Opsi p-ISSN 1693-2102
Vol. 18, No. 2, December 2025 e-ISSN 2686-2352

Risk assessment using ERIN and CVL methods to minimize musculoskeletal disorders for operators in the food industry

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Article history:
Received: 22 May 2024
Revised: 14 December 2024
Accepted: 29 December 2025
Published: 30 December 2025

Keywords:
Musculoskeletal disorders
Nordic body map
Cardiovascular load
ERIN
Redesign

ABSTRACT
Workers in small-scale industries often experience physical fatigue and musculoskeletal complaints during manual production activities. This research focuses on operators in a Small and Medium Enterprise (SME) producing cowhide crackers, where symptoms of Musculoskeletal Disorders (MSDs) are commonly reported. The purpose of this study is to identify the level of worker discomfort, assess the likelihood of MSD occurrence, and determine appropriate recommendations to reduce ergonomic risk. The Nordic Body Map (NBM) was used to identify complaint areas, Cardiovascular Load (CVL) was employed to assess physical workload intensity, and the ERIN method was applied to evaluate postural risk. The NBM results showed high discomfort levels at the boiling and frying workstations, with scores of 81 and 76.3, respectively. CVL findings also indicated elevated workload at the same stations, with values of 45% and 38%, suggesting fatigue and the need for improvement. Meanwhile, the ERIN assessment showed medium postural risk in one frying activity, low risk in two sub-activities, and high risk in two boiling sub-activities. As a result, a redesign of tools and workstation layout was proposed and simulated using CATIA. The simulation results demonstrate a reduction in MSD risk, where the ERIN score decreased from 34 (high) to 14 (low), confirming the effectiveness of the redesigned workstation.

DOI:
https://doi.org/10.31315/opsi.v18i2.12370

1. INTRODUCTION

Workers who have Musculoskeletal Disorders (MSDs) commonly experience persistent fatigue and diminished work performance, leading many to require ongoing medical treatment. Reported symptoms range from mild discomfort to severe pain affecting the spine, muscles, joints, and peripheral nerves, which are often triggered by repetitive or biomechanically unfavorable working postures that accumulate strain over time [1], [2]. Recent literature highlights that work-related MSDs particularly those involving the neck, shoulders, waist, and lower back have become a growing concern in public health discourse. Beyond physical discomfort, MSDs have been linked to sleep disturbance, reduced functional capacity in daily activities, psychological distress such as depression, comorbid conditions including hypertension and malnutrition [3].

According to earlier studies by the Indonesian Ministry of Health, Musculoskeletal Disorders (MSDs) accounted for 40.5% of worker diseases [4]. An individual's productivity at work may decline if their muscles become problematic, hindering their ability to perform their duties. MSDs are increasingly recognized as significant contributors to the decline in productivity in various occupational settings. Research indicates that these disorders, often resulting from ergonomic risk factors—such as poor posture, repetitive movements, and lengthy static positions—can lead to discomfort, pain, and impairment in workers' abilities to perform their tasks efficiently. An investigation has shown that prolonged static postures significantly correlate with job-related pain, particularly in manufacturing sectors where the nature of the work accentuates the risk for MSDs [5]. Poor working postures and less ergonomic environments have been linked to MSDs complaints, according to a study [4].

Manual material handling is the activity of moving or handling goods, material flows, finished products, or objects using human physical effort [6]. Human labor remains widely utilized because it allows flexible movement, accommodates irregular tasks, and enables the handling of materials in confined spaces where mechanization is often not feasible. Manual Material Handling (MMH) tasks—such as lifting, carrying, transporting, and unloading—are still predominantly performed across many labor-intensive sectors [7]. However, these tasks substantially increase the incidence of MSDs complaints, particularly when performed repetitively or under non-ergonomic conditions [8].

These risks are clearly reflected in the production of cowhide crackers—traditional Indonesian cowhide-based crackers—where processing relies almost entirely on manual labor across multiple work stages. *Cowhide crackers* are produced through sequential manual operations, including boiling, chopping, frying, and packaging. The workflow requires continuous manual handling of raw cowhide, frequent bending, repetitive slicing, prolonged standing, and bilateral upper-limb exertion. Workers at the boiling workstation reported discomfort in the shoulders and wrists due to forward-bent postures while placing materials into hot water. At the chopping workstation, prolonged flexion during repetitive cutting generated complaints in the neck and shoulder regions. Frying activities involved static standing and repetitive stirring movements that strained the legs, shoulders, and wrists.

