Biomechanical evaluation of rice farmers during paddy threshing activity

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Abstract

The activity of paddy threshing has been associated with an increase in back injuries among rice farmers. Therefore, this research evaluated the compressive and shear forces at L5/S1 during a real paddy threshing task and identified the associated contributing biomechanics factors. Data were collected from thirty rice farmers with the 3DSSPP application used to compute their predicted L5/S1 compression and shear forces. Furthermore, the relationship between these two factors was analyzed by multiple regression analysis. The result showed that ninety-three percent of paddy threshing activity exceeded the safe limit for the task of 1.588 kN for L5/S1 compression force at a mean and minimum-maximum range of 1.8223 kN and 1.522 – 2.079 kN. A combination of rice farmer's weight, back flexion angle, and flexion angle at mean values of 65.53 kg, 73 degrees, and 35.13 degrees, predicted 76.9 percent of the compressive force variation. These findings can be used as a basis for developing some preventative measures and redesigning the rice paddy threshing equipment to minimize the forward bending of the trunk. Corrective exercises focusing on the back posture and specific to the rice threshing activities should be developed. In contrast, collaborative activities between rice farmers need to be promoted to minimize the hand load leading to compressive force at L5/S1.

***Keywords*:** *3DSSPP; Biomechanical evaluation; L5/S1 back compression and shear forces; paddy threshing; rice farmer*

1. Introduction

The most common rice farming activities in Asian countries are still performed traditionally in risky environmental conditions (Kristanto et al., 2019). These activities typically include plowing, seeding, planting, nursing, fertilizing, and harvesting (Karukunchit et al., 2015). Almost all stages implicate repetitive movement, uncomfortable postures, strenuous lifting and carrying, prolonged standing, as well as keeping heavy and vibrating equipment under control (Sombatsawat et al., 2019). The farmers work bare feet on the rice field's sloppy and slippery surface and plow it using heavy vibrating plowing machines. The seeding, nursing, and fertilizing activities involve heavy lifting, carrying, and stepping on muddy terrains filled with water. The planting stage involves repetitive forward trunk bending and twisting, as well as prolonged standing on the muddy ground. At the same time, the harvesting activity requires stooping and walking on coarse surfaces for hours. These risky situations may lead to biomechanical dysfunction and chronic musculoskeletal disorders (MSDs), particularly in the lower limbs, as evidenced by an earlier study indicating an incidence rate of 10.3 to 73.3 percent among Thai rice farmers (Karukunchit et al., 2015). Moreover, a high prevalence of foot pronation and knee valgus has been found, with percentages of 20.9 percent and 18.5 percent, respectively (Karukunchit et al., 2015). The farmers' predilection for carrying out their tasks barefoot further exacerbates the lower extremity dysfunction due to increased load on the ankle and knee joints as well as the muscles associated with viscous ground force in the muddy paddy field (Juntaracena et al., 2018; Kristanto et al., 2022). Furthermore, heavy physical activities can lead to the deterioration of L5/S1 and L4/L5 discs (Witwit et al., 2018; Cui et al., 2021; Salo et al., 2022; Macedo & Battié, 2019). The back compression force magnitude on the lumbar spine contributes to low back pain (LBP) and injury, specifically at the L5/S1 intervertebral disc (Varrecchia et al., 2022). An earlier investigation regarding manual handling reveals that the L5/S1 or L4/L5 intervertebral disc compression might be the source of LBP and other low back injuries (Ahmad & Muzammil, 2022). Several factors contribute to L5/S1 and L4/L5 discs injuries, including characteristic factors such as body height and weight (Prairie et al., 2016), frequent bending, fatigue from over physical exertion, repetitive heavy lifting, and awkward postures (Tafazzol et al., 2016).

