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LIFE CYCLE ASSESSMENT OF PROCESSING FOR CHROME TANNED COWHIDE UPPER LEATHER

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LIFE CYCLE ASSESSMENT OF PROCESSING FOR CHROME TANNED COWHIDE UPPER LEATHER

ABSTRACT. Pollution has become a serious problem in leather industry, however, current method to evaluate its environmental effect usually used data from literature review, those data generated while leather manufacturing were rarely collected and analyzed. Thereby, the aim of this study was to evaluate the environmental effect of manufacturing process of chrome tanned cowhide upper leather by applying the Life Cycle Assessment protocols. Following the guidance of ISO 14010, we first combined data obtained from field study and empirical review; and then these data were input into eFootprint for calculation. Results, including four environmental indicators (global warming potential [GWP], primary energy demand [PED], water utility [WU] and acidification [AP]), show that producing 1 kg of cowhide upper leather releases 7.040 kg of CO_2 eq, consumes 106.793 MJ of energy and 89.144 kg of water and emits 0.058 kg of SO_2 eq. Sensitivity analysis of inventory data demonstrated that chrome tanning and retanning processes accounted for more than 40% of PED, AP and GWP, whereas the beamhouse was more than 78% of WU. Therefore, we could optimise the tanning process by using alternative materials or technologies in the critical sections to achieve cleaner production and sustainable leather manufacturing.

KEYWORDS: life cycle assessment, leather processing, leather cleaner production, carbon footprint

EVALUAREA CICLULUI DE VIAȚĂ PENTRU PRELUCRAREA PIELII BOVINE TĂBĂCITE ÎN CROM PENTRU FEȚE ÎNCĂLȚĂMINTE

REZUMAT. Poluarea a devenit o problemă serioasă în industria de pielărie; cu toate acestea, metoda actuală de evaluare a efectului său asupra mediului a folosit deseori datele din literatură, rareori colectându-se și analizându-se date generate în procesul de fabricare a pielii. Prin urmare, scopul acestui studiu a fost de a evalua efectul asupra mediului al procesului de fabricare a pielii bovine tăbăcite în crom pentru fețe încălțăminte prin aplicarea protocoalelor de evaluare a ciclului de viață. Urmărind indicațiile prevăzute în ISO 14010, s-au combinat mai întâi datele obținute din studiul de teren și datele empirice, apoi aceste date au fost introduse în programul eFootprint pentru calcul. Rezultatele, inclusiv patru indicatori de mediu (potențialul de încălzire globală [GWP], cererea de energie primară [PED], utilitatea apei [WU] și acidificarea [AP]), arată că în urma fabricării a 1 kg de piele bovină pentru fețe încălțăminte se eliberează 7,040 kg de CO_2 echivalent, se consumă 106,793 MJ de energie și 89,144 kg de apă și se emit 0,058 kg de SO_2 echivalent. Analiza de senzitivitate a datelor de inventar a demonstrat că procesele de tăbăcire și retăbăcire în crom au reprezentat mai mult de 40% din PED, AP și GWP, în timp ce procesele de înmuiere și cenușărire a depășit 78% din WU. Prin urmare, procesul de tăbăcire ar putea fi optimizat utilizând materiale sau tehnologii alternative în secțiunile critice pentru a realiza o producție mai curată și sustenabilă a pielii.

CUVINTE CHEIE: evaluarea ciclului de viață, prelucrarea pielii, fabricarea pielii prin procese ecologice, amprentă de carbon

ÉVALUATION DU CYCLE DE VIE POUR LE TRAITEMENT DU CUIR BOVIN TANNÉ AU CHROME POUR TIGES CHAUSSURES

RÉSUMÉ. La pollution est devenue un problème sérieux dans l'industrie du cuir ; cependant, la méthode actuelle d'évaluation de son effet sur l'environnement a souvent utilisé des données de la littérature, tandis que les données générées dans le processus de fabrication du cuir ont rarement été recueillies et analysées. Par conséquent, le but de cette étude était d'évaluer l'effet environnemental du processus de fabrication du cuir bovine tanné au chrome pour les tiges chaussures en appliquant des protocoles d'évaluation du cycle de vie. Suivant les indications fournies dans l'ISO 14010, les données issues de l'étude de terrain et les données empiriques ont d'abord été combinées, puis ces données ont été saisies dans le logiciel eFootprint pour le calcul. Les résultats, dont quatre indicateurs environnementaux (potentiel de réchauffement planétaire [GWP], demande d'énergie primaire [PED], service d'eau [WU] et acidification [AP]), montrent qu'après la fabrication de 1 kg de cuir bovin pour chaussures 7 040 kg de CO_2 équivalent sont libérés, 106 793 MJ d'énergie et 89 144 kg d'eau sont consommés et 0,058 kg d'équivalent SO_2 est émis. L'analyse de sensibilité des données d'inventaire a montré que les processus de tannage et de retannage au chrome représentaient plus de 40% des PED, AP et GWP, tandis que le travail de rivière dépassait 78% de WU. Par conséquent, le processus de tannage pourrait être optimisé en utilisant des matériaux ou technologies alternatives dans les sections critiques pour obtenir une production de cuir plus propre et durable.

MOTS CLÉS : analyse du cycle de vie, traitement du cuir, production de cuir plus propre, empreinte carbone

INTRODUCTION

China has become the largest leather producer in the world [1]. However, pollution resulting from the leather-making process continuously affects the environment, making the future of the tannery industry pessimistic. Light leather (mainly chrome tanned leather)

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production in China has shown a downward trend since 2012. Furthermore, monitored by the China Leather Industry Association [2], the production of standard light leather and the income of leather industry decreased by 10.93% and 2.23%, respectively, in 2019. In addition to being affected by the economic environment, pollution is a significant factor affecting the development of the leather industry. Therefore, pollution in the leather industry should be seriously considered to achieve sustainable development.

At present, the major pollutants in the leather industry include tannery effluent, solid waste, sludge and waste gas. The components of these pollutants mainly include protein, chromium, sodium chloride, sulfate, sulfide and so on. Current data reveal that the amount of water discharged by the Chinese leather industry is approximately 120 million tonnes a year [3]. Meanwhile, 500–600 kg of solid waste and 35–40 tonnes of effluent containing different chemicals are generated to convert 1 tonne of raw hide into finished leather [4, 5]. Therefore, studies focusing on the leather manufacturing process should be taken into consideration before developing pollution reduction strategies and the manufacturing process of leather products must be evaluated and analysed to identify the source and degree of pollution. In this manner, the production process can be optimised, consequently reducing waste emissions and achieving the goal of sustainable development.

Life cycle assessment (LCA) is a widely accepted methodology that has proven its efficiency as a decision-making tool for the assessment of environmental burdens associated with production processes; this approach is used to move towards sustainable production practices [6]. The relevant algorithms also include: Input-Output Analysis (IOA) and Hybrid Life Cycle Assessment (HLCA). Among them, LCA is specialised on the assessment of environmental links within manufacturing processes in terms of energy consumption, material utilisation and environmental waste emissions [7]; the method can accurately identify the processes with a great impact on surroundings and thus can provide suggestions for the reduction of environmental pollution. Therefore, LCA is an effective method that can provide reference and strategy for clean and sustainable processes in tannery.

Currently, LCA has been applied in the leather industry. Aiming for usage in sports shoes, Chen *et al*. [8] evaluated the carbon footprint of finished leather which specially used for sport shoes. Their results suggested that the average power consumption was the largest factor causing carbon emissions, followed by the consumption of acrylic resin, and chromium tanning agent; meanwhile, the amount of carbon dioxide emission was related to thickness of finished leather. Chen *et al*. [9] compared the differences of carbon dioxide emissions of cowhide upper leather among distinctive countries and found that average power consumption is the largest factor causing carbon emissions, followed by the consumption of acrylic resin and chromium tanning agent. LCA was also conducted on a new continuous system consisting of dehydration and tanning and post-tanning by immersion versus [10]; the results showed that a reduction in the use of acetone during the process positively affects the environmental outcomes. However, the above studies either lack practical data or have an incomplete assessment process; hence, a comprehensive analysis of LCA for cowhide upper leather manufacturing processes is still needed.

Therefore, this study aims to use LCA in assessing the impact of the intact leather-making process of chrome tanned cowhide upper leather on the environment by using practical data. Moreover, it aims to explore the major contributing factors during production. Suggestions are provided by virtue of inventory data sensitivity.

METHODS

On the basis of the ISO 14040 environmental management system [11], LCA of 1 kg of chrome tanned cowhide upper leather was divided into four sections: target and scope determination, life cycle inventory analysis (LCI), life cycle impact assessment (LCIA) and result interpretation. The reason why chrome tanned cowhide upper leather was chosen as the research object was because of its large output and representative

production process. eFootprint software (online version, IKE Environmental Technology Co., Ltd., China) was utilised for the modelling process. This protocol was developed by IKE and was designed for LCA studies [12], where functions, such as supply chain data survey, database processing, LCA modelling and analysis and data distribution are embedded.

Target and Scope Determination

In accordance with the modelling principle of 'cradle to door', the target was first determined to quantify environmental impact from raw materials to finished leather using chrome tanning technology. Chrome tanning technology means that chrome powder was used as tanning agent. Then, the key contributing factors were identified by assessing the contribution rate of each process.

