improved method are sometimes expressed in increase in output in percent and sometimes in time saved in percent. These two percentages do not mean the same thing. The next computations may serve to clarify this point.

- Time saving rate %.

$ST = \frac{OWT - MWT}{OWT} * 100$. ……………….. Equation no. 6.

Where:
ST: Savings in time in percent (%).
OWT: Time per tree in the old way (sec/tree).
MWT: Time per tree in the modern way (sec/tree).

- Output increase rate %.

$OI = \frac{MMR - OMR}{OMR} * 100$. ……………….. Equation no. 7.

Where:
OI: Increase in output in percent (%).
MMR: Number of trees completed per minute using the modern method (tree/min).
OMR: Number of trees per minute using the old method (tree/min).

The number of trees per minute in the old fashioned way = the reciprocal of time

$MR\ (AC) = \frac{1}{AT} * 100.$ ……………….. Equation no. 8.

Where:

MR: Number of trees per minute

AT: Actual Time

- Focused Comparison of climb and descent times for manual and automatic method.
- The worker's wages and return from saving time and increasing the product.
- Calculate cost of the required workers number and number of days that needed to serve 100 palm trees. Then compare the cost of the machine and the number of work team to serve 100 palm trees.

3 Results and discussion

3-1 Labor Anthropometry and BMI

Anthropometric measurements are crucial for establishing a foundation for the design of tools, equipment, and work methodologies, thereby ensuring the maximal alignment with productivity standards. The anthropometric data pertaining to the operator is presented in table 4. The characteristics of the respondents were subjected to analysis based on various parameters including age, weight, height, select body dimensions, body mass index (BMI), years of experience, and daily labor costs.

Table 4. Operators Anthropometric.

No	Data	Operators				
		No. 1	No. 2	No.3	No.4	No.5
1	Age (years)	19	26	23	22	21
2	Weight (Kgs)	51	65	58	50	64
3	Height (cm)	165	171	169	170	168
4	Eye height (cm)	156	147	163	159	149
5	Shoulder height (cm)	140	137	142	145	138
6	Elbow height (cm)	103	104	108	100	107
7	Fingertip height (cm)	69	70	59	77	75
8	Forward fingertip reach (cm)	89	75	83	77	81
9	Forward grip reach (cm)	70	72	71	66	69
10	Shoulder breadth (cm)	46	44	45	42	44
11	Hip breadth (cm)	40	44	41	43	45
12	Chest depth (cm)	11	10	12	13	11
13	Experience (year)	5	8	6	6	6
14	Body Mass Index (BMI) (kg/m^2)	18.73	22.23	20.31	17.30	22.68
15	(BMI) status	Normal	normal	normal	underweight	normal
16	Cost (EGP/day)	200	300	250	250	250

3-2 Manual climbing study and clustering

The usual method to serve date palm crowns is by climbing palm trees manually by humans without any machine, it only depends on the rope to climb palm trees. This method is very dangerous and needs highly focused and experienced workers to climb. Time of climbing and other movements of workers who climb the palm tree were collected by designing a Questionnaire and were clustered as shown in figure 4. The date palm tree in the study had average height of 20 meters which caused a high risk of falling climbing worker from date palm tree. This made the need urgently to design a climbing machine as shown in figure 2. This machine designed to improve the performance, working environment and ergonomics, and reduce or prevent the risk of falling worker from heights.

The climbing time was divided into three clusters, as shown in figure 5a & figure 5b illustrated that from clustering data it can define that first cluster is for highly skilled and experienced workers, that average of climbing time is 1.23 min, second cluster is for mid skilled and mid experienced workers, that average of climbing time is 1.55 min, and third cluster is for low skilled and low experienced workers, that average of climbing time is 2.25 min. Which made it clear that third cluster is get more time and money in deferent date palm tree crown operation along of year.

