



Ergonomic design and performance evaluation of a tea (*Camellia sinensis*) plucking basket for minimising musculoskeletal disorders

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ABSTRACT

Tea [*Camellia sinensis* (L.) Kuntze] plucking operation is predominantly conducted by female workers, who perform repetitive motions in constrained postures, leading to discomfort and reduced productivity. An ergonomic tea plucking basket was designed during 2022–23. It was designed to reduce risk of musculoskeletal disorders (MSDs), as it is a common issue among tea plucking workers due to various limitations of traditional bamboo baskets. Theoretical design of basket was developed based on a survey of tea plucking workers aged 25–40 years, who had been actively involved in tea plucking for past five years. A CAD model was subsequently created using SolidWorks, followed by fabrication of the basket. Tea plucking workers were selected from various tea gardens in Assam to assess newly developed improved ergonomic tea plucking basket. Assessment involved subjective feedback, energy expenditure measurements, discomfort ratings, monitoring of physiological parameters, productivity evaluations, and assessments of overall user comfort. Ergonomic assessment tools such as Rapid Upper Limb Assessment (RULA), Nordic musculoskeletal questionnaire, and Quick Exposure Check (QEC) were used for evaluation purposes. This study observed a significant reduction in discomfort scores for neck, upper back, and lower back by 1.65, 0.85, and 0.35 points, respectively. Physiological improvements were observed, with a lowered heart rate from 100 bpm to 95 bpm and a decreased oxygen consumption rate of 13.04%. Energy expenditure rate was also reduced by 12.36%, thus, the developed basket demonstrated enhanced consistency in performance across users.

Keywords: Body discomfort scale, BMI, Energy expenditure rate, Oxygen consumption rate

India stands as second largest global tea [*Camellia sinensis* (L.) Kuntze] producer, with north-eastern state of Assam accounting for more than 50% of national tea output (Parida *et al.* 2024, Surya and Anbarasan 2025). Plucking tea leaves is a crucial and labour intensive field operation in tea production, which is performed mainly by women workers (Deka and Dhandapani 2023). Some crops are unsuitable for mechanised harvesting due to their delicate crop structures and high bruising risk (Hayati and Marzban 2025). Tea is also such a crop where traditional selective plucking method is preferred over mechanical plucking devices for ensuring quality of shoots plucked. During manual tea plucking method, workers carry out fast and repetitive movements while maintaining specific postures for extended periods. In addition, they also have to balance their heavy baskets on their backs using a head strap. Working in unnatural postures for long working hours with insufficient rest breaks and engaging in repetitive movements results in severe musculoskeletal disorders (Burman *et al.* 2020). Rapid and

repetitive body movements of tea plucking workers create considerable physical strain, resulting in significant localised fatigue. In long term, this exhaustion severely impacts both productivity and health of workers (Rejeki *et al.* 2023). As there is no hip support, workers have to carry basket weight on their head, which creates a backwards pull that causes strain and injury to neck and back muscles. This strain in long term can lead to forward contracture and potential injury due to constant load. Tea leaf plucking can cause discomfort due to repeated hand movements in an awkward posture while carrying basket weight on back (Kouhnavard *et al.* 2025). One out of every 300 female workers suffers from work related illnesses, with musculoskeletal disorders being most prevalent issue (Bernard 1997). Moreover, round shape of traditional bamboo basket does not conform to back curvature, making it prone to slipping and thus, workers need to exert extra effort to balance it while bending. A suitable design intervention that considered local materials increased the productivity and improved work life balance of tea leaf plucking workers in hilly terrains (Prasad 2022). Prasad (2022) developed a support strap for existing basket after a qualitative assessment based on interviews, observations and journey mapping. However, in the present study, an anthropometrically designed tea plucking basket

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was introduced and ergonomic evaluations were conducted before and after the intervention.

MATERIALS AND METHODS

The experiment was conducted in two phases: analysis of ergonomic challenges associated with tea plucking and assessment of physical workload experienced by subjects. Study site was selected randomly within garden to minimise variation due to environmental effects, site conditions, and plant size. Ergonomic evaluation of women workers engaged in tea leaf plucking was conducted from 6:00 a.m. to 2:00 p.m.

Survey and performance evaluation were conducted under field conditions in North Lakhimpur (27°14' N, 94°5' E; at an elevation of 94 m amsl), as it is among leading tea producing districts of Assam. Forty subjects were randomly chosen for ergonomic assessment after careful observation. Each subject was medically and physically fit and actively involved in plucking activity for last 5 years. Subjects between 25–40 years of age were selected because individuals in this age range typically attain their peak physical strength.