The overall scope was determined as material and energy input–output and pollutant emissions when 1 kg cowhide upper leather was produced. Furthermore, the technology included beamhouse, tanning and finishing section, excluding the construction stage of the machine and workshop. The beamhouse mainly included processing raw hide into pelt suitable for tanning, removing hair, grease, dirt and unnecessary skin tissue, and loosening collagen fibers moderately. Tanning section referred to the conversion of pelt into leather. Finishing section's purpose was to make leather meet the requirements in appearance and service performance. The boundary of the LCA system is shown in Figure 1.

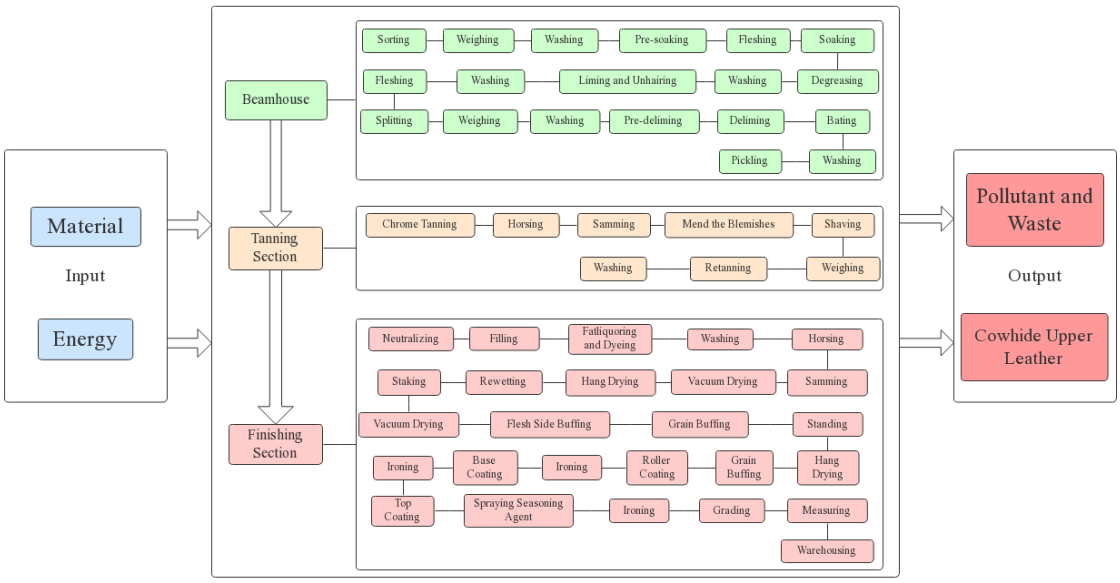

Figure 1. System boundary of chrome tanned cowhide upper leather

Life Cycle Inventory Analysis

Life cycle inventory analysis (LCI) refers to the quantitative analysis of the input for all substances, energy and discharge of pollutant waste within the system's boundary, covering all the processes and activities of manufacturing. To quantify LCI, we executed inventory data sensitivity, which expresses the contribution rate of each production process in each indicator. In accordance with LCI, optimisation and improvement throughout the process could be achieved.

Data was collected from our laboratory's workshop; the detailed list is shown in Table 1. Dosage of raw materials was adjusted according to the change of leather weight during the production process. Majority of upstream data were from the CLCD-China-ECER 0.8.1 and Ecoinvent databases, which were included in eFootprint; however, a few empirical data were cited in accordance with relevant literature. For instance, leather yield was reported as 20%–25% [13]; thus, we chose the value of 20% in this study. The 20% leather yield meant that to produce 1 kg of cowhide upper leather, 5 kg of raw hide was required

and input into the manufacturing process. In addition, power consumption data came from an overall estimate of working hours and efficiency of all production and processing equipment. By recording the working time and energy consumption of each machine on the spot, it is calculated that electrical energy consumption in the entire production processes was 30 kw/h per 1 kg of finished leather.

Table 1: Process flow

Process Flow	Raw Materials	Dosage (%)
Pre-soaking	Water	300.0
	Soaking Bactericide KF	0.5
	Wetting Agent WT-H	0.2
Soaking	Water	300.0
	Bactericide KL	0.2
	Degreasing Agent DFH	0.2
	Wetting Agent WT-H	0.3
	Sodium Carbonate	0.2
	Sodium Sulfide	0.3
Liming and Unhairing	Water	380.0
	Degreasing Agent DN	0.1
	Wetting Agent WT-H	0.2
	Liming Additives	1.0
	Lime	5.0
	Sodium Sulfide	2.5
	Liming Additives SP	1.0
Pre-deliming	Water	150.0
	Ammonium Sulfate	1.0
Deliming	Water	80.0
	Ammonium Sulfate	3.0
Bating	Water	80.0
	Bating Enzyme U2	1.0
Pickling	Water	50.0
	Salt	6.0
	Formic Acid	0.7
	Sulfuric Acid	0.8
Chrome Tanning	Cationic Oil	1.0
	Chrome Tanning Agent (Cr_2O_3 24%, Basicity 33%)	7.0
	Sodium Formate	1.0
	Sodium Bicarbonate	1.5
	Water	150.0
Retanning	Water	100.0
	Formic Acid (85%)	0.2
	Glutaraldehyde (50%)	2.0
	Acrylic Retanning Agent	2.0
	Chromium Powder (Cr_2O_3 24%, Basicity 33%)	4.0
	Anionic Fatliquor Agents	2.0
	Sodium Bicarbonate	0.5
Neutralizing	Water	100.0
	PAK-N	1.0
	Sodium Acetate	1.0
	Sodium Bicarbonate	0.5
Filling	Water	150.0
	Acrylic Retanning Agent	6.0
	Amino Resin	8.0
	Tanning Extract	8.0
	Syntan	8.0
	Protein Filling Agent	3.0
	Fatliquoring Agents	3.0

Process Flow	Raw Materials	Dosage (%)
Fatliquoring and Dyeing	Formic Acid (85%)	1.0
	Water	100.0
	Dyestuff	2.0
	Fatliquoring Agents	7.0
Base Coating	Formic Acid (85%)	2.0
	Water	300.0
	Pigment Paste 2.0	10.0
	Acrylate Resin Emulsion s-1	2.0
	Filler Resin	2.0
Top Coating	Water	710.0
	Pigment Paste 2.0	10.0
	Casein Solution	1.3
	Urethane Resin	4.0
	Filling Agent	0.2

Life Cycle Impact Assessment

Life cycle impact assessment (LCIA) is a qualitative and quantitative method to explain the environmental impact identified by LCI and determine the impact of the material and energy exchange of the system on the external environment. Through LCIA, four environmental impacts most closely related to our target product were determined: primary energy demand (PED, MJ), global warming potential (GWP, kg CO_2 eq), water utility (WU, kg) and acidification (AP, kg SO_2 eq). By considering these indicators, we gained insights into the impact of the leather manufacturing process on the environment.

Modelling Process

Figure 2 showed the modelling sequences. First, specific materials related to by-products, renewable energy consumption and waste recycling treatment were neglected; meanwhile, according to the rule of CLCD, raw materials used less than or equal to 1% of the production target mass and those lacking of traceable upstream sources were then regarded to have zero environmental impact. These data would not enter the LCA modelling process. Additionally, this study complied with the integrity check of the LCA study.

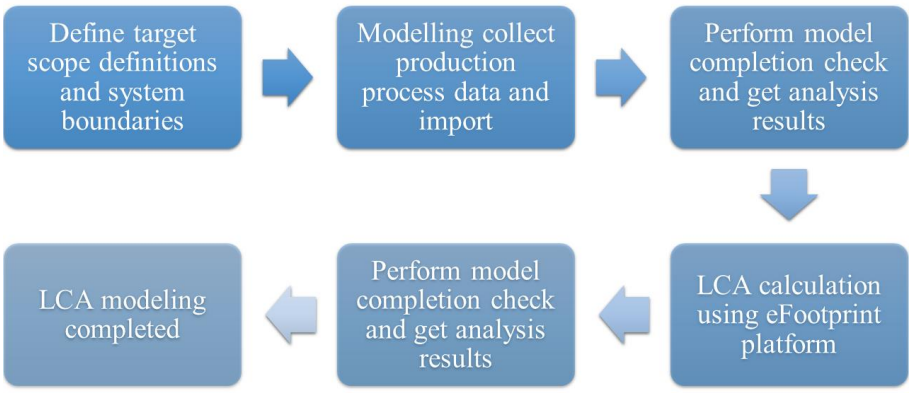

Figure 2. Modelling flow chart of chrome tanned cowhide upper leather

RESULTS AND DISCUSSION

The environmental impacts of chrome tanned cowhide upper leather with a functional unit of 1 kg were evaluated in this study. The four main indicators were applied to gain insights into the influence of manufacturing processes on the environment.

As shown in Figure 3, the GWP, PED, WU and AP of 1 kg of cowhide leather produced by chrome tanning were 7.040 kg CO_2 eq, 106.793 MJ, 89.144 kg and 0.058 kg SO_2 eq,

respectively; the source of AP was ammonium sulphate. In general, the AP and GWP during the process was limited, whereas PED and WU were relatively large. Especially, water was significantly consumed in the beamhouse and tanning section, thus contributing a relatively higher value of WU.