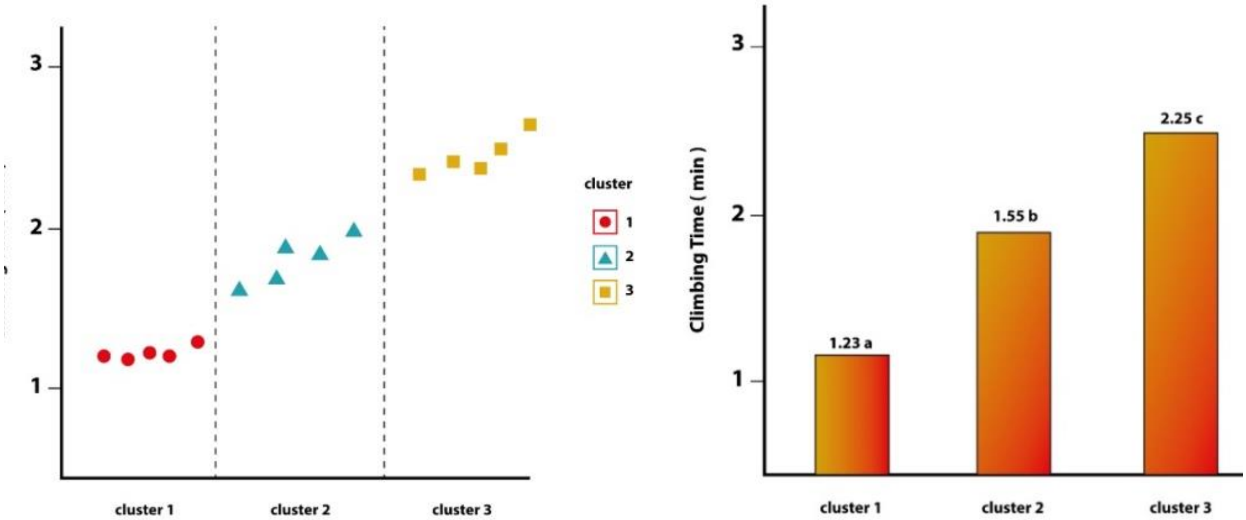
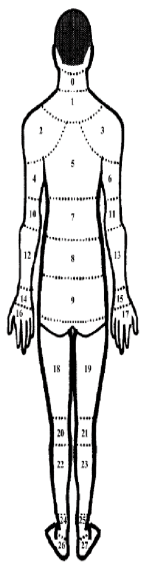


Fig. 5. Average manual climbing time by three clusters.

Table 5. Nordic result Body Map (Sample Percentage, % and Score, Point).

Musculoskeletal	**Scoring**				**NBM**	**Musculoskeletal**	**Scoring**			
	1	**2**	**3**	**4**			**1**	**2**	**3**	**4**
0. Upper Neck	0	20	0	80		1. Lower Neck	0	20	0	80
2. Left Shoulder	0	0	0	100		3. Right Shoulder	0	0	0	100
4. Upper Left Arm	0	0	0	100		5. Back	0	0	0	100
6. Upper Right Arm	0	0	0	100		7. Waist	0	0	60	40
8. Hip	0	0	20	80		9. Bottom	100	0	0	0
10. Left Elbow	0	40	60	0		11. Right Elbow	0	40	60	0
12. Lower Left Arm	0	0	20	80		13. Lower Right Arm	0	0	20	80
14. Left Wrist	0	0	80	20		15. Right Wrist	0	0	80	20
16. Left Hand	0	0	0	100		17. Right hand	0	0	0	100
18. Left Thigh	40	60	0	0		19. Right Thigh	40	60	0	0
20. Left Knee	0	80	20	0		21. Right Knee	0	80	20	0
22. Left Leg	100	0	0	0		23. Right Leg	100	0	0	0
24. Left Ankle	20	80	0	0		25. Right Ankle	20	80	0	0
26. Left Foot	0	0	0	100		27. Right Foot	0	0	0	100
Sum Score Right (Point)				**45**		**Sum Score Left (Point)**				**41**
Individual Sum Score MSDs = 45 + 41 = 86 point										

3-3 Nordic Body Map (NBM)

