Ergonomic optimization in forestry harvesting: analysis of indicators and workstation layout for machine operators

Otimização ergonômica na colheita florestal: análise de indicadores e layout para operadores de máquinas

Optimización ergonómica en operaciones forestales: análisis de indicadores y layout para operadores de máquinas

DOI: 10.54033/cadpedv21n9-212

Originals received: 08/19/2024
Acceptance for publication: 09/09/2024

Cássio Furtado Lima
Master in Forestry Science
Institution: Instituto Federal de Educação, Ciência e Tecnologia do Pará (IFPA)
Address: Ananindeua, Pará, Brazil
E-mail: cassio.lima@ifpa.edu.br

Luciano José Minette
Doctor in Forestry Sciences
Institution: Universidade Federal de Viçosa (UFV)
Address: Viçosa, Minas Gerais, Brazil
E-mail: minette@ufv.br

Roldão Carlos Andrade Lima
Doctor in Forestry Sciences
Institution: Universidade Estadual de Goiás (UEG)
Address: Ipameri, Goiás, Brazil
E-mail: roldao.carlos@ueg.br

Fernanda Araujo Lima
Doctor Applied Biochemistry
Institution: Centro Estadual de Atenção Especializada de Viçosa
Address: Viçosa, Minas Gerais, Brazil
E-mail: fernanda.oaufv@yahoo.com.br

Stanley Schettino
Doctor in Forestry Sciences
Institution: Universidade Federal de Minas Gerais (UFMG)
Address: Montes Claros, Minas Gerais, Brazil
E-mail: schettino@ufmg.br

Nilton Cesar Fiedler
Doctor in Forestry
Institution: Universidade Federal do Espírito Santo (UFES)
Address: Jerônimo Monteiro, Espírito Santo, Brazil
E-mail: niltoncesarfiedler@yahoo.com.br

Rômulo Furtado Faria
Master in Energy
Institution: Instituto Federal de Educação, Ciência e Tecnologia do Espírito Santo (IFES)
Address: Nova Venécia, Espírito Santo, Brazil
E-mail: romulo.faria@ifes.edu.br

Angleson Figueira Marinho
Master in Food Science and Technolog
Institution: Instituto Federal de Educação, Ciência e Tecnologia do Pará (IFPA)
Address: Bragança, Pará, Brazil
E-mail: angleson.marinho@ifpa.edu.br

Lucas Moraes Rufini de Souza
Master in Mechanical Engineering
Institution: Universidade Federal de Viçosa (UFV)
Address: Viçosa, Minas Gerais, Brazil
E-mail: lucas.m.souza@ufv.br

Leonardo França da Silva
Doctor in Agricultural Engineering
Institution: Universidade da Grande Dourados (UFGD)
Address: Dourados, Mato Grosso do Sul, Brazil
E-mail: leonardo.silva117@academico.ufgd.edu.br

Bruno Leão Said Schettini
Doctor in Forest Sciences
Institution: Universidade Federal de Viçosa (UFV)
Address: Viçosa, Minas Gerais, Brazil
E-mail: bruno.schettini@ufv.br

Arthur Araújo Silva
Doctor in Forest Sciences
Institution: Universidade Federal de Viçosa (UFV)
Address: Viçosa, Minas Gerais, Brazil
E-mail: arthur.araujo@ufv.br

ABSTRACT
The planted tree sector in Brazil plays a significant role in the national economy, driven by technological advancements in forestry machines, especially in

harvesting. The interaction between operators and machines has become essential for improving performance and ensuring occupational health. This study analyzed forest harvesting machine operators, focusing on anthropometric surveys and proposing indicators for ergonomic satisfaction and cabin layout. Conducted between May 2022 and July 2023 in a northeastern Brazilian forestry company, data were collected during mechanized harvesting of a six-year-old *Eucalyptus* spp. stand using the cut-to-length system. A questionnaire was applied to 111 employees to assess their ergonomic satisfaction and health. Two indices were created: the Ergonomic Satisfaction Coefficient and the Occupational Health Coefficient. The anthropometric analysis evaluated operators' percentiles and BMI, revealing that 77.77% were overweight, highlighting the need for health protection measures. The ergonomic indices proved effective in assessing operator satisfaction. The study also determined an adequate workstation layout for the sample group. From the Ergonomic Work Analysis perspective, FW2 and HV3 machines received a good rating based on the adopted parameters.

Keywords: Forestry Ergonomics. Body Mass Index. Forest Work Safety. Occupational Health.

RESUMO

O setor de árvores plantadas no Brasil desempenha um papel significativo na economia nacional, impulsionado pelos avanços tecnológicos em máquinas florestais, especialmente na colheita. A interação entre operadores e máquinas tornou-se essencial para melhorar o desempenho e garantir a saúde ocupacional. Este estudo analisou operadores de máquinas de colheita florestal, com foco em levantamentos antropométricos e na proposição de indicadores para satisfação ergonômica e layout das cabines. Realizado entre maio de 2022 e julho de 2023 em uma empresa florestal no nordeste do Brasil, os dados foram coletados durante a colheita mecanizada de um talhão de *Eucalyptus* spp. com seis anos, utilizando o sistema de toras curtas. Um questionário foi aplicado a 111 funcionários para avaliar sua satisfação ergonômica e saúde. Dois índices foram criados: o Coeficiente de Satisfação Ergonômica e o Coeficiente de Saúde Ocupacional. A análise antropométrica avaliou os percentis e o IMC dos operadores, revelando que 77,77% estavam com sobrepeso, destacando a necessidade de medidas de proteção à saúde. Os índices ergonômicos mostraram-se eficazes na avaliação da satisfação dos operadores. O estudo também determinou um layout adequado de estação de trabalho para o grupo amostral. Sob a perspectiva da Análise Ergonômica do Trabalho, as máquinas FW2 e HV3 receberam a classificação BOA com base nos parâmetros adotados.

Palavras-chave: Ergonomia Florestal. Índice de Massa Corporal. Segurança do Trabalho Florestal. Saúde Ocupacional.

RESUMEN

El sector de árboles plantados en Brasil desempeña un papel significativo en la economía nacional, impulsado por los avances tecnológicos en máquinas forestales, especialmente en la cosecha. La interacción entre operadores y máquinas se ha vuelto esencial para mejorar el rendimiento y garantizar la salud ocupacional. Este estudio analizó a los operadores de máquinas de cosecha forestal, centrándose en encuestas antropométricas y la propuesta de indicadores para la satisfacción ergonómica y el diseño de las cabinas. Realizado entre mayo de 2022 y julio de 2023 en una empresa forestal del noreste de Brasil, los datos se recopilaron durante la cosecha mecanizada de una plantación de *Eucalyptus* spp. de seis años, utilizando el sistema de corte en troncos cortos. Se aplicó un cuestionario a 111 empleados para evaluar su satisfacción ergonómica y salud. Se crearon dos índices: el Coeficiente de Satisfacción Ergonómica y el Coeficiente de Salud Ocupacional. El análisis antropométrico evaluó los percentiles y el IMC de los operadores, revelando que el 77.77% tenía sobrepeso, destacando la necesidad de medidas de protección de la salud. Los índices ergonómicos demostraron ser efectivos en la evaluación de la satisfacción de los operadores. El estudio también determinó un diseño de estación de trabajo adecuado para el grupo de muestra. Desde la perspectiva del Análisis Ergonómico del Trabajo, las máquinas FW2 y HV3 recibieron la clasificación BUENA según los parámetros adoptados.