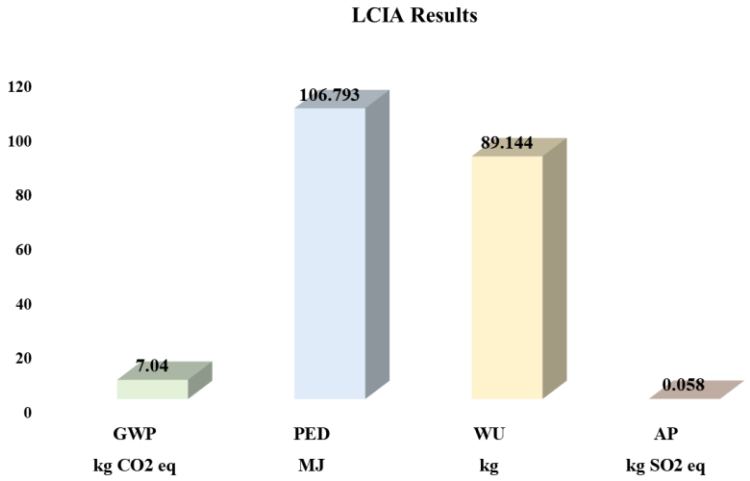

Figure 3. LCIA: Environmental impact potential of chrome tanned cowhide upper leather

Combining LCIA and LCI, we could understand environmental impact from the viewpoint of manufacturing process. Our findings suggested that the tanning section was responsible for the majority of PED and GWP values, whereas the beamhouse had the largest water consumption. Furthermore, deliming, chrome tanning and retanning caused environment significant acidification.

Given the considerable impact of the tanning section in terms of GWP and PED, we could hypothesise that chemical usage is a major factor; thus, a comparison was performed between chrome tanning and chrome-free tanning. The chromium free tanning process consisted on using a yellowish-clear-bright-liquid polymer-modified glutaraldehyde (without free formaldehyde). In Figure 4, results presented a clear preference for the chrome-free tanning process, which reduces the GWP impact by 42% in comparison with the chrome tanning process, whereas PED in the chrome-free tanning process was 21% lower than in that in chrome tanning [14]. Therefore, chrome-free tanning technologies, such as titanium tanning, vegetable tanning and organic phosphine tanning, could be considered to reduce GWP and PED [15-17].

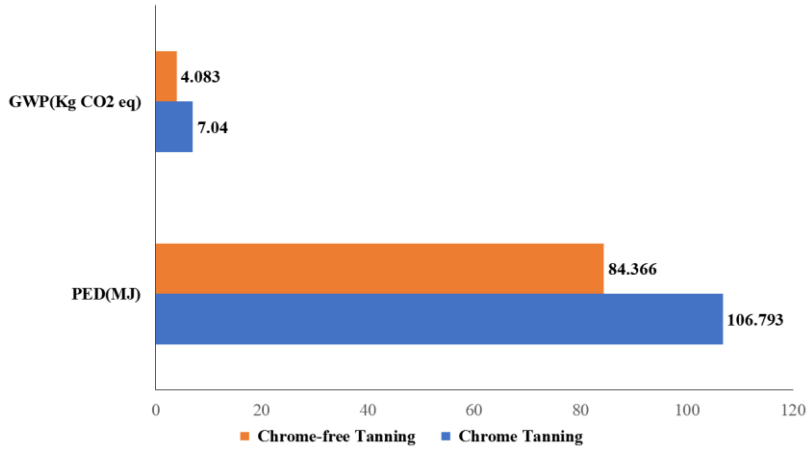

Figure 4. LCIA: GWP and PED results

In terms of PED, the tanning section used more than 92% of the total power in leather making. According to the technologies list, we found hour- or even day-long drum running in these two procedures. Therefore, machinery power consumption was the major source of PED. To reduce PED, the tanning process must be improved using ultrasound, microwave or other methods to reduce tanning time and improve tanning agent exhaustion [18, 19]. In addition, chrome-free tanning could be applied in tannery.

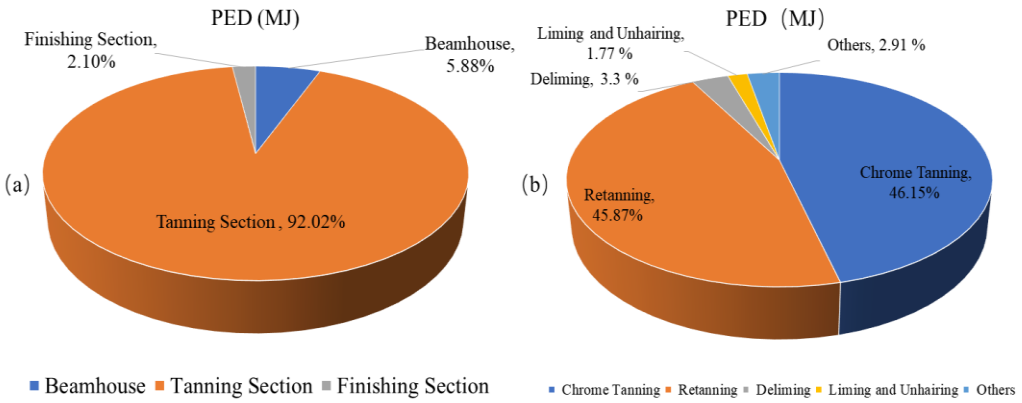

Figure 5. LCI: Inventory data sensitivity of PED: (a) based on section, (b) based on process

In terms of GWP, as shown in Figure 6, the tanning section accounted for approximately 88%, whereas the beamhouse and finishing sections accounted for 10.67% and 1.01%, respectively. During the tanning and retanning processes, chromium powder was largely used. According to the CLCD-China-ECER 0.8.1 database, the mining process of chromium powder emitted substantial carbon dioxide. Therefore, the results indicated that the chromium powder utilised in these two processes accounted for 44% of GWP. Therefore, focus must be shifted to the application of chromium powder, and alternative agents must be identified to reduce carbon dioxide emissions during leather making [20]. Similarly, the effects of sodium sulphide and lime during the unhairing and liming processes on carbon dioxide emissions were substantial; enzyme unhairing and collagen fibre opening without lime may be potential options [21-23]. Cleaner methods for tanning and retanning sections have also been discussed by Giannetti [24], who proved that lime and tanning float recovery reduces sodium sulphide, lime and chromium consumption during effluent treatment for unhairing and tanning. Other innovations, including the use of lower dosages of chemical materials in leather making, could also reduce environmental impact.

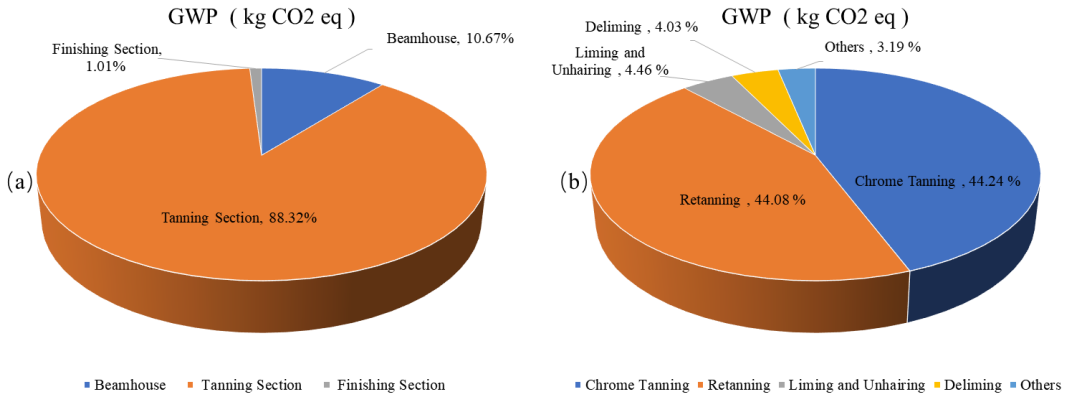

Figure 6. LCI: Inventory data sensitivity of GWP: (a) based on section, (b) based on process

Figure 7 showed the results of the in-depth study conducted on a beamhouse. Results showed that the pickling process contributed to GWP because of salt usage. Salt-free or low-salt pickling was an effective approach to decrease the usage of salt. Luo *et al*. [25] developed a nonpickling chrome tanning technology in which a macromolecular aliphatic aldehyde was synthesised and used to pre-tan bated pelt prior to chrome tanning, eventually eliminating the conventional pickling process. The results showed that the performance of leather produced using this technology was comparable to conventionally processed leather in terms of hydrothermal stability and property evaluation. Hence, salt-free or low-salt pickling could be widely applied in tanneries to decrease GWP.