Worker-reported discomfort and pain in specific body regions indicate musculoskeletal strain, underscoring the importance of evaluating work posture to identify critical ergonomic risk factors. Therefore, the objective of this study is to assess musculoskeletal risk in cowhide cracker production by identifying high-risk workstations and activities, quantifying physical workload, and evaluating postural exposure as a basis for ergonomic intervention. To achieve this objective, a structured ergonomic assessment approach was applied using three complementary methods: Nordic Body Map (NBM), Cardiovascular Load (CVL), and Evaluación del Riesgo Individual (ERIN). The integrated use of these methods enables a comprehensive analysis, combining subjective musculoskeletal complaints assessed by NBM, physiological workload quantified through CVL, and objective postural risk evaluated using ERIN.

The NBM is a standardized 28-item questionnaire that identifies discomfort intensity in various body segments [9]. The CVL method evaluates physical exertion by measuring heart rate, including the resting pulse rate, the working pulse rate, and the difference between them as an indicator of cardiovascular strain [10]. Meanwhile, the ERIN method assesses seven postural and activity-related variables—including upper limb posture, trunk flexion, wrist movement, neck inclination, task frequency, perceived effort intensity, and daily work duration—to determine the level of musculoskeletal risk [11].

The scientific reason for using these three methods together is to obtain a comprehensive analysis. NBM represents workers' subjective perception of pain, CVL quantifies workload based on physiological response, and ERIN objectively evaluates biomechanical posture. When combined, these tools provide a multi-dimensional perspective, enabling deeper analysis of ergonomic exposure and intervention priorities. The novelty of this study lies in its integrated application of NBM–CVL–ERIN specifically within cowhide crackers processing, where research remains limited and rarely considers subjective, cardiovascular, and postural stress as a unified analytical framework. This combination not only strengthens the validity of the findings but also provides a basis for developing targeted workstation redesign to reduce MSD risks.

2. METHODS

The research was conducted at a Small- and Medium-sized Enterprise (SME) producing cowhide crackers, comprising four primary workstations: boiling, cutting, frying, and packaging. A sequential ergonomic evaluation strategy was implemented to quantify musculoskeletal risk and determine priority stations requiring redesign.

2.1. Nordic Body Map (NBM)

The first assessment stage applied the NBM, a standardized 27-item questionnaire used to evaluate musculoskeletal discomfort across major body regions. A total of 43 workers, representing all four production workstations, participated in this stage. The questionnaire was administered at the end of the shift to ensure that reported symptoms reflected actual work exposure. In practice, workers marked specific areas on a body diagram to indicate discomfort, and each response was classified into severity levels ranging from *no pain* to *very painful*, generating a visual distribution of musculoskeletal complaints over time. The quantified results were then grouped per workstation and processed using the NBM risk index to identify dominant pain regions and determine which stations exhibited the highest ergonomic burden [12], [13]. Workstations with high NBM scores were subsequently selected for further evaluation using CVL and ERIN. The risk categories applied in this study are shown in Table 1.

Table 1. NBM risk level classifications

Score	Risk Level	Corrective Action
28 - 49	Low	No Correction action needed
50 - 70	Medium	Correction action may be needed in the future
71 - 90	High	Immediate action needed
92 - 112	Very High	Comprehensive action is needed as soon as possible

2.2. Cardio Vascular Load (CVL)

The second stage evaluated physiological workload using the CVL method. Heart rate data were recorded using a digital pulse meter over three consecutive workdays, producing three key biometric indicators: (1) resting heart rate before work, (2) working heart rate during activity, and (3) the pulse difference between working and resting conditions. CVL analysis quantifies physical workload by calculating the percentage increase of working pulse relative to resting and maximum heart rate, providing an objective measure of work intensity and fatigue risk. The resulting %CVL values were then classified according to cardiovascular workload thresholds to determine whether workers experienced normal load, moderate strain, or fatigue that posed a risk [14]. Worker samples for CVL assessment were drawn exclusively from stations identified as high-risk by NBM, ensuring targeted evaluation and analytic accuracy [15]. The %CVL computation used in this study followed the standard cardiovascular workload formula referenced in. %CVL is calculated using the formula:

$$\%\mathrm{CVL}=\frac{(100x(Pulse\ Rate-Resting\ Pulse\ Rate))}{(Maximum\ Pulse\ Rate-Resting\ Pulse\ Rate)} \quad (1)$$

The maximum pulse rate varies depending on the individual; for men, it is 220 beats per minute, and for women, it is 200 beats per minute [16]. Table 2 contains the results of the CVL.

