EVALUATION OF THE PHYSICAL WORKLOAD IN COFFEE PRODUCTION: BIOMECHANICAL AND PHYSIOLOGICAL ASPECTS

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ABSTRACT: The main objective of this research was the assessment of the physical workload of farm coffee workers from southern Minas Gerais, Brazil. Twelve workers were reconded and their heart rate monitored during one hour execution of five different tasks, both on flat and sloping ground. The assessment of body postures adopted and the actions performed were achieved through the "Captiv" software. We attempted to correlate the results of the assessments and interpret them in the light of the observation of the activities of the workers. The most significant cardiovascular demands occurred in subtasks of foliar and manual fertilization, classifying them as moderate work. Harvesting and thinning were the subtasks that appeared to have the greatest variability of postural combinations: the harvest due to the variety of operating actions; the thinning, although only one relevant operational action, due to the very nature of the task. Either the cardiovascular or the biomechanical indicators revealed no statistically significant differences between the subtasks carried by workers in conditions of flat and sloping ground.

Index terms: Ergonomics, heart rate, postural combinations, workload, coffee growing.

AVALIAÇÃO DA CARGA FÍSICA DE TRABALHO NA PRODUÇÃO DE CAFÉ: ASPECTOS BIOMECÂNICOS E FISIOLÓGICOS

RESUMO: *Objetivou-se, nesta pesquisa, avaliar a carga física do trabalho na cafeicultura do sul de Minas Gerais, Brasil. Doze trabalhadores foram filmados e sua frequência cardíaca foi monitorada durante uma hora na execução de cinco diferentes tarefas, ambas em condições de terreno plano e em declive. Foram avaliadas as combinações posturais adotadas através do software "Captiv". Buscou-se correlacionar os resultados das avaliações e interpretá-los à luz da observação das atividades dos trabalhadores. As cargas cardiovasculares mais elevadas ocorreram nas subtarefas de adubação foliar e adubação a lanço, classificando-as como trabalho moderado. A colheita e a desbrota foram as subtarefas que apresentaram maior variabilidade de combinações posturais: a colheita devido à variedade de ações operacionais; a desbrota, apesar de uma única ação operacional relevante, por conta da própria natureza da tarefa. Tanto os indicadores cardiovasculares, como os biomecânicos não revelaram diferenças estatisticamente significativas entre as subtarefas desenvolvidas pelos trabalhadores, em condições de terreno plano e em declive.*

Termos de indexação: *Ergonomia, carga cardiovascular, combinações posturais, carga de trabalho, cafeicultura.*

1 INTRODUCTION

Agribusiness is responsible for 33% of Brazil's gross domestic product, 42% of total exports and 37% of Brazilians jobs, employing about 17.7 million workers, occupying a prominent position in the Brazilian economy. Coffee production is very important in the context of the Brazilian economy since Brazil is responsible for about a third of the world production, which makes the country the largest producer - a position maintained in the last 150 years. Brazil has a planted area of 2.3 million hectares, producing 3.05 million tons of coffee. The state of Minas Gerais is the largest producer in the country with 51,14% of the Brazilian production, around 1.56 million tones (INSTITUTO BRASILEIRO DE GEOGRAFIA E ESTATÍSTICA - IBGE, 2012).

There are many researches on coffee production regarding technical, agronomic or socioeconomic issues; few researches, however, try to identify the characteristics of the human workload of the coffee farming, under an ergonomic perspective. In that sense, a participatory ergonomics approach was used during two Nicaraguan shade-grown coffees harvesting seasons to reduce the physical load on harvesters with the use of a newly designed bag instead of a basket strapped around the waist. Among basket users, 84.2% reported pain in at least one body area compared to 78.9% of bag users. Nonetheless, 74% of participants liked the bag much more than the basket (SILVERSTEIN; BAO; RUSSEL, 2012).