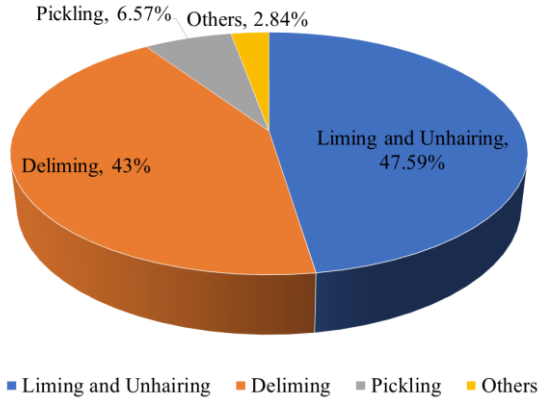

Figure 7. Inventory data sensitivity: GWP of the beamhouse

As shown in Figure 8, the beamhouse accounted for more than 71% of WU. The entire tanning process also occupied 23.24%. Figure 9 showed that almost every process, especially washing, in the beamhouse consumed a substantial amount of water; thus, water reduction strategies must focus on the beamhouse.

To reduce WU, the washing equipment could be strengthened, and washing using running water should be eliminated. In addition, the recycling of effluent would be a practical and effective way for tanneries to reduce WU, e.g., treated wastewater after the tanning process could be used for the next washing and pickling processes [26].

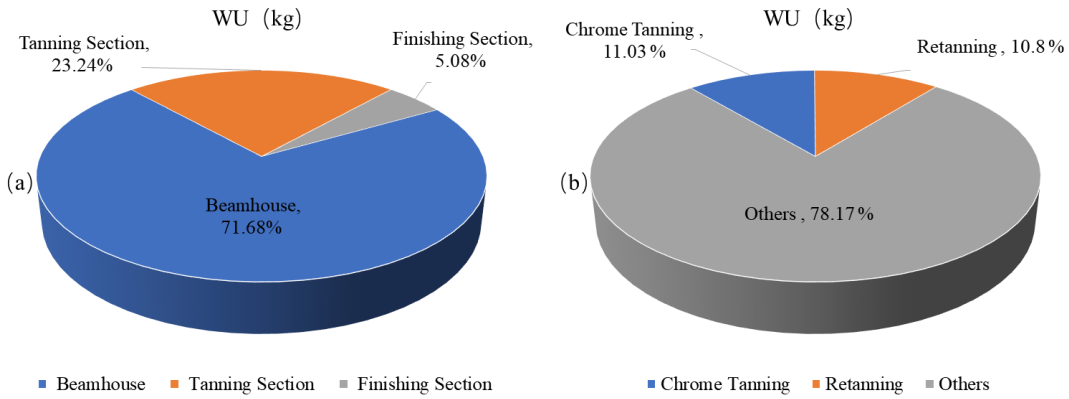

Figure 8. LCI: Inventory data sensitivity of WU: (a) based on section, (b) based on process

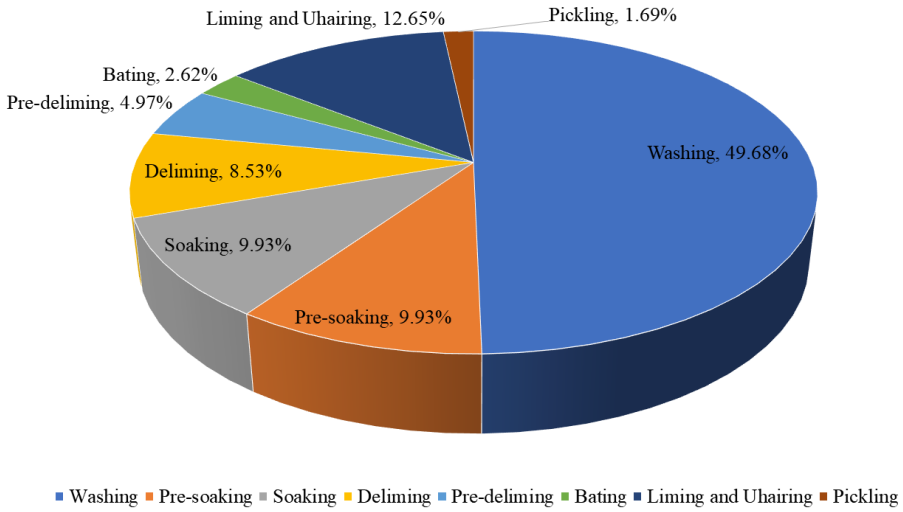

Figure 9. Inventory data sensitivity: WU of the beamhouse

In terms of AP, the tanning section accounted for approximately 91% of the total AP, whereas the beamhouse accounted for 8.23%. The contribution of deliming, chrome tanning and retanning was prominent due to the usage of chromium powder in the tanning section and the sulphides generated during deliming. According to the upstream database, the exploitation and synthesis of chrome powder caused the acidification of the environment. Therefore, the use of alternative raw materials was encouraged. Enzymes are a high-efficiency unhairing agent; hence, their usage can reduce the amount of sodium sulphide and minimise the generation of hydrogen sulphide during deliming. Ammonium-free and chrome-free tanning agents could also be applied to reduce the acidification of the environment [27]. In addition, electrochemical and photo-assisted electrochemical oxidation processes could be used to convert sulphide to sulphate in tannery lime wastewater (wastewater from the deliming process) to diminish AP [28].

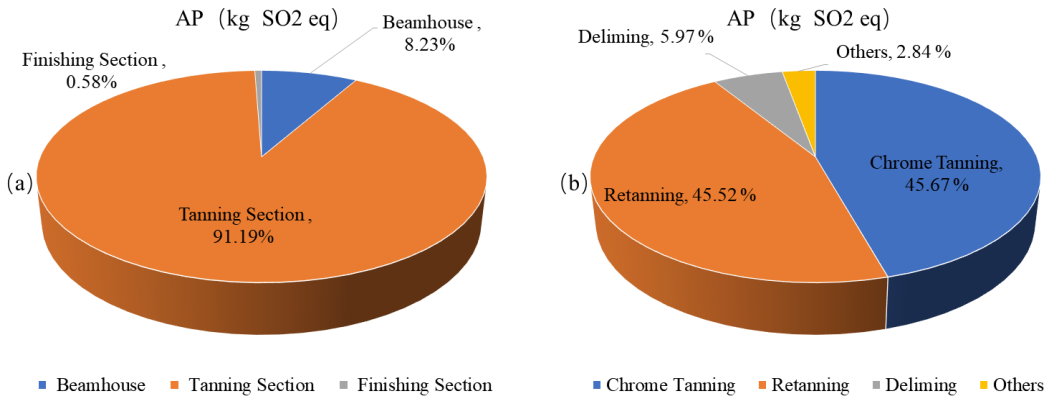

Figure 10. LCI: Inventory data sensitivity of AP: (a) based on section, (b) based on process

Although this study completed LCA modelling for the manufacturing process of chrome tanned cowhide upper leather, it still has a few limitations. First, the data of raw materials not included in the upstream database were not input to the calculation; these materials included rising cowhide and animal slaughter. Second, the results might not be compatible for all tanning industries because the production data of different tanneries vary widely [29]. Future research will be conducted on other leather manufacturing technologies to achieve wide and reliable application.

CONCLUSION

When we obtain 1 kg of chrome tanned cowhide upper leather, we usually generate considerably negative influences on the environment; meanwhile, the usage of chromium powder in tanning and retanning process, as well as sodium sulphide and lime in the liming and unhairing are primary causes. Overall, technological innovations, particularly for the beamhouse, tanning and retanning sections, should be seriously considered. Furthermore, the use of eco-friendly alternative materials or biomaterials is encouraged to improve the cleanliness and sustainability of the leather-making process.

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Conflicts of Interest

The authors declared no conflict of interest. No subjects or animals were included in this study. Neither participants nor informed consent were included in the study.

Author Contributions

Heng Yang: the first author, responsible for data analysis and manuscript writing;

Dexin An: responsible for data analysis of this study;

Carmen Gaidau: assisting for the review of the manuscript;

JinWei Zhang: responsible for data analysis and manuscript review;

Jin Zhou: the corresponding author, responsible for all the procedure of this study and manuscript review.

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BIOMECHANICAL PARAMETERS CHARACTERISING THE FOOT DURING NORMAL GAIT

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BIOMECHANICAL PARAMETERS CHARACTERISING THE FOOT DURING NORMAL GAIT

ABSTRACT. The biomechanical analysis allows to understand the normal and pathological gait, the mechanics of neuromuscular control, and last but not least, allows the visualisation of the effects of footwear on human gait or feet. Biomechanical analyses are very important for the footwear development process, as they can identify the incorrect loading of the foot or the incorrect gait pattern, thus avoiding the occurrence of deformations. This paper aims to create an average representative model of barefoot loading based on an extended group of participants by applying an optimal procedure for measuring biomechanical parameters. The variation of four basic biomechanical parameters, namely force, pressure, contact time and contact area, was measured using a pressure platform and a specialised software system. The data was collected from 32 healthy females, without particularities regarding foot health and the practice of performance sports, aged between 18 and 30 years, divided into three size groups – 36, 37 and 38. The T-Student test was applied to verify if there are significant differences between the left and right foot. Statistical indicators for each parameter were calculated, in order to characterize and establish the degree of variation of the obtained values, as follows: mean, standard deviation, minimum and maximum values, the amplitude of variation and coefficient of variation (CV). The study results confirm that the obtained mean values can be used as input data to load the foot and perform virtual simulations of footwear products.