Table 2. CVL Percentage Classification

% CVL	%CVL Classification
≤ 30 %	Fatigue does not occur
30% < %CVL ≤ 60%	Needs Improvement
60%< %CVL ≤ 80	Work in short time
80 < %CVL ≤ 100	Urgent action need
%CVL > 100%	Not allowed to move

2.3. Evaluación del Riesgo Individual (ERIN)

The third stage evaluated biomechanical risk using the Evaluación del Riesgo Individual (ERIN) method. Observation was conducted on high-risk stations identified through earlier NBM and CVL screening. ERIN analysis assessed seven posture-related variables—including neck, back, shoulder/arm, and wrist positioning—along with movement frequency, daily task duration, perceived exertion intensity, and work rhythm [16]. Each variable was scored using an ERIN assessment sheet, then aggregated to produce a total ergonomic risk value. Final scores were interpreted using the ERIN risk-level categories shown in Table 3 to determine whether risk severity was low, medium, or required immediate intervention [11], [14]. The risk level of the ERIN method can be seen in Table 3 [26].

Table 3. Risk level of the ERIN

Score	Risk Level	Recommended Action
7-14	Low	There is no need to make change
15-23	Medium	In-depth research is needed change may be made
24-35	Hard	Changes are made over a short period of time
>36	Very Hard	Urgent change is needed

2.4. Workstation Redesign and CATIA Simulation

Following ergonomic diagnosis, workstation redesign recommendations were developed to reduce musculoskeletal exposure and improve posture efficiency. Design concepts focused on modifying workstation geometry, work height, reach distance, and load handling orientation. The proposed redesign was then simulated using CATIA software, enabling digital evaluation of posture improvement and joint-load reduction before physical implementation. Pre–post score comparisons objectively validated the ergonomic impact, ensuring that the redesigned workstation effectively decreased risk levels and reduced musculoskeletal burden, as indicated by ERIN and CVL indicators.

3. RESULTS AND DISCUSSION

3.1. Nordic Body Map (NBM)

The results of the NBM assessment were used to determine the level of musculoskeletal discomfort experienced by workers across each workstation involved in the production of *cowhide crackers*. The average pain scores obtained from 43 respondents were then categorized into risk levels to identify which stations required immediate ergonomic attention. A summary of the NBM results is presented in Table 4.

Table 4. Summary of the NBM score on the production of cowhide crackers

No	Work station	Number of Respondents	Average Results	Information
1.	Boiling	3	81	High, Immediate action needed
2.	Chopping	15	43.2	Medium, Correction action may be needed in the future
3.	Frying	6	76.3	High, Immediate action needed
4.	Packaging	10	42.2	Medium, Correction action may be needed in the future

The NBM assessment revealed variations in musculoskeletal discomfort across the four production workstations. As shown in Table 4, the boiling (81) and frying (76.3**)** stations recorded the highest discomfort values, indicating *high risk* and requiring immediate ergonomic intervention. In contrast, the chopping (43.2) and packaging (42.2) stations were identified as *medium risk*, suggesting that SME may require improvements that can be implemented progressively rather than urgently.The findings indicate that musculoskeletal discomfort was highest at the boiling and frying workstations, suggesting greater postural load than at other stages. Repetitive upper-limb activity, trunk flexion, and prolonged standing are likely contributors to shoulder, lower back, and wrist pain, which aligns with findings in similar manual food-processing environments, where continuous stirring and static posture elevate MSD risk [17]. Meanwhile, chopping and packaging show moderate discomfort levels, indicating lower but still relevant biomechanical exposure, consistent with studies reporting that repetitive but less force-intensive hand tasks produce moderate symptom intensity [18]. Based on the NBM assessment of 43 workers, the boiling and frying workstations showed the highest scores. Therefore, CVL analysis was conducted only at these two workstations, with two workers selected from each workstation for further evaluation.Overall, these results reinforce that boiling and frying require priority ergonomic intervention and justify follow-up assessment using CVL and ERIN for more detailed verification. Overall, the NBM results clearly identify boiling and frying as priority targets for deeper ergonomic evaluation, supporting the need to proceed with CVL and ERIN assessments to verify workload and redesign the workstation.