Palabras clave: Ergonomía Forestal. Índice de Masa Corporal. Seguridad en el Trabajo Forestal. Salud Ocupacional.

1 INTRODUCTION

The planted tree sector in Brazil has gained global prominence due to the intelligent use of land, care for nature, and respect for the people involved. In 2022, the planted tree industry reached a planted area of over 9.93 million hectares and a productivity of 38.9 m³/ha/year (IBÁ, 2023). The Brazilian forestry sector holds a significant position in the national economy, having generated 2.97 million direct and indirect jobs in 2021, representing a 7.5% growth compared to the previous year. Gross revenue reached R$ 244.6 billion, and the investments planned until 2028 total R$ 60.4 billion, allocated to research, operations, factory modernization, and new units (IBÁ, 2023). Organizations are increasingly concerned with making forestry operations more sustainable (Furtado Lima *et al*., 2024).

This high demand for investments is primarily directed towards the production of pulp and fiberboard, derived directly from planted forests, which are essential for the manufacture of a wide range of products. It is worth noting that the wood harvesting sector is the most impacted by technological and operational advances, focusing on increasing productivity and global competitiveness. These advances must align with a model of environmental and social sustainability, considering that wood production is inherently costly and impactful.

Wood harvesting, one of the most critical stages of the production chain, can represent up to 60% of the final product cost (Machado, 2014). Therefore, optimizing this phase is crucial for cost reduction and increasing operational efficiency. The mechanization and automation of harvesting operations are essential to achieve these objectives, ensuring greater safety and efficiency, as well as contributing to the sustainability of the sector (Lima *et al*., 2019).

Forest harvesting in Brazil has seen significant advancements in recent years with the introduction of machinery such as harvesters, forwarders, and feller-bunchers, which are generally adapted or imported from predominantly European countries, where the anthropometric characteristics of the operators differ from the Brazilian reality (Carmo *et al*., 2015; Oliveira *et al*., 2020).

In this context, there is a concern to investigate workers' perceptions of the ergonomics of the machines as well as the health symptoms they experience, since their activities are performed within the cabins. Therefore, it becomes necessary to propose the adoption of measures aimed at improving workers' satisfaction levels and, consequently, productivity (Souza *et al*., 2015).

According to Lima (2018), another important factor in this work segment is understanding the anthropometric profile of workers involved in the forestry production chain. This data provides insight into their physical constitution and helps to ergonomically fit the workstation to the worker. Thus, anthropometric measurements are relevant information for designing projects or correcting production means, such as workstations. Therefore, considering the anthropometric analysis of operators and the work they perform will result in greater productive efficiency and a higher degree of comfort and safety in the task.

It is evident that forest harvesting requires special attention from companies due to its high impact on production costs, high risk, and significant demand for specialized labor, often outsourced (Lacerda *et al*., 2017; Lima *et al*., 2019; Lima *et al*., 2023). The elements that require this attention in the analysis are the variations in nature, intensity, concentration, and duration of worker exposure to ensure optimal conditions for performing tasks and determining productivity limits that are compatible with the occupational health of operators (Guedes *et al*., 2017).

In this work environment with forestry machinery, a new class of occupational diseases has emerged, related to musculoskeletal disorders of the upper limbs. This is due to workers remaining seated for long periods in a fixed position and performing repetitive movements with their hands and arms (Minette *et al*., 2015; Schettino *et al*., 2018). Therefore, the interaction between man and machine has become crucial for understanding occupational health in forestry operators (Lima *et al*., 2019; Oliveira *et al*., 2020).

In this context, this study proposed an analysis of occupational health in forest harvesting machine operators, focusing on anthropometric surveys and the development of indicators for ergonomic satisfaction and perception, as well as determining an optimal workstation for operators in a company in northeastern Brazil.

2 MATERIALS AND METHODS

2.1 CHARACTERIZATION OF THE STUDY AREA AND DATA COLLECTION

The research was conducted at a forestry company located in the northeastern region of Brazil, between May 2022 and July 2023. The study focused on a *Eucalyptus* spp. plantation, approximately six years old. The selected area features low slopes and good drainage, making it suitable for the research objectives.

The geographical coordinates of the study area range between 39º00'00" and 39º10'00" West longitude and 16º20'00" and 16º30'00" South latitude, with a central point at Latitude: -16.4511, Longitude: -39.0646 (16° 27′ 4″ S, 39° 3′ 53″ W). According to the Köppen climate classification, the area experiences a tropical rainforest climate (Af), with an average annual temperature of 23°C and an average annual precipitation of 1,256 mm (Santos *et al*., 2016).

Data collection for the research was conducted in the second half of 2022 during mechanized wood harvesting operations using a cut-to-length system. The operators performed their tasks within two distinct configurations: Consisting of Felling with a Feller Buncher, Processing with a Harvester, and Extraction with a Forwarder (System 1); Comprised of Cutting and Processing with a Harvester, followed by Extraction with a Forwarder (System 2).

The evaluation included two Feller Bunchers (FB1 and FB2), three Forwarders (FW1, FW2, and FW3), and four Harvesters (HV1, HV2, HV3, and HV4). According to Lima *et al*. (2019), these are the primary machines used in wood harvesting. The author's research highlights the need for improvements in the occupational health of operators, particularly concerning risks related to vibration and noise exposure.

2.2 ANALYSIS OF ERGONOMIC SATISFACTION AND OCCUPATIONAL HEALTH INDICATORS

The analysis of ergonomic perception and satisfaction involved 111 workers, representing 100% of the forestry machinery operators engaged in felling or cutting, processing, and extraction who agreed to participate in this study.

To develop the ergonomic assessment, a survey questionnaire was administered to the operators, which had been previously used in study Lima (2018). The questionnaire was administered through interviews conducted at the workplace to minimize errors in interpreting the questions and to allow respondents to answer individually or with the interviewer's assistance.

The questionnaire was divided into two sections. The first section addressed the specifications of the machinery, including: name; manufacturer; type and model; year of manufacture; and time of use of the machine. This data was collected to provide necessary context for the ergonomic analysis.

The second section of the questionnaire focused on the operators' perception of ergonomics and physical health symptoms related to the work. This section included a subjective assessment of ergonomic factors affecting comfort and possible physical symptoms resulting from operating the forestry machinery.

Questions were formulated with graded scales for each ergonomic factor analyzed and for the overall comfort experienced during machine operation.

