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A LINEAR PROGRAMMING APPROACH TO ANALYZE MUSCULOSKELETAL DISORDER RISK FACTORS IN HAZELNUT HARVESTING WORKERS

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Abstract

Harvesting hazelnuts is a labor-intensive agricultural activity crucial for sustaining the global nut industry. Despite its significance, this activity poses a potential risk to workers' musculoskeletal health due to the demanding nature of the work. This study proposes a linear programming approach to analyze risk factors associated with work-related musculoskeletal disorders among hazelnut harvesting workers. The initial phase of the study includes the identification of key risk factors through a literature review, field observations, and expert consultations. An expert team is formed to evaluate these factors from both academic and producer perspectives. The selection of the experts is done by considering their experience, educational background, knowledge, and publications relevant to the research topic. To determine the importance of the factors, the LP-GW-AHP method (a linear programming method to generate weights in the analytic hierarchy process) is employed. Once the pairwise comparison matrix is established, a mathematical model is created to obtain optimal weights. Additionally, a comparative analysis is conducted to support the validity of the model results. According to the results, harvest area, repetitive movements, and prolonged standing are the top three most important factors. Furthermore, the least important factors are determined to be experience, vibration, and mental and occupational stress. This study presents its novelty by formulating the evaluation of musculoskeletal disorder risk factors as a linear programming-driven multicriteria decision-making problem and applying the LP-GW-AHP method to the problem.

Keywords: Ergonomics, LP-GW-AHP, Linear programming, Musculoskeletal issues

FINDIK HASADI İŞÇİLERİNDE KAS-İSKELET SİSTEMİ RAHATSIZLIĞI RİSK FAKTÖRLERİNİ ANALİZ ETMEK İÇİN BİR DOĞRUSAL PROGRAMLAMA YAKLAŞIMI

Özet

Fındık hasadı, küresel fındık endüstrisinin sürdürülmesi için hayati önem taşıyan, emek yoğun bir tarımsal faaliyettir. Önemine rağmen bu faaliyet, işin zorlu doğası nedeniyle çalışanların kas-iskelet sağlığı açısından potansiyel bir risk oluşturmaktadır. Bu çalışma, fındık hasadı işçilerinde işe bağlı kas-iskelet sistemi rahatsızlıklarıyla ilişkili risk faktörlerini analiz etmek için bir doğrusal programlama yaklaşımı önermektedir. Çalışmanın ilk aşaması, literatür taraması, saha gözlemleri ve uzman istişareleri yoluyla kilit risk faktörlerinin tanımlanmasını içermektedir. Bu faktörleri hem akademik hem de üretici bakış açılarından değerlendirmek için uzman bir ekip oluşturulmaktadır. Uzmanların seçimi deneyimleri, eğitim geçmişleri, bilgileri ve araştırma konusuyla ilgili çalışmaları dikkate alınarak yapılmaktadır. Faktörlerin önemini belirlemek için LP-GW-AHP yöntemi (analitik hiyerarşi prosesinde ağırlıkları üretmek için bir doğrusal programlama yöntemi) kullanılmaktadır. İkili karşılaştırma matrisi oluşturulduktan sonra optimal ağırlıkları elde etmek için bir matematiksel model oluşturulmaktadır. Ayrıca, model sonuçlarının geçerliliğini desteklemek için bir karşılaştırmalı analiz yapılmaktadır. Sonuçlara göre, hasat alanı, tekrarlayan hareketler ve uzun süreli ayakta durma en önemli üç faktördür. En az önemli faktörler ise deneyim, titreşim ve zihinsel ve mesleki stres olarak belirlenmiştir. Bu çalışma, kas-iskelet sistemi rahatsızlığı risk faktörlerinin değerlendirilmesini doğrusal programlamaya dayalı birçok kriterli karar verme problemi olarak formüle ederek ve probleme LP-GW-AHP yöntemini uygulayarak yeniliğini sunmaktadır.

Anahtar Kelimeler: Ergonomi, LP-GW-AHP, Doğrusal programlama, Kas-iskelet sorunları

Cite

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1. Introduction

Work-related musculoskeletal disorders (WMSDs) constitute a significant health concern within workplaces and occupational activities and encompass a variety of painful conditions that affect muscles, tendons, ligaments, joints, and other soft tissues [1]. Prolonged exposure to repetitive motions, awkward postures, and forceful exertions, especially without adequate rest or ergonomic support, can significantly contribute to the development of WMSDs [2]. Poorly designed workstations, improper tools, and insufficient training on ergonomic practices can exacerbate these issues. Additionally, factors such as high job demands, work-related stress, and lack of control over tasks may contribute to the onset of WMSDs. Prevention and mitigation strategies often involve ergonomic interventions, employee education, and workplace design improvements [3].

Hazelnut harvesting is a labor-intensive agricultural activity that poses risks for WMSDs. Workers engaged in hazelnut harvesting perform various tasks, including bending, reaching, and lifting heavy loads of nuts. These repetitive movements, coupled with extended periods of stooping and manual labor, increase the likelihood of developing musculoskeletal issues. Harvesting hazelnuts places strain on different parts of the body, such as the back, shoulders, and wrists. The cumulative impact of these physical demands over time can lead to discomfort, pain, or more severe musculoskeletal conditions [4].