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Being mostly a non-repetitive, non-monotonous type of work, agricultural work needs a group of methods, both objective and subjective, to characterize its workload. In this perspective, a study (ABRAHÃO; RIBEIRO; TERESO, 2012) was done aiming the characterization of the physical workload of the organic horticulture, by determining the frequency of exposure of operators to some activity categories. The approach included an evaluation of physical effort demanded to perform the tasks in the work systems from a systematic sampling of work situations from a synchronized monitoring of the heart rate; a characterization of posture repertoire adopted by workers by adapting the OWAS method; an identification of pain body areas using the Corlett diagram; and a subjective evaluation of perceived effort using the RPE Borg scale. The results of the individual assessments were cross correlated and explained from an observation of the work activity. Postural demands were more significant than cardiovascular demands for the studied tasks, and correlated positively with the expressions of bodily discomfort.

Ribeiro, Tereso and Abrahão (2009) analyzed the operator's workload in six fresh tomatoes packing house unities, focusing in manual material handling tasks, using the ergonomic work analysis method, the NIOSH equation and the body discomfort diagram. The application of the NIOSH equation showed that the risks of musculoskeletal disorders were moderate or high in all of the workplaces analyzed. The workers reported great body discomfort in shoulders, neck and lumbar regions.

Heart rate is traditionally used as an indicator of physiological effort, being increasingly used instead of oxygen consumption to estimate the workload of a task (FRUTUOSO; CRUZ, 2005).

Cardiovascular parameters commonly used include the average heart rate during work − the working heart rate (HR_W), the resting heart rate (HR_R), the maximum heart rate (HR_{max}), the limit heart rate (HR_L) and the relative heart rate (HRR). The relative heart rate at work is an important indicator of physiological strain and should not exceed 40% for an eight hour period to avoid fatigue (ASTRAND; RODAHL; SIGMUND, 2006).

The working heart rate is also used as a strain indicator and determines the following categories of work intensity: light ($HR_W<90$); moderate ($90 \leq HR_W<110$); heavy ($110 \leq HR_W<130$), very heavy ($130 \leq HR_W<150$) and extremely heavy ($HR_W>150$) (ABRAHÃO; RIBEIRO; TERESO, 2012; ASTRAND; RODAHL; SIGMUND, 2006).

The main objective of this work was the assessment of the physical workload in an agriculture context, applying the proposed method in a case study of the work on coffee farming system. We sought to evaluate the cardiovascular load and the postural combinations adopted in coffee production. This kind of study can help to direct research efforts towards the technological development of coffee farming, both to improve human work productivity and to reduce ergonomic hazards.

2 MATERIAL AND METHODS

The proposed study is experimental under field conditions with quantitative and qualitative elements. The descriptors of the physical workload are the group of dependent variables, including those of physiological (working heart rate, cardiovascular load) and biomechanical (postural combinations).The independent variables are composed by tasks, subtasks and the topography of the farms.

Twelve workers from seven small family coffee farms from Santo Antonio do Amparo, southern Minas Gerais, agreed to participate in this study. Each subject was voluntary and received adequate information about the research. They had the right to withdraw from participation at any time, without penalty of any kind and without providing reasons. Each of them was filmed performing one hour work of the subtasks, both in flat terrain and in areas with more than 10% slope.

The tasks from the coffee farming systems considered in this study are crop handling and harvest. They had the following subtasks and respective operations:

a) **Crop Handling: manual fertilization** (empty bag displacement, bag stuffing, full bag displacement and manual fertilization); foliar fertilization (empty costal pulverizer displacement, costal pulverizer refuelling, full costal pulverizer displacement and application); **t**hinning (thinning); and herbicide application (empty costal pulverizer displacement, costal pulverizer refuelling, full costal pulverizer displacement and application).

b) **Harvest: harvest** (canvas placement, manual harvest, canvas displacement, sieving, manual cleaning and bagging).

We measured resting heart rate (HR_R) and calculated maximum heart rate (HR_{max}) for each of the workers. The work heart rate (HR_W) was measured continuously for each subject, synchronized with the video recording.

A Polar RS800CX G3 heart rate monitor was used with a sampling rate of 2 seconds.