Materials selection: Developed ergonomic tea plucking basket was constructed from lightweight and durable materials to facilitate ease of carrying. A meshed nylon net (1 mm × 1 mm) was used in the basket which offers strength, water resistance and easy replacement. Its canvas shoulder strap distributes basket weight evenly across shoulders of workers. Its hip support belt shifts some load to hips, thus reducing shoulder strain and long term health risks. These materials are cost effective, locally available and ensure sustainability through easy repairs. This design prioritises worker comfort and practicality for prolonged use in tea plucking.

Design intervention: An ergonomic tea plucking basket was developed to enhance efficiency and comfort during tea leaf harvesting. It was designed using anthropometric data of female mean stature of north-eastern states of India (Dewangan *et al.* 2005).

Development of a 3D model: A three dimensional (3D) model of the ergonomic basket was first developed using SolidWorks modelling software followed by its fabrication (Fig. 1).

Fabrication of the basket: Frame of basket was

constructed from durable 5 mm high grade steel, ensuring strength and longevity. Its body features a 1 mm × 1 mm nylon net, promoting airflow to protect tea leaves while being easy to repair and maintain. Design features a tapered lower section to enable smooth movement through dense bushes, thereby preventing damage to delicate tea buds (Fig. 2).

Measurement of physiological parameters: Physical fitness of respondents was assessed using Body Mass Index (BMI), calculated as weight of subject in kilograms divided by square of their height in meters (kg/m²), as per Quetelet's Index (Eknayan 2008). Subjects were classified as normal weight, underweight, overweight or obese based on standardized BMI thresholds (Weir *et al.* 2023). Heart rate (HR) was measured using a Polar M200 wristwatch with subjects resting for 5 min before recording to ensure baseline accuracy. Working HR was monitored continuously for 20 min during task performance, followed by a recovery period until HR returned to resting levels.

Change in HR (Δ HR) was calculated as the difference between average working HR and resting HR (Equation 1) (Kumar and Parihar 2018). Oxygen consumption rate (OCR), a critical indicator of metabolic demand, was derived from HR (Equation 2) (Singh *et al.* 2008, Ningthoujam and Shrivastava 2018). Energy expenditure rate (EER) reflecting physiological strain during labour was calculated to determine necessary rest intervals and workload sustainability (Equation 3) and validated by Varghese *et al.* (1994). These metrics collectively provided insights into physiological demands of tasks and informed strategies to optimise worker health and productivity under varying work conditions.

$$\Delta \text{ HR (bpm)} = \text{Average working heart rate} - \text{Average resting heart rate} \quad (1)$$

$$\text{OCR} = (0.0114 \times \text{AWHR}) - 0.68 \quad (2)$$

Where OCR, Oxygen consumption rate (L/min); AWHR, Average working heart rate (bpm).

$$\text{EER} = (0.0159 \times \text{AWHR}) - 8.72 \quad (3)$$

Where EER, Energy expenditure rate (kJ/min).

Body part discomfort analysis: To evaluate physical strain of workers during tea plucking, their subjective responses to task demands were scored by using Body Discomfort Scale. A modified version of (Corlett and



Fig. 1 3D model developed using SolidWorks and the developed basket.



Fig. 2 Tea plucking worker working with the traditional and developed basket.

Bishop 1976) body chart was divided into distinct regions to localise pain perception. With an eye toward ergonomic and epidemiological guidelines, standard Nordic Musculoskeletal Questionnaire (NMQ) (Kuorinka *et al.* 1987) was used to check musculoskeletal diseases (MSDs) systematically.

Postural hazards were quantified using a two tiered analysis of Rapid Upper Limb Assessment (RULA), which evaluates upper body exposure to MSD risk factors (McAtamney and Corlett 1993). Group A comprised of upper arm, forearm, wrist and wrist rotation while Group B comprised of neck, legs and torso. Quick Exposure Check (QEC) was employed to evaluate effectiveness of intervention by monitoring musculoskeletal risk factors both prior to and following ergonomic adjustments. Physiological data were gathered using Polar Electro (Finland) heart rate monitors; measurements were taken every 20 min while work cycle was in progress. Statistically evaluating data transferred using proprietary software in Microsoft Excel enabled determination of mean heart rates and total pain levels. These facts facilitated comparison of degree of effort and patterns of localized discomfort.