One of the essential stages in paddy harvesting is the threshing activity, a task used to separate the grain from the straw. This process is usually conducted manually by beating out the grains with sticks (Amare et al., 2015; Singh & Vinay, 2014), rubbing out under feet (Abdeen et al., 2021; Singh & Vinay, 2014), bullock treading (Abdeen et al., 2021), and hitting bundles of rice on stone or wooden boards (Khadatkar et al., 2018). These manual thresher methods are still practiced in all paddy growing areas in Asian countries (Kristanto et al., 2019) despite leading to more significant grain damage, lower output, and more drudgery for the farmers (Sa'diyah et al., 2021). In a conventional beating operation, the farmers have to work in a bent position for 9 hours per day on average which is ergonomically inappropriate because an incorrect posture leads to severe injuries. A preliminary study by Jain, Meena, and Dangayach (2018) reported that the body parts with the highest perceived pain were the lower back, right upper and lower leg, right foot, right upper arm, and right forearm in the descendent rank. The perceived pain is mainly triggered by the stooping position adopted by farmers while hitting the rice crop bundle on the drum (Jain, Meena, Dangayach, et al., 2018). The use of modern agricultural apparatuses and equipment for paddy threshing is gaining popularity among farmers to solve the unergonomic working position problem. It includes using appropriate technology, such as a modified pedal and drum length thresher by two farmers (Lad et al., 2020) or manually operated by a paddy thresher (Waghmode & Patel, 2019). It consists of high-speed and powerful machines, such as motorized threshers operated mechanically using technology (Mutai et al., 2018). Although several power-operated paddy threshers have been employed in rice farming, some farmers confront substantial problems in implementing high-technology apparatus and equipment due to design misalignment with their needs (Khayer et al., 2017). This is in accordance with the research by Trisusanto et al. (2020) that the existence of dimensional mismatch in the human-machine interaction in the work activity might impact the welfare, health, comfort, and safety of workers. Therefore, to achieve better performance, new tools, equipment, and workstations need to be designed by considering the anthropometric data of the potential agriculture workers (Abouee-Mehrizi et al., 2022).

The common paddy thresher using appropriate technology is a single-pedal paddy thresher, which requires farmers to pedal on one leg while supporting the body weight. As a result, the farmer tilts their neck to the right to balance the body posture while the right knee is always bent because it is continuously swinging the pedal. The hand's position is always stretched out and twisted while directing the paddy bundle to the thresher. These risky situations sometimes lead to biomechanical dysfunction and MSDs. However, no previous studies performed the biomechanical evaluation of rice farmers during paddy threshing activity.

2. Objectives

This study aims to conduct a biomechanical assessment of farmers engaged in semi-mechanized paddy threshing activity using the 3DSSPP program to evaluate compression and shear forces imposed on the lumbar spine.

3. Materials and methods

3.1 Participants

The combination of the entire population with 95 percent of desired level of accuracy was used as a justification for the sample size in this study. Thirty experienced male rice farmers between 46-56 years were recruited from Peneket Village, Sub-district of Ambal, Kebumen Regency, Central Java Province, Indonesia. The rice farmers were required to have not less than a year of rice cultivation experience and no previous medical record impacting lower limb alignment, such as surgery or fracture. The threshing of paddy in this study was practiced in a real rice field and was approved by The Human Ethics Committee of Universitas Ahmad Dahlan. Before the farmers' participation, they were required to read and sign a consent form.

3.2 Data collection

Rice farmers' anthropometric measures, such as height (cm) and weight (kg), were obtained. A measuring tape was used to determine their height while standing against the wall, with weight determined by walking onto the weight-measuring device, registered in kilos. Individual rice farmers' anthropometric data have been put into the 3DSSPP program (University of Michigan Center for Ergonomics, USA). The models were fed sagittal segmental angles from the forearm, upper arm, back, and leg, both upper and lower sides. These sagittal segmental angles were estimated manually using a static snapshot that had been broken up by the recorded movie. Other input data included rice farmers' gender, weight, and height, as well as hand load.

3.3 Equipment

All actions were recorded using a digital video camera with quantitative data acquired using the 3DSSPP software from the University of Michigan. This program is capable of estimating low back muscle forces and joint moments based on body postural angles and weights lifted by the hands (Ghezelbash et al., 2020). Meanwhile, a video of rice farmers threshing the paddy field was recorded at 30.02 frames per second, along with their still images. The video was then divided into a sequence of static photos. The 3DSSPP application was used to investigate each image to calculate the farmer's shoulder moments, low back compression, and shear forces. The sequence of static postures was selected at 10-s intervals, while the most awkward postures were determined after three researchers watched every participant's whole video clip together.