Occupational health and safety is a crucial aspect of ensuring the well-being of workers and preventing work-related injuries and illnesses. Identifying hazards, assessing risks, and implementing control measures are pivotal components of effective risk management [5]. Risk assessment is a fundamental step in occupational health and safety management. It involves identifying, analyzing, and evaluating potential/known hazard risks and determining the best ways to control or eliminate these risks. This process helps prevent accidents and health issues. Qualitative, quantitative, and combined risk assessment methods can be employed to gain a thorough understanding of risks and ensure the implementation of effective preventive measures [6].

In the literature, many studies have focused on work-related musculoskeletal injuries and disorders. Leite et al. [7] employed the OCRA method to assess the risk of WMSDs in a footwear company. The cross-sectional study conducted by Rahimi et al. [8] highlighted the high prevalence of musculoskeletal disorders among Iranian physiotherapists. The research specifically identified elevated rates in the lumbar, neck, shoulder, and upper back regions. Shin and Park [3] focused on optimizing workstation specifications through the utilization of a three-dimensional human modeling tool and presenting well-balanced work scheduling as an administrative control. Abdul Aziz et al. [9] integrated the analytic hierarchy process (AHP) method into a web-based ergonomics assessment system to prioritize some risk factors. In a study conducted by Khan et al. [10], the factors contributing to lower back pain among industrial workers were prioritized through the utilization of the best-worst method. Qureshi and Solomon [11] employed the REBA and RULA methods for the ergonomic assessment of postural loads in foundry units. Jain et al. [12] focused on addressing the prevalent issue of musculoskeletal disorders among users of mobile devices. The researchers employed the best-worst method to assign priority to various risk factors. Sharma et al. [13] used the ordinal priority approach to analyze risk variables associated with musculoskeletal disorders in professional vehicle drivers in India. Tatar et al. [14] proposed a risk assessment model that integrates the Fine-Kinney and spherical fuzzy AHP-TOPSIS methods to address work-related musculoskeletal disorders in tea harvesting workers. Sing et al. [15] reported that increasing job control leads to improved physical and psychological well-being among employees. Alyousef et al. [16] asserted that individuals with lower limb osteoarthritis experience decreased work ability, diminished work performance, and struggle to meet physical and scheduling demands in the workplace. Marimuthu et al. [17] employed the SWARA method to examine risk factors affecting workers in the mining sector. Their findings highlighted musculoskeletal disorders, stress, fatigue, and dust exposure as the primary concerns adversely impacting the health and safety of mine workers. Sardar et al. [18] applied the RULA, REBA, and OWAS methods to calculate posture-related physical risk levels. Aksüt et al. [19] utilized the AHP and PROMETHEE methods to emphasize the importance of wearable technological devices in enhancing workplace health and safety. In a study conducted by Das et al. [20], the interrelationships of eight risk factors were analyzed using interpretative structural modeling. According to the results, organizational culture and repetitive tasks emerged as significant concerns. Gerger et al. [21] indicated that factors related to physical exposure in the workplace, such as frequent repetition, high velocity, and the concurrent presence of multiple physical stressors, were linked to a heightened likelihood of developing carpal tunnel syndrome. Fathimahhayati et al. [22] compared the AWBA, RULA, REBA, and OWAS methods to assess potential WMSDs in oyster mushroom farmers. Huang et al. [23] proposed a spatial relationship-aware rapid entire body fuzzy assessment approach for prevention of WMSDs. Zhang and Huang [24] reported that tilting waste containers could notably enhance the ergonomics of sanitation workers' posture and mitigate the likelihood of WMSDs. Zohair et al. [25] uncovered a significant occurrence of WMSDs among schoolteachers, with the predominant issue being neck pain. Principal factors contributing to this situation included age, workload, and insufficient physical activity. Given the inadequacy of mathematical programming-based studies in addressing musculoskeletal disorders within agricultural activities, this study aims to conduct a linear programming-driven multicriteria analysis to assess risk factors affecting hazelnut workers.

Multicriteria decision-making methods (MCDMs), such as AHP, can be used to analyze decision problems related to WMSDs. The AHP method involves structuring a decision problem into a hierarchy of criteria and alternatives and evaluating the pairwise comparisons of these elements to determine priority values. This hierarchical approach helps in organizing and understanding the different components of decision problems [26]. The AHP method considers both quantitative and qualitative factors to enable the inclusion of a wide range of decision inputs. The incorporation of mathematical consistency checks contributes to the credibility of model results [27]. One of the critical aspects in the application of the AHP method is the derivation of a priority vector from a pairwise comparison matrix. This process provides a weighted ranking of criteria or alternatives [28]. Many MCDM methods rely on intricate algorithms that necessitate the determination of numerous parameters. Hence, the quest for efficient and reliable methods of extracting priority vectors from decision matrices has emerged as a critical and ongoing research topic in the field of MCDM [29].

A linear programming method to generate weights in the AHP (LP-GW-AHP) offers a distinct approach for deriving local weights from pairwise comparison matrices within the AHP framework. The LP-GW-AHP method streamlines the weight derivation process by incorporating concepts from data envelopment analysis (a non-parametric efficiency measurement method) into the AHP method. The traditional AHP method necessitates the normalization of pairwise comparison matrices to obtain weight vectors. In contrast, the LP-GW-AHP method reduces computational complexity by solving only one linear programming model constructed through decision-makers' evaluations [30]. The LP-GW-AHP method and its variants have been successfully employed to solve various decision problems, including academic course design [31], elective course selection [32], staff selection [33], evaluation of customer preferences in product design [34], and service strategy planning [35].

