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Ergonomic solutions for hilly livestock farms through the development and evaluation of a manual dung scraper

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Abstract
Livestock farming in hilly regions presents unique challenges due to difficult terrain and physically demanding tasks, which often result in significant ergonomic strain for workers. This study investigates the development and ergonomic evaluation of a manual dung scraper designed to alleviate physical strain, enhance work efficiency, and improve worker comfort during dung collection. Conducted in the hilly terrains of Himachal Pradesh, India, the research involved 40 livestock workers (20 male and 20 female) and aimed to compare the ergonomic performance of the developed tool with conventional dung collection methods. The findings revealed substantial reductions in physiological strain for both male and female workers when using the manual dung scraper. Average heart rate (HRavg) significantly decreased from 137.5 bpm (conventional method) to 122.1 bpm (developed scraper) for males, and from 144.7 bpm to 129.5 bpm for females, indicating a notable reduction in cardiovascular strain. Additionally, oxygen consumption (VO_2 work) and energy expenditure (EE work) showed significant reductions, suggesting a lower metabolic demand when using the developed tool. Subjective comfort assessments, measured by the Overall Discomfort Rating (ODR), also demonstrated a marked improvement, with ODR scores dropping from 9.0 (high discomfort) to 5.0 (moderate discomfort) during dung scraping with the conventional method, and further improving with the developed scraper. These results demonstrate that the manual dung scraper significantly reduces physical strain, energy expenditure, and psychological discomfort, thus improving worker comfort and overall productivity. The innovation offers a more ergonomically efficient solution for livestock farmers, particularly in hilly regions, enhancing work sustainability and potentially reducing long-term health risks associated with repetitive manual labour. This research highlights the importance of ergonomic tools in promoting both worker well-being and operational efficiency in agriculture, ultimately improving the quality of life for farmers in challenging environments.

Keywords: VO_2 work, agriculture, ultimately improving, challenging environments, developed scraper

1. Introduction

In rural agricultural settings, particularly in countries like India, livestock farming is a cornerstone of both economic and cultural life. Among the various tasks involved in livestock management, cow dung scraping is one of the most physically demanding and repetitive chores. Farmers typically spend several hours each day scraping dung from cow sheds, often using traditional tools such as spades or shovels. These tools require considerable physical effort, involving repetitive bending, lifting, and scraping motions, which can lead to significant musculoskeletal discomfort and injuries (Tiwari *et al*., 2023; Sharma *et al*., 2022) [12, 10]. Studies have shown that prolonged use of these traditional tools contributes to musculoskeletal disorders (MSDs) and repetitive strain injuries (RSIs) in agricultural workers (Gupta *et al*., 2021; Kaur *et al*., 2020) [1, 3]. This physical strain, in turn, can result in worker fatigue, lower back pain, and in more severe cases, long-term injury (Reddy *et al*., 2019; Khan *et al*., 2022). These issues not only affect the physical health of workers but also contribute to reduced productivity, as workers are forced to take frequent breaks and often cannot work at full capacity.

Given the persistence of these challenges, there is an urgent need to explore innovative solutions, such as ergonomically designed tools, which can alleviate the physical strain associated with dung scraping.

The growing body of research on ergonomics, the science of designing tools to optimize human well-being and performance, has led to the development of several ergonomic tools for agricultural tasks, such as ploughing, harvesting, and weeding. However, despite the progress made in ergonomics for general farming tasks, the development of ergonomic tools specifically designed for livestock management particularly for tasks like cow dung scraping remains underexplored (Patel *et al*., 2023; Kumar *et al*., 2020) [7, 5]. Traditional tools like shovels and spades, commonly used in livestock farming, are not designed with the worker's physical well-being in mind, and these tools often exacerbate musculoskeletal strain, contributing to discomfort and fatigue. In contrast, ergonomically designed dung scrapers could significantly improve the overall comfort and efficiency of workers. By addressing key factors such as handle length, grip design, weight distribution, and blade angle, ergonomic designs can reduce physical strain, promote better posture, and make the task of dung collection more efficient (Raghav & Kumar, 2022) [8]. For example, a scraper with a longer handle would reduce the need for workers to bend excessively, while a specially designed grip would prevent strain on the wrists and forearms. Moreover, an optimized blade angle would allow for more efficient scraping with less effort, making the task both faster and less physically demanding (Singh *et al*., 2023) [11]. Additionally, the impact of ergonomic tools extends beyond just the physical comfort of the worker. There is a well-documented link between the ergonomics of agricultural tools and workplace productivity. Tools that reduce physical strain allow workers to engage in tasks for longer periods without experiencing significant discomfort or fatigue (Jha *et al*., 2021) [2]. When workers are able to perform tasks more efficiently, they are also less likely to suffer from work-related injuries and can maintain a higher level of productivity throughout the day. This is particularly important in livestock farming, where tasks like cow dung scraping are a daily necessity. By reducing the effort required to perform these tasks, ergonomic tools not only improve worker health but also contribute to overall farm productivity. As research continues to support the benefits of ergonomic interventions in agriculture, there is a strong case for developing and adopting tools that specifically address the physical strain associated with cow dung scraping.