KEYWORDS: foot, biomechanics, normal gait

PARAMETRII BIOMECANICI CARE CARACTERIZEAZĂ PICIORUL ÎN TIMPUL MERSULUI NORMAL

REZUMAT. Analiza biomecanică permite înțelegerea mersului normal și patologic, mecanica controlului neuromuscular și, nu în ultimul rând, permite vizualizarea efectelor încălțămintei asupra mersului uman și a picioarelor. Analizele biomecanice sunt foarte importante pentru procesul de dezvoltare a încălțămintei, deoarece permit identificarea încărcării incorecte a piciorului sau depistarea modelului incorect al mersului, evitând astfel apariția deformațiilor. Această lucrare are drept scop crearea unui model mediu reprezentativ de încărcare a piciorului desculț bazat pe un grup extins de participanți prin aplicarea unei proceduri optime pentru măsurarea parametrilor biomecanici. Variația a patru parametri biomecanici de bază, și anume forța, presiunea, timpul de contact și suprafața de contact, a fost măsurată utilizând o platformă de presiuni plantare și un sistem software specializat. Studiul s-a realizat pentru un eșantion de 32 de persoane de sex feminin, fără anumite particularități referitoare la starea de sănătate a picioarelor și practicarea sporturilor de performanță, cu vârsta cuprinsă între 18-30 de ani, împărțite pe 3 grupuri de mărimi, respectiv 36, 37 și 38 în sistem francez. Testul T-Student a fost aplicat pentru a verifica dacă există diferențe semnificative între valorile pentru piciorul stâng și cel drept. Au fost calculați indicatorii statistici pentru fiecare parametru analizat în vederea caracterizării și stabilirii gradului de variație a valorilor obținute, și anume: media aritmetică, abaterea standard, minimul, maximul, amplitudinea variației și coeficientul de variație. Rezultatele studiului confirmă faptul că valorile medii obținute pot fi utilizate ca date de intrare pentru a încărca piciorul și a simula comportamentul încălțămintei.

CUVINTE CHEIE: picior, biomecanica mersului, mers normal

LES PARAMÈTRES BIOMÉCANIQUES QUI CARACTÉRISENT LE PIED PENDANT LA DÉMARCHE NORMALE

RÉSUMÉ. L'analyse biomécanique permet de comprendre la démarche normale et pathologique, la mécanique du contrôle neuromusculaire et, enfin et surtout, permet de visualiser les effets des chaussures sur la démarche et les pieds humains. Les analyses biomécaniques sont très importantes pour le processus de développement de la chaussure, car elles permettent l'identification de la charge incorrecte du pied ou la détection du modèle de démarche incorrect, évitant ainsi l'apparition de déformations. Cet article vise à créer un modèle moyen représentatif de la charge des pieds nus basé sur un groupe étendu de participants en appliquant une procédure optimale pour mesurer les paramètres biomécaniques. La variation de quatre paramètres biomécaniques de base, à savoir la force, la pression, le temps de contact et la surface de contact, a été mesurée à l'aide d'une plate-forme de pression plantaire et d'un système logiciel spécialisé. L'étude a été menée pour un échantillon de 32 femmes, sans aucune particularité concernant la santé des pieds et les sports de performance, âgées de 18 à 30 ans, réparties en 3 groupes de taille, respectivement 36, 37 et 38 dans le système français. Le test T-Student a été appliqué pour voir s'il y avait des différences significatives entre les valeurs pour le pied gauche et le pied droit. Des indicateurs statistiques ont été calculés pour chaque paramètre analysé afin de caractériser et d'établir le degré de variation des valeurs obtenues, à savoir : la moyenne arithmétique, l'écart type, le minimum, le maximum, l'amplitude de variation et le coefficient de variation. Les résultats de l'étude confirment que les valeurs moyennes obtenues peuvent être utilisées comme données d'entrée pour charger le pied et simuler le comportement de la chaussure.

MOTS CLÉS: pied, biomécanique de la démarche, démarche normale

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INTRODUCTION

The foot has a complex anatomical and biomechanical structure, which ensures the transmission of the forces created during its interaction with the ground [1] and fulfils multiple functions such as support, balance, thermoregulation [2, 3] force absorption, impact attenuation and body displacement [4]. These aspects are considered and evaluated by biomechanics – the study of human movement.

The biomechanical analysis allows understanding the normal and pathological gait [5], the mechanics of neuromuscular control [6], and visualising the effects of footwear on human gait or feet. Biomechanical analyses are very important for the footwear development process, as they can identify the improper loading of the foot or the incorrect gait pattern, thus avoiding the occurrence of deformations [7].

Specific studies include two components: kinematic and kinetic analyses. The kinematic analysis evaluates movement patterns, including body movement and specific angles [8], ignoring the generated forces [9]. Kinematic components of the foot evaluated during movement are width, foot deformation under the influence of the load while walking, medial longitudinal arch length, the angle between the ankle and the foot at the initial contact, ankle movement, etc. [10].

The term kinetics is used in biomechanics to describe the relationship between forces and movement produced in the joints. These movements are produced by both internal forces (derived mainly from muscle activity and bone contact) and external forces (derived mainly from body weight or reaction forces). Kinetic studies correlate joint's angles and movements in dynamics with joint moments [11]. The main kinetic parameters are force, pressure and centre of pressure.

Human movement is composed of different rotational and translational movements, which are the result of the action of a complex field of forces - normal (perpendicular) and tangential (parallel) or torques acting on the body [1, 9, 12].

The field consists of two categories of forces: external and internal. The tensions in the muscle groups represent the active internal forces. During walking, muscle forces are added to inertia forces, which occurs due to the interaction of different body elements [2]. The most common external force applied to the human body while walking is the reaction force. This force is a three-dimensional vector comprising a vertical component and two horizontal components. In the mid-stance phase, the foot exerts an exchange of forces with the ground. In the heel strike phase, the human foot touches the support, generating two forces in the x-direction and the y-direction. The foot passes through the mid-stance phase immediately after the entire plantar surface touches the support. In the next stage, the foot exerts the most significant force to ensure that the body moves forward. The support reacts with the same amount of force in the opposite direction [13]. The magnitude of the ground reaction forces depends on the speed and body weight [14].

The extent and direction of the internal forces are significant. According to Jacob [15], the force applied on the first metatarsal reaches about 119% of body weight, while the second metatarsal is subjected to a high bending moment, with a resulting force of about 45% of the body weight acting on foot.

In the first 100 ms of each step, the force acting in the Z direction reaches a maximum of 120% of body weight, decreasing to about 60-80% of body weight during support on one foot. The centre of gravity is located in the middle of the pelvis and makes a sinusoidal movement while walking. The horizontal reaction forces are considerably smaller than the vertical reaction force. The horizontal reaction force acting in the Y direction has an amplitude of 25% of the body weight [14].

Wiedemeijer and Otten [16] and Stefanyshyn *et al*. [17] have analysed the distribution of forces while walking in high-heeled shoes. This condition significantly influences angles and force distributions. The maximum vertical reaction force is about 5% higher than walking with a low heel in the impact phase. The reaction force, in this case,

is higher in the forward and rearward directions and corresponds to an increase in deceleration and acceleration forces in the vertical direction.

During walking barefoot or with low heel shoes, the heel takes on a load of about 57% of body weight and the metatarsals 43%. During walking with a 10 cm heel, about 100% of the weight is applied to the metatarsals. The most balanced weight distribution is made on a 2 cm heel (approximately 50% on each vector). The calcaneus is loaded on 25-43% of body weight. The metatarsals carry 57-75% of body weight for medium-high heels [7].

The distribution of force also changes during running. A lower load and a more evenly distributed force were identified in the heel strike phase [18].

Body weight, speed, step length, type and structure of footwear are the factors that influence the distribution of plantar pressure [19].

Biomechanical measurements of the pressure distribution between the plantar surface of the foot and the support plane provide valuable information on the structure and function of the foot [14], which can indicate the impact of footwear or the necessary shape of the insole [7] and provide suggestions for improving design structure of footwear [19, 20].

During human walking, the centre of pressure advances during each step, creating a rolling motion between the foot and the support [21]. The average pressure distribution determines the centre of pressure. It could be standardised according to the length of the foot [22].

During the mid-stance phase, the maximum plantar pressure is transferred from the heel area to the rear-foot area [3].

The contact pressure at the metatarsophalangeal joints intensifies and reaches its maximum value in the push-off phase. The maximum contact pressure in the metatarsal area during push-off increases at least four times (third metatarsophalangeal joint) and up to 11 times (first metatarsophalangeal joint) compared to the heel strike phase [23].

Both peak plantar pressure and ground reaction forces can vary at similar walking speeds, as they can be produced by different combinations of length and cadence [14]. In general, maximum pressures and total force increase with walking speed.

The type of footwear influences the pressure distribution. Comfortable footwear contributes significantly to a balanced distribution of pressure on the plantar surface of the foot. Shoes with flexible soles reduce the plantar pressure and contribute to the proper functioning of the foot [19].

Several studies have investigated the influence of the heel on pressure distribution. During high-heeled walking, the joints showed different loading patterns [23]. This condition influenced the increase in pressure in the peak area compared to the barefoot. The maximum pressure is observed in the rear-foot area (hallux), followed by the midfoot and forefoot. Walking in high-heeled shoes resulted in a 30% increase in peak pressures in the II-IV metatarsal area compared to walking in low-heeled shoes [16, 24].