RESULTS AND DISCUSSION

Physical characteristics of subjects: This study examined a group of tea plucking workers with an average age of 34.75 years, ranging from 25–40 years. These workers had tea plucking experience from 12–15 years with a mean of 14.7 years of field experience. Participants showed relatively uniform anthropometric characteristics with their weights ranged from 38–55 kg (mean 46.2 kg), heights varied between 1.3–1.6 m (mean 1.49 m), and body mass indices (BMI) from 18.0–24.6 kg/m² with a median of 20.2 kg/m². These physical parameters collectively describe a workforce of predominantly lightweight, petite stature individuals with healthy BMI values, suggesting good adaptation to physically intensive tea plucking tasks.

Variation of HR between traditional bamboo basket

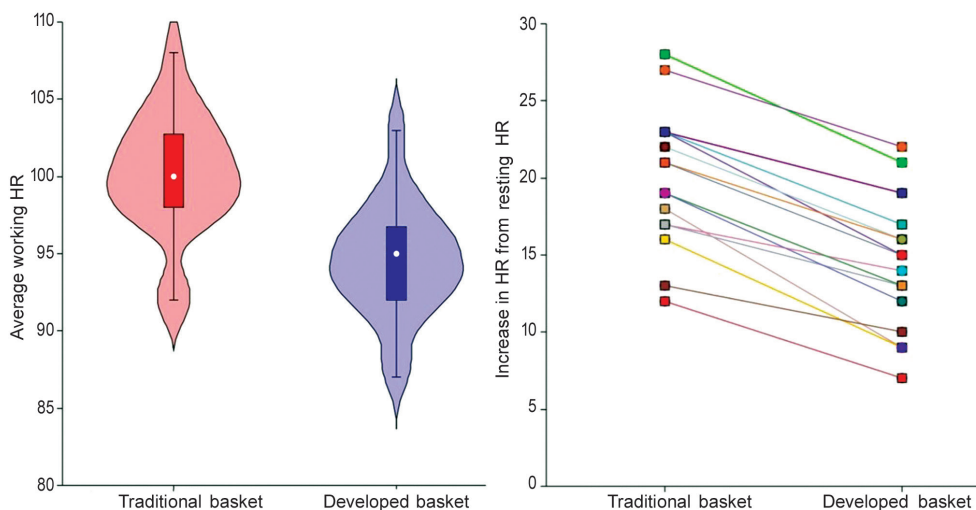


Fig. 3 Average working heart rate (HR) and difference of HR increase from resting HR while using traditional and developed basket.

and developed ergonomic tea plucking basket: Resting heart rate (HR) of subjects within range of 76–83 signifies a good cardiovascular health (Saxena *et al.* 2013). This study followed a standardised three phase measurement protocol to assess cardiovascular responses during tea plucking. Participants were allowed to rest for 5 min to achieve the baseline heart rate. Then they were allowed to work continuously for 20 min to get their working heart rate. After working period, they were again allowed to rest till their heart rate returned to its resting levels. This rest work recovery design enabled comprehensive evaluation of physiological demands throughout complete work cycle, from initial rest through active plucking to full cardiovascular recovery.

Average work rest pattern consisted of 6 ± 0.2 h for plucking activities and 2.0 ± 0.2 h for resting. This study revealed that working heart rates of workers while plucking leaves with traditional bamboo basket ranged from 92 to 108 bpm ± 4.184 , with an average of 100 bpm. Notably, a decrease in working heart rate of workers was observed while using developed ergonomic tea plucking basket. Working heart rate while plucking with developed basket ranged from 87–103 bpm, with an average of 95 bpm ± 3.732 . Decrease of average working heart rate between traditional bamboo basket and developed basket was observed when HR data was plotted in a violin graph (Fig. 3).

Difference of increase in HR between workers while using existing traditional bamboo basket and newly developed basket from resting HR (Fig. 3) was with a mean difference of 20 bpm ± 4.09 and 15 bpm ± 4.51 . Two sample independent t-test revealed a statistically significant difference between the two, as $p < 0.001$. This indicates that scores of existing group were significantly higher than those of improved group, with a substantial magnitude of difference. These results suggest that new intervention was effective compared to existing condition.