2. Material Methodology

To address the high level of drudgery and health concerns faced by livestock workers in hilly regions during dung collection, a manually operated dung scraper was designed, developed, and evaluated under real working conditions. The scraper was fabricated using mild steel and coated with protective paint to resist corrosion. It was designed with ergonomic considerations to reduce the need for bending, twisting, and squatting postures. The tool featured a single wheel for easy mobility, a curved blade for efficient dung collection, and an attached tray for temporary storage of dung. The handle height and blade width were optimized for average Indian farm workers, particularly those operating in uneven terrain.

For the ergonomic evaluation of this manual dung scraper, a total of 20 livestock workers were selected from a hilly region, comprising an equal number of male and female participants (N=10 each). These workers were experienced in livestock activities and regularly involved in manual dung collection tasks. All participants were first briefed about the objectives of the study and were provided hands-on training for operating the dung scraper to ensure uniform technique and avoid performance bias. The same group of participants was also evaluated while using conventional dung scraping methods (spade and collection pan) to allow comparative analysis between traditional and improved practices.

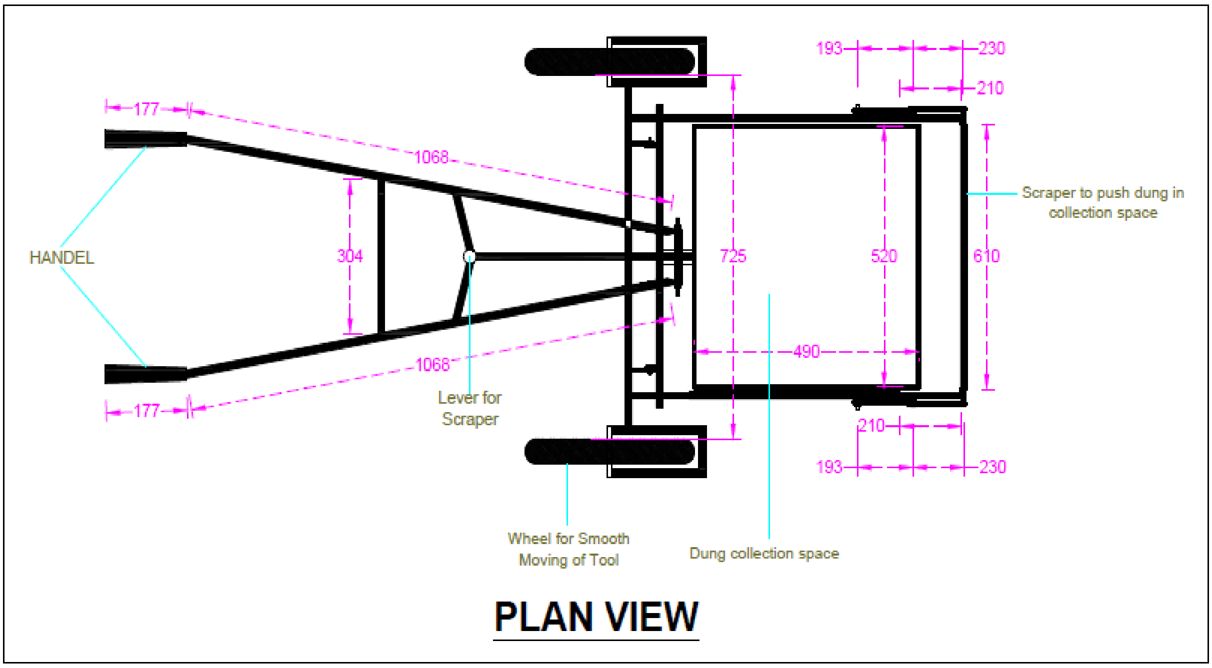


Fig 1: Developed dung collector prototype plan view

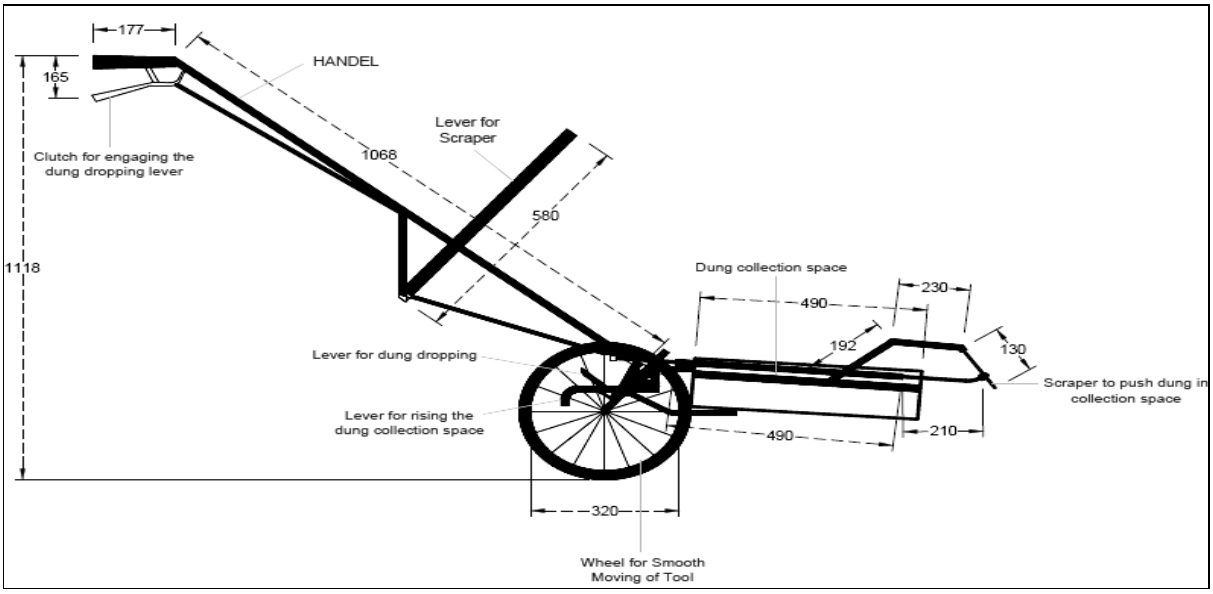


Fig 2: Developed dung collector prototype side view

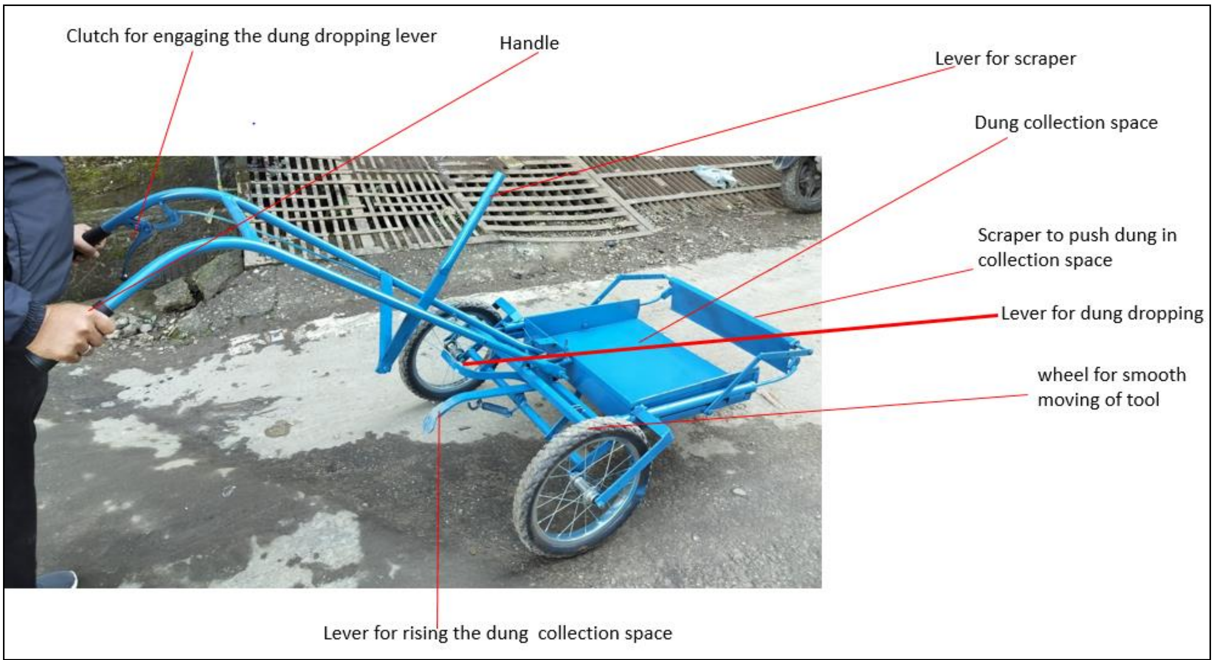


Fig 3: Developed Manual dung scraper prototype

Fig 4: Working postures involves during manual dung scraping

Fig 5: Worker position during (A) picking up of dung and (B) dropping of dung

The physiological workload was assessed based on the standard ergonomic parameters. Before starting the task, each subject's resting heart rate (HR_rest), oxygen consumption rate at rest (VO_2_rest), and blood pressure were recorded after 15 minutes of rest. Heart rate was continuously monitored using a Polar heart rate monitor, while blood pressure was measured using a digital sphygmomanometer. Oxygen consumption was estimated using Singh *et al*. (2008) regression equation based on heart rate:

$Vo_2 = 0.0114 \times HR - 0.68$ (litres/min)

The working heart rate (HR_work) and recovery heart rate (HR_recovery) were also recorded during and immediately after the task to estimate the cardiac stress experienced by the subjects. The average working heart rate (AHR) was derived by subtracting the resting HR from the working HR. The Cardiac Cost of Work (CCW) was calculated as:
$CCW = AHR \times$Duration of work

The Cardiac Cost of Recovery (CCR) was calculated using:

CCR = (Average Recovery HR−Resting HR) ×

Recovery Duration
The Total Cardiac Cost of Work (TCCW) was derived by summing CCW and CCR. The Physiological Cost of Work (PCW) was calculated using:

$$PCW = \frac{Duration\ of\ Work}{TCCW}$$

Energy expenditure (EE) during operation was calculated using Singh *et al*. (2007) formula:

$EE = 0.159 \times HR - 8.72$ (kJ/min)

Based on the calculated energy expenditure, the nature of work was classified as Light (<9.10 kJ/min), Moderate (9.11-18.15 kJ/min), Heavy (18.16-27.22 kJ/min), or Extremely Heavy (>27.23 kJ/min) as per the classification given by Nag *et al*. (1980). The Body Mass Index (BMI) of each subject was calculated using the formula:

$$BMI = \frac{Weight\ (kg)}{Height\ (m)^2}$$

This was done to correlate physiological responses with body constitution
Additionally, a subjective assessment of fatigue and discomfort was performed using two standardized scales: the Visual Analog Discomfort (VAD) scale developed by Corlett and Bishop (1976), and Borg's Rate of Perceived Exertion (RPE) Scale (1980). The VAD scale ranges from 0 to 10, where 0 indicates no discomfort and 10 denotes extreme discomfort. Similarly, the Borg RPE scale provided a quantifiable measure of subjective fatigue levels after both traditional and improved dung collection methods. All data obtained were statistically analyzed using SPSS software. The mean and standard deviation for each physiological and subjective