The heart rate indicator adopted in this work was calculated as follows (ABRAHÃO; RIBEIRO; TERESO, 2012; ASTRAND; RODAHL; SIGMUND, 2006):

$$HR_{max} = 220 - age$$

$$HRR = \frac{(HR_W - HR_R)}{(HR_{max} - HR_R)} \; x \; 100$$

The working heart rate (HR_W) was calculated by averaging the frequencies measured during the period of work evaluated. With the heart rate work the cardiovascular loads (HR_R) were calculated, which allowed the evaluation of the cardiac stress in the execution of different subtasks.

Workers' personal and biometric data are shown in Table 1.

The postural protocol was adapted from OWAS (IIDA, 2005; MESSIAS; OKUNO, 2012; NWE et al., 2012) to include the characteristics postures of coffee farm labor (Figure 1).

The experiment was conducted in a randomized block design, where each worker was considered a block in a 5x2 factorial design. The factors were slope and the subtasks. It was performed an analysis of variance and the Tukey test was applied to compare means. When necessary, we applied the F-test and Scott Knott for additional statistical analyzes to evaluate differences between variables (FERREIRA, 2011).

TABLE 1 - Personal and biometric data of the workers.

Worker	Gender	Age (years)	Seniority (years)	Weight (kg)	Height (cm)	HR_R (bpm)	HR_{max} (bpm)
1	M	59	22	64	165	66	161
2	M	30	8	93	179	52	190
3	M	60	11	70	171	63	160
4	M	30	10	60	163	59	190
5	M	40	20	94	187	64	180
6	M	34	9	63	165	56	186
7	M	31	20	61	172	66	189
8	F	25	6	66	160	53	195
9	M	35	20	100	190	65	185
10	M	39	19	84	182	67	181
11	M	29	20	74	180	53	192
12	M	68	39	54	169	71	153

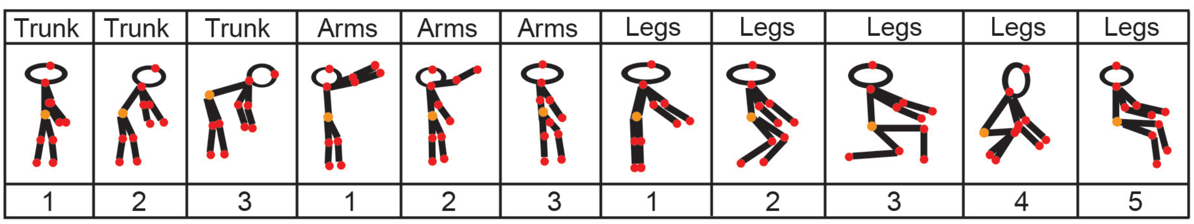

FIGURE 1 - Postural protocol adopted.

3 RESULTS AND DISCUSSION

The mean working heart rate and relative heart rate results, for the twelve workers performing all subtasks in both topographic conditions, with its standard deviation, are summarized on Table 2.

Table 2 shows that 58,3% of the workers exhibited HRW between 90 and 110 bpm, configuring moderate work intensity, while 41,7% had HRW less than 90 bpm, configuring light work intensity. All of the HRR results are under 40% and in safe limits according to the literature, according to Astrand, Rodahl and Sigmund (2006).

ANOVA results showed that the slope factor was not statistically significant with respect to heart rate results. On the other hand, the subtask factor was statistically significant for ($p<0,05$).

Table 3 shows mean heart rate values for all the workers performing the subtasks. Means followed by same letter do not differ at the 5% level of significance by the Tukey test. Foliar and manual fertilization exhibited significantly greater values of HR_W and HRR than the other subtasks. The results showed that heart rates are statistically different among the subtasks. Foliar and manual fertilization, classified as moderate work, were more demanding than the other subtasks. Subtasks herbicide application, thinning and harvesting were classified as light work on the basis of averages for working heart rate and cardiovascular workload.

Statistical analysis showed no significant difference in the execution of the subtasks among both working heart rate and cardiovascular workload on different topographical conditions, as shown in table 4.