The Nordic Body Map (NBM) constitutes a systematic approach for eliciting reports pertaining to Musculoskeletal Disorders (MSD) (Sofyan and Amir, 2019). This methodology was operationalized through a questionnaire that encompassed complaints associated with 28 distinct anatomical regions, categorized into four gradations: absence of pain, mild discomfort, moderate pain, and severe pain. An analysis of the operators' subjective experiences was conducted to identify which anatomical regions manifested the highest frequency of MSD complaints in the context of climbing date palm trees. The resultant percentage derived from the Nordic Body Map sample is presented in table 5. The Nordic Body Map is completed in accordance with the severity of complaints as delineated in table 1. Ultimately, the assessment of risk levels and potential improvements can be ascertained based on the information provided in table 2.

NBM score was 86, according to table 2, NBM total score has medium degree of risk and improvement decision is needed. Immediate action as table 5 is needed. It is because the climbing workers' posture is bending for a long time and work carefully during climbing so that the fatigue mostly occurred in neck, shoulder, back, upper arm, hand, and foot. The recommended improvement is use the mechanical climbing method or manual labor training programs which should be based on recommended working posture and condition so that the labor that passes the training can surely have safe working posture.

3-4 Range of Motion (ROM)

Work analysis is conducted through the observation of the kinetic actions associated with the manual ascent of date palms, with particular emphasis on the range of motion (ROM) of the human body. The range of motion exhibited by the operator must be calibrated to align with the body's ROM to ensure that the movements occur within the prescribed zones. As articulated in (Openshaw, 2006). the data pertaining to the motion intervals for each component of work is systematically analyzed by categorizing it into four distinct zones. The outcomes derived from the motion analysis, in conjunction with the ROM during the manual climbing of date palms, can be graphically represented to illustrate the risk distribution of operator movements in relation to these zones. Utilizing this ROM methodology facilitates the identification of potential injuries that may arise during the operator's work-related motions. table 6 presents a summary of the sample findings from the analysis of motion intervals pertaining to the manual climbing process, both with and without the application of the ROM method.

Table 6 elucidates the propensity for cumulative motion-related risks associated with each joint segment during various work movements. In the context of manual climbing, it is established that the typical range of motion fluctuates between safe and perilous positions. Nonetheless, the predominant motion interval identified falls within the perilous zone. In contrast, the mechanical climbing process presents an average positional assessment that spans from comfortable to hazardous; conversely, when employing minimal tools for climbing, a perilous position is ascertained.

Moreover, table 6 illustrates that the cervical region during manual climbing predominantly engages in neck extension, with an angle attaining values between 30° and 70°. Furthermore, the zone of neck extension associated with manual climbing is delineated as the alert zone transitioning into the perilous zone. Similarly, concerning other body segments, specifically back flexion, the average angle observed during manual climbing is reported to be between 15° and 21°. In addition, the range of motion (ROM) analysis indicates that during manual climbing, shoulder flexion, hip flexion, and knee flexion all exhibit an angle range extending from 20° to 120°, with respective ranges of motion intervals recorded at 32° to 56°, 38° to 120°, and 20° to 111°.

Table 6. Range of motion analysis.

		Traditional/manual Date palm climbing					Mechanical climbing
		Operator 1	Operator 2	Operator 3	Operator 4	Operator 5	
NF		30	52	57	67	70	-
NE		32	15	-	-	-	7
BF		15	16	13	21	18	5
SF	R	32	42	44	52	56	29
	L	32	42	44	52	56	29
Se	R	-	-	-	-	-	-
	L	-	-	-	-	-	-
EF	R	57	92	46	70	52	67
	L	57	92	46	70	52	67
HF	R	62	38	55	58	60	-
	L	120	100	120	106	108	-
KF	R	46	20	24	70	75	-
	L	91	106	91	100	111	-

Information:

(white) = Zone 0 (comfort)	Nf = Neck flexion	Bf = Back flexion	R = Right
(green) = Zone 1 (safe)	Ne = Neck extension	Ef = Elbow flexion	L = Left
(yellow) = Zone 2 (alert)	Sf = Shoulder flexion	Hf = Hip flexion	
(red) = Zone 3 (danger)	Se =Shoulder extension	Kf = Knee flexion	