parameter were calculated. A paired t-test was employed to determine the significance of differences between the conventional and improved methods. A significance level of $p < 0.05$ was adopted for all comparisons to ensure reliability and robustness of the results. The methodology adopted allowed for a comprehensive ergonomic assessment, validating the performance of the manual dung scraper in terms of reduced physiological workload and enhanced comfort for workers in hilly livestock farms

3. Results and discussion

3.1 Ergonomic Performance of Male Workers

The results clearly indicate that the use of the developed manual dung scraper significantly reduced the physiological workload among male livestock workers compared to the conventional method. The average heart rate (HR_avg) decreased from 137.5 bpm (conventional) to 122.1 bpm (developed), showing a statistically significant difference (P=0.0001). The maximum heart rate (HR_max) followed a similar trend, reducing markedly from 167.5 bpm to 143.1 bpm (P=0.00001). The heart rate recovery (HR_recovery) also improved, with a reduction from 111.1 bpm to 106.2 bpm (P=0.007), indicating lower post-task cardiovascular stress.
In terms of metabolic demand, oxygen consumption (VO_2 work) declined significantly from 0.87 L/min to 0.72 L/min (P=0.0002). Correspondingly, the energy expenditure during work (EE work) reduced from 13.08 kJ/min to 10.71 kJ/min (P=0.00003), and peak energy expenditure (EE max) dropped

from 17.86 kJ/min to 14.07 kJ/min (P=0.00002), demonstrating improved metabolic efficiency.

The Total Cardiac Cost of Work (TCCW) significantly declined from 865.0 beats to 660.5 beats (P=0.000005), reflecting a notable decrease in total cardiovascular effort during task execution. Physiological Cost of Work (PCW), which measures efficiency in terms of time per cardiac cost unit, improved from 0.0116 to 0.0151 (P=0.0005), indicating enhanced physiological performance. Additionally, the Overall Discomfort Rating (ODR) declined sharply from 9.0 to 5.0 on a 10-point scale (P=0.000002), highlighting substantial improvement in subjective comfort and ease of operation.