Operators were instructed to evaluate the forestry machinery using these scales, assigning a value corresponding to their perceived comfort. The 11 ergonomic parameters assessed were: cabin access; cabin; visibility; seat; controls; work posture; noise; thermal comfort; gases and particles; typical workday; and overall operator evaluation. The ergonomic classification was based on the following scale:

- ✓ 5 – Excellent Ergonomic Rating
- ✓ 4 – Good Ergonomic Rating
- ✓ 3 – Average Ergonomic Rating
- ✓ 2 – Fair Ergonomic Rating
- ✓ 1 – Poor Ergonomic Rating

Given the information presented, it became possible to compare ergonomic ratings with occupational health complaints. To address this, the present study developed an index called the “Ergonomic Satisfaction Coefficient” (ESC), designed to measure the ergonomic acceptance of operators based on the ergonomic classification analyses. The ESC is derived from the perception and evaluation of each parameter assessed by the 111 operators of the studied forest machinery. The adopted formula is:

$$ESC\ (\%) = \frac{\sum \text{Ergonomic Classification Score}}{\sum \text{Parameter Points}} \ X\ 100 \qquad (1)$$

Where:

the ESC is calculated as a percentage based on the score obtained from the ergonomic classification and the total possible points across the 11 parameters, totaling 55 points for this case. Forest machinery was classified according to the following ESC definitions:

- ✓ 85% – 100% – EXCELLENT Ergonomic Rating (E)
- ✓ 75% – 84.9% – GOOD Ergonomic Rating (G)
- ✓ 60% – 74.9% – AVERAGE Ergonomic Rating (M)

- ✓ 35% – 59.9% – FAIR Ergonomic Rating (F)
- ✓ 0% – 34.9% – POOR Ergonomic Rating (P)

In the third part of the questionnaire, operators reported their perception of physical symptoms related to occupational health. For evaluating the frequency of occurrence of these symptoms (discomfort), the following body parts and 10 parameters were established: head; neck; shoulders; upper back; elbows; lower back; wrists/hands; hips; knees; and ankles/feet. Each item was assigned the following score:

- ✓ 5 – NEVER experience physical symptoms
- ✓ 4 – RARELY experience physical symptoms
- ✓ 3 – SOMETIMES experience physical symptoms
- ✓ 2 – FREQUENTLY experience physical symptoms
- ✓ 1 – VERY FREQUENTLY experience physical symptoms

For the analysis of these symptoms, a similar approach to that of ergonomic data was employed, leading to the creation of the "Occupational Health Coefficient of Operators" (OHCO). This coefficient is used to diagnose the physical pains or discomforts experienced by workers for each piece of machinery. The OHCO is based on the perception and tolerance to pain for each of the 10 symptomatic parameters analyzed. The formula used is:

$$OHCO\ (\%) = \frac{\sum Occupational\ Health\ Score}{\sum Parameter\ Points}\ X\ 100 \qquad (2)$$

Where:

the OHCO is calculated as a percentage based on the score obtained from the occupational health classification and the total possible points across the 10 parameters analyzed. Discomfort sensations with forest machinery were classified according to the following OHCO definitions:

- ✓ 85% – 100% – ALMOST NEVER experience physical symptoms (AN)
- ✓ 75% – 84.9% – RARELY experience physical symptoms (R)
- ✓ 60% – 74.9% – SOMETIMES experience physical symptoms (S)
- ✓ 35% – 59.9% – FREQUENTLY experience physical symptoms (F)
- ✓ 0% – 34.9% – ALMOST ALWAYS experience physical symptoms (AA)

2.3 ANTHROPOMETRIC ASSESSMENT OF FOREST MACHINERY OPERATORS

The collection and analysis of human body variables in this study were based on the methodology employed by the National Institute of Technology (INT) as detailed in the publication "Antropometric and Biomechanical Research of Transformation Industry Workers – RJ: Measurements for Workstations" (INT, 1988).

A total of 81 forest machine operators, representing 73% of the initial study sample and the workforce of the unit, agreed to participate in the anthropometric assessment, constituting the study sample. Measurements were conducted using a stadiometer and a non-elastic tape measure. The procedures for weight and measurement were as follows:

- ✓ Body Mass: Measured using a digital scale from Filizola®, calibrated and certified by Inmetro.
- ✓ Standing Measurements: Included height, eye level height, ear height, wrist height, knee height, thorax height (nipple line), shoulder height, elbow height, inseam, maximum lower reach, and hip width.
- ✓ Sitting Measurements: Included head height, eye level height, shoulder height, elbow height, thigh height, knee height, popliteal height, chest depth, abdominal depth, buttocks-to-popliteal depth, buttocks-to-knee depth, maximum forward reach, forearm reach, bideltoid width, chest width, elbow-elbow width, hip width, forearm length, and hand length.

To classify the nutritional status of the operators, the Body Mass Index (BMI) was calculated using the formula:

$$BMI = \frac{Mass\ (Kg)}{Height^2 (m^2)} \ X\ 100 \qquad (3)$$

The classification was based on the cut-off points established by the World Health Organization (WHO, 1998):

- ✓ BMI < 18.5 → Underweight (Inadequate)
- ✓ 18.6 < BMI < 24.9 → Normal Weight (Adequate)

- ✓ 25 < BMI < 30 → Overweight (Inadequate)
- ✓ 30 < BMI < 34.9 → Obesity Class I (Inadequate)
- ✓ 35 < BMI < 40 → Obesity Class II (Inadequate)
- ✓ BMI > 40 → Obesity Class III (Inadequate)

To facilitate analysis, BMI was categorized into two groups: adequate and inadequate. The database was compiled using Excel, and descriptive statistical analyses were performed with the Statistical Package for the Social Sciences (SPSS) for Windows, version 17.0, both licensed individually for the author's use.

Descriptive statistics for anthropometric variables (weight, height, and BMI) included calculations of mean, median (minimum and maximum), standard deviation, standard deviation of the mean, and coefficient of variation. Percentiles were also calculated for the anthropometric variables, dividing the sample into 100 equal parts from the smallest to the largest value for each body dimension. The percentiles used were 5%, 50%, and 95%.

Percentiles for the variables studied in the machines were calculated at 5% and 95%, depending on the variable analyzed. This means that at the lower percentile (5%), 5% of the operator population was below the researched value, and at the higher percentile (95%), 5% was above.

Finally, anthropometric data were compared with ergonomic measurements of the forest machines, evaluating the dimensions of the cabins and seats, and determining an optimal workstation for forest operators.

2.4 ERGONOMIC EVALUATION OF FOREST MACHINERY WORKSTATIONS

The ergonomic evaluation of forest machinery encompassed a thorough examination of nine different machines employed in cutting and extraction operations. This evaluation utilized a methodology adapted from Almqvist *et al*. (2006), which was developed in accordance with the "Ergonomic Guidelines for Forest Machines" published by Skogforsk (1999) and the Regulatory Standards (NRs) established by the Ministry of Labor and Employment (BRASIL, 2024). This approach aimed to ensure that the machinery met the ergonomic standards necessary for operator comfort and safety.

The assessment began with a detailed examination of the cabin access. It was essential to determine whether the cabin entry was easy and secure, minimizing the risk of accidents. The evaluation focused on whether the cabin was equipped with individual steps or a ladder, and if there were handrails or handles to aid entry. The design needed to allow the operator to maintain three points of contact while entering. This part of the evaluation included checking the condition of the steps or ladder, the height of the first step from the ground, the presence of any sharp edges, and overall ease of access.

Following the assessment of cabin access, the evaluation proceeded to a detailed examination of various machine components. This involved quantitative measurements based on the methodologies proposed by Lima (2018) and the ergonomic guidelines from Skogforsk (1999). Key aspects such as the cabin's dimensions and layout were critically analyzed. A well-designed cabin is crucial for maintaining an ergonomic working posture. If the cabin is too restricted or poorly designed, it forces the operator into uncomfortable or static postures, which can lead to fatigue and long-term health issues.

The methodology proposed by this study included a comprehensive approach to evaluating the cabin. Measurements were taken to assess the cabin's height, width at the forearm supports, and length at these supports (anterior-posterior). Additional measurements included the distance from the backrest to the rear wall at both head and seat positions, and the distance from the backrest to the front wall. The evaluation also considered the space available for knees and feet, especially with the seat adjusted to the maximum forward position. These measurements were essential for determining whether the cabin dimensions allowed for comfortable and ergonomic operation.