3.4. Activity description

The rice farmers were asked to perform a paddy threshing activity with a single-pedal paddy thresher. Therefore, one leg swings the pedal while the other leg only supported the whole weight of the body. This condition tilted the neck to the right to balance the body posture with the knee bent while continuously swinging the pedal. The hand position was always stretched out and twisted while directing the paddy bundle of 8 kg to the thresher, as shown in Figure 1.

Figure 1: The body posture on the paddy thresher

3.5. Data and statistical analysis

3.5.1. Rice farmer hand load

To approximate the rice farmer hand force, static moments about the paddy inlet section contact point on the thresher were calculated based on the weight of the paddy bundle (F_P). The moment equilibrium equations (1) were used to assess the hand load (F_{hand}), as described below.

$$F_{hand} = \left(\frac{(F_p \times D_p)+(F_a \times D_a)}{D_{hand}}\right) \quad (1)$$

F_p denoted the weight of the paddy bundle, which was deemed constant for all the farmers at 8kg. F_a expressed the total weight of the upper arm, forearm, and hand. Corresponding to an earlier study by Plagenhoef et al. (1983), the total weight of the arm for males was 5.7 percent of the total body weight. D_p was the moment arm between the position of F_p and the paddy inlet section contact point on the thresher. Since the average length of the paddy bundle (L_p) was approximately 60 cm, the moment arm of D_p was deemed constant for all farmers at 30cm. D_a was the moment arm between the position of F_a and the paddy inlet section contact point on the thresher. Meanwhile, D_{hand} denoted the moment arm between the position of F_{hand} and the paddy inlet section contact point on the paddy thresher. Both D_a and D_{hand} depended on the anthropometric dimension of each farmer's shoulder-grip (SG) length.

3.5.2. L5/S1 back compressive and shear force on the intervertebral disc

The 3DSSPP software (Michigan University, USA) sagittal plane low back evaluation computed the compressive and shear forces. The software measured the L5/S1 intervertebral disk back compressive and shear forces, which were compared to the compressive (Widyanti, 2018) and the shear force standard thresholds of 1.588 kN and 1.00 kN (Kristanto & Munim, 2021) in order to examine the safety of the jobs.

3.5.3. Statistical analysis

The descriptive statistics were applied for all dependent variables. Furthermore, multiple regression analyses were applied to assess predictor sets affecting L5/S1 compression and shear forces since the relationship between both variables met the test's assumptions. These include linear relationships, no multicollinearity, independence, homoscedasticity, and multivariate normality. The predictor variables were: (1) weight (in kilograms) and height (in centimeters); (2) the segmental angle (in degree) of the back, upper arms (right and left), forearms (right and left), thigh (right only), and leg (right only) throughout the paddy threshing process; and (3) hand load (in Newton). All analyses were carried out using the IBM SPSS 26 software (IBM, New York, US) using a significance threshold of $p < 0.05$.

4. Results

4.1 Participants

The descriptive statistics for the rice farmers are summarized in Table 1. The result showed that sixty percent of participants had a normal body mass index (BMI).

Table 1: Rice farmers' descriptive statistics (n = 30)

	Mean	SD	Minimum	Maximum
Age (years)	49.90	2.50	46.00	56.00
Experience (years)	16.07	3.27	10.00	21.00
Weight (kg)	65.53	3.38	60.00	72.00
Height (cm)	164.10	2.22	160.00	169.00

4.2. Rice farmer hand load

The rice farmer's hand load was determined by equation 1. All required variables for hand load computation were given on the free body diagram of force through the paddy threshing process, as shown in Figure 2 and Table 2. The mean hand load force was 45.90 ± 1.61 N with minimum and maximum values of 43.29 N and 48.75 N. The typical posture adopted by the rice farmer during the paddy threshing process was presented in Table 3 and Figure 3.