3.2. Cardiovascular Load (CVL)

Following the NBM findings, CVL measurements were conducted to determine whether physiological workload conditions support the previously identified discomfort patterns. The average heart rate (HR) of workers was measured before (Heart Rate Initial – HRI) and during (Heart Rate Work - HRW). As shown in Table 5, the boiling workstation recorded the highest %CVL (45%), placing it in the *needs improvement* category, while the frying station reached 38%, indicating elevated cardiovascular demand. These values suggest that both workstations require ergonomic intervention to prevent excessive physical fatigue. In contrast, chopping (24%) and packaging (26%) remained within the *fatigue-free classification*, indicating lower physiological strain than boiling and frying.

Table 5. Summary of Cardiovascular Load (CVL) assessment across workstations

No	Work Station	Name	Age	$\bar{X}$HRI	$\bar{X}$HRW	HR Maks	CVL	CVL Classification
1	Boiling	1st worker	43	72.50	119.6	177	45%	Needs Improvement
2	Chopping	2nd worker	30	64.83	90	170	24%	Fatigue does not occur
3	Frying	3rd worker	26	71.67	118.5	194	38%	Needs Improvement
4	Packaging	4th worker	40	63.33	88.5	160	26%	Fatigue does not occur

The findings on CVL across different workstations under physiological conditions provide critical insights into the ergonomic risks posed by various tasks. It has been reported that the boiling workstation exhibited a high CVL, while the frying station also had a comparatively high CVL [19]. Tasks that involve continuous, repetitive motion, particularly those that require standing for extended periods and high upper-limb exertion, correlate significantly with increased cardiovascular demands [20], [21]. These findings are consistent with previous studies indicating that heat exposure increases energy expenditure during manual work. The boiling process in batik fabric production shows higher energy expenditure than other processes, primarily due to the elevated ambient temperature (34.8°C) that increases physiological workload [22]. Therefore, the findings suggest that both the boiling and frying workstations induce physical strain and necessitate ergonomic interventions to mitigate excessive fatigue and the risk of musculoskeletal disorders (MSDs) [21], [23].

The correlation between cardiovascular strain and discomfort reported in ergonomic assessments, such as the NBM, reinforces these findings, as specific workstations have been shown to have high discomfort levels [20]. This highlights the need for improved ergonomic design to reduce repetitive strain and thermal exposure, which exacerbates discomfort and fatigue [21]. Studies have indicated a relationship between strenuous work conditions, sustained standing, and increased incidences of MSDs, often attributed to poor posture and inadequate workspace design [20], [24]. Effective ergonomic interventions, including workstation adjustments and task rotations, have demonstrated their efficacy in reducing workplace fatigue and discomfort [23].

In contrast, the roles of chopping and packaging, with lower CVL values, are affirmed to involve less forceful manual tasks, leading to lower physiological stress [23]. This aligns with findings that lighter manual tasks associated with minimal physical strain have reduced cardiovascular demand [25]. Therefore, workers involved in activities such as chopping and packaging exhibit lower risks of fatigue and MSDs, making them less of an ergonomic priority than those engaged in more strenuous roles. Conclusively, the alignment between NBM findings and CVL measurements for boiling and frying workstations underscores the necessity for further analysis using methods such as the Ergonomic Risk Assessment to characterize specific joint movements and identify postural deviations responsible for increased workload. This approach will serve as a basis for informed workstation redesign efforts aimed at enhancing worker health and comfort [20], [21].

3.3. Evaluation Del Riesgo Individual (ERIN)

The results from NBM and CVL provided clear evidence that the boiling and frying workstations carry the highest musculoskeletal and physiological load, making them the most critical points for further ergonomic investigation. While NBM identified discomfort in the shoulders, lower back, and wrists, the CVL assessment confirmed elevated cardiovascular strain, particularly during boiling and frying, further supporting the assumption that these stations require greater physical effort. To verify which specific movements contribute to the workload, the ERIN method was then applied to assess postural deviations, joint stress, movement frequency, and work intensity in detail. ERIN serves as the final diagnostic stage, providing a more granular evaluation before workstation redesign.

The main ingredient in the production is cowhide. Therefore, the primary activity observed with ERIN is cowhide handling. Activities at the boiling station include boiling, removing, and storing the cowhide. Frying activities include frying, draining, and storing the cooked cowhide.

The ERIN results in Table 6 show that postural risk varies across work activities at both high-risk stations. At the boiling workstation, "Lifting" (score 30) and "Laying " (score 31) fall into the *high-risk* category, indicating repetitive lifting, forward trunk flexion, and elevated arm posture that require immediate ergonomic intervention. Meanwhile, "Boiling the " (score 14) remains low risk, suggesting lesser strain during this task. At the frying station, "Frying " (score 23) is categorized as *medium risk*, while "Draining " (10) and "Laying " (13) are low risk, indicating minimal postural strain under typical working conditions.