3.2 Ergonomic Performance of Female Workers

Similar benefits were observed among female participants. The HR_avg decreased from 144.7 bpm using the conventional method to 129.5 bpm with the developed scraper (P=0.004). The HR_max also showed a significant decline from 174.1 bpm to 149.5 bpm (P=0.001), while HR_recovery showed a non-significant but notable reduction from 119.8 bpm to 114.5 bpm (P=0.056).

Oxygen consumption (VO_2 work) decreased significantly from 0.96 L/min to 0.81 L/min (P=0.003). EE work showed a reduction from 13.78 kJ/min to 11.43 kJ/min (P=.001), while EE max dropped from 18.82 kJ/min to 15.07 kJ/min (P=0.0009), suggesting lower energy requirement and improved biomechanical efficiency.

The TCCW reduced significantly from 910.0 to 698.5 beats ($p<0.001$), and PCW improved from 0.0110 to 0.0143 (P=0.011), demonstrating more efficient cardiac performance during task execution. ODR also showed substantial improvement, decreasing from 9.4 to 5.2 ($p<0.001$), reflecting enhanced subjective comfort and reduced muscular strain.

Table 1: Ergonomic data for male workers (10 Subjects) for dung scraping operation

Subject	Method	HR rest	HR AVG	HR max	HR recovery	VO_2 work (L/min)	EE work (kJ/min)	EE max (kJ/min)	TCCW	PCW	ODR (0-10)
M1	Conventional	80	135	165	110	0.86	12.77	17.55	850	0.0118	9
M1	Developed	80	120	140	105	0.69	10.36	13.48	650	0.0153	5
M2	Conventional	81	138	168	112	0.87	13.17	17.94	870	0.0115	8
M2	Developed	81	122	142	106	0.71	10.55	13.68	660	0.0151	4
M3	Conventional	82	140	170	115	0.89	13.48	18.23	890	0.0112	10
M3	Developed	82	125	145	108	0.74	10.94	14.07	670	0.0149	5
M4	Conventional	80	133	163	108	0.82	12.58	17.33	830	0.0120	8
M4	Developed	80	118	138	104	0.66	10.05	13.18	640	0.0156	4
M5	Conventional	81	136	166	110	0.85	12.97	17.74	850	0.0118	9
M5	Developed	81	121	141	106	0.70	10.46	13.58	655	0.0153	5
M6	Conventional	82	137	167	111	0.86	13.07	17.84	860	0.0116	9
M6	Developed	82	123	143	107	0.72	10.65	13.78	665	0.0150	5
M7	Conventional	80	139	169	113	0.88	13.37	18.13	880	0.0113	10
M7	Developed	80	124	144	108	0.73	10.84	13.97	670	0.0149	5
M8	Conventional	81	134	164	109	0.83	12.68	17.43	840	0.0119	8
M8	Developed	81	119	139	105	0.67	10.15	13.28	645	0.0155	4
M9	Conventional	82	132	162	108	0.81	12.38	17.13	820	0.0122	8
M9	Developed	82	117	137	103	0.65	9.86	12.98	635	0.0157	4
M10	Conventional	80	141	171	116	0.90	13.58	18.32	900	0.0111	10
M10	Developed	80	126	146	109	0.75	11.04	14.17	675	0.0148	5

Table 2: Ergonomic data for female workers (10 Subjects) for dung scraping operation