Figure 2 shows the postural combinations observed in different subtasks of coffee production.

The postural combinations 131 (neutral trunk, two arms below the shoulder line, legs extended) and 231 (moderate trunk flexion, two arms below the shoulders, legs extended) were characteristics of the subtask manual fertilization, as can be seen in figure 3.

These postural combinations were constrained by operational actions, since the worker carried a bag of granulated fertilizer in one hand while with the other he threw the fertilizer toward the base of the coffee trees.

In subtask foliar fertilization the characteristics postural combinations were 121 (neutral trunk, one arm above the shoulder line, legs extended), 131 and 231 (Figure 4). These postural combinations were also conditioned by the nature of the operational actions. The workers carried the backpack sprayer (keeping the torso upright or in moderate bending), operated a hand pump with one hand and with the other applied the foliar fertilizer, alternating one arm below and the other above shoulder height.

The postural combinations 131 and 231 were characteristic of subtask herbicide application, as can be seen in figure 5. In this subtask, workers also carried the backpack sprayer (keeping the torso upright or in moderate bending), keeping the two arms were below shoulder height.

TABLE 2 - Heart rate results for workers performing all subtasks.

Worker	$HR_W \pm SD$ (bpm)	HRR ± SD (%)	Work Intensity
1	88,9 ± 5,1	24,11 ± 5,4	Light
2	90,0 ± 5,8	27,54 ± 4,2	Moderate
3	95,5 ± 3,9	31,05 ± 4,1	Moderate
4	105,8 ± 5,1	38,99 ± 3,7	Moderate
5	79,9 ± 2,0	14,63 ± 2,2	Light
6	98,9 ± 3,3	33,99 ± 2,4	Moderate
7	96,8 ± 2,9	32,42 ± 3,1	Moderate
8	96,2 ± 6,1	32,03 ± 4,4	Moderate
9	81,6 ± 4,5	16,42 ± 4,8	Light
10	88,4 ± 5,7	26,38 ± 4,1	Light
11	101,2 ± 4,2	37,05 ± 4,4	Moderate
12	85,9 ± 4,4	24,57 ± 3,2	Light

TABLE 3 - Averages results of HR_W and HRR for the subtasks.

Subtasks	Topography	$(HR_W)^*$ (bpm)	$(HRR)^*$ (%)
Thinning	Flat	88,17 b	24,39 b
	Sloping	83,75 b	20,42 b
Harvest	Flat	84,58 b	21,14 b
	Sloping	92,00 b	27,55 b
Herbicide application	Flat	91,17 b	26,73 b
	Sloping	85,92 b	23,20 b
Manual fertilization	Flat	98,33 a	33,39 a
	Sloping	100,58 a	36,37 a
Foliar fertilization	Flat	99,17 a	33,73 a
	Sloping	100,58 a	35,74 a

*Results followed by the same letter do not differ at 5% significance level for the Scott-Knott test.

TABLE 4 - Averages results of HR_W and HRR for topography.

Topography	Averages HR_W*(bpm)	Averages HRR*(%)
Flat	92,28 a	27,87 a
Sloping	92,57 a	28,65 a

* Results followed by the same letter in columns do not differ at the 1% level of significance by F test.