The purpose of this study is to employ a linear programming approach for analyzing risk factors associated with WMSDs among hazelnut harvesting workers. The study intends to utilize the LP-GW-AHP method to systematically prioritize these risk factors. The proposed decision-making framework includes identifying key risk factors, assessing their relative importance, and obtaining a priority ranking result. The study contributes to the literature by addressing several gaps related to risk assessment and management in hazelnut harvesting. The study examines the key risk factors associated with WMSDs for hazelnut harvesting workers and formulates the decision problem as a linear programming-driven MCDM problem. The utilization of the LP-GW-AHP method to analyze musculoskeletal disorder risk factors represents another contribution to the literature. By examining the decision problem from an expert viewpoint, the study adds credibility and depth to its findings. The study reveals the importance weight of the risk factors specific to hazelnut harvesting. Furthermore, the study offers a valuable guide for decision-makers involved in occupational health and safety management. Further research can employ the devised decision-making framework to analyze different risk factors and can consider different decision support tools to address the issue. The findings of this research are expected to inform occupational health and safety practices in hazelnut harvesting and provide valuable insights for similar agricultural contexts.

The paper comprises four sections. The first section provides a brief overview of the research topic and surveys the relevant literature. Section 2 outlines the methodology used in the study. Section 3 presents the decision-making framework and the study's findings. Finally, Section 4 concludes the paper.

2. LP-GW-AHP Approach

The AHP method is widely employed to simplify and solve complex decision-making problems. It involves structuring a decision problem into a hierarchical model with three main levels: goal, criteria, and alternatives [36]. Decision-makers compare each element in a given level of the AHP hierarchy with every other element in the same level, considering how much one element is preferred over another. A 1-9 scale is used to compare decision elements and construct pairwise comparison matrices [37, 38]. The consistency ratio can be calculated to measure the reliability and consistency of decision-makers' judgments in pairwise comparisons. Comparisons are considered consistent if the consistency ratio is within an acceptable range, typically below 0.1 [39]. After the normalization of comparison matrices, the arithmetic mean is calculated for each row. These row averages serve as weights. The final step involves synthesizing model results to determine the best decision element [40].

The LP-GW-AHP method presents a different strategy for obtaining local weights from pairwise comparison matrices. In contrast to the conventional AHP method, which necessitates the normalization of pairwise comparison matrices to derive weight vectors, the LP-GW-AHP method simplifies the weight derivation process by solving a linear programming model generated from pairwise evaluations. The objective of the LP-GW-AHP model is to enhance the minimal weight of criteria or alternatives. The LP-GW-AHP model imposes a constraint on the sum of weights, ensuring that they total to one. Weights must be greater than or equal to zero. To tackle the challenge of generating counterintuitive local weights and minimizing overinsensitivity to certain comparisons in decision matrices, the concept of assurance regions is introduced for deriving weights. The formulation of the LP-GW-AHP model is as follows [30]:

$$\text{Max } Z \tag{1}$$

Subject to

$$w_i \geq Z \qquad i = 1,\ldots,n \tag{2}$$

$$\sum_{j=1}^{n} a_{ij} v_j - w_i = 0 \qquad i = 1,\ldots,n \tag{3}$$

$$\sum_{i=1}^{n} w_i = 1 \tag{4}$$

$$v_i - \frac{1}{\beta} w_i \geq 0 \qquad i = 1,\ldots,n \tag{5}$$

$$v_i - \frac{1}{n} w_i \leq 0 \qquad i = 1,\ldots,n \tag{6}$$

$$w_i \geq 0;\ v_i \geq 0 \qquad i = 1,\ldots,n \tag{7}$$

Here, the symbol w_i represents weights for decision elements, v_j denotes output weights produced by the linear programming model, and a_{ij} (i,j=1,…,n) refers to the elements of the AHP matrix. Assurance regions are defined by constraints (5) and (6). β is obtained using the following equation [30]:

$$\beta = \min\left\{\max_i\left(\frac{1}{r_i}\sum_{j=1}^{n} a_{ij} r_j\right), \max_i\left(\frac{1}{c_i}\sum_{j=1}^{n} a_{ij} c_j\right)\right\} \tag{8}$$

Here, r_i and c_i represent, respectively, the row and column sums of the AHP matrix.

3. Application

3.1. Decision-making framework

The harvesting of hazelnuts is a crucial and labor-intensive aspect of the agricultural sector, occupying a key position in sustaining the global nut industry. Hazelnuts contribute significantly to various culinary products and the overall economy [41]. The labor-intensive nature of hazelnut harvesting exposes workers to the risk of WMSDs. To effectively manage occupational health and safety in hazelnut harvesting, it is crucial to conduct a risk assessment. This involves identifying and prioritizing factors that contribute to the occurrence of WMSDs among hazelnut harvesting workers. By understanding these factors, targeted interventions and preventive measures can be implemented to safeguard the health and well-being of the workforce.