Table 6. Summary ERIN Results

No.	Work Station	Work Activities	Assessment							Total	Risk Level
			Body	Shoulders/ Sleeves	Hand/ Wrist	Neck	Work Activities	Business Intensity	Job Assessment		
1	Boiling	Boiling	1	2	2	2	3	2	2	14	Low
		Lifting	4	5	4	6	3	8	2	30	High
		Laying	4	7	5	6	3	7	2	31	HIgh
2	Frying Crackers	Frying	1	5	5	6	3	8	3	23	Medium
		Draining	1	1	2	1	3	1	1	10	Low
		Laying	1	1	5	1	3	1	1	13	Low

The ERIN method aligns with discomfort trends observed in the Nordic Body Map (NBM) and with Cardiovascular Load data from the CVL assessments. NBM and CVL suggest that the most significant ergonomic challenges during tasks are related to repetitive handling, lifting, and upper-limb exertion. Specifically, high ERIN scores identified during cowhide-lifting and laying processes highlight risk patterns frequently encountered in manual material handling in food production. In these tasks, the dual demands of frequent bending and elevated shoulder positions notably increase the risk of musculoskeletal disorders (MSDs) [26]. Medium risk levels noted in frying tasks, primarily due to moderate wrist-arm loads during stirring activities, align with the literature suggesting that cyclic, but less force-intensive, upper-limb motions can yield moderate stress levels [27]. This relationship underscores the importance of ergonomic evaluations, even for tasks deemed lower risk but still capable of contributing to cumulative fatigue if not carefully managed. Furthermore, low-risk ratings observed in activities such as draining and laying crackers bolster existing evidence that shorter, less repetitive movements impose minimal ergonomic strain, thus reducing the likelihood of discomfort [28]. In summarizing the ERIN outcomes, it is clear that significant postural risks are concentrated in lifting and laying activities, making them primary targets for workstation redesign initiatives. This finding is supported by studies advocating for improvements in task mechanics, particularly in frying tasks, to alleviate ergonomic burdens and enhance worker safety. Consequently, these insights advocate implementing targeted ergonomic reforms that address specific posture deviations and task dynamics that are conducive to higher MSD risks [29]. This comprehensive approach not only aligns with existing ergonomic literature but also underscores the critical need for preventive strategies to reduce MSD incidence through effective workstation design and operational adjustments. By addressing these high-risk tasks, organizations can foster safer work environments that significantly enhance workers' Well-being and productivity.

3.4. Ergonomic Improvement Recommendations

Based on the integrated findings from NBM, CVL, and ERIN, it is evident that the boiling and frying workstations generate the highest ergonomic risk within the *cowhide cracker* production process. NBM revealed concentrated discomfort in the shoulders, lower back, wrists, and upper arms, while CVL confirmed elevated cardiovascular load during boiling and frying activities, indicating sustained physical strain. ERIN further validated these results by identifying high postural risk specifically during cowhide-lifting and laying activities, as well as moderate strain during frying due to repetitive upper-limb movements. The consistency across these three assessment methods strengthens the conclusion that ergonomic intervention is required to reduce musculoskeletal burden and prevent long-term injury. Therefore, the subsequent stage of this research focuses on workstation redesign to improve posture, reduce joint load, and minimize repetitive strain, thereby shifting the physical workload toward safer, more sustainable operational conditions.

3.4.1. Boiling Workstation

The ERIN assessment results indicate that the boiling workstation falls into a high-risk category, signifying the need for immediate ergonomic intervention. This workstation consists of three primary sub-activities boiling the hide, lifting the hide, and placing the hide—where the lifting and placing stages recorded the highest risk scores. This confirms that post-boiling handling activities are the most significant contributor to musculoskeletal strain.

The dominant source of risk is associated with the low height of the boiling tank, which forces workers to bend excessively when lifting or positioning the cowhide. This posture promotes early fatigue and increases the likelihood of cervical and lumbar spine injury, making it an unnatural and unsustainable work position. Therefore, ergonomic redesign is required, particularly regarding tank dimensions and workstation layout.