The 3D biomechanical analysis that includes a description of the movement of different anatomical segments of the foot is the most common assessment of the foot and gait. A motion capture system and a force plate must perform both kinematic and kinetic (dynamic) analysis.

Plate [13, 3] and insole systems with in-shoe sensors [14, 15] are used to register plantar pressures, both of which allow the determination of maximum pressures, weight distribution, surface and contact time, the position of the centre of pressure in both static and dynamic conditions [22, 25].

External forces, i.e., ground reaction forces, are measured using a force plate [3]. Intramuscular forces and Achilles' tendon forces are taken from electromyography and sensitive analysis of the centre of pressure [26, 27].

Kinematic parameters, such as the contact time, can be measured using high-speed cameras (i.e., MotionBLITZ EoSens® mini) [28].

There are complex systems with sensors (i.e., Vicon) [27, 29], which allow the simultaneous capture and determination of

kinetic and kinematic parameters, such as: walking or running speed, duration of heel strike, mid-stance and push-off, cadence, impact index, maximum reaction force, average load rate, initial speed, initial tibia angle, initial ankle flexion angle.

This paper investigates the biomechanical parameters to create an average representative model of foot loading for an extended target group.

EXPERIMENTAL

Materials and Methods

Equipment

The biomechanical parameters were registered using the Footscan system produced by RS Scan International. The equipment consists of a pressure platform and a software system (Figure 1), ensuring the collection, visualisation, and processing of static and dynamic biomechanical measurements. This system is mentioned in several research studies [28, 30], and is also used by various institutions and specialised laboratories. The platform incorporates 5 mm x 7 mm sensors that ensure the variation analysis of the pressures and forces for all the regions of the plantar footprint.

Figure 1. Footscan system

Subjects

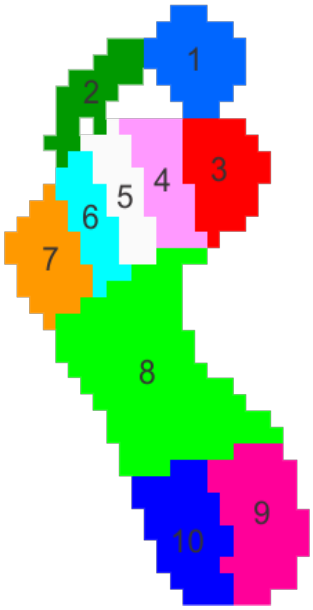
The biomechanical study was made based on data collected from 32 volunteer subjects, female, representing students from the "Gheorghe Asachi" Technical University of Iasi, 18-30 years old, wearing footwear size numbers 36 (group 1), 37 (group 2), 38 (group 3) in the French system. None of the subjects practice performance sports or other activities that could significantly influence the gait pattern. The subjects are included in the height range of 153-175 cm and weight range of 40-72 kg.

Method. Recording and Analysis of Biomechanical Parameters in Dynamics

To obtain the most accurate results, a working methodology was developed. Each subject was asked to reproduce three types of barefoot gait: normal gait (N), slow gait (L) and fast gait (R). The subjects established by themselves the specific speed for all three types of gait, considering the following ranges for total step time: normal gait 700-900 ms, slow gait 900-1100 ms, fast gait 500-700 ms. The subjects were tested using the three-step approach considered the most suitable in terms of results [31, 32]. According to this protocol, the subjects contact the platform on

the third step after initiating gait and walk a few more steps after platform contact. The invalid trials in which the contact between the foot and platform were not made correctly were not saved. The subjects repeated the same procedure with the opposite foot, thus recording values specific to the right and left foot. For each condition, three trials were recorded, resulting in 9 measurements/subject.

The plantar footprint is divided into 10 distinct regions (Figure 2) 242 [35]: 1 –toe I (Z1); 2 - toe II-V (Z2); 3 – metatarsal I (Z3); 4 – metatarsal II (Z4); 5 –metatarsal III (Z5); 6 - metatarsal IV (Z6); 7 - metatarsal V (Z7); 8 - midfoot (Z8); 9 – heel medial (Z9); 10 – heel lateral (Z10).



Toe I	Z1
Toe II-V	Z2
Meta I	Z3
Meta II	Z4
Meta III	Z5
Meta IV	Z6
Meta V	Z7
Midfoot	Z8
Heel medial	Z9
Heel lateral	Z10

Figure 2. Anatomical division of the plantar footprint in 10 regions

The force (N), contact area (cm^2), contact time (ms), and pressure (N/cm^2) for the 10 regions of the plantar surface were recorded and analysed using the Footscan system. Deviant values were excluded from the list, so the average of the tests was done with the remaining values.

The results were divided into three groups, according to the subjects' foot size, and the average values for the three trials for each analysed parameter were centralised in a table.

This paper presents the analysis of the biomechanical parameters during the normal gait.

RESULTS AND DISCUSSIONS

Verification of the Statistical Significance of the Differences between the Biomechanical Parameters of the Left and Right Foot Using the Student's Test and the Fisher's Test

The T-Student test was applied to confirm that there are no significant differences between the left and right foot. The averages of the set of values for the left and right foot for each of the 10 regions of the plantar footprint were compared, taking into account the following biomechanical parameters: force (N), contact area (cm^2), contact time (ms) and pressure (N / cm^2).

The calculated values are compared with p = 0.05 for a probability of 95% to determine if the results obtained are statistically significant. The values must be

greater than p = 0.05 to confirm the null hypothesis.

The Fisher test was used with p = 0.05 to verify that the variances in terms of biomechanical parameter values for the left foot did not differ significantly from the variances for the right foot.

According to both tests (Table 1), the null hypothesis for the contact area parameter was not confirmed, which highlights that most subjects have differences between the gait patterns of the left (L) foot compared to the right (R) foot in terms of the area of the plantar surface that contacts the ground. While in the case of force, pressure, and contact time parameters, the opposite is demonstrated – namely, there are no significant differences between the left and right foot. As a result, using the averages between the two feet in the next stage is possible. These hypotheses validate that the values are representative of the population.

Table 1: T and F Test results

Size 36		Z1	Z2	Z3	Z4	Z5	Z6	Z7	Z8	Z9	Z10
Force	Test T	0.279	0.382	0.321	0.480	0.890	0.759	0.485	0.013	0.314	0.532
	Test F	0.691	0.501	0.795	0.269	0.429	0.858	0.532	0.264	0.102	0.184
Contact area	Test T	0.135	0.044	0.002	0.000	0.000	0.001	0.002	0.814	0.000	0.000
	Test F	0.012	0.060	0.429	0.354	0.559	0.579	0.985	0.981	0.803	0.922
Contact time	Test T	0.316	0.971	0.743	0.446	0.944	0.999	0.839	0.350	0.294	0.519
	Test F	0.392	0.967	0.315	0.425	0.625	0.710	0.323	0.340	0.732	0.958
Pressure	Test T	0.499	0.712	0.039	0.669	0.215	0.526	0.896	0.005	0.048	0.434
	Test F	0.619	0.512	0.039	0.903	0.997	0.744	0.850	0.147	0.028	0.155

Size 37		Z1	Z2	Z3	Z4	Z5	Z6	Z7	Z8	Z9	Z10
Force	Test T	0.263	0.202	0.212	0.392	0.938	0.220	0.413	0.005	0.707	0.548
	Test F	0.448	0.094	0.003	0.925	0.247	0.080	0.856	0.175	0.058	0.045
Contact area	Test T	0.105	0.605	0.002	0.000	0.000	0.007	0.001	0.339	0.000	0.000
	Test F	0.982	0.942	0.282	0.968	0.080	0.137	0.040	0.837	0.981	0.413
Contact time	Test T	0.420	0.473	0.809	0.681	0.794	0.744	0.075	0.247	0.836	0.650
	Test F	0.343	0.603	0.194	0.945	0.672	0.632	0.000	0.532	0.581	0.594
Pressure	Test T	0.648	0.147	0.601	0.922	0.145	0.073	0.697	0.006	0.489	0.724
	Test F	0.741	0.061	0.012	0.984	0.408	0.173	0.693	0.072	0.112	0.086

Size 38		Z1	Z2	Z3	Z4	Z5	Z6	Z7	Z8	Z9	Z10
Force	Test T	0.096	0.795	0.596	0.287	0.555	0.533	0.517	0.364	0.638	0.896
	Test F	0.317	0.896	0.224	0.577	0.636	0.812	0.436	0.229	0.539	0.527
Contact area	Test T	0.003	0.789	0.009	0.006	0.001	0.013	0.228	0.432	0.050	0.002
	Test F	0.378	0.321	0.099	0.833	0.842	0.129	0.852	0.544	0.123	0.445
Contact time	Test T	0.587	0.881	0.726	0.667	0.630	0.297	0.583	0.525	0.668	0.396
	Test F	0.761	0.411	0.632	0.343	0.174	0.139	0.904	0.236	0.212	0.307
Pressure	Test T	0.276	0.724	0.761	0.994	0.468	0.347	0.634	0.295	0.346	0.633
	Test F	0.822	0.712	0.567	0.954	0.136	0.510	0.766	0.596	0.839	0.853

Statistical Indicators for Characterisation and Variation of Biomechanical Parameters

The statistical indicators [33] which characterise the set of values are mean, standard deviation (S), the minimum, maximum, amplitude of variation (A), and the coefficient of variation (CV). The values of statistical indicators of measured biomechanical parameters are presented in Tables 2-5.