In addition to cabin dimensions, the study also evaluated the seat's ergonomic characteristics. This included measurements of legroom, seat height adjustment, lateral tilt, anterior/posterior tilt, and backrest tilt. The seat's design was assessed for its ability to accommodate various adjustments, including the tilt of the seat and backrest, and the distance between forearm supports. It was also essential to evaluate the horizontal and vertical rotation of the forearm supports, the length of these supports, and the lateral tilt of the seat. Each of these parameters was scrutinized to ensure that the seat could be adjusted to meet the needs of operators and promote comfort during extended use.

The overall goal of this ergonomic evaluation was to improve workstation conditions by ensuring that the machinery provided an optimal balance between operator comfort and functionality. By addressing these detailed aspects of cabin and seat design, the study aimed to enhance the overall ergonomic quality of forest machinery, thereby improving operator productivity and reducing the risk of musculoskeletal disorders. This comprehensive approach not only aimed at improving the immediate comfort of the operators but also sought to ensure their long-term health and efficiency in the field.

In Brazil, the dimensions of workspaces and access to forestry machinery are regulated by standards such as NBR 4252, NR-12, and NR-17, which were referenced in this study. Additionally, the Swedish standard, specifically the Ergonomic Guidelines for Forest Machines (ALMQVIST, 2006), was also utilized for evaluating machinery and workstation layout. These guidelines ensure that the design and operation of forest machinery adhere to both national and international ergonomic standards, thereby improving safety and efficiency in the workplace.

2.5 STATISTICAL ANALYSES

For statistical analysis and result presentation, the study utilized "GraphPad Prism 8," "Statistical 7.0," and "SPSS 11.0" software. These tools were selected for their robustness and capability to perform complex analyses with precision. They offer user-friendly interfaces and advanced features that facilitate the processing of large datasets and the application of various statistical techniques.

The study was based on the use of descriptive statistical analysis tools, which allow for the summarization and description of key characteristics of the collected data, such as means, standard deviations, and coefficients of variation. Additionally, percentiles were applied to assess the data distribution and identify the values that divide observations into equal parts, providing a more detailed and accurate view of the variability and central tendency of the results. These approaches are essential for providing a clear and well-founded interpretation of the data, contributing to the reliability and validity of the study's conclusions.

3 RESULTS

3.1 EVALUATION USING ERGONOMIC SATISFACTION AND OCCUPATIONAL HEALTH INDICATORS

Tables 1 and 2 present the classification of the nine types of forestry machines studied, based on pre-established ergonomic and occupational health parameters, as measured by the "Ergonomic Satisfaction Coefficient" (ESC) and the "Occupational Health Coefficient of Operators" (OHCO).

Table 1. Ergonomic Classification of Forestry Machinery

Parameters	FB1	FB2	FW1	FW2	FW3	HV1	HV2	HV3	HV4	ESC %
Cabin Access	P	P	G	G	G	G	G	E	G	M 73,3
Cabin	E	E	G	E	G	M	G	E	G	E 86,7
Visibility	G	G	G	E	G	M	M	G	M	G 75,6
Seat	G	G	M	G	M	M	M	G	M	M 68,9
Controls	G	G	G	G	M	G	M	G	M	M 73,3
Working Posture	G	G	M	G	G	M	G	E	G	G 77,8
Noise	P	P	M	M	M	M	M	E	P	P 57,8
Thermal Comfort	G	G	G	E	G	G	G	E	G	G 84,4
Gases and Particles	G	G	M	M	P	M	M	P	P	P 57,8
Typical Workday	M	M	G	G	M	M	M	G	G	M 68,9
Overall Operator Rating	P	P	P	G	M	M	M	G	M	P 57,8
Final Classification	**M (69)**	**M (69,1)**	**M (69,)**	**G (81,9)**	**M (67,3)**	**M (65,4)**	**M (67,3)**	**G (85,4)**	**M (65,4)**	**–**

Note: The Ergonomic Satisfaction Coefficient (ESC) provides a quantitative measure of ergonomic performance for the machinery studied. The classification is based on the following scale: 85% – 100%: EXCELLENT Ergonomic Rating – Indicates that the machinery offers optimal ergonomic conditions, ensuring the highest level of comfort, safety, and efficiency for the operator. 75% – 84.9%: GOOD Ergonomic Rating – Reflects good ergonomic practices, with minor areas for improvement that do not significantly impact overall operator well-being. 60% – 74.9%: AVERAGE Ergonomic Rating – Suggests adequate ergonomic conditions, though several aspects may require attention to enhance operator comfort and reduce fatigue. 35% – 59.9%: FAIR

Ergonomic Rating – Indicates suboptimal ergonomic conditions, with noticeable deficiencies that could affect operator performance and health. 0% – 34.9%: POOR Ergonomic Rating – Highlights significant ergonomic issues, where the working conditions are likely to cause discomfort, health risks, and reduced productivity. Source: Prepared by the Authors (2024).

Beyond setting production goals based on machinery performance factors, cognitive and ergonomic parameters, including scheduled breaks, have become increasingly important to ensure a sustainable work environment that respects workers' functional limitations. It is essential to study operators' perceptions of these ergonomic parameters, as this analysis can help identify potential weaknesses that must be addressed to create a more humane and sustainable workplace. Operators' insights into workplace safety are critical for providing the necessary support for their health within the environment where they carry out their tasks.

The evaluation of the Ergonomic Satisfaction Coefficient (ESC) across various forestry machines reveals significant variability in ergonomic performance, highlighting areas for both improvement and commendation. Machines such as the FW2 and HV3 emerged as the most ergonomically favorable, consistently receiving high marks in key parameters like cabin design, visibility, and thermal comfort. Conversely, the Feller Bunchers (FB1 and FB2) demonstrated notable deficiencies, particularly in cabin access and noise levels, underscoring the need for design enhancements to mitigate potential risks and improve operator safety. The overall ESC ratings, ranging from FAIR to EXCELLENT, underscore the importance of targeted interventions to address specific ergonomic shortcomings. This comprehensive assessment not only provides a benchmark for current ergonomic standards in forestry machinery but also serves as a guide for future design and operational improvements aimed at enhancing operator well-being and productivity.

Table 2. Occupational Health Assessment of Forest Machinery Operators

Parameters	FB1	FB2	FW1	FW2	FW3	HV1	HV2	HV3	HV4	OHCO %
Head	R	R	R	R	S	R	R	S	S	S 73.3
Neck	R	R	R	R	S	S	S	S	S	S 68.9
Shoulders	R	R	S	R	S	S	S	S	S	S 66.7
Upper Back	R	R	R	R	R	S	S	S	S	S 71.1

Elbows	AN	AN	AN	R	R	R	R	S	S	R 82.2
Lower Back	S	S	S	S	S	S	S	S	S	S 60.0
Wrists/Hands	AN	AN	R	S	R	S	R	S	S	R 75.6
Hips	R	R	S	R	R	R	R	S	S	S 73.3
Knees	R	R	S	R	R	R	R	S	S	S 73.3
Ankles and Feet	AN	AN	R	R	R	R	R	S	S	R 80.0
Final Classification OHCO (%)	**R (84,0)**	**R (84,0)**	**R (74,0)**	**R (76,0)**	**R (72,0)**	**S (70,0)**	**R (72,0)**	**S (60,0)**	**S (60,0)**	**-**

Note: The table presents the classification of physical symptoms experienced by operators based on the Occupational Health Coefficient (OHCO). The percentages correspond to the frequency with which operators report experiencing physical symptoms: 85% – 100%: Almost Never experience physical symptoms (AN); 75% – 84.9%: Rarely experience physical symptoms (R); 60% – 74.9%: Sometimes experience physical symptoms (S); 35% – 59.9%: Frequently experience physical symptoms (F); 0% – 34.9%: Almost Always experience physical symptoms (AA). Source: Prepared by the Authors (2024).