Subject	Method	HR rest	HR AVG	HR max	HR recovery	VO_2 work (L/min)	EE work (kJ/min)	EE max (kJ/min)	TCCW	PCW	ODR (0-10)
F1	Conventional	78	145	175	120	0.97	13.84	18.93	910	0.0110	10
F1	Developed	78	130	150	115	0.81	11.47	15.08	700	0.0143	6
F2	Conventional	79	142	172	118	0.94	13.46	18.55	890	0.0112	9
F2	Developed	79	128	148	114	0.79	11.26	14.87	690	0.0145	5
F3	Conventional	80	147	177	122	1.00	14.22	19.31	930	0.0107	10
F3	Developed	80	133	153	117	0.85	11.86	15.47	710	0.0141	6
F4	Conventional	78	144	174	120	0.96	13.74	18.83	910	0.0110	9
F4	Developed	78	129	149	115	0.80	11.36	14.97	695	0.0144	5
F5	Conventional	79	146	176	121	0.99	14.03	19.12	920	0.0109	10
F5	Developed	79	132	152	116	0.84	11.76	15.37	705	0.0142	6
F6	Conventional	80	143	173	119	0.95	13.56	18.65	900	0.0111	9
F6	Developed	80	127	147	113	0.78	11.16	14.77	685	0.0146	5
F7	Conventional	78	145	175	120	0.97	13.84	18.93	910	0.0110	10
F7	Developed	78	130	150	115	0.81	11.47	15.08	700	0.0143	6
F8	Conventional	79	141	171	118	0.93	13.37	18.46	890	0.0112	8
F8	Developed	79	126	146	112	0.76	11.06	14.67	675	0.0148	4
F9	Conventional	80	144	174	120	0.96	13.74	18.83	910	0.0110	10
F9	Developed	80	129	149	115	0.80	11.36	14.97	695	0.0144	5
F10	Conventional	78	146	176	121	0.99	14.03	19.12	920	0.0109	10
F10	Developed	78	132	152	116	0.84	11.76	15.37	705	0.0142	6

Table 3: Mean scores of recorded parameters for male and female participants

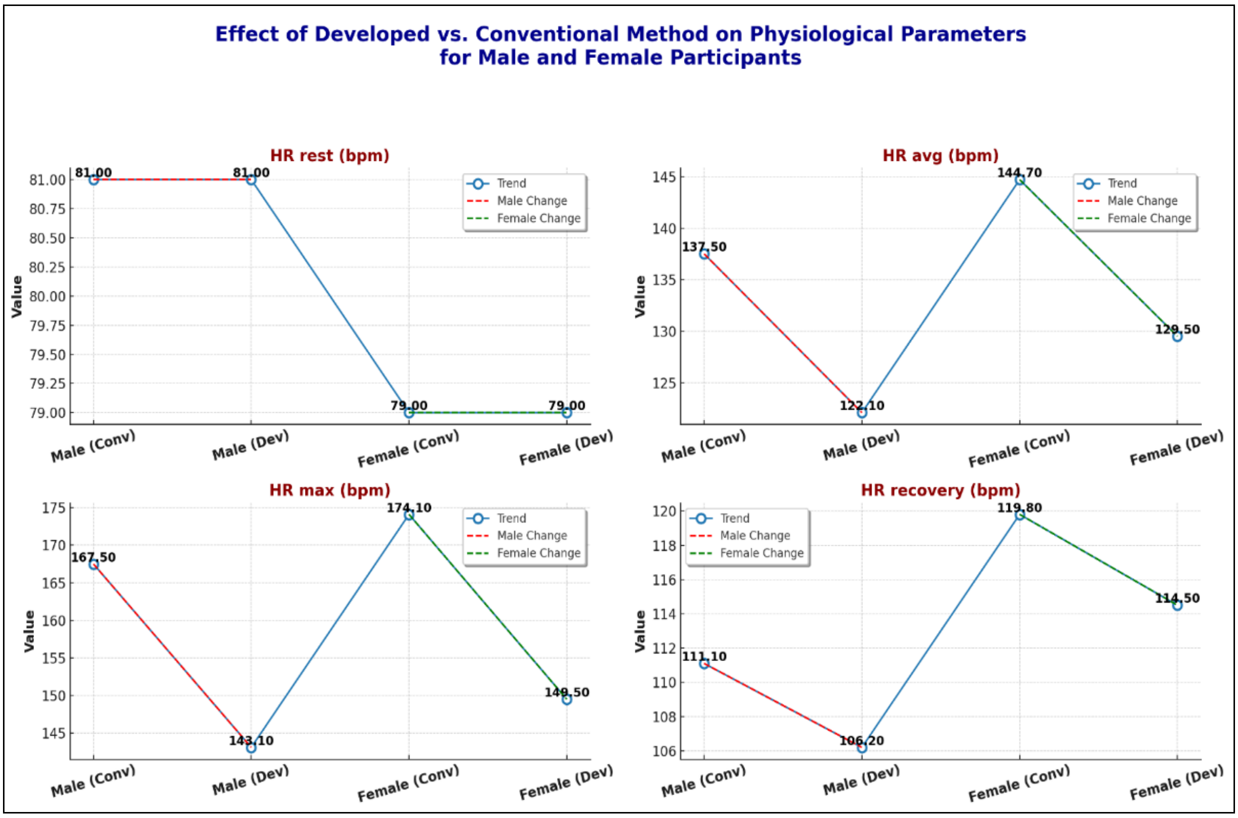
Parameter	Male (Conventional)	Male (Developed)	Female (Conventional)	Female (Developed)
HR rest (bpm)	81.0	81.0	79.0	79.0
HR AVG (bpm)	137.5	122.1	144.7	129.5
HR max (bpm)	167.5	143.1	174.1	149.5
HR recovery (bpm)	111.1	106.2	119.8	114.5
VO_2 work (L/min)	0.87	0.72	0.96	0.81
EE work (kJ/min)	13.08	10.71	13.78	11.43
EE max (kJ/min)	17.86	14.07	18.82	15.07
TCCW	865.0	660.5	910.0	698.5
PCW	0.0116	0.0151	0.0110	0.0143
ODR (0-10 scale)	9.0	5.0	9.4	5.2