This study aims to employ a linear programming approach to analyze the most important risk factors associated with WMSDs in hazelnut harvesting. The LP-GW-AHP method is utilized to prioritize these risk factors. The research area encompasses the Eastern Black Sea coastline of Turkey, which includes the provinces of Artvin, Rize, Trabzon, Giresun, and Ordu. The region's long-standing tradition in hazelnut farming, coupled with its economic significance, makes it a key area for hazelnut harvesting. The initial phase of the study focuses on structuring the decision problem. It includes the identification of key risk factors for hazelnut harvesting workers through field observations, expert consultations, and a literature review focusing on musculoskeletal disorder risk factor studies. The field observations are conducted during the summer months, coinciding with the hazelnut harvest. This period allows for a close examination of agricultural activities, thereby enhancing the reliability of the data obtained through the field observations. Furthermore, face-to-face discussions and meetings with the experts serve as crucial tools for identifying the most important risk factors. The knowledge and experience of the experts, combined with the findings from the field observations, contribute to the identification of potential risks during the hazelnut harvesting process. To quantify the relative importance of the factors, the LP-GW-AHP method is employed. This method allows for a pairwise comparison of factors based on experts' judgments and modeling of pairwise evaluations based on linear programming. The goal is to establish a set of weights reflecting the importance of each risk factor. The subsequent phase involves determining a priority ranking result. Additionally, the results of the study are supported by a comparative analysis. The steps of this study are shown in Fig. 1.

A decision-making team consisting of five experts (academicians and hazelnut producers) is created to structure and solve the handled problem. Initially, the literature review yields a list of risk factors. Potential risk factors are identified through an analysis of musculoskeletal disorder studies within the paper. The team then refines this list based on their individual knowledge and expertise. The final risk factors are identified through collective efforts and rigorous discussions. The identified factors are as follows: weather conditions, harvest area, repetitive movements, equipment and tool usage, experience, anthropometry, prolonged standing, prolonged kneeling, forceful exertions, mental and occupational stress, posture, vibration, and age and condition (Fig. 2). The assessment of these risk factors is conducted by experts with a minimum of five years of experience and prior involvement in MCDM-related studies. The selection of these experts is done by considering their experience, educational background, knowledge, and publications relevant to the research topic.

3.2. Results and discussion

The decision-making team conducts a comparative assessment of the risk factors using the LP-GW-AHP questionnaire, prepared in accordance with Table 1. Each expert is assigned the task of expressing their

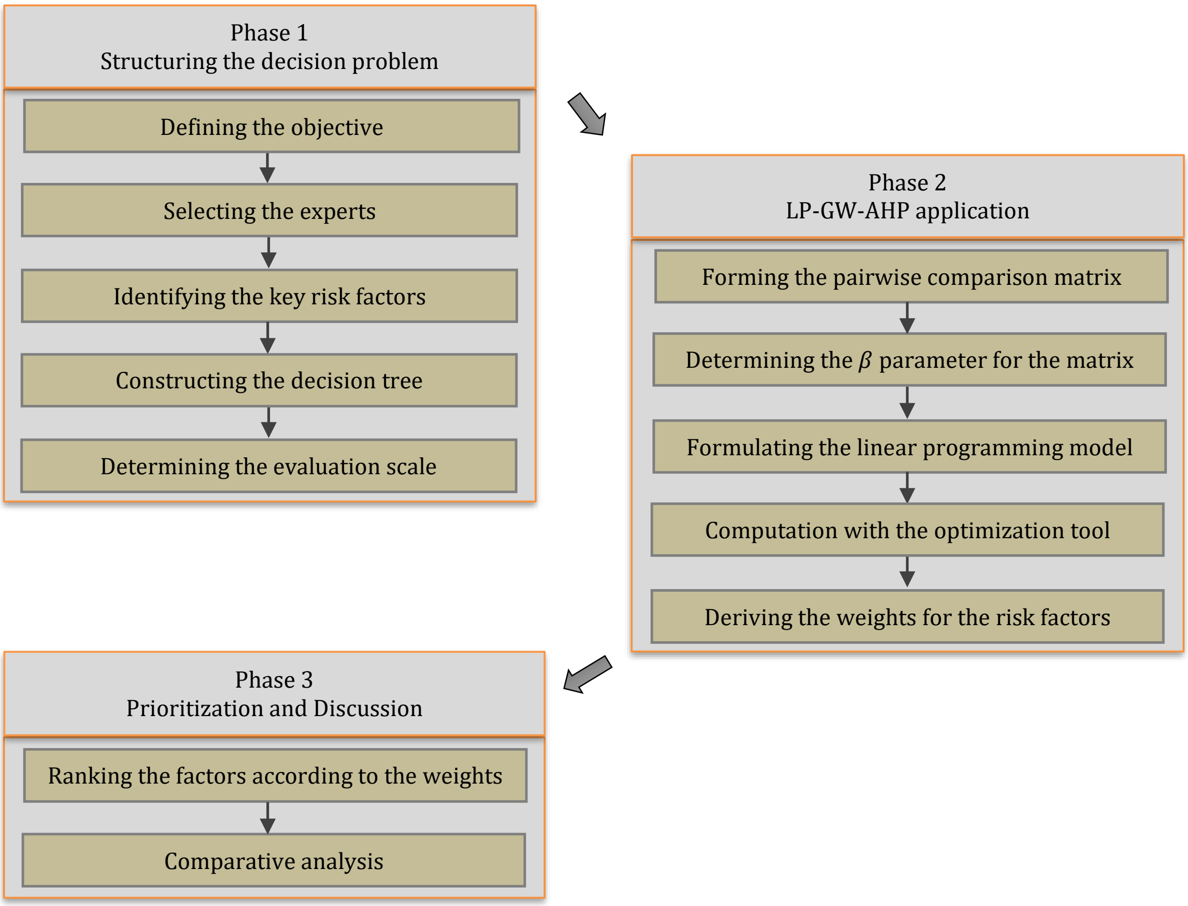

Figure 1. Decision-making framework.

preferences for each pair of factors based on personal knowledge and expertise. To collect the required data for the analysis, the face-to-face interview method is employed. The initial responses from the experts are compiled and then progress to the second evaluation round. Following the three-round consensus-building process, the final agreement is reached. The resulting pairwise comparison matrix is presented in Table 2.