3-5 Rapid Entire Body Assessment (REBA)

Upon acquiring the motion interval data through the Range of Motion (ROM) methodology, the subsequent analysis is conducted utilizing the Rapid Entire Body Assessment (REBA) framework. Various anatomical postures incorporated in the REBA scoring evaluation encompass segments of the cervical region, torso, lower extremities, and the load magnitude. The data analysis employing the REBA technique in this investigation juxtaposed the manual climbing process with the utilization of specialized tree climbing apparatus. The manual climbing procedure is assigned a score of +2 as a result of the climber's body mass being unsupported, which exceeds 10 kg. In contrast, the climbing process utilizing specialized equipment yields a score of +0, as the climber's weight is adequately supported by the aforementioned apparatus. Furthermore, all activities receive a score of +2 for each movement executed more than four times within a minute. The outcomes derived from the REBA evaluation are presented in table 7.

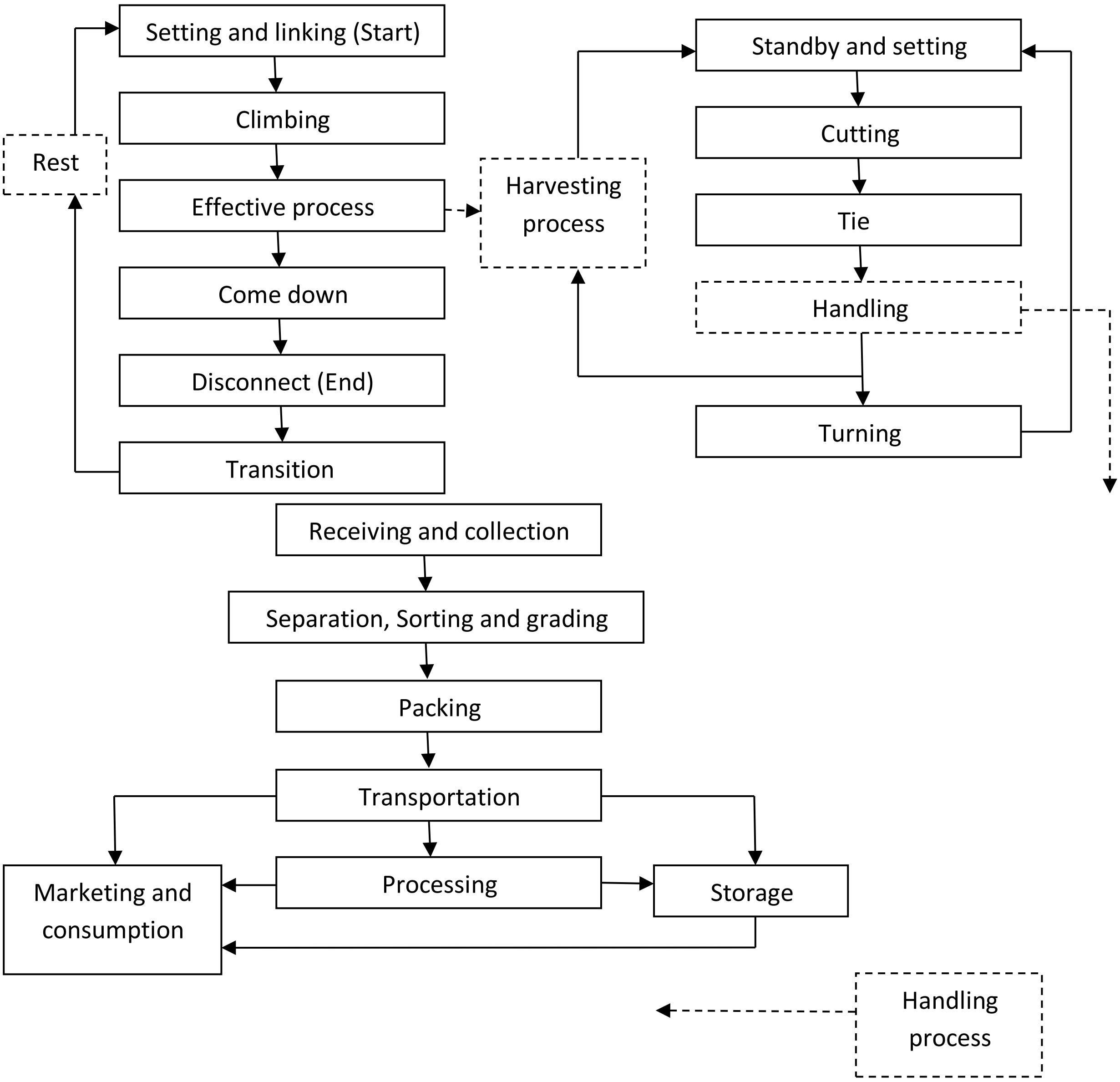
Table 7 describes the risk, the main result was the medium to very risk for work movement in manual climbing, medium risk for mechanical climbing.