In analyzing Table 2, the physical symptom "lower back pain" stands out prominently. Operators across all nine types of machinery reported experiencing this symptom at some point. This issue is complex to evaluate, as its causes can be multifaceted. Key contributing factors include genetic predisposition, overload from overtime work, lack of abdominal musculature, obesity, and stress.

Moreover, the prevalence of "lower back pain" among operators indicates a significant trend across various types of machinery. This finding highlights the need for a more in-depth examination of working conditions and machinery ergonomics. The high frequency of this symptom suggests the necessity for comprehensive preventive and intervention strategies, including reassessing workstation designs, improving seat and support structures, and implementing physical training and appropriate break programs.

The fact that all operators reported experiencing this symptom underscores the importance of adopting a holistic approach to mitigation. Solutions should address both ergonomic improvements in machinery and individual factors contributing to discomfort. Understanding and addressing these factors are crucial for enhancing operator health and well-being, thereby reducing the negative impact on their performance and safety in the workplace.

ISSN: 1983-0882

3.2 ANTHROPOMETRIC ASSESSMENT OF FOREST HARVESTING MACHINERY OPERATORS

To improve operational efficiency and minimize the risk of accidents and occupational illnesses, it is crucial that operators are properly aligned with their workstations. This alignment encompasses ensuring that operators work with optimal attention, enhanced visibility, controls that are adjusted to their working posture, and overall comfort. Table 3 provides a detailed analysis of the anthropometric profile of forest machinery operators, which is vital for understanding how physical dimensions impact their interaction with the machinery and overall performance.

Table 3 – Anthropometric Profile Analysis of Forest Machinery Operators

Variable (Cm)	**Percentiles**			**Mean**	**Standard Deviation (±) cm**	**σ* cm (±)**	**CV** (%)**
	5	**50**	**95**				
Standing Individual							
Stature	169,90	175,55	182,11	175,95	1,04	4,43	2,52
Eye Level Height	157,40	162,65	170,24	163,49	1,10	4,67	2,85
Ear Height	154,88	159,50	165,65	159,47	0,95	4,05	2,54
Wrist Height	81,42	86,35	90,87	86,80	0,69	2,95	3,40
Knee Height	48,42	52,20	56,05	52,42	0,61	2,60	4,96
Thorax Height	123,92	130,00	134,53	129,48	0,87	3,69	2,85
Shoulder Height	138,34	145,50	150,88	145,44	0,98	4,15	2,85
Elbow Height	104,22	109,00	113,46	108,92	0,77	3,27	3,01
Inseam	76,28	81,55	88,09	81,50	0,87	3,71	4,55
Maximum Reach Below	63,77	67,30	70,34	67,16	0,52	2,20	3,27
Hip Width	33,00	35,40	37,79	35,29	0,43	1,84	5,21
Seated Individual							
Elbow Height (Seated)	64,84	67,25	72,83	68,00	0,70	2,95	4,34
Thigh Height	57,85	60,00	63,58	60,56	0,45	1,91	3,15
Knee Height (Seated)	54,93	56,75	61,00	57,33	0,47	1,99	3,46
Popliteal Height	42,85	46,50	49,15	46,14	0,56	2,36	5,12
Chest Depth	21,43	23,00	26,08	23,41	0,37	1,55	6,64
Abdomen Depth	22,93	24,50	27,21	24,99	0,40	1,70	6,81
Buttocks-to-Popliteal Depth	42,28	45,00	49,23	44,86	0,53	2,26	5,04
Buttocks-to-Knee Depth	49,70	55,60	58,15	55,08	0,73	3,09	5,62
Maximum Forward Reach	75,28	80,00	85,45	80,00	0,83	3,54	4,43
Forearm Reach	42,35	46,00	49,58	46,03	0,52	2,20	4,78
Biacromial Width	43,28	45,40	48,70	45,78	0,49	2,07	4,51
Chest Width	28,54	31,60	32,73	31,12	0,37	1,57	5,04
Elbow-to-Elbow Width	42,93	46,50	52,08	46,99	0,68	2,88	6,14
Hip Width (Seated)	34,35	36,25	41,78	37,39	0,83	3,52	9,42
Forearm Length	26,00	28,25	31,65	28,53	0,41	1,72	6,03
Hand Length	16,17	17,50	20,00	17,76	0,29	1,24	6,96

Seat Height	39,93	43,35	47,56	43,85	0,58	2,47	5,63
Weight (kg)	73,46	82,00	94,60	83,77	1,68	7,12	8,51

Note: *Standard Deviation (**σ**) refers to the variation of the mean. **Coefficient of Variation (CV) expresses the relative variability of the data as a percentage of the mean. Source: Prepared by the Authors (2024).

However, it is evident that the workers analyzed deviated from the average in all the assessed variables. They also displayed low standard deviations, indicating a high degree of statistical homogeneity in the anthropometric variables of the sample, as evidenced by the very low coefficients of variation. This implies that, due to minimal variation within the sample, the installation of adjustable mechanisms is feasible to accommodate the range between the 5th and 95th percentiles.

Additionally, the Body Mass Index (BMI) is a critical measure for evaluating the health status of employees within an organization. After conducting weight and measurement procedures, individuals were classified (refer to Table 4) using the BMI parameter for nutritional status categorization as outlined by the World Health Organization (WHO, 1998). This classification provides valuable insights into the overall health and fitness of the workforce, helping to identify potential health issues that may affect job performance and safety.

Table 4 – BMI Classification of Forestry Operators

BMI Category	N	%	Description
Eutrophy	18	22.22%	Adequate
Overweight	49	60.49%	Inadequate
Obesity Grade 1	14	17.28%	Inadequate
Total	81	100	

Note: Where: n = number of operators, BMI = Body Mass Index. Source: Prepared by the Authors (2024).

When individuals categorized as inadequate are grouped, it is evident that 77.77% are classified as overweight. This observation may be attributed to the work routines of these operators, who spend extended periods seated in static positions, with minimal movement and potentially poor dietary habits. The prolonged sedentary nature of their work environment, combined with unbalanced nutrition, significantly contributes to elevated BMI levels. This underscores the need for targeted health and wellness interventions within the workplace to address and mitigate these health risks.

3.3 ERGONOMIC EVALUATION OF THE IDEAL WORKSTATION

To propose adaptations for forestry machinery, the dimensions of the workspaces were investigated. Tables 5, 6 and Figure 1 present the results of the measurements of the cabins and seats of the forestry machines studied, along with the values from the Guideline (SKOGFORSK, 1999) and the relevant anthropometric recommendations for the operators.