Once the pairwise comparison matrix is established, the subsequent step is to compute β. This is accomplished through the application of Equation (8). Table 3 presents the results of the β calculation procedure considered in the study.

Table 1. Evaluation scale [42, 43].

Scale	Degree of importance	Reciprocal (decimal)
1	Equally important	1 (1.000)
2	Equally to moderately important	1/2 (0.500)
3	Moderately important	1/3 (0.333)
4	Moderately to strongly important	1/4 (0.250)
5	Strongly important	1/5 (0.200)
6	Strongly to very strongly important	1/6 (0.167)
7	Very strongly important	1/7 (0.143)
8	Very strongly to extremely important	1/8 (0.125)
9	Extremely important	1/9 (0.111)

The next step involves formulating a linear programming model by considering the established pairwise comparison matrix and the computed β value. This mathematical model is designed to obtain optimal weights. When designing the mathematical model, the objective function and constraints outlined in Equations (1)-(7) of the LP-GW-AHP procedure are considered. The pairwise comparison data are input into the equations. As a result, the problem at hand is formulated as a linear programming-driven MCDM problem. The code required to solve the decision problem is written in the GAMS 24.1.3 optimization software. The code is available upon request. After the established model runs, the importance of the risk factors is revealed. Fig. 3 presents the weights obtained for the risk factors.

The analysis reveals that the harvest area is a prominent risk factor influencing WMSDs in hazelnut harvesting. The extensive hazelnut orchards in the Eastern Black Sea region require prolonged physical exertion from workers. This challenge is intensified by the rugged and sloping terrain. The sheer scale of the harvest area significantly adds to the physical strain experienced by workers, emphasizing the necessity for targeted interventions to mitigate associated risks. Another

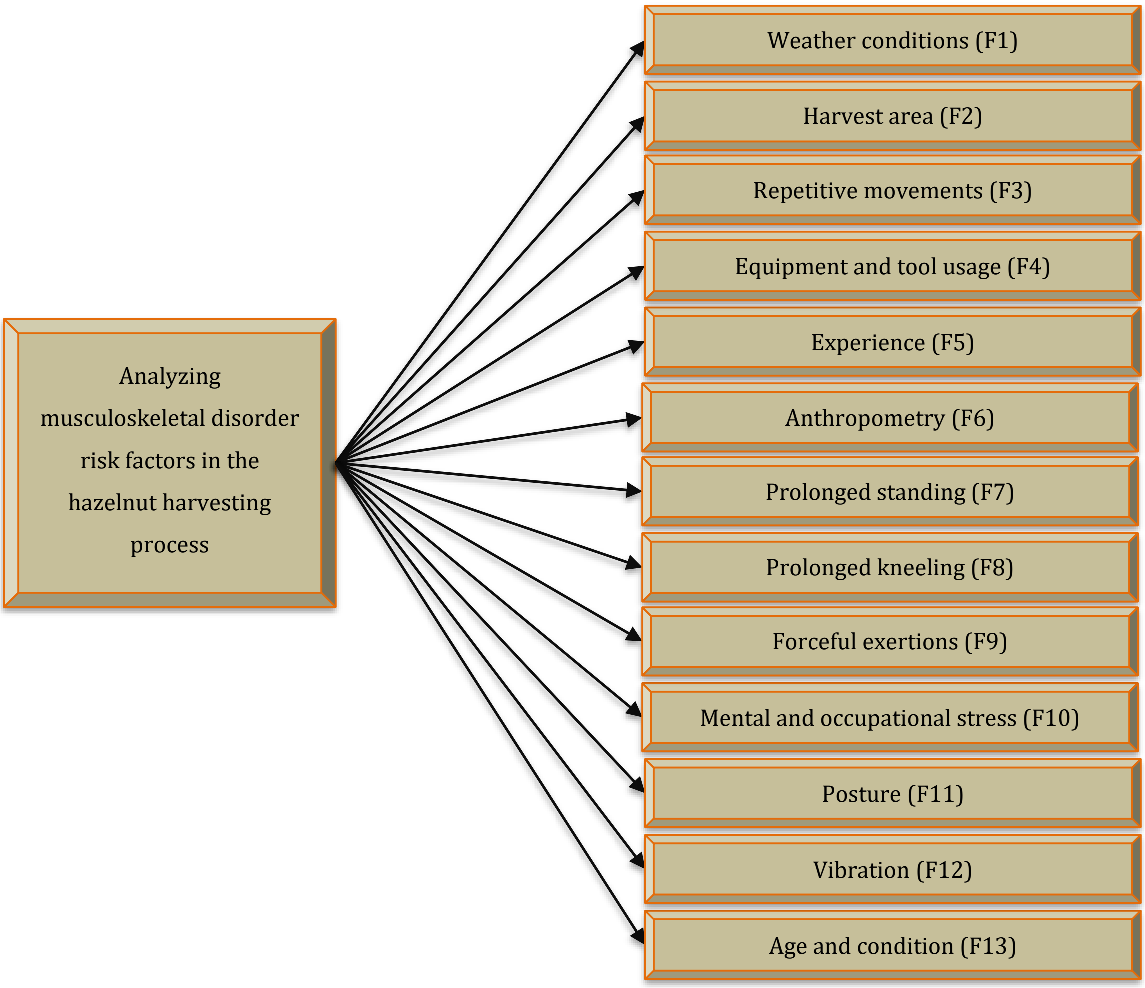

Figure 2. Decision hierarchy.