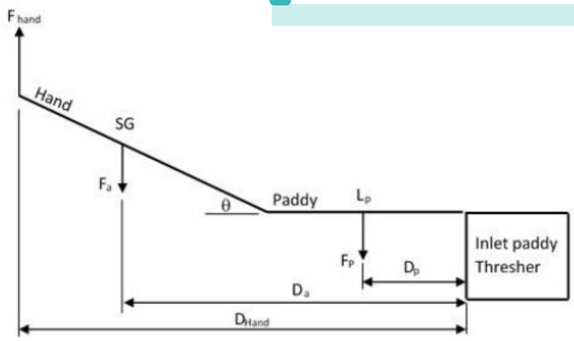

Figure 2: Illustration of the free body diagram of paddy threshing activity

Table 2: Rice farmer hand load variables

Variables	Formula	Value			
L_p (m)	Direct measurement	0.6			
D_p (m)	$0.5L_p$	0.3			
F_p (N)		78.40			
Variables	Formula	Mean	SD	Minimum	Maximum
Shoulder-grip length, SG (m)	Direct measurement	0.70	0.03	0.65	0.73
F_a (N)	5.7 percent of body weight	36.61	1.89	33.52	40.22
D_a (m)	L_p + 0.5SG.cos θ	0.93	0.01	0.90	0.94
The angle of θ (degree)		21.13	1.37	18.47	23.73
D_{hand} (m)	L_p + 0.5SG.cos θ	1.25	0.03	1.20	1.29
F_{hand} (N)		45.90	1.61	43.29	48.75

Table 3: Segmental angles of the posture implemented by rice farmers during the paddy threshing process

Angles (degree)	Mean	SD	Minimum	Maximum
Back	73.00	2.60	69	78
Right upper arm	-41.57	6.04	-58	-31
Left upper arm	-35.13	5.82	-47	-25
Right forearm	-17.77	4.59	-30	-9
Left forearm	-7.77	4.54	-16	-1
Right thigh	-20.30	3.82	-27	-13
Right leg	-65.80	4.12	-75	-55

SD = standard deviation. The negative sign showed the angle direction

4.3. Back compression and shear force on L5/S1 intervertebral disc

The mean of compressive and shear forces applied on a farmer's back at L5/S1 were 1822.30 ± 150.92 N (1522 N minimum and 2079 N maximum) and 157.97 ± 10.82 N (138 N minimum and 176 N maximum), respectively. Among 30 paddy threshing tasks investigated, 93 percent surpassed the compressive criterion maximum value, and none for the shear, as shown in Figure 4.

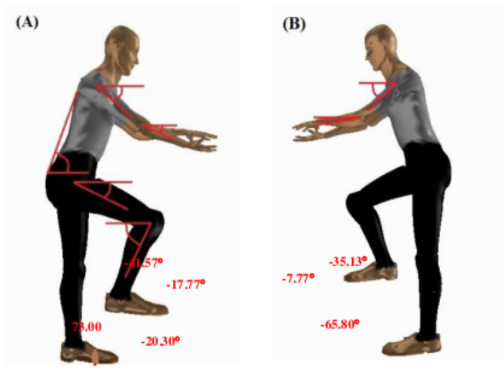

Figure 3: Average segmental angles of the posture implemented by rice farmers during paddy threshing process (A) right view; (B) left view

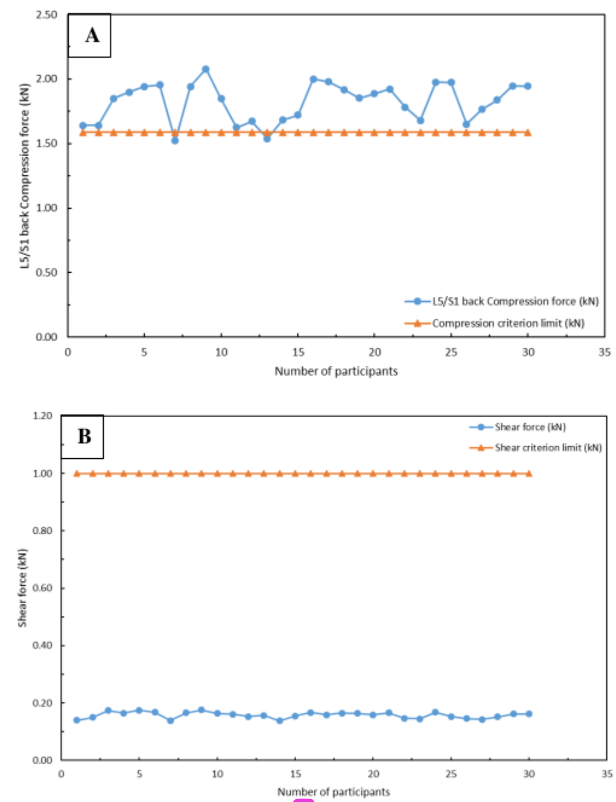

Figure 4: L5/S1 spine compressive (A) and shear forces (B) experienced by rice farmers while paddy threshing activity