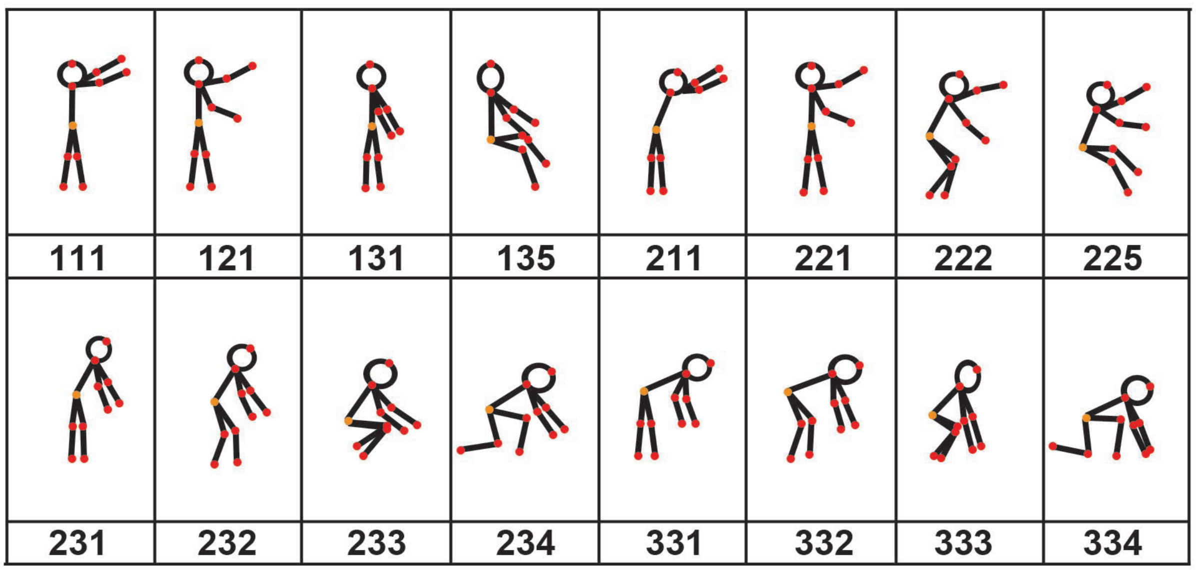

FIGURE 2 - Postural combinations adopted by the workers.

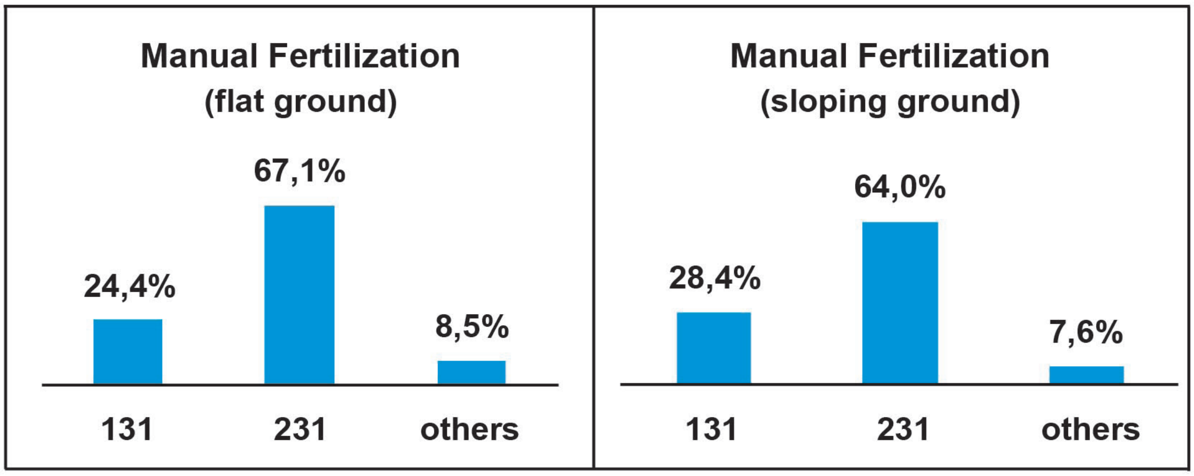

FIGURE 3 - Postural combinations the manual fertilization.