Table 7. REBA assessment results.

	Traditional/manual Date palm climbing					Mechanical climbing
	Operator 1	Operator 2	Operator 3	Operator 4	Operator 5	
Neck score	**2**	**2**	**2**	**2**	**2**	**1**
Trunk score	**2**	**2**	**2**	**3**	**2**	**1**
Leg score	**3**	**3**	**3**	**4**	**4**	**2**
Upper arm score	**2**	**2**	**2**	**3**	**3**	**2**
Lower arm score	**2**	**1**	**2**	**1**	**2**	**1**
Wrist score	**2**	**2**	**2**	**2**	**2**	**1**
Posture (A) score	**3**	**3**	**3**	**6**	**4**	**2**
Posture (B) score	**3**	**2**	**3**	**4**	**5**	**1**
Load/Force	**2**	**2**	**2**	**2**	**2**	**0**
Coupling	**1**	**1**	**1**	**1**	**1**	**1**
Score (A)	**5**	**5**	**5**	**8**	**6**	**2**
Score (B)	**4**	**3**	**4**	**5**	**6**	**2**
Score (C)	**5**	**4**	**5**	**10**	**8**	**2**
Activity	**2**	**2**	**2**	**2**	**2**	**2**
FINAL SCORE	**7**	**6**	**7**	**12**	**10**	**4**
Risk	**Medium**	**Medium**	**Medium**	**Very risk**	**High risk**	**Medium**

3-6 Motion and Time Study (MTS)

Study Stages: This process is generally described in the flow chart shown in figure 6.



Climbing steps times were studied and analyzed using video recording and frames to find the net time to validate it in machine comparison with traditional date palm climbing method. Timing and observational data for both methods were recorded as shown in table 8. figure 7 shows comparison between climbing, come down, and operation total times for manual method and mechanical method with three forward speeds.

Table 8. The obtained times for manual and mechanical climbing.

	Overall working processes	**Average Time (sec/tree)**			
		Manual	**Mechanical with speed**		
			10 cm/sec	**20 cm/sec**	**30 cm/sec**
1	Setting and linking	84	84	84	84
2	**Climbing**	**109**	**200**	**100**	**66.67**
3	Effective process	492	492	492	492
4	**Come down**	**112**	**200**	**100**	**66.67**
5	Disconnect and Transition	149	149	149	149
	Σ (sec)	**946**	**1125**	**925**	**858.34**
	Σ (min)	**15.77**	**18.75**	**15.42**	**14.31**
6	Rest (sec)	120	120	120	120
	Σ (sec)	1066	1245	1045	978.34
	Σ (min)	**17.77**	**20.75**	**17.42**	**16.31**