The ergonomic evaluation of cabin height, Parameter A, aligns with the operator's stature in the anthropometric analysis, which is 182 cm at the 95th percentile. This measurement exceeds the 180 cm recommended by the Guideline (VRG). Consequently, the cabins of the forestry machines studied generally accommodate operators within the specified height range. However, discrepancies were noted in certain models, particularly Feller Bunchers (FB1 and FB2) and Harvesters (HV1 and HV2), which did not meet the recommended height, thus indicating potential ergonomic concerns for taller operators.

Continuing this assessment, Parameter B, which refers to the cabin width at armrest height, has a VRA of 85 cm, aligning with the operator's maximum forward reach of 85.45 cm at the 95th percentile. This suggests that the cabin dimensions are well-suited for operators' reach requirements. Nevertheless, the Feller Bunchers (FB1 and FB2) and Harvesters (HV1 and HV2) were identified as non-compliant with this parameter, while all Forwarders exhibited measurements that met ergonomic standards. This variation underscores the need for targeted ergonomic adjustments in specific machine models.

Table 4 – Ergonomic Evaluation of Machine Cabins

Parameter (cm)	**VRG***	**VRA****	**FB1**	**FB2**	**FW1**	**FW2**	**FW3**	**HV1**	**HV2**	**HV3**	**HV4**
A) Cabin height	180	182	180	180	166	179	179	151	160	189	180

REVISTA CADERNO PEDAGÓGICO – Studies Publicações Ltda.
ISSN: 1983-0882

B) Cabin width at armrest height	100	85	91	91	112	137	137	91	89	127	137
C) Cabin length measured at armrest height	162	-	151	151	178	160	160	160	172	176	185
D) Distance from the backrest to the rear wall of the cabin	55	-	44	44	42	49	49	73	49	65	59
E) Distance from the backrest to the front wall of the cabin	65	-	103	103	62	122	122	91	54	83	100
F) Distance from the backrest at knee height	83	-	92	92	88	69	69	74	48	81	80
G) Distance from the backrest at foot height	115	-	116	116	48	75	75	113	112	101	116

Note: *VRG – Ergonomic Reference Value for Forestry Machines, Guideline (SKOGFORSK, 1999). **VRA – Anthropometric Value obtained for Feller Bunchers, Forwarders, and Harvesters, based on the operators used in the study. Blank spaces indicate that there is no exact anthropometric value available for the parameter. FB1, FB2, FW1, FW2, FW3, HV1, HV2, HV3, and HV4 refer to the forestry machines studied in this work. The letters correspond to the measurement outline in the methodology. Source: Prepared by the Authors (2024).

In practical terms, the Guideline's recommended value of 162 cm for Parameter C (cabin length) proved effective, as on-site technical visits revealed complaints about cabin dimensions in Feller Bunchers (FB1 and FB2), Harvester (HV1), and Forwarders (FW2 and FW3). These models did not conform to the recommended guidelines, highlighting a need for further refinement to ensure that all machinery adheres to ergonomic best practices.

Table 5 – Ergonomic Evaluation of Machine seats

Parameter	VRG *	VRA **	FB1	FB2	FW1	FW2	FW3	HV1	HV2	HV3	HV4
a)Le-groom (cm)	≥ 24	-	15	15	16	≥ 24	≥ 24	13	20	12	6
b) Seat height ad-justment (cm)	40-55	40-48	48-56	48 -56	40 -53	40 - 55	40 -55	44 - 49	44 - 54	40 - 55	42 -51
c) Lateral inclination (degrees)	±10-15	-	0	0	0	±10-15	±10-15	0	0	±10-15	0

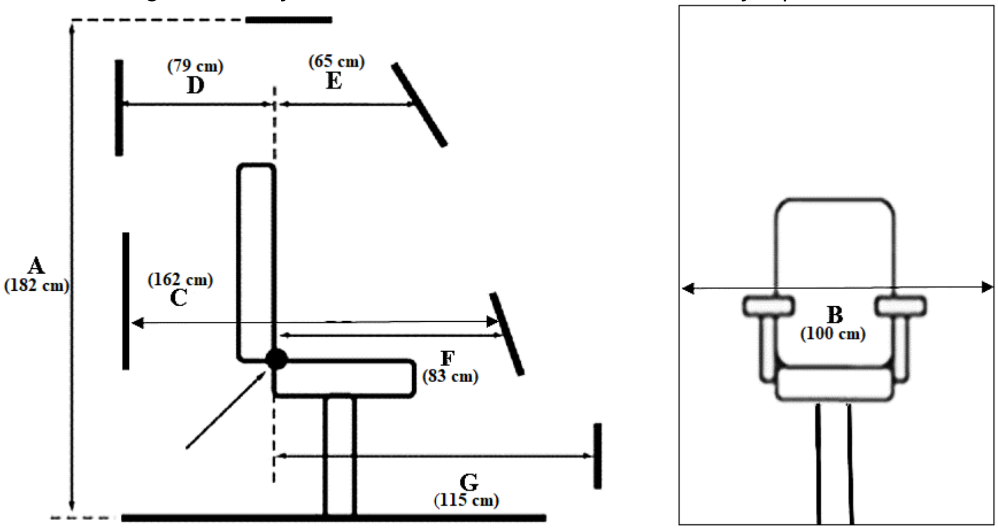
d) Fore/aft inclination (degrees)	> ±20	-	0	0	> ±20	> ±20	> ±20	0	> ±20	> ±20	> ±20
e)Backrest inclination (degrees)	-5-30	-	-5-30	-5-30	-5-30	0	- 0	0	31º	-5-30	-5-30
f) Seat inclination (degrees)	+8 a -15	-	0	0	+8 a -15	+8 a -15	+8 a -15	0	0	+12 a 20	0
g)Distance between armrests (cm)	42-52	43-49	52	52	44	40,5	40,5	61,5	50,5	50	44
h)Horizontal swivel of armrests (degrees)	In.:30 Out.:15	- -	In.:30 Out.:15	In.: 30 Out.:15	In.:30 Out.:15	In.:30 Out.:15	In.:30 Out.:15	0 0	0 0	In.:30 Out.:15	In.:30 Out.:15
i) Armrest height adjustment (cm)	12-27	25	6	6	10	12-27	12-27	6,5	15-40	12-23	12-27
j) Vertical swivel of armrests (degrees)	< -30-0	-	0	0	< -30-0	< -30-0	< -30-0	***	< -30-0	-30	< -30-0
k) Armrest length (cm)	20-30	26-32	25	25	33	36	36	33	35,5	24-32,5	36
l) Seat lateral inclination (degrees)	±10	-	0	0	0	0	0	0	0	0	0

Note: *VRG – Ergonomic Reference Value for Forestry Machines, Guideline (SKOGFORSK, 1999). **VRA – Anthropometric Value obtained for Feller Bunchers, Forwarders, and Harvesters, based on the operators used in the study. Blank spaces indicate that there is no exact anthropometric value available for the parameter. FB1, FB2, FW1, FW2, FW3, HV1, HV2, HV3, and HV4 refer to the forestry machines studied in this work. The letters correspond to the measurement outline in the methodology. Source: Prepared by the Authors (2024).

Additionally, the analysis of seat inclination and the distance between armrests revealed significant differences between the evaluated models. The seat inclination (parameter f) varied between +8 to -15 degrees, which is consistent with ergonomic recommendations, except for some specific models that exhibited limitations in adjustment capabilities. The distance between the armrests (parameter g), which should be between 42 and 52 cm, showed compliance in some models, such as the Forwarders, but not in all, as observed in the Feller Bunchers and Harvesters. These additional aspects underscore the importance of ergonomic adjustments not only in cabin height and width but also in the adjustments of seat components to ensure operator comfort and operational effectiveness.