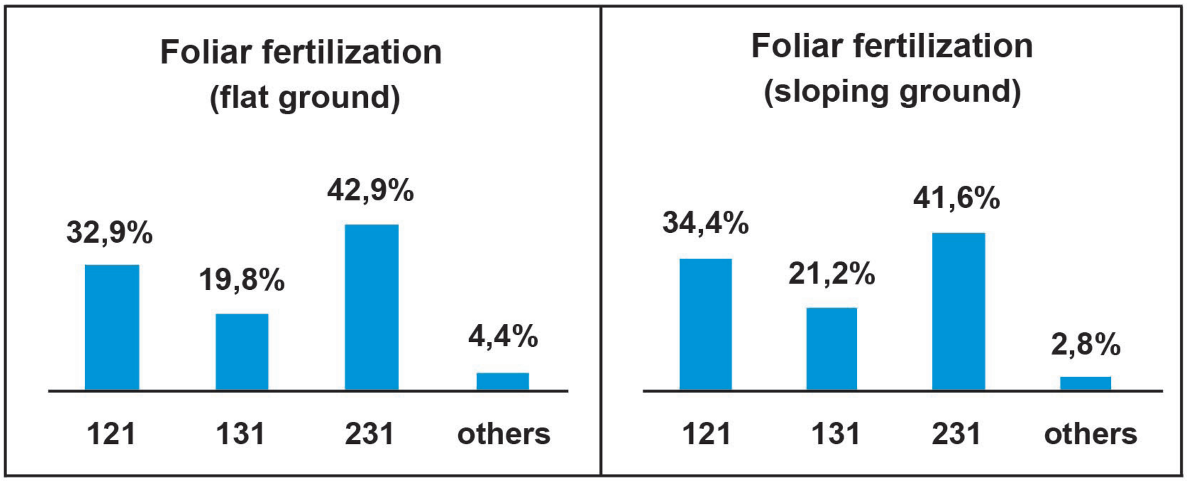

FIGURE 4 - Postural combinations in the foliar fertilization.

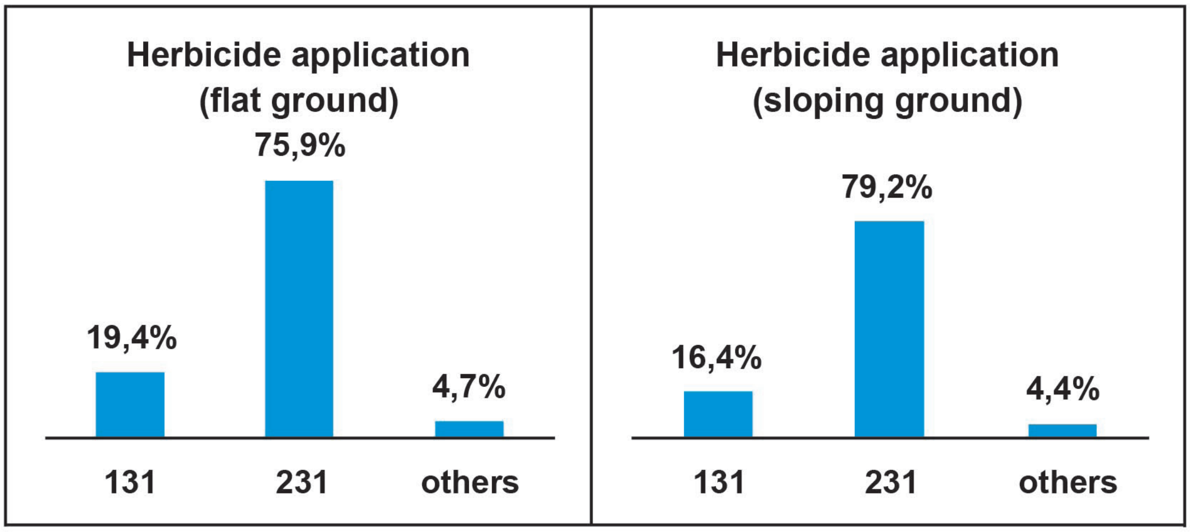

FIGURE 5 - Postural combinations in the herbicide application.

In subtask thinning, body posture characteristics are shown in Figure 6. Although this subtask presents a single operational action, as the workers walk around the coffee tree removing unwanted shoots on any plant height, there is a large number of postural combinations.

In the harvest subtask the characteristics postural combinations are shown in Figure 7. In this case, the large variability of postural combinations is explained by the greater amount of operational actions required to perform the subtask.