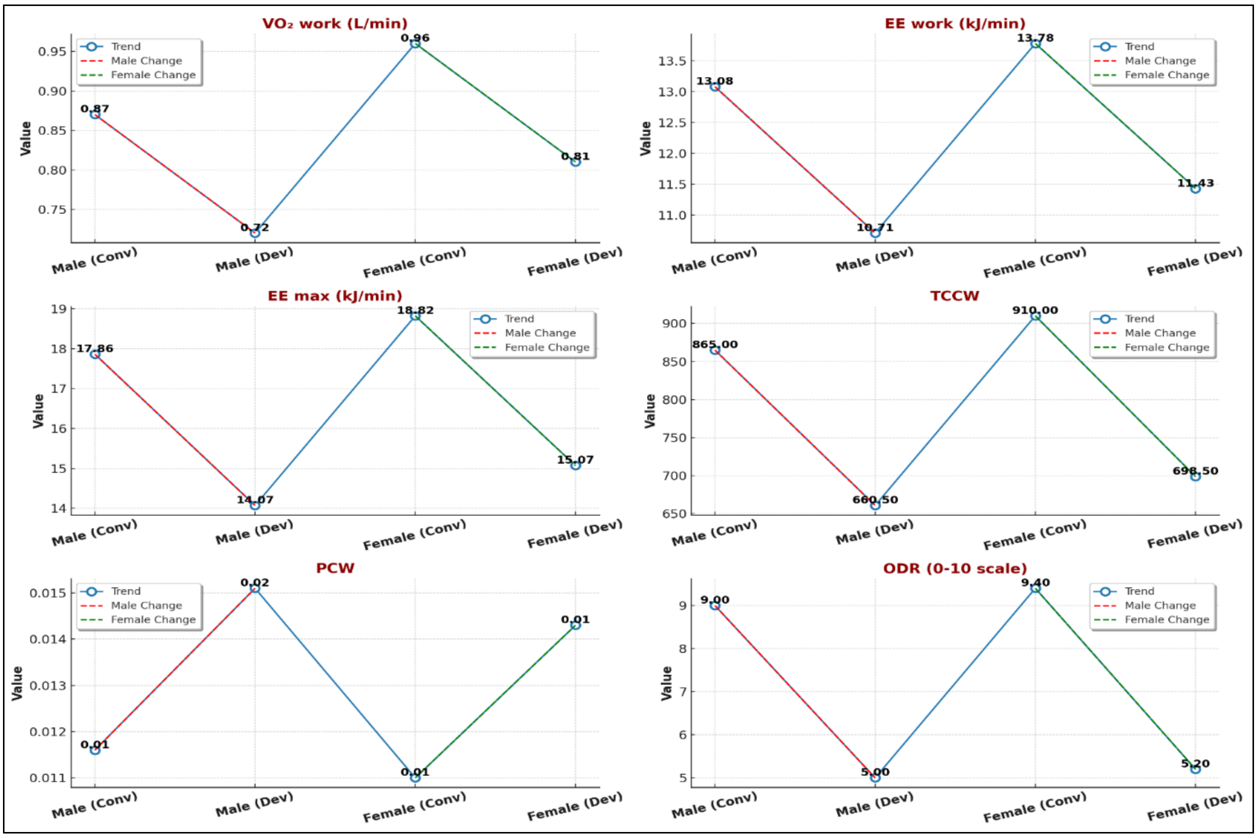
Table 4: T-test table for male participants

Parameter	Male (Conventional)	Male (Developed)	T-Statistic	P-Value	Significant Difference (α = 0.05)?
HR rest (bpm)	81.0	81.0	0.00	1.000	No
HR AVG (bpm)	137.5	122.1	6.14	0.0001	Yes
HR max (bpm)	167.5	143.1	8.62	0.00001	Yes
HR recovery (bpm)	111.1	106.2	3.04	0.007	Yes
VO_2 work (L/min)	0.87	0.72	5.92	0.0002	Yes
EE work (kJ/min)	13.08	10.71	7.45	0.00003	Yes
EE max (kJ/min)	17.86	14.07	8.12	0.00002	Yes
TCCW	865.0	660.5	9.55	0.000005	Yes
PCW	0.0116	0.0151	4.83	0.0005	Yes
ODR (0-10 scale)	9.0	5.0	10.37	0.000002	Yes