Based on the results obtained from this research, modifications have been proposed for the workstation to ensure it meets the anthropometric profile of the analyzed operators (Figure 1). These adaptations are aimed at optimizing the ergonomic fit and improving overall comfort and efficiency. The proposed changes include adjustments to cabin dimensions, seat inclination, and armrest positions to better accommodate the range of operator sizes and preferences observed in the study. By implementing these recommendations, the workstation can be better tailored to the ergonomic needs of operators, thereby enhancing their performance and reducing the risk of discomfort or injury during operation.

Figure 1 – Layout of an Ideal Workstation for Forestry Operators



Source: Prepared by the Authors (2024).

4 DISCUSSION

According to Minette *et al*. (2015) and Lima (2018), organizations are increasingly demanding the implementation of production targets based on scientific and legal frameworks that prioritize workers' health, safety, and well-being. In this context, in addition to setting production goals based on machinery performance, cognitive and ergonomic parameters—including scheduled breaks and the design of an ideal work station—are being frequently implemented (LIMA *et al*., 2019). To address workers' functional limitations, it is essential to study operators' perceptions (Schettino *et al*., 2021). Such analyses are crucial for identifying potential weaknesses that need to be addressed, thereby fostering a more human-centered and sustainable work environment (Lima *et al*., 2023).

Noise has been identified as a significant source of discomfort for operators. Factors such as exposure duration, noise intensity, and individual susceptibility are directly related to health damage (Mattas *et al*., 2010). The adverse effects of noise extend beyond hearing impairment; they can also cause emotional disturbances, cardiovascular issues, fatigue, and stress (Lima *et al*., 2019). In a recent study by Lima *et al*. (2019), the author notes that the noise levels inside the cabins of forestry harvesting machinery did not exceed the safety standards established by Brazilian regulations. However, the noise levels outside the cabin could pose risks to external workers.

Additionally, back pain has emerged as the parameter with the highest volume of complaints in this study. In recent years, this condition has topped the list of the most common illnesses among sickness benefits granted by the National Institute of Social Security (INSS) (Lima, 2018). This data highlights the need for effective interventions to mitigate the incidence of spinal discomfort.

In this context, Minette *et al*. (2015) emphasize the importance of anthropometric analysis of operators in research focusing on the ergonomics of mechanized harvesting systems, given the anthropometric variability of the Brazilian population and associated risks. Incorporating specific anthropometric measurements is crucial for adapting harvesting systems to the physical characteristics of operators, thereby promoting a safer and more efficient work environment.

A poorly designed entryway into machinery can pose significant challenges, particularly for older operators (Skogforsk, 1999). Fontana & Seixas (2007) emphasize the necessity of adapting forestry machinery workstations imported into Brazil to suit the anthropometric profile of Brazilian forestry workers. In this context, understanding and adapting to the physical characteristics of the workforce is crucial for enhancing safety and efficiency.

Another key measure for assessing the health of an organization's employees is the Body Mass Index (BMI). Accurate ergonomic analysis requires a thorough understanding of workers' anthropometric dimensions, which allows for the development of a worker profile and enables the identification of discrepancies between the workers' physical characteristics and the demands of their work environment (Britto *et al*., 2015). This approach not only enhances ergonomic quality but also contributes to the overall well-being of the workforce by ensuring that the work environment is tailored to their needs.

The analysis of Body Mass Index (BMI) revealed that 77.77% of the operators are overweight, which is an alarming statistic. This finding is supported by the study by Silva *et al*. (2016), which identified a correlation between working hours and BMI. Their results showed that among employees working six to eight hours per day, 46.7% were overweight or obese. These data underscore the importance of health promotion interventions in the workplace, particularly given the impact of excess weight on the overall health of workers and their ability to perform the physical tasks required for operating forestry machinery.

The layout of the operator's cabin and the design of the seat are engineered to create optimal working conditions, thereby minimizing the incidence of occupational diseases and workplace accidents while enhancing machine productivity (Schettino *et al*., 2022). Key risks mitigated include those associated with vibrations, noise, and accidental impacts against internal machine structures, such as head injuries caused by contact with cabin components (Lima, 2018). The integration of suspension and vibration-damping systems in the seat and cabin is an effective measure to reduce these hazards, ensuring a safer and more comfortable working environment for operators (Forastiere *et al*., 2016). Moreover, these technological solutions are crucial for extending the operational longevity of workers, preventing the development of chronic health conditions that can be exacerbated by prolonged exposure to suboptimal ergonomic factors (Minette *et al*., 2015; Lima *et al*., 2019).

5 CONCLUSIONS

The proposed indicators, the "Ergonomic Satisfaction Coefficient" (ESC) and the "Occupational Health Coefficient of Operators" (OHCO), demonstrated strong performance and accurately measured ergonomic and occupational factors. However, it is important to emphasize that further studies should be conducted under varying productivity conditions and with different machinery types to strengthen the evidence. The FW2 and HV3 machinery received the highest ESC scores, indicating that their ergonomic parameters were better evaluated by the operators. Regarding the OHCO, most forestry machines were categorized as RARELY, reflecting minimal occupational health complaints. Nevertheless, the issue of lower back pain stands out and warrants further investigation to identify its causes.

The anthropometric analysis of operators facilitated the determination of a suitable workstation for the sample group of forestry machine operators. The most notable Anthropometric Reference Values (ARV) identified in the analysis were: 182 cm for cabin height, 85 cm for width, 40-48 cm for seat height adjustment, and 43-49 cm for forearm distance. These findings highlight the importance of tailoring machinery design to the specific anthropometric profiles of operators to enhance safety, comfort, and overall productivity.

Furthermore, the integration of these ergonomic and health indicators into routine evaluations can contribute to the continuous improvement of forestry machinery, ensuring that they meet the evolving needs of operators. This approach not only promotes the well-being of the workforce but also aligns with broader industry goals of sustainability and efficiency.

ACKNOWLEDGEMENTS

We extend our sincere gratitude to the Instituto Federal de Educação, Ciência e Tecnologia do Pará (IFPA), and the Universidade Federal de Viçosa (UFV) for their support and resources provided throughout this research. We also acknowledge the financial support from Coordenação de Aperfeiçoamento de Pessoal de Nível Superior - Brasil (CAPES) and the Conselho Nacional de Desenvolvimento Científico e Tecnológico - Brasil (CNPq). Special thanks to the Grupo Técnico de Colheita e Logística Florestal da Sociedade de Investigações Florestais and the Laboratório de Ergonomia, Colheita e Logística Florestal for their valuable collaboration and technical expertise.

REFERENCES

ALMQVIST, R.; GELLERSTEDT, S.; TOBISH, R. Ergonomic Checklist for Forest Machines. **Swedish University of Agricultural Sciences**, p. 23-29, 2006.

BRASIL. Ministério do Trabalho e Emprego. **Norma Regulamentadoras** - NR's. Brasília, 2024. Disponível em: https://www.gov.br/trabalho-e-emprego/pt-br/assuntos/inspecao-do-trabalho/seguranca-e-saude-no-trabalho/ctpp-nrs/normas-regulamentadoras-nrs. Acesso em: 16 ago. 2024.

BRASIL. MINISTÉRIO DO TRABALHO E EMPREGO. **NR 31 - Segurança e Saúde no Trabalho na Agricultura, Pecuária, Silvicultura, Exploração Florestal e Aquicultura.** Portaria nº 86, de 03 de março de 2005.