The proposed redesign dimensions were determined using anthropometric data representative of the Indonesian population, specifically the 50th percentile standing elbow height (95.65 cm), supported by direct field measurements. Based on this reference, the recommended workstation dimensions are 95.65 cm in height, 200 cm in length, and 100 cm in width. These dimensions are expected to improve working posture, reduce forward bending, and consequently minimize the risk of developing Musculoskeletal Disorders (MSDs). Figure 1 illustrates the workstation conditions before and after the redesign.

Figure 1. *Sub-activities at the boiling workstation before redesign*

The proposed redesign dimensions were determined using anthropometric data representative of the Indonesian population, specifically the 50th percentile standing elbow height (95.65 cm). Based on this reference, the recommended workstation dimensions are 95.65 cm in height, 200 cm in length, and 100 cm in width. These dimensions are expected to improve working posture, reduce forward bending, and consequently minimize the risk of developing MSDs. The ergonomic redesign aligns with prior research demonstrating that anthropometric-based equipment design enhances operator comfort, safety, and work efficiency [30]**.** Figure 2 illustrates the workstation conditions after the redesign.

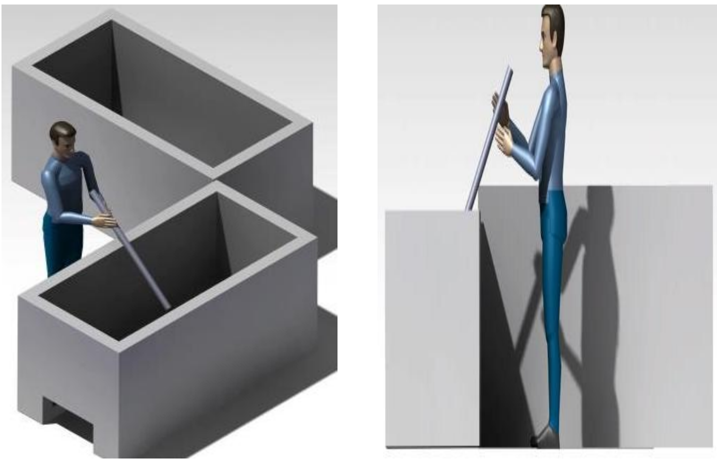

Figure 2. Redesigned boiling workstation

The posture changed following the improvement in Figure 1 and Figure 2, with the neck posture returning to normal and the back being neutral and not bending. The proposed ergonomic redesign of workstations, particularly for soaking and boiling tubs used in SME, aims to alleviate musculoskeletal discomfort while ensuring operational efficiency. Adjustments made to the tub height to align with the Standing Elbow Height are critical, as such alignments have been linked to reductions in neck and back strain, promoting a more natural posture and reducing fatigue [31], [32]. This adjustment allows workers to maintain a neutral spine position while performing their tasks, which is essential in preventing long-term injuries associated with awkward body positioning [33].

The redesigned tank dimensions presented in Figure 3 directly address the postural issues identified during the initial ergonomic assessment. The impact of these modifications is reflected in the ERIN evaluation shown in Table 7 , where improvements in tank height and working posture resulted in substantial reductions across all postural risk variables. Table 7 shows a substantial reduction in postural risk following the redesign of the boiling workstation. All ERIN variables improved after the intervention. Trunk flexion decreased (back: 4 → 2) due to the higher tank height that allows a more upright posture. Shoulder and arm strain dropped significantly (7 → 2), reflecting reduced elevation and improved reach distance. Hand and wrist scores also improved (5 → 3) due to fewer twisting movements. Neck posture showed the most significant improvement (6 → 1), indicating that workers no longer need to bend their necks excessively. Reductions in work activity and effort intensity (7 → 3 and 7 → 4) demonstrate lower task frequency and reduced physical exertion. Overall, the total ERIN score decreased from 31 (high risk**)** to 14 (low risk**)**, confirming that the redesign effectively minimized musculoskeletal risk at the boiling workstation.