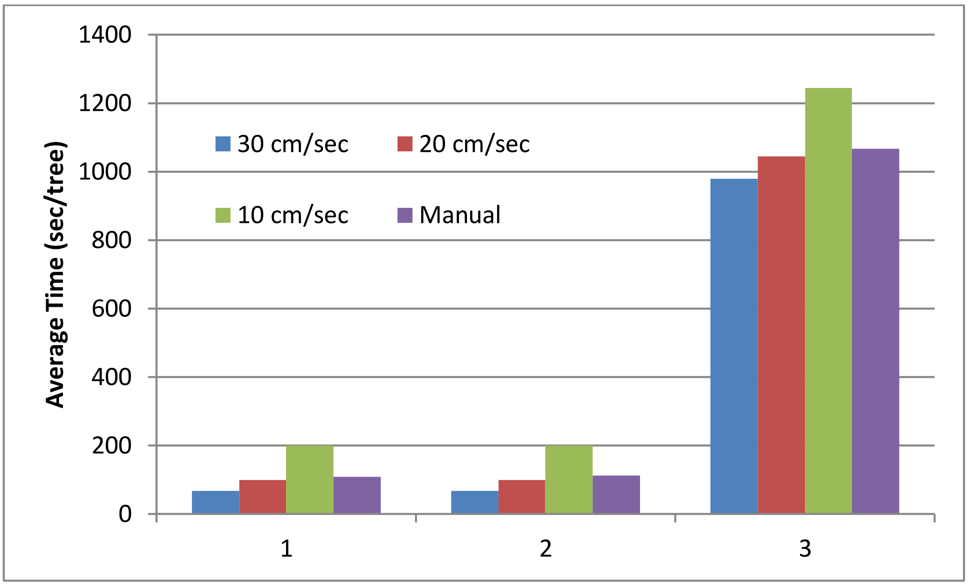


Fig. 7. Manual and mechanical climbing times, 1) Climbing, 2) Come down, and 3) Total.

The result show that time was separated into 6 main categories as shown in figure 8. First, preparing and setting time that worker getting ready to climb date palm tree by the traditional rope and it was 8 % of total time. Second, climbing time that worker climb from ground to the top of date palm crown it was 10 % of total climbing time. Third, operation time that was the main time of serving date palm crown it was 46 % of total time. Forth, down climbing that time worker take after finishing the crown serving, it takes 11 % of total time. Fifth, disconnect and transition that time worker take after come down, it takes 14%. Finally, Rest time, it takes 11% of total time. To evaluate the contribution of the major parts of the sequence, the results from table 8 were converted to percentages of sequence time as declared in figure 8 and table 9. Serving date palm crown time contributed the most (46 %) to sequence time, while climbing time was (10%) and coming down was time (11 %) to sequence time.

As for the proposed automated method, the focus was on recording the times of climbing and descending, using three different speeds (10, 20, and 30 cm/s). In the end, these times for the two methods were compared to reach the most appropriate speed that is equal to or less than the speed of manual labor and at the same time leads to improving the labor work environment (ergonomics) in a way that does not harm the quality of work or the impact on trees and their deterioration, thus achieving savings in operation time and also increasing outputs in the form of a percentage.