4.4. Predictors of compression forces

A multiple regression analysis was used to identify the association between the predictors and the dependent outcome of the L5/S1 compression force. The result showed an overall significant correlation between the predictors and the L5/S1 compressive force ($p<0.05$) with a 76.9 percent variation during the combination of 10 paddy threshing operations. Table 4 shows the weight, back sagittal flexion angle, and left upper arm angle ($p<0.05$). It revealed that for each one-kilogram increase in weight and one-degree rise in left upper arm angle, there was an increase in compression force of 37.117 kN and 13.127 kN, respectively. Conversely, the result showed that for each one-degree increase in back sagittal flexion angle, there was a decrease in compression force by 50.237 kN.

Table 4: Multiple regression analysis models predicting L5/S1 compression force through paddy threshing activity

Variable	Regression Coefficients	T	Sig.
Constant	5297.655		
Weight	37.117	2.247	0.037*
Height	1.663	0.167	0.869
Back angle	-50.237	-7.104	<0.0001*
Right upper arm angle	-4.658	-1.293	0.212
Left upper arm angle	13.127	2.592	0.018*
Right forearm angle	-11.195	-1.980	0.062
Left forearm angle	12.394	1.687	0.108
Right thigh angle	-2.567	-0.524	0.606
Right leg angle	-0.258	-0.058	0.954
Hand load	-52.661	-1.472	0.158
F-value	6.328		<0.0001**
R square		0.769	

* Denoted a significant correlation partially. ** explained a significant difference concurrently.

4.5. Predictors of shear forces

A multiple regression analysis was used to identify the association between the predictors and the dependent outcome of L5/S1 shear force with an overall significant correlation of $F=10.586$ and $p<0.05$ obtained in the rice threshing activity. The combination of 10 factors predicted 84.8 percent of the variation in L5/S1 shear forces for the duration of rice threshing activity. Among these ten predictors, the angles of back flexion left upper arm, and right leg was significant for the L5/S1 shear force ($p<0.05$), as shown in Table 5. It illustrates that for each one-degree increase in the back and right leg angles, there was a decrease in the shear force of 2.100 kN and 0.733 kN, respectively. On the other hand, the result indicated that for each one-degree increase in the left upper arm angle, the shear force rose by 0.653 kN.

Table 5: Multiple regression analysis models predicting L5/S1 shear force through paddy threshing activity

Variable	regression coefficients	T	Sig.
Constant	81.966		
Weight	1.614	1.679	0.110
Height	0.599	1.034	0.314
Back angle	-2.100	-5.102	<0.0001*
Right upper arm angle	-0.047	-0.224	0.825
Left upper arm angle	0.653	2.214	0.039*
Right forearm angle	-0.318	-0.968	0.345
Left forearm angle	0.799	1.869	0.077
Right thigh angle	-0.506	-1.777	0.092
Right leg angle	-0.733	-2.846	0.010*
Hand load	-0.256	-0.123	0.903
F-value	10.586		<0.0001**
R square		0.848	

* Denoted a significant correlation partially. ** explained a significant difference concurrently.

5. Discussion

Previous research on rice farming practices has shown a substantial risk of harm (Karukunchit et al., 2015). Gurav et al. (2020) stated that padding threshing was one of the rice farming operations with a significant risk of injury. According to the current analysis, 93 percent of the 30 paddy threshing operators are at risk for a low back injury with a criteria safety threshold ≥ 1.588 kN (Widyanti, 2018). Rice farmers are inevitably in danger of harm while executing this activity because they exceed the safe limit. When several field settings of paddy threshing activities were considered, the variation in compression forces was mostly explained by hand load, rice farmer's weight, and certain postural characteristics. Furthermore, this process in the current investigation was executed in an actual rice field involved in various occupation environments, such as different ground terrains and inclines, the condition of the paddy bundle to be threshed, and climate and environmental circumstances. All those factors can affect the postural control throughout the process of paddy threshing activity and the internal loading on the spine.