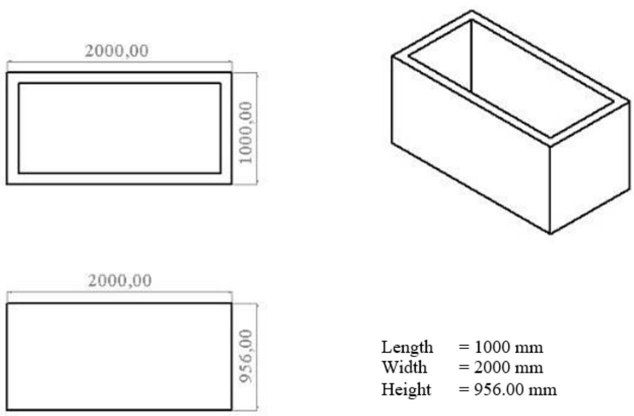

Figure 3. Dimension of the boiling tub

Table 7. ERIN scores before and after the boiling workstation redesign

Variables	Before	After	Description
Back	4	2	Back posture initially bends, then straightens when the cowhide is placed.
Shoulder or arm	7	2	Repositioning the shoulder or arms to a less-lifting, rotating, 180-degree angle after first rotating to a 90-degree angle.
Hand or wrist	5	3	To reduce the frequency of twisting movements, modify the wrist or hand posture to the standing elbow height by first putting the cowhide face downward and rotating the wrist—Indonesian anthropometry.
Neck	6	1	The height of the tub caused changes in neck position, which at first made the cowhide look down, to straighten out.
Work activity	3	3	-
Effort intensity	7	1	Due to modifications in posture and frequency, the business intensity that had previously required greater effort became more relaxed.
Job Assessment	2	2	-
Total	31	14	The ERIN score assessment showed a drop from 31 to 14, indicating a low risk level and no changes are required.
Risk Level	High	Low	The redesign of the work pattern and recommendations for tank height and size reduced the risk level from high to low.

3.4.2. Frying Workstation

Following the identification of high ergonomic risk at the boiling workstation, an evaluation was also conducted on the frying workstation to determine the extent of musculoskeletal strain during frying, draining, and placing activities. The pre-redesign assessment, illustrated in Figure 4, showed that the frying sub-activity received a medium ERIN score (23), primarily due to excessive forward reaching, frequent trunk rotation, and asymmetric upper-limb positioning during the transfer of crackers between the frying pan and the draining barrel. The layout required workers to repeatedly walk and twist, leading to non-neutral postures and cumulative strain. To address these issues, a redesign of the workstation was proposed, as shown in Figure 5, by repositioning the filtering station closer to the frying furnace. This adjustment reduced reach distance, minimized unnecessary movement, and allowed workers to maintain more neutral trunk and shoulder positions.

Figure 4. Sub-activities at the frying workstation before redesign

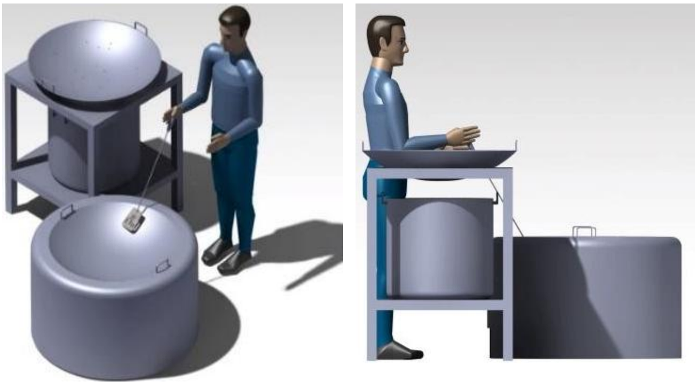

Figure 5. Redesigned frying workstation

Additionally, the filtering barrel was replaced with an ergonomically improved stainless-steel container equipped with bilateral handles, enhancing grip stability and reducing wrist deviation during lifting and draining tasks, as depicted in Figure 6. These modifications resulted in noticeable postural improvements, with workers adopting a more upright stance, reducing neck flexion, and moving their hands closer together during the draining process. The ERIN further supports the redesign's effectiveness, as shown in Table 8, which shows the total score decreased from 23 (medium risk) to 12 (low risk). Significant reductions occurred in shoulder/arm (5 → 2), hand/wrist (5 → 2), and neck (6 → 1) scores, confirming that the redesigned layout and tools successfully lowered postural risk and improved ergonomic safety at the frying workstation.