Statistical analysis showed no significant difference in the adoption of postural combinations for the significance level of 5% by the Scott Knott test for different topographical conditions.

Contrary to what was expected by common sense, the topography factor had not shown decisive influence neither on the cardiovascular workload nor in the postural combinations adopted by workers in the execution of the subtasks. This can be explained by the working strategies adopted by workers to cope with this difficulty.

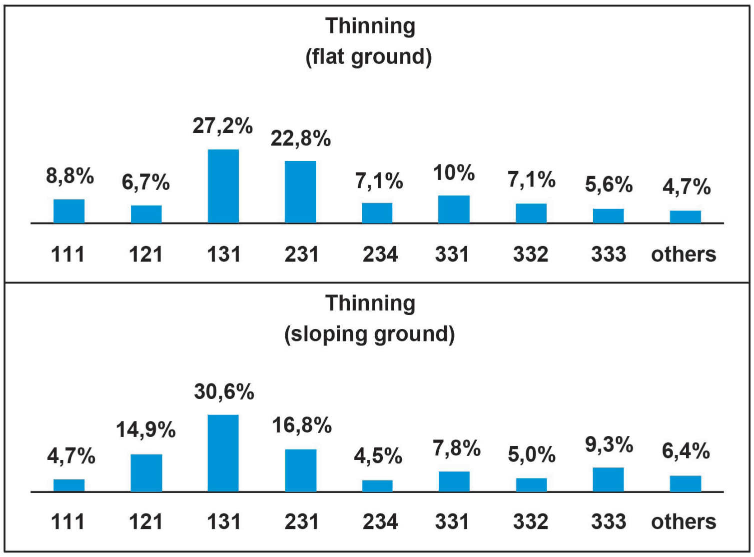

FIGURE 6 - Postural combinations in the thinning.

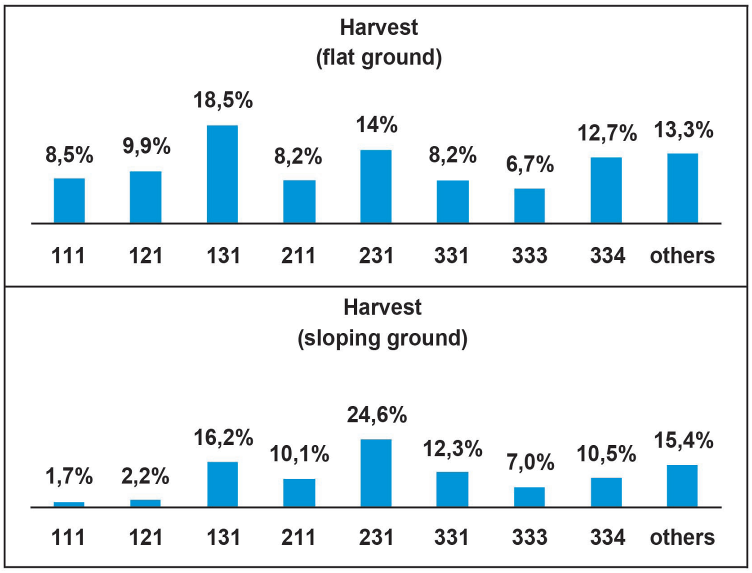

FIGURE 7 - Postural combinations in the harvest.

4 CONCLUSION

Subtasks foliar fertilizer, manual fertilizer, drying and storage showed the greater cardiovascular demands.

Often, for best results at work in terms of productivity, workers adopt more demanding postural combinations or increase the pace of work, with a consequent increase in heart rate.

The analysis of all tasks showed that the most frequent postural combinations were 231 (moderate trunk flexion, two arms below the shoulders, legs extended) and 131 (neutral trunk, two arms below the shoulder line, legs extended).

By its nature, the subtasks thinning and harvest presented greater variability of postural combinations.

Both cardiovascular and biomechanical indicators revealed no statistically significant differences between the subtasks developed in different topographic conditions. This was due mainly because the strategies adopted by workers, who planned the execution of the tasks considering the topographic characteristics of the terrain.

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