Prairie et al. (2016) research shows that being overweight is related to greater lumbar force on manual materials handling. This is in addition to an increase in moment of force due to large body mass on the spinal column and the possibility of musculoskeletal injury. This study discovered that the bodyweight of rice farmers significantly influenced the compression force of the L5/S1. Bond et al. (2022) and Mathias et al. (2020) defined obesity as the process of raising the cardiovascular illness risk, injury of musculoskeletal, obstructive sleep apnea, and socioeconomic repercussions. Presently, 40 percent of rice farmers are overweight, therefore, further studies need to determine the preventive strategy for the prevention of this ailment.

Spine sagittal flexion was the principal postural indication of compression and shear force differences in L5/S1 due to its anatomical position, and rise in angles of the upper arm and forearm. Meanwhile, the back sagittal contributes to a rise in the L5/S1 moment arm and impacts the muscle force needed to counteract the forward centre of mass and hand load relative to the lumbar spine (Chaffin et al., 2006). Maintaining a straight back and keeping the upper and forearms near the body reduced the moment and compression stresses on the back. The paddy thresher designs significantly impact the rice farmers' posture during operation. According to a study, the design aspects of paddy threshers, such as weight, shape, placement of handles, and the height adjustment mechanism, impact back and shoulder muscular tension (Khayer et al., 2017). The current research regression analysis models revealed that smaller and taller rice farmers had greater L5/S1 compressive force, which may be explained in part by the fixed location of the paddy feeding height platform. The fixed position caused a mismatch between the dimension of the farmer's body and the rice threshing machine used for smaller and taller rice farmers. This dimensional mismatch led to having to perform a body posture with an awkward upper arm angle. The results of multiple regression analysis revealed that the left upper arm and right leg angles significantly affected compression force and the shear force. The rice farmers will benefit from the training on minimizing the moment arm at the back when threshing paddy. The team's design must also be examined to ensure awkward postures are avoided.

The hand load during the task was impacted by paddy bundle weight, its position and collaboration and was implied in the angle of the forearm on the right and left sides of the farmer. Meanwhile, paddy threshing alone, rather than in a squad, should be forbidden, as this practice dramatically increased the hand load and the internal strain on the farmer's spine. This research highlighted the significance of collaboration in numerous vocations, with its importance already proven by Prairie et al. (2016). The choice to establish a paddy threshing process system on its own may indicate a habit created by prior paddy threshing process systems. The task can be modified when two rice farmers work together to change the design to fit two people (Hota et al., 2021).

This study is associated with some limitations. Firstly, the 3DSSPP results are based on the assumption that the movements under consideration were static or extremely slow, with the hand force in the vertical direction. As a result, the acceleration effect, the inertia impact, and a concurrent pull or push force factor were omitted in the computation of backbone compressive and shear forces on the lumbar spine. This potentially underestimated the true load in muscles and joints (Chaffin et al., 2006). However, those simplifying assumptions are required to handle the technological and environmental obstacles in data collection in a wide range of job activities conducted in real-world conditions. The 3DSSPP program is still expected to offer a satisfactory assessment of L5/S1 back compressive and shear forces on the intervertebral disc, as shown in a prior study by Pinupong et al. (2020). Secondly, the actuality that asymmetric force resulted in uneven backload distribution as well as higher compressive and shear forces was not addressed (Lee et al., 2021). Finally, asymmetric factors were not considered in this current research.

6. Conclusion

In conclusion, this study assessed the potential risk of back musculoskeletal problems during field paddy threshing using compression and shear force criteria restrictions. The result showed that most paddy threshing behaviors exceeded the compressive force maximum value at the L5/S1 joint. The most significant compressive predictors were weight, back sagittal flexion, and left upper arm angles. Hand load contributed to compressive force and was determined mainly by the rice farmer's weight and paddy bundle's weight. Therefore, preventive measures must be developed and implemented while encouraging teamwork to lower the potential harm of musculoskeletal spine disorders through the paddy threshing operation.

7. Acknowledgments

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8. References

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