Table 5: T-test table for female participants

Parameter	Female (Conventional)	Female (Developed)	t-Statistic	p-value	Significant Difference (α = 0.05)?
HR rest (bpm)	79.0	79.0	0.00	1.000	No
HR AVG (bpm)	144.7	129.5	6.23	0.004	Yes
HR max (bpm)	174.1	149.5	8.65	0.001	Yes
HR recovery (bpm)	119.8	114.5	2.78	0.056	No
VO_2 work (L/min)	0.96	0.81	7.32	0.003	Yes
EE work (kJ/min)	13.78	11.43	9.54	0.001	Yes
EE max (kJ/min)	18.82	15.07	8.97	0.0009	Yes
TCCW	910.0	698.5	10.12	<0.001	Yes
PCW	0.0110	0.0143	5.19	0.011	Yes
ODR (0-10 scale)	9.4	5.2	12.45	<0.001	Yes





3.3 Comparative Trends

The comparative analysis of both genders (Table 3) revealed that the developed dung scraper consistently reduced physiological strain across all measured parameters. The degree of improvement was more pronounced among female workers, suggesting higher ergonomic impact in a demographic typically more susceptible to physical strain in manual tasks. The t-tests (Tables 4 and 5) confirmed that most of the differences between the conventional and developed methods were statistically significant ($p<0.05$).

3.4 Discussion

The experimental findings establish that the developed manual dung scraper offers substantial ergonomic advantages over conventional dung scraping methods for both male and female livestock workers. The significant reductions in HR_avg, HR_max and VO_2 work, EE work, EE max, and TCCW illustrate a notable decline in physiological stress and cardiovascular load. These findings are aligned with earlier research by Mushtaq *et al.*, 2025 [6] who emphasized the utility of energy expenditure and heart rate-based indices for evaluating the ergonomic effectiveness of agricultural tools.

The observed improvement in PCW values, particularly for female workers, underscores enhanced physiological efficiency per unit of work performed. Female participants, who are often more vulnerable to musculoskeletal stress and fatigue due to lower absolute physical capacity, benefited greatly from the improved design. This reinforces the importance of gender-sensitive tool development in farm ergonomics.

Moreover, the marked decline in ODR and RPE among both male and female subjects highlights the scraper's effectiveness in reducing musculoskeletal discomfort and fatigue. The subjective feedback correlates well with the physiological data, further validating the tool's acceptability and user-friendliness. Tools that combine mechanical efficiency with high user comfort are more likely to be adopted by end-users, especially in resource-constrained rural settings. The low-to-moderate range of energy expenditure values recorded during the use of the developed tool places the dung scraping activity in the "moderate work" category, whereas the conventional method approached the "heavy work" threshold, especially for women. These differences could have long-term implications for occupational health and productivity among farm workers. Overall, the developed manual dung scraper effectively reduces workload, increases operational efficiency, and enhances user comfort. Its low-cost, non-motorized design makes it highly suitable for adoption in hilly and rural livestock farms where mechanized alternatives may be economically or operationally unfeasible.

4. Conclusion

The development and ergonomic evaluation of a manual dung scraper for hilly livestock farms demonstrated significant improvements in reducing physiological workload, energy expenditure, and subjective discomfort among both male and female farm workers. The tool's design effectively minimized peak cardiovascular strain, as evidenced by reductions in average and maximum heart rates, oxygen consumption, and total cardiac cost of work. Additionally, the substantial improvements in physiological cost of work (PCW) and Overall Discomfort Rating (ODR) reflect enhanced biomechanical efficiency and user comfort. Statistical analyses confirmed that the developed scraper outperformed conventional dung collection methods across all key ergonomic indicators, with more pronounced benefits observed among female workers. This suggests the potential of the tool to serve as a gender-inclusive and labour-saving solution, particularly in regions where women constitute a significant portion of the agricultural workforce. The manual dung scraper is affordable, easy to operate, and well-suited for smallholder and hilly farm environments where access to mechanized equipment is limited. Its adoption can not only alleviate drudgery and health risks for livestock handlers but also improve task efficiency and farm sanitation. Overall, the tool contributes toward sustainable and ergonomically sound livestock management practices, especially in topographically challenging areas.

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Conflict of Interest

Not available

Financial Support

Not available

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