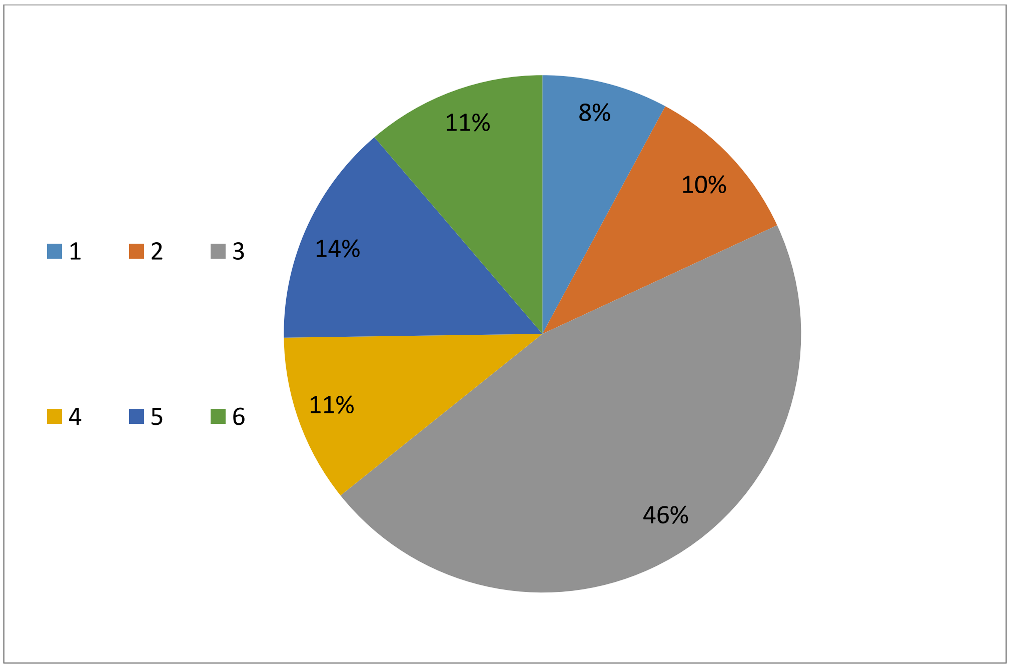


Fig. 8. Average time percentage of overall working processes.

Also, the steps followed for the targeted effective process, which is the date harvesting process, were monitored and recorded, as well as the processes required to complete the entire work until moving to the next palm tree (from the beginning of the process until its end, the functional analysis of which is explained in the form of flowchart) through recording video clips using a smart phone.

The video which recorder at a realistic rate (Rating = 1) was transcribed in order to determine the time of each work step. The average values for sample iterations of 35 service workers were as shown in table 9, which shows the average values recorded and obtained. The times were converted to percentages of the total process time and are shown in the figure 8.

Table 9. Steps time percentages to sequence time.

Overall working processes		**% From Total Time (sec/tree)**			
		Manual	**Mechanical with speed**		
			10 cm/sec	**20 cm/sec**	**30 cm/sec**
1	Setting and linking	7.88	7.88	7.88	7.88
2	**Climbing**	**10.23**	**16.06**	**9.57**	**6.81**
3	Effective process	46.15	46.15	46.15	46.15
4	**Come down**	**10.51**	**16.06**	**9.57**	**6.81**
5	Disconnect and Transition	13.98	13.98	13.98	13.98
6	Rest (sec)	11.26	11.26	11.26	11.26

In addition to filming the entire process, a stopwatch was used to record the total time as well as the times of the actual operations steps, and by comparing these times with the time recorded through the video, the time utilization coefficient for the effective process only (harvesting process) was calculated through the equation (3) and its value was 0.9 and process efficiency was 90.5 % approximately.

Timing data and observational data for effective process (harvesting process) included standby and setting, cutting, tie, handling, and turning were registries using video recording and stopwatch also. Overall sequence harvesting time was 445 and 492 seconds via video recording and stopwatch respectively. The recorded times were used to calculate the time utilization coefficient and process efficiency table 10. Observations were also made when the catcher operation was interrupted.

Table 10. Harvesting process steps time and time utilization coefficient.

Effective process (Harvesting process)		**Average Time (sec)**	
		Stopwatch	**Video**
1	**Standby and setting**		
2	**Cutting**		117
3	**Tie**		108
4	**Handling**		99
5	**Turning**		121
Σ (sec)		**492**	**445**
Lost Time		**47**	
Time utilization coefficient		**0.9**	
Process Efficiency (%)		**90.45**	
Tree height		**20**	
Package no.		**9**	

Also, the savings time percent and the increase in output percent were calculated through the equation (6) and (7), based on the climbing and comedown times only, and the results were 39.67 % and 65.74 % respectively, when using Mechanical with speed by 30 cm/sec. as shown in table 11

Table 11. Process steps time savings in time (%), and increase in output (%).