important factor is repetitive movements. Workers engage in repetitive actions such as picking, sorting, and handling hazelnuts throughout the harvesting season. The repetitive nature of these tasks can lead to cumulative stress on specific muscle groups and joints, increasing the risk of WMSDs. Implementing effective ergonomic strategies and task rotation may be crucial in alleviating the impact of repetitive movements on the workforce. Prolonged standing emerges as the third most significant risk factor contributing to WMSDs among hazelnut harvesters. The nature of hazelnut harvesting requires workers to stand for extended periods, placing increased pressure on the lower back, legs, and feet. Considering ergonomic factors, such as providing adequate seating and breaks, could prove instrumental in mitigating the adverse effects of prolonged standing on musculoskeletal health. Understanding the hierarchy and importance of the risk factors enables targeted interventions to reduce the incidence of WMSDs among hazelnut harvesters. Strategies should not only focus on ergonomic improvements but also consider important challenges posed by the topography. This may involve developing specialized equipment, providing terrain-specific training for workers, and carefully planning work processes to ensure safety and efficiency on uneven surfaces.

In MCDM applications, model results are usually supported through additional analyses. In this context, a comparative analysis is conducted in the study. The outputs of the applied method are examined using the SWARA and BWM methods (for mathematical details, see Appendix A and Appendix B). The results of the comparative analysis are presented graphically in Fig. 4. It is observed that while the methods yield different weight values, the sequence of the risk factors is highly consistent. In the analysis, harvest area, repetitive movements, and prolonged standing retain their top three positions as the most significant factors. Similarly, experience, vibration, and mental and occupational stress continue to rank as the least important factors. Consequently, the obtained results are reliable and acceptable.

The harvesting of hazelnuts is a labor-intensive agricultural endeavor. This study has the potential to impact hazelnut harvesting practices by informing targeted interventions, influencing policy development, and contributing valuable knowledge to the field of agricultural occupational health and safety. The study's findings can contribute to enhancing occupational

Table 2. Pairwise comparison matrix.

Factor	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12	F13
F1	1	1/6	1/5	2	4	2	1/4	1/3	1/3	3	1/2	3	2
F2		1	2	6	9	7	3	4	4	8	5	8	7
F3			1	5	8	6	2	3	3	7	4	7	6
F4				1	4	2	1/4	1/3	1/3	3	1/2	3	2
F5					1	1/3	1/7	1/6	1/6	1/2	1/5	1/2	1/3
F6						1	1/5	1/4	1/4	2	1/3	2	2
F7							1	2	2	6	3	6	5
F8								1	2	5	2	5	4
F9									1	5	2	5	4
F10										1	1/4	2	1/2
F11											1	4	3
F12												1	1/2
F13													1

inconsistency: 0.03

Table 3. β calculation.

Row	r_i	$\sum_{j=1}^{n} a_{ij}r_j$	$\frac{1}{r_i}\sum_{j=1}^{n} a_{ij}r_j$	Column	c_i	$\sum_{j=1}^{n} a_{ij}c_j$	$\frac{1}{c_i}\sum_{j=1}^{n} a_{ij}c_j$
1	18.783	229.117	12.198	1	26.417	327.148	12.384
2	70.000	1261.513	18.022	2	3.513	57.924	16.486
3	57.500	949.396	16.511	3	5.561	74.977	13.483
4	17.283	202.442	11.713	4	27.917	367.523	13.165
5	4.079	66.273	16.247	5	60.000	1083.540	18.059
6	12.343	147.315	11.935	6	35.833	498.390	13.909
7	45.833	689.362	15.041	7	8.710	103.015	11.828
8	36.083	511.829	14.185	8	12.733	143.191	11.245
9	34.583	459.204	13.278	9	14.233	163.041	11.455
10	7.751	97.209	12.541	10	47.000	742.173	15.791
11	25.783	322.864	12.522	11	19.367	226.669	11.704
12	6.251	87.082	13.930	12	48.500	813.423	16.772
13	10.843	130.300	12.017	13	37.333	552.890	14.810
max			18.022	max			18.059
			β = 18.022				

Note: a_{ij} (i,j=1,…,n) refers to the matrix elements, while r_i and c_i denote the row and column sums, respectively, of the AHP matrix.

health and safety practices in hazelnut harvesting. By identifying and prioritizing risk factors through the LP-GW-AHP method, safety interventions can be developed to address the most critical issues. Insights gained from the study can be utilized to design targeted training programs for hazelnut harvesting workers. Organizations involved in hazelnut harvesting can focus their efforts and resources on addressing the most significant risk factors. The study's findings can serve as a basis for the development or refinement of occupational health and safety policies specific to hazelnut harvesting. The research outcomes can provide valuable insights for other agricultural sectors facing similar challenges. The study's methodology and results can encourage collaboration among researchers, occupational health professionals, and industry stakeholders. This research endeavors to enhance the welfare of hazelnut harvesting workers by presenting an alternative framework.