Table 2: Statistical indicators for characterising the force distribution during normal gait

Size 36	Number of subjects	10	Z1	Z2	Z3	Z4	Z5	Z6	Z7	Z8	Z9	Z10
Force (N)	Mean value		159.4	9.2	54.7	125.2	156.5	113.3	42.0	38.3	244.3	186.7
	Min		63.2	0.0	16.6	18.9	80.7	38.6	1.0	5.1	160.9	133.2
	Max		241.3	26.1	96.7	202.9	229.0	220.7	84.0	69.6	326.9	272.9
	A		178.1	26.1	80.1	184.0	148.3	182.1	83.0	64.5	166.0	139.7
	S		60.4	7.6	28.9	50.3	41.2	52.9	31.4	23.3	63.8	46.0
	CV %		37.9	83.0	52.8	40.2	26.3	46.7	74.8	60.9	26.1	24.6
Size 37	Number of subjects	13	Z1	Z2	Z3	Z4	Z5	Z6	Z7	Z8	Z9	Z10
Force (N)	Mean value		141.9	19.0	40.8	142.9	163.2	92.2	34.0	34.0	184.4	170.8
	Min		57.8	0.0	0.4	50.8	76.6	40.3	5.1	4.1	106.0	75.0
	Max		247.1	42.2	144.2	340.6	253.0	170.5	142.7	55.6	262.7	278.4
	A		189.3	42.2	143.8	289.9	176.4	130.2	137.6	51.5	156.8	203.3
	S		62.9	14.3	36.7	83.8	52.6	33.8	36.5	15.2	49.0	61.7
	CV %		44.3	75.3	89.9	58.7	32.2	36.6	107.5	44.8	26.6	36.1
Size 38	Number of subjects	9	Z1	Z2	Z3	Z4	Z5	Z6	Z7	Z8	Z9	Z10
Force (N)	Mean value		201.2	48.2	79.9	166.7	180.2	115.5	40.1	44.9	256.7	215.6
	Min		9.9	6.2	11.2	83.7	115.9	51.1	0.0	5.8	107.0	94.8
	Max		345.7	177.5	188.8	270.4	282.7	273.9	111.7	133.5	471.5	381.8
	A		335.9	171.3	177.6	186.7	166.9	222.8	111.7	127.7	364.5	287.0
	S		109.1	54.5	66.3	61.4	56.3	71.3	38.6	37.0	137.7	102.0
	CV %		54.2	113.2	83.0	36.9	31.2	61.7	96.3	82.3	53.7	47.3

Table 3: Statistical indicators for characterising the contact time during normal gait

Size 36	Number of subjects	10	Z1	Z2	Z3	Z4	Z5	Z6	Z7	Z8	Z9	Z10
Contact time (ms)	Mean value		618.2	541.9	519.9	586.4	589.8	565.1	496.9	207.4	178.9	180.8
	Min		542.7	296.0	394.3	499.8	474.8	454.0	393.5	181.0	140.7	151.5
	Max		685.0	726.0	644.3	662.5	703.3	711.2	644.5	264.5	221.0	218.2
	A		142.3	430.0	250.1	162.7	228.5	257.2	251.0	83.5	80.3	66.7
	S		53.0	138.1	67.7	55.5	67.5	83.9	82.7	27.6	28.4	22.8
	CV %		8.6	25.5	13.0	9.5	11.5	14.8	16.7	13.3	15.9	12.6

Size 37	Number of subjects	13	Z1	Z2	Z3	Z4	Z5	Z6	Z7	Z8	Z9	Z10
Contact time (ms)	Mean value		612.4	504.9	501.1	585.8	587.2	575.5	488.4	199.0	173.1	178.5
	Min		563.5	0.0	93.0	531.5	521.8	508.0	238.5	107.7	86.5	120.0
	Max		675.0	672.5	650.0	650.0	658.5	664.5	614.5	338.8	215.5	235.5
	A		111.5	672.5	557.0	118.5	136.7	156.5	376.0	231.1	129.0	115.5
	S		38.2	207.9	137.2	40.2	42.3	44.7	107.5	53.1	37.2	32.2
	CV %		6.2	41.2	27.4	6.9	7.2	7.8	22.0	26.7	21.5	18.0
Size 38	Number of subjects	9	Z1	Z2	Z3	Z4	Z5	Z6	Z7	Z8	Z9	Z10
Contact time (ms)	Mean value		633.0	625.6	575.4	616.2	611.9	605.5	463.7	228.6	184.7	183.6
	Min		561.0	542.3	479.0	535.0	537.5	520.5	0.0	190.3	148.2	158.0
	Max		795.0	721.3	766.0	781.5	700.0	738.0	599.0	315.5	266.5	244.3
	A		234.0	178.9	287.0	246.5	162.5	217.5	599.0	125.2	118.3	86.3
	S		79.2	65.7	95.2	77.7	51.4	74.8	180.5	40.7	37.0	27.3
	CV %		12.5	10.5	16.6	12.6	8.4	12.4	38.9	17.8	20.0	14.9

Table 4: Statistical indicators for characterising the contact area during normal gait

Size 36	Number of subjects	10	Z1		Z2		Z3		Z4		Z5		Z6		Z7		Z8		Z9		Z10	
			S	D	S	D	S	D	S	D	S	D	S	D	S	D	S	D	S	D	S	D
Contact area (cm²)	Mean value		14.2	12.7	11.8	9.4	7.3	10.1	7.8	9.6	7.1	8.4	7.6	8.5	10.7	7.8	19.9	19.3	12.2	14.3	10.8	12.7
	Min		12.8	8.5	6.0	6.1	5.6	7.1	6.4	8.6	6.4	7.6	6.9	7.6	7.3	3.4	9.8	9.4	11.2	13.0	9.8	11.3
	Max		16.1	17.1	15.6	11.3	10.3	12.6	10.0	10.7	8.0	9.2	8.5	9.4	13.0	9.2	26.5	27.4	14.2	15.8	12.4	14.1
	A		3.4	8.6	9.6	5.1	4.7	5.4	3.6	2.1	1.6	1.6	1.6	1.8	5.7	5.9	16.7	18.0	3.0	2.8	2.7	2.8
	S		1.1	2.8	3.0	1.6	1.5	1.9	1.0	0.8	0.4	0.5	0.6	0.5	1.7	1.7	6.0	6.0	0.9	0.8	0.8	0.8
	CV %		7.8	21.7	25.9	16.6	20.0	18.9	13.5	7.9	6.3	6.5	7.5	5.5	16.0	21.5	30.0	31.3	7.0	5.5	7.8	6.4
Size 37	Number of subjects	13	Z1		Z2		Z3		Z4		Z5		Z6		Z7		Z8		Z9		Z10	
			S	D	S	D	S	D	S	D	S	D	S	D	S	D	S	D	S	D	S	D
Contact area (cm²)	Mean value		14.0	12.7	12.3	11.4	7.1	10.6	8.2	10.2	7.0	8.7	8.0	8.6	10.5	8.4	24.4	22.0	13.2	15.3	11.4	13.6
	Min		10.9	9.0	4.5	4.6	3.6	4.0	6.4	7.7	5.6	7.7	7.4	7.5	9.0	7.5	10.3	12.6	11.3	13.7	10.5	12.2
	Max		18.2	16.0	17.6	17.2	10.0	14.6	11.1	11.8	8.1	9.4	8.6	9.6	14.7	9.9	32.2	35.3	15.0	17.1	13.2	14.8
	A		7.4	7.0	13.1	12.6	6.3	10.6	4.7	4.1	2.5	1.7	1.2	2.1	5.7	2.4	22.0	22.6	3.8	3.4	2.7	2.7
	S		1.9	1.9	4.5	4.4	2.2	3.0	1.2	1.1	0.7	0.4	0.4	0.6	1.7	0.9	6.0	6.4	1.1	1.1	0.7	0.9
	CV %		13.9	15.2	36.8	38.9	30.9	28.4	14.1	11.3	10.4	5.0	5.1	7.3	15.8	10.5	24.6	28.9	8.4	7.3	6.4	6.9
Size 38	Number of subjects	9	Z1		Z2		Z3		Z4		Z5		Z6		Z7		Z8		Z9		Z10	
			S	D	S	D	S	D	S	D	S	D	S	D	S	D	S	D	S	D	S	D
Contact area (cm²)	Mean value		14.4	10.6	14.3	14.7	9.5	12.1	8.1	9.3	6.5	7.1	6.8	7.6	9.1	7.5	22.9	22.0	11.7	12.6	10.0	11.3
	Min		11.8	1.9	4.5	4.4	2.2	3.0	1.2	1.1	0.5	0.2	0.2	0.4	1.7	0.8	6.0	6.4	1.1	1.1	0.5	0.9
	Max		16.5	15.2	36.8	38.9	30.9	28.4	14.1	13.1	10.4	10.3	8.9	10.2	15.8	11.4	35.9	40.6	15.8	18.2	13.4	15.6
	A		4.7	13.3	32.2	34.4	28.7	25.4	13.0	12.0	9.9	10.1	8.7	9.7	14.2	10.6	29.9	34.2	14.6	17.1	12.8	14.7
	S		1.7	3.9	8.1	8.8	7.1	6.2	3.7	3.9	3.0	3.4	3.2	3.4	4.2	3.7	8.6	8.9	5.3	6.0	4.7	5.4
	CV %		12.0	37.0	56.8	60.0	74.8	51.1	45.8	42.1	45.5	48.2	47.3	44.9	45.5	48.8	37.4	40.5	45.0	47.6	47.6	47.4