BRITTO, P. C.; DA SILVA LOPES, E.; DRINKO, C. H. F.; GONÇALVES, S. B. Fatores Humanos e Condições de Trabalho em Atividades de Implantação e Manutenção Florestal. **Floresta e Ambiente**, v. 22, n. 4, p. 503-511, 2015.

CARMO, F. C. D. A.; FIEDLER, N. C.; MINETTE, L. J.; DE SOUZA, A. P. Otimização do uso do trator florestal forwarder em função da produtividade, custos e capacidade de carga. **Revista Árvore**, v. 39, n. 3, p. 561-566, 2015.

FERNANDES H. C.; BRITO, A. B.; MINETTI, L. J.; LEITE, D. M.; LEITE, E. S. Aplicação de índices ergonômicos na avaliação da cabine de um trator florestal "*Feller-Buncher*". **Sci. For.**, Piracicaba, v. 39, n. 90, p. 273-281, 2011.

FONTANA, G. & SEIXAS, F. Avaliação ergonômica do posto de trabalho de modelos de "forwarder" e "skidder". **Rev. Árvore,** v. 31, n. 1, 2007.

FORASTIERE, P. R.; FERNANDES, H. C.; TEIXEIRA, M. M.; CECON, P. R.; DO NASCIMENTO SANTO, D. W. F. Caracterização das Vibrações Mecânicas no e Ruído no Posto de Operação no Trator Agrícola Modificado "Transformax". **Revista Engenharia na Agricultura**, v. 24, n. 4, p. 291-301. 2016.

FURTADO LIMA, Cássio *et al*. Is there a relationship between forest fires and deforestation in the Brazilian Amazon?. **Journal Plos One**, v. 19, n. 6, p. e0306238, 2024.

GUEDES, I. L. ; AMARAL E. J.; LEITE, E. S. ; FERNANDES, H. C. ; SANT'ANNA, C. M. Performance and Cost Evaluation of Two Cable Yarder Systems in The Extration Of Eucalyptus Wood. **Ciência Florestal**, v. 27, n. 2, p. 571-580, 2017.

IBÁ - Indústria Brasileira de Árvores. (2023). **Relatório 2023**. São Paulo: IBÁ. Acesso em: 25 de Janeiro de 2024. Disponível em: https://iba.org/datafiles/publicacoes/relatorios/relatorio-anual-iba2023-r.pdf

IBGE – INSTITUTO BRASILEIRO DE GEOGRAFIA E ESTATÍSTICA – IBGE. **Pesquisa de Orçamentos Familiares 2008-2009: tabela de medidas referidas para os alimentos consumidos no Brasil.** Rio de Janeiro. IBGE, 2011.

INT – INSTITUTO NACIONAL DE TECNOLOGIA. **Pesquisa antropométrica e biomecânica dos operários da indústria de transformação - RJ. (Medidas para postos de trabalho).** Rio de Janeiro, v. 1, 1988, 128 p.

LACERDA, L. C.; FIEDLER, N. C.; CHICHORRO, J. F.; MINETTE, L. J.; CARMO, F. C. D. A. D. Analysis of The Production Capacity From a Harvester in the Forest in Own and Outsourced Modules. **Revista Árvore**, v. 41, n. 1, 2017.

LIMA, Cássio Furtado *et al*. Occupational noise and vibration assessments in forest harvesting equipment in North-eastern Brazil. **Journal of Experimental Agriculture International**, 2019.

LIMA, Cássio Furtado. Fatores ergonômicos, operacionais e produtividade de operadores de máquinas de colheita florestal. **Dissertação** (Mestrado em Ciência Florestal) Universidade Federal de Viçosa, Campus Viçosa (MG). 2018.

LIMA, Roldão Carlos Andrade *et al*. Measurement Time in the Evaluation of Whole-Body Vibration: The Case of Mechanized Wood Extraction with Grapple Skidder. **Forests**, v. 14, n. 8, p. 1551, 2023.

MACHADO, C. C. **Colheita Florestal**. 3 ed.Editora UFV. Viçosa - MG: UFV, 2014. 543 p.

MATTAS, D. M. P.; DALLMEYER, A. U.; SCHOLOSSER, J. F.; DORNELLES, M. E. Conformidade de acessos e de saídas de postos de operação em tratores agrícolas segundo norma NBR/ISO 4252. **Revista Engenharia Agrícola**, Viçosa, v. 30, n. 1, p. 74-81, 2010.

MINETTE, L. J.; DE SOUZA, A. P.; DA SILVA, E. P.; MEDEIROS, N. M. Postos de trabalho e perfil de operadores de máquinas de colheita florestal. **Revista Ceres**, v. 55, n 1, 2015.

OLIVEIRA, FELIPE MARTINS DE; LOPES, ELIZIANE DE SOUZA; FIEDLER, NILSON CÉSAR; KOEHLER, HENRIQUE SEELIG**.** Indicador para avaliação da urgência na intervenção ergonômica de máquinas de colheita da madeira. **Revista Árvore,** v. 44, p. e4428, 2020.

SANTOS, D.W.F.N.; VALENTE, D.S.M.; FERNANDES, H.C.; FORASTIERE, P.R.; SILVA, R.M.F. Análise técnica e econômica do harvester operando em dois subsistemas de colheita de madeira. **Revista Engenharia na Agricultura-REVENG**, 24(6), 484-490. 2016.

SCHETTINO, S. *et al.* Forest harvesting in rural properties: Risks and worsening to the worker's health under the ergonomics approach. **International Journal of Industrial Ergonomics**, [*s. l.*], v. 82, p. 1–7, 2021.

SCHETTINO, S.; MINETTE, L. J.; SORANSO, D. R.; CAMARINHA, A. C. M.; SCHETTINO, C. F. Avaliação ergonômica da colheita florestal em área com madeira danificada pelo vento. **Agropecuária Científica no Semiárido**, v. 14, n. 1, p. 70-78, 2018.

SCHETTINO, S.; MINETTE, Luciano José; SORANSO, D. R.; LIMA, R. C. A. Influence of Ergonomic Factors on the Productivity of Man-Machine System in Mechanized Forest Harvesting**. Scientia Forestalis**, v. 50, p. e3779, 2022. DOI: http://dx.doi.org/10.18671/scifor.v50.20

SEIXAS, F.; BATISTA, J. L. F. Comparação técnica e econômica entre *harvesters* de pneus e com máquina base de esteiras. **Ciência Florestal,** Santa Maria, v. 24, n. 1, p. 185-191, 2014.

SILVA, P. N.; CAPDEBOSCQ, M.C.; SANTOS, A. C. B.; IEKER, A. S. D.; RINALDI, W. Associação entre o índice de massa corporal, jornada de trabalho e nível de atividade física dos servidores do hemocentro do hospital universitário de Maringá. **Arq. Ciênc. Saúde UNIPAR**, v. 20, n. 3, p. 165-170, 2016.

SKOGFORSK – THE FOREST RESEARCH INSTITUTE OF SWEDEN. **Ergonomic guidelines for forest machines.** Uppsala, Sweden: Swedish National Institute for Working Life, 86 p, 1999.

WHO – ORGANIZAÇÃO MUNDIAL DE SAUDE – OMS. **Promoción de la salud glosario**. Genebra: OMS, 1998.