4. Conclusion

The harvesting of hazelnuts is a crucial aspect of the global nut industry. The economic significance, versatility in culinary applications, contribution to various products, health benefits, and participation in international trade collectively make hazelnuts an important commodity in the world market. The demanding nature of hazelnut harvesting involves intricate tasks such as picking, sorting, and transporting

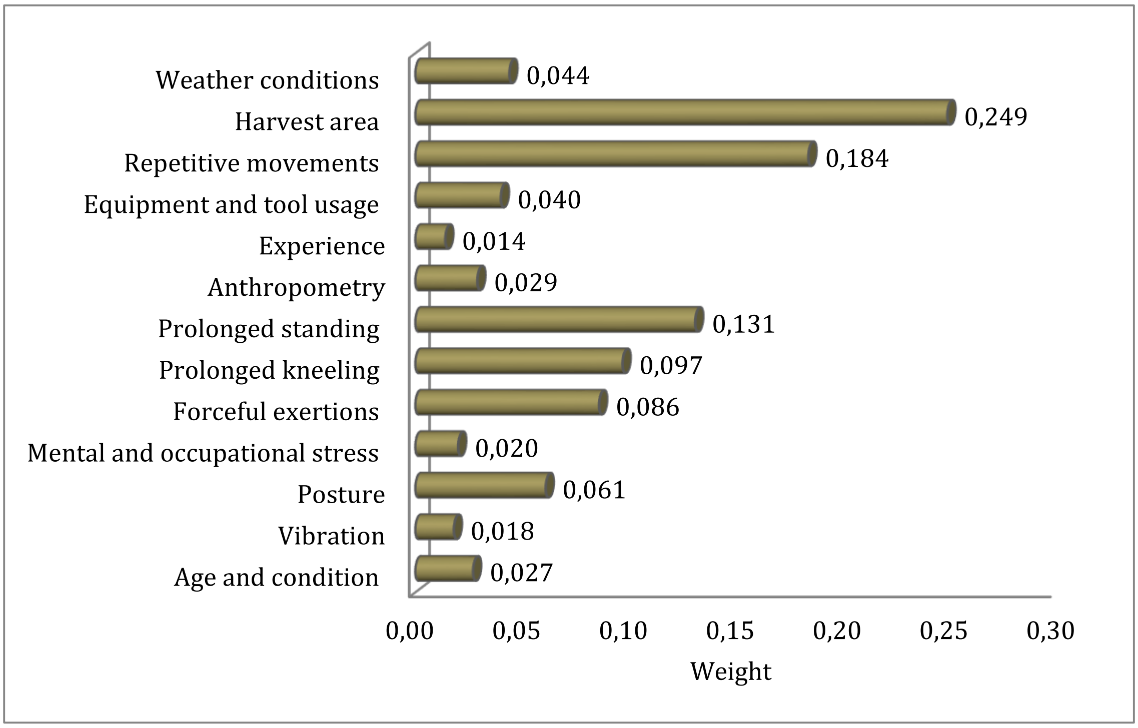

Figure 3. Modeling results for the risk factors.

hazelnuts. Workers often find themselves engaged in repetitive motions and physically demanding activities. This prolonged and strenuous labor puts a strain on the musculoskeletal system, increasing the likelihood of injuries, strains, and other orthopedic issues among workers. Evaluating these challenges is crucial not only for the welfare of the workers but also for the sustainability of the hazelnut industry.

This study utilizes a linear programming approach for the analysis of key risk factors linked to WMSDs among hazelnut harvesting workers. The proposed decision-making framework consists of distinct phases. Firstly, the most important risk factors associated with WMSDs in hazelnut harvesting are identified through a literature review, on-field observations, and expert consultations. Subsequently, the LP-GW-AHP method is applied to compare and prioritize these identified risk factors. In the final phase, a comparative analysis is conducted using the SWARA and BWM methods.

According to the results, harvest area, repetitive movements, and prolonged standing are the top three most important factors. The physical environment