Oxygen consumption rate (OCR) and Energy expenditure rate (EER):

OCR and EER of subjects were calculated using Equations (2) and (3). This study found that developed tea plucking basket was associated with lower physical exertion and effort during use compared to traditional basket design. Both oxygen consumption rate and energy expenditure rate are lower on average for developed basket, which was 0.40 L/min and 6.31 kJ/min, respectively, compared to 0.46 L/min and 7.20 kJ/min for traditional basket, shown in Fig. 4. This indicates that developed basket requires, on average, about 12.36% less physical

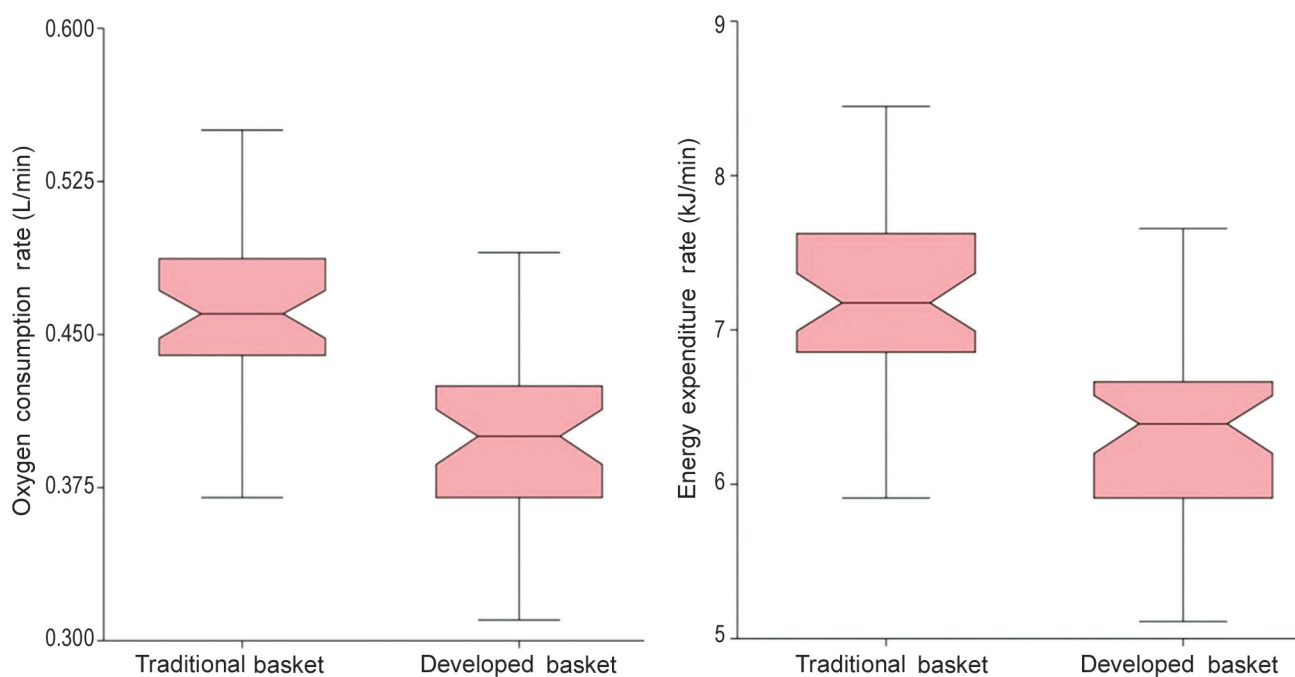


Fig. 4 Oxygen consumption rate and energy expenditure rate for traditional and developed basket.

demand during tea plucking. Developed basket also leads to more consistent performance among users, as indicated by narrower ranges of 0.31–0.51 L/min for oxygen consumption rate and 5.56–8.27 kJ/min for energy expenditure rate, compared to 0.37–0.57 L/min and 6.36–9.22 kJ/min for traditional basket. This shows around 25–30% less variation in physical effort required by developed basket. For majority of individual data points, oxygen consumption rate was approximately 15–20% lower, and energy expenditure rate was approximately 10–15% lower for developed basket. This suggests that developed basket can reduce physical exertion and effort required for most users during tea plucking.

Nordic musculoskeletal questionnaire (NMQ): Questions of NMQ, along with summary of responses, are shown in Table 1. This study found that lower back pain was predominant among tea plucking workers, followed by neck, wrist, hand, shoulder and knee pain. Lower back pain is commonly seen among agricultural workers requiring

static repetitive work in uncomfortable postures (Kundu *et al.* 2021). Repetitive tasks strain same muscles repeatedly, pushing them beyond their limits without enough rest.

Quick exposure check (QEC): QEC assessment of tea leaves harvesting provides body part specific exposure scores for back, shoulder/arm, wrist/hand, and neck regions. Out of 176 QEC score, plucking task score was found to be 130. QEC score for neck region was 89 which was highest among all. It was because their position creates dual muscular loading as workers must simultaneously (a) look downward at tea bushes to identify shoots for plucking, and (b) counterbalance weight of harvesting basket suspended from their head onto their back. These findings highlight substantial cervical strain inherent in traditional tea plucking methods.