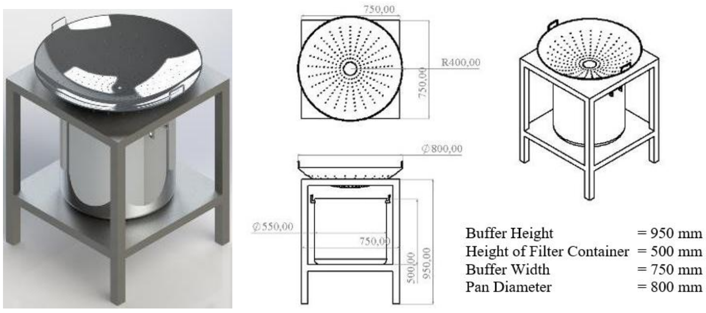

Figure 6. Improvement filter tool

Table 8. ERIN scores before and after frying workstation redesign

Variables	Before	After	Description
Back	1	1	-
Shoulder or arm	5	2	Alterations in shoulder or arm position, such as going closer to the filtering area after first approaching it
Hand or wrist	5	2	Transitioning from a lifting posture to a filtering stance becomes easy on the hand or wrist.
Neck	6	1	As a result of the container's closer screening, the tilt of the neck, which had previously looked down when the cowhide was placed, became more upright.
Work activity	3	3	-
Effort intensity	1	1	-
Job Assessment	2	2	-
Total	23	12	The ERIN score evaluation shows a drop from 23 to 12 with a low danger level, proving that this is accurate and doesn't need to be changed.
Risk Level	Medium	Low	Because of the suggested redesign of the work layout and suggested tools, the risk level, which was previously moderate, changed to low

3.5. Discussion

The integrated results from the NBM, CVL, and ERIN assessments provide a comprehensive understanding of the musculoskeletal risks faced by workers in the boiling and frying workstations during the production of cowhide crackers. The consistently high discomfort levels in NBM, elevated CVL percentages, and medium-to-high ERIN scores collectively indicate that these tasks expose workers to significant physical strain. The findings are aligned with prior research showing that repetitive handling, improper work heights, and asymmetric postures contribute substantially to the development of MSDs in small-scale food-processing industries. At the boiling workstation, the repetitive lifting and placing of cowhide—performed at a suboptimal tank height—was identified as the primary contributor to ergonomic risk [34], [35]. Similarly, at the frying workstation, excessive reach distances and inefficient layout contributed to medium-risk postures that could lead to cumulative fatigue.

The ergonomic redesigns implemented in this study directly addressed these underlying risk factors. Increasing the boiling tank height and optimizing its dimensions helped restore neutral trunk and shoulder posture, effectively reducing biomechanical load. Meanwhile, repositioning the filtering area and integrating an improved handling container in the frying workstation minimized torso rotation and arm elevation. CATIA simulations confirmed that these modifications significantly improved worker posture, reducing trunk flexion, reach distance, and neck deviation [36]. This simulation-based validation approach is consistent with prior research demonstrating that virtual ergonomic modeling can objectively evaluate the effectiveness of workstation redesign before implementation, particularly in SMEs with limited resources [37]**.** The reduction in ERIN scores from high to low risk in boiling and from medium to low risk in frying—further validates the redesign's impact. These results are consistent with established ergonomic principles that emphasize the role of anthropometric-based design and layout optimization in minimizing musculoskeletal strain and enhancing worker well-being [38], [39]. Similar findings have been reported in previous studies, where workstation redesign based on ergonomic assessment and anthropometric considerations effectively reduced musculoskeletal complaints and worker fatigue in a small-scale manufacturing environment [40]**.**

Overall, the study highlights the importance of integrating multiple ergonomic assessment tools with simulation-based validation to achieve targeted and practical workstation improvements in SME environments. The findings demonstrate that even low-cost and practical interventions can produce meaningful reductions in ergonomic risk when grounded in evidence-based design principles.

4. CONCLUSION

The results of the NBM assessment indicated high musculoskeletal complaint scores at the boiling and frying workstations in the cowhide cracker production process, which was further supported by CVL analysis showing the highest physical workload at these stations. Consequently, ERIN analysis was conducted at the boiling and frying workstations. At the boiling workstation, three sub-activities placing, lifting, and boiling the cowhide were evaluated, with two tasks classified as high risk and one as low risk. At the frying workstation, the sub-activities of frying, draining, and placing the cowhide were assessed, where one task fell into the medium-risk category, and two were classified as low risk. These findings demonstrate a strong alignment between NBM, CVL, and ERIN in identifying critical workstations within cowhide cracker production.

Based on these results, ergonomic improvement recommendations were proposed. At the boiling workstation, redesigning work tools and increasing tub dimensions were suggested to reduce excessive bending during cowhide handling. At the frying workstation, improvements included redesigning the workstation layout and developing an ergonomic cracker filtering tool to enhance efficiency and posture. The study emphasizes the importance of implementing ergonomic interventions in small-scale cowhide cracker industries to mitigate musculoskeletal complaints and enhance worker comfort. Future research is recommended to apply additional ergonomic methods and conduct more in-depth and long-term evaluations of working posture in similar food-processing SMEs.

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