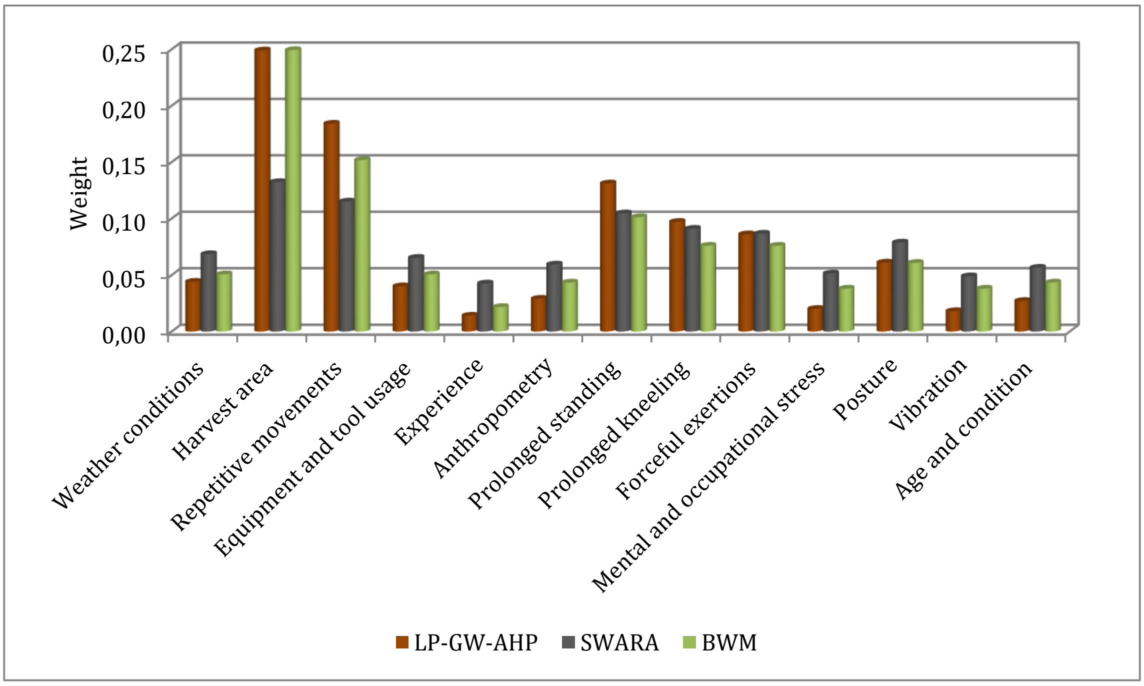

Figure 4. Results of the comparative analysis.

where harvesting takes place has a substantial impact on the risk of WMSDs. Factors such as terrain, layout, and accessibility may contribute to this risk. Repetitive motions increase the likelihood of developing WMSDs, as they can strain muscles and joints over time. This underscores the importance of minimizing repetitive tasks or implementing ergonomic solutions to reduce strain. Prolonged standing can also lead to fatigue and strain on the body, especially if workers are not provided with adequate breaks or ergonomic support. Experience, vibration, and mental and occupational stress are found to be the least important factors. While these factors may still have some impact on worker health, they may not be as significant as the other factors and may require less attention in prevention efforts. Consequently, the results provide valuable insights for developing targeted interventions and ergonomic strategies to mitigate the risk of WMSDs among hazelnut harvesting workers.

The value of the current study can be elucidated as follows: (i) the study identifies and analyzes key risk factors associated with WMSDs for hazelnut harvesting workers; (ii) the study formulates the decision problem as a linear programming-driven MCDM problem; (iii) the LP-GW-AHP method is used for the first time to prioritize work-related risk factors and provides a novel perspective; (iv) the decision problem is examined from an expert viewpoint; (v) the study reveals the importance weights of the risk factors specific to hazelnut harvesting; (vi) the study presents a valuable guide for decision-makers. In future studies, the proposed decision-making framework can be applied to analyze different work-related risk factors, and different decision support tools can be incorporated into the problem to compare decision results.

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Appendix A

SWARA procedure [44].

Step 1: Decision criteria are ranked in descending order according to their expected significance.

Step 2: The comparative importance of the average value (s_j) is revealed. Decision-makers articulate the relative importance of criterion j in comparison to the preceding (j-1) criterion.

Step 3: Comparative coefficients (k_j) are computed.

$$k_j = \begin{cases} 1 & j = 1 \\ s_j + 1 & j > 1 \end{cases} \tag{A.1}$$

Step 4: Recalculated weights (q_j) are determined.

$$q_j = \begin{cases} 1 & j = 1 \\ \dfrac{q_{j-1}}{k_j} & j > 1 \end{cases} \tag{A.2}$$

Step 5: The final weights (w_j) of decision criteria are revealed.

$$w_j = \frac{q_j}{\sum_{j=1}^{n} q_j} \tag{A.3}$$

where n is the number of decision criteria.

Appendix B

BWM procedure [45].

Step 1: Decision criteria are determined for the decision-making problem.

Step 2: The best and worst criteria are specified.

Step 3: The Best-to-Others vector ($A_B = (a_{B1}, a_{B2}, \ldots, a_{Bn})$) is obtained by determining the preference of the best criterion over others using a 1-9 scale. a_{Bj} is the level of importance of the best criterion B over criterion j.

Step 4: The Others-to-Worst vector ($A_W = (a_{1W}, a_{2W}, \ldots, a_{nW})^{\mathrm{T}}$) is obtained by comparing the worst criterion with others. a_{jW} is the level of importance of criterion j over the worst criterion W.

Step 5: Optimal weights ($w_1^*, w_2^*, \ldots, w_n^*$) are revealed. In this process, the maximum absolute differences $\left|\frac{w_B}{w_j} - a_{Bj}\right|$ and $\left|\frac{w_j}{w_W} - a_{jW}\right|$ for all j is minimized. The decision-making problem is obtained as follows:

$$\min \max_j \left\{ \left|\frac{w_B}{w_j} - a_{Bj}\right|, \left|\frac{w_j}{w_W} - a_{jW}\right| \right\} \tag{B.1}$$

subject to:

$$\sum_j w_j = 1 \tag{B.2}$$

$$w_j \geq 0, \text{ for all } j \tag{B.3}$$

The current model can be transformed into the following model:

$$\min \xi \tag{B.4}$$

subject to:

$$\left|\frac{w_B}{w_j} - a_{Bj}\right| \leq \xi, \text{ for all } j \tag{B.5}$$

$$\left|\frac{w_j}{w_W} - a_{jW}\right| \leq \xi, \text{ for all } j \tag{B.6}$$

Equation (B.2) and Equation (B.3).

As the value of ξ rises, the consistency of expert evaluation declines.