Similarly, QEC score for back was found to be 77% which was also on higher side. It was because continuous bending with basket weight on back creates a cumulative

Table 1 Nordic musculoskeletal questionnaire along with the summary of responses

Nordic musculoskeletal questionnaire	Response
Q1: Have you at any time during the last 12 months had trouble (such as ache, pain, discomfort, numbness) in:	90% of workers reported experiencing trouble in their lower back, followed by the neck (85%), wrists/hands (70%), shoulders (60%), and knees (65%)
Q2: During the last 12 months have you been prevented from carrying out normal activities (job, housework, hobbies) because of this trouble in:	The highest percentage of workers, 70%, reported experiencing trouble in their wrists/hands and lower back, closely followed by the neck (65%) and knees (65%).
Q3: During the last 12 months have you seen a physician for this condition	None of the tea leaf plucking workers have seen a physician
Q4: During last 7 days have you had trouble in:	30% of workers reported experiencing trouble in their lower back, followed by the knees (20%), neck (15%), shoulders (15%), and hips/thighs (15%).

musculoskeletal stress on these tea plucking workers. QEC Scores for shoulder/arm and wrist/hand were 75% and 74%, respectively. It was because those workers had to maintain prolonged arm reach to distant bushes while continuously performing repetitive wrist rotations during plucking. QEC score shows that there is a significant ergonomic risk associated with tea leaves plucking, particularly for neck and back of workers. These results highlight urgent need for workplace interventions to reduce musculoskeletal strain for tea plucking workers.

Rapid upper limb assessment (RULA): RULA score indicates likelihood of a task contributing to musculoskeletal disorders (Rahman 2014). Higher RULA scores mean a greater risk of musculoskeletal disorders (MSDs) associated with an activity. Table 2 presents scores for various parts including upper arm, lower arm, wrist twist, wrist, neck, trunk, and leg. It was found that design does not affect risk of MSDs for all these body parts. However, scores for neck, trunk, and legs were lower for modified design (Table 2). This means changes to basket design may make it more ergonomic, helping to reduce risk of MSDs related to how workers hold and position their trunks and posture.

Findings of this study revealed that developed basket design is more ergonomically suitable and comfortable compared to traditional bamboo basket. Hayati *et al.* (2022) also observed that simple ergonomic interventions can have a large impact in mitigating the severe ergonomic and safety problems of date palm harvesting workers. Discomfort scores of workers have been significantly reduced, especially in neck, upper and lower back regions while using newly developed basket. This is because newly developed basket design has eliminated need for workers to maintain a specific forward bending static posture with a concentrated basket load, which was required when using traditional bamboo

basket. Instead, load is uniformly distributed over body through shoulder and hip supporting straps, which has led to a reduction in discomfort scores. Neck region discomfort scores were 2.2 for bamboo basket and 0.55 for developed basket. Similarly, discomfort scores in upper and lower back regions were 1.95 and 1.2 for bamboo basket and 1.1 and 0.85 for developed basket respectively. This indicates that newly developed basket design has eliminated need for workers to constantly balance their basket on head like that of traditional bamboo basket. This has significantly reduced discomfort scores in neck region.

In conclusion, it was observed that newly developed basket design was more ergonomic and comfortable than traditional bamboo basket. Workers experienced significantly reduced discomfort, especially in neck and back regions, while using developed basket. RULA analysis also revealed that newly developed basket has a lower trunk and posture score compared to traditional bamboo basket, which reduces risk of musculoskeletal disorders (MSDs). Newly developed basket minimized local fatigue by distributing load uniformly across the body of workers. Moreover, physiological response, heart rate, Oxygen Consumption Rate, and Energy Expenditure Rate were also decreased as a result of using newly developed basket while plucking.

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Table 2 RULA scores for the body parts

Body Parts	Scores for traditional basket	Scores for developed basket
Upper Arm Score	2	2
Lower Arm Score	3	3
Wrist Twist Score	2	2
Wrist Score	4	4
Posture A Score	5	5
Muscle Use Score	1	1
Force/Load Score	0	0
Wrist and Arm Score	6	6
Neck Score	3	3
Trunk Score	3	1
Leg Score	2	2
Posture B Score	5	3
Muscle Use Score	1	1
Force/Load Score	2	2
Neck, Trunk, Leg Score	8	6

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