process	Average Time (sec/tree)			
	Manual	Mechanical with speed		
		10 cm/sec	20 cm/sec	30 cm/sec
Climbing	**109**	200	100	66.67
Come down	**112**	200	100	66.67
Σ (sec/tree)	**221**	**400**	**200**	**133.34**
Σ (min/tree)	**3.68**	**6.67**	**3.33**	**2.22**
Time Saving (sec/tree)		**-179**	**21**	**87.66**
Time Saving (min/tree)		**-2.98**	**0.35**	**1.46**
Time (h/100 tree)	6.14	11.11	5.56	3.70
Time Saving (h/100 tree)		**-4.97**	**0.58**	**2.44**
Savings in time(%)		**-81.00**	**9.50**	**39.67**
Increase in output (%)		**-44.75**	**10.50**	**65.74**
	(tree/min)			
	Manual	**Mechanical with speed**		
		10 cm/sec	**20 cm/sec**	**30 cm/sec**
Σ (tree/min)	**0.271**	**0.150**	**0.300**	**0.450**
Σ (tree/h)	**16.3**	**9.0**	**18.0**	**27.0**

The average time saving was also calibrated when dealing with 100 palm trees, and the result was a one working hour saved for each palm tree.

The average operating cycle time was calculated and it was 17.77 minutes/palm, including the transition and rest times (rest time actually assumed as 2 minutes/palm).

What is worth mentioning here is the following procedure: During the rest time for climbing and serving labor, the assistant worker moves and adjusts the machine at the point or position of the next palm tree. Therefore, the benefit can be maximized from this period of time.

Therefore, when working an average shift of 8 hours/day, it is possible to produce a number of palm trees amounting to 27.02 palm trees/day, using the usual manual method. When working with the proposed mechanism, the operating cycle time can be reduced to 16.31 minute/palm, and thus the daily performance rate for the same shift time (8 hours/day) is 29.44 palm/day, with an increase about 2.5 palm tree table 12. Thus, 100 palm trees can be completed when working 8 hours/day in a number of days that is...... a day using the traditional manual method and ... a day using the automated method, with the same number of work crew (which consists of 2 workers, one for climbing and service and the other is an assistant for other land operations) and thus an amount of pounds can be saved, considering that the average daily work for a climbing worker is 300 pounds/day and that of an assistant worker is 250 pounds/day.

Table 12. Process performance rate.

	Performance Rate (tree/day)			
	Manual	Mechanical with speed		
		10 cm/sec	20 cm/sec	30 cm/sec
Tree/day	**27.02**	**23.13**	**27.56**	**29.44**
Tree/h	3.38	2.89	3.44	3.68
Σ (h/tree)	0.30	0.35	0.29	0.27
Shift (hours/day)	**8**	**8**	**8**	**8**
Σ (min/tree)	**17.77**	**20.75**	**17.42**	**16.31**

4. Conclusion

The study aims and done through four tests to compare the mechanical method and the traditional manual method used to climb date palms in order to carry out service operations.

According to (Muhammad D, 2021) ergonomic interventions that can be implemented to mitigate occupational hazards simultaneously facilitate enhanced productivity, which includes the optimization of work procedures, the advancement of tool designs, and the utilization of personal protective equipment/clothing (PPE).

The recent study indicated many complaints with manual climbing method. Besides, high palm heights with increased risk of falling from heights, climbing with primitive tools, and scarcity of automation of Date palm operations in Egypt. NBM test results showed that; the sample agreed that there were many physical complaints of manual labor. In addition to accidents related to falls and slips, and then bruises and frsactures. REBA score in the process of climbing using a machine get an average score of 4 which means a moderate level of risk, it needs investigation and change. Whereas in manual climbing the average score is 10-12 which means a very high level of risk and the operator's posture needs to be changed immediately that require current intervention towards changing the procedures followed or the entire method. Through the study of the work that includes functional analysis (motion and time), the comparison between the traditional method and the automated method showed the superiority of the automated method, which in turn improves the work environment for the work team by modifying the conditions towards the comfortable range and also reduces the operating period, which in turn reduces the possibility of the continuation of unhealthy and uncomfortable conditions for the workers and reduces the risk of health problems or accidents and ultimately increases the quantity and quality of productivity of the process carried out.

Finally, all of which contribute to the transition to automated use instead of the usual manual method, taking into account the points that must be developed and improved in the proposed mechanism to reach the highest productivity and required quality.

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