Table 5: Statistical indicators for characterising the pressure distribution during normal gait

Size 36	Number of subjects	10	Z1	Z2	Z3	Z4	Z5	Z6	Z7	Z8	Z9	Z10
Pressure (N/cm²)	Mean value		11.6	0.9	6.4	14.4	20.7	14.2	4.2	1.8	18.6	15.9
	Min		5.7	0.0	1.6	2.5	9.6	5.0	0.1	0.5	12.7	12.1
	Max		18.0	2.1	10.5	23.5	30.3	28.3	9.8	3.0	26.9	20.6
	A		12.3	2.1	8.9	21.0	20.7	23.3	9.7	2.5	14.3	8.5
	S		3.9	0.7	3.2	5.9	5.7	6.8	3.2	0.9	4.8	3.0
	CV %		33.5	84.3	49.6	41.2	27.6	47.7	75.6	49.8	26.0	19.0
Size 37	Number of subjects	13	Z1	Z2	Z3	Z4	Z5	Z6	Z7	Z8	Z9	Z10
Pressure (N/cm²)	Mean value		10.8	1.4	4.2	15.3	21.0	11.1	3.6	1.4	13.1	13.8
	Min		4.5	0.0	0.1	6.3	10.4	4.9	0.5	0.4	7.8	5.9
	Max		19.8	3.4	12.4	31.3	31.3	20.2	17.0	2.5	19.3	21.0
	A		15.4	3.4	12.3	25.0	20.9	15.3	16.5	2.1	11.5	15.1
	S		5.0	1.0	3.1	8.1	6.3	3.9	4.3	0.6	3.6	4.8
	CV %		46.7	72.7	74.1	53.1	29.9	35.2	119.9	44.5	27.9	34.9
Size 38	Number of subjects	9	Z1	Z2	Z3	Z4	Z5	Z6	Z7	Z8	Z9	Z10
Pressure (N/cm²)	Mean value		14.8	4.7	7.3	16.7	22.4	13.2	3.7	2.0	16.8	16.2
	Min		0.8	0.5	1.6	11.0	14.4	5.7	0.0	0.2	7.2	7.0
	Max		24.9	22.4	16.5	26.4	35.0	30.5	8.7	3.9	28.4	27.2
	A		24.1	22.0	14.9	15.4	20.5	24.8	8.7	3.7	21.1	20.3
	S		7.4	6.9	5.5	5.0	6.9	8.1	3.1	1.2	8.0	7.1
	CV %		49.8	145.7	75.0	29.9	30.7	61.3	83.2	59.8	47.6	44.1

The highest values of force are highlighted in the region of the medial heel (Z9), lateral heel (Z10), toe I (Z1), followed by the metatarsal II, III and IV (Z4, Z5, Z6). The lowest values of the force are registered for the region of toes II-V (Z2), metatarsal V (Z7) and midfoot (Z8) of the plantar surface of the foot (Figure 3). The same trend could be seen in the case of pressure (Figure 4). Regarding the mean values for the contact time (Figure 5), higher values are recorded at the toe I, metatarsal II, III and IV, while in the heel area, these values decrease significantly. This distribution is specific to all three groups of analysed subjects. The highest contact area mean values (Figure 6) are recorded in the case of the midfoot, followed by the inner region of the heel for both left and right foot. The lowest values for contact area are noted in the region of metatarsal III and IV (Z5 and Z6).

The analysis of the chromatic maps generated by Footscan software and the evaluation of diagrams demonstrate that the most loaded, in terms of force and pressure, are toe I, metatarsal II-IV, lateral and medial heel, being in the same time the regions with the minimum contact areas. This conclusion is supported by previous studies, which confirm that the maximum loading and plantar pressure are transferred from heel to rear-foot. Thus, in the barefoot gait, the heel takes a load of about 57% and metatarsals 43% of the body weight, while the stresses in midfoot and toe II-V regions are not significant [3, 34]. Some studies have reported that the highest pressure has been identified in the area of the toe I [35]; others highlighted the metatarsal II and III regions [32]. These differences in pressure distributions could be caused by the rules used to divide the plantar surface into regions, the software used for the analysis, the subjects involved in the study, the protocols, the experimental conditions, the characteristics of the sensor and the measurement technologies.

The mean values for the contact time are higher in the rear-foot regions and decrease on the heel area. A similar distribution is identified in the literature [36,

37]. The values obtained justify that the heel strike phase is shorter than the support and propulsion phase and confirm that the contact time between the heel region and the support increases pressure [34].

The contact area is an important variable which in alliance with the pressure, provides valuable information regarding the loading model of the foot. As can also be identified in other studies [32, 36], this parameter has higher values in the heel and midfoot regions, which have the function of force absorption and pressure redistribution. In contrast, the metatarsal region has a significantly smaller contact area and higher pressures.

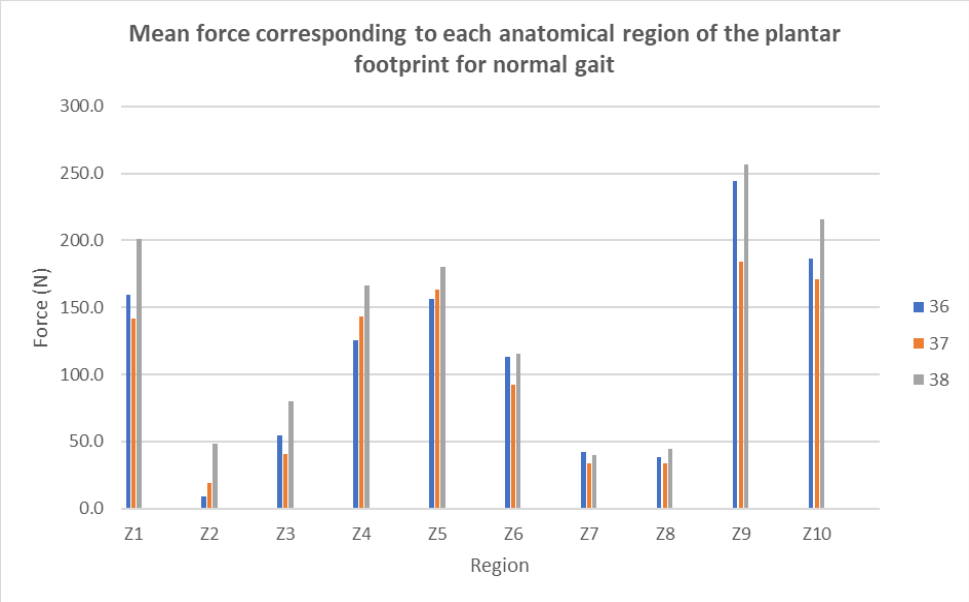


Figure 3. Mean force corresponding to each anatomical region of the plantar footprint for normal gait

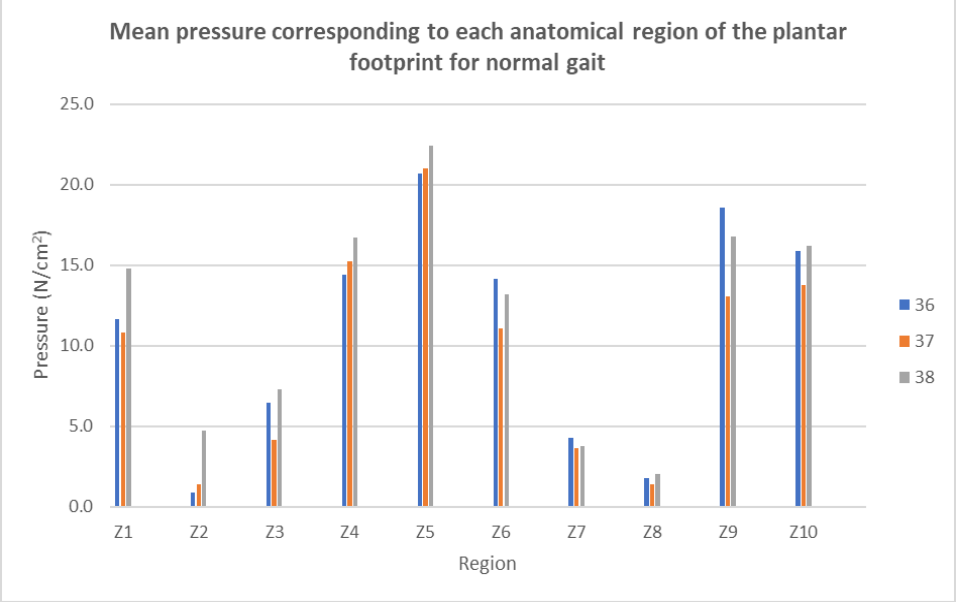


Figure 4. Mean pressure corresponding to each anatomical region of the plantar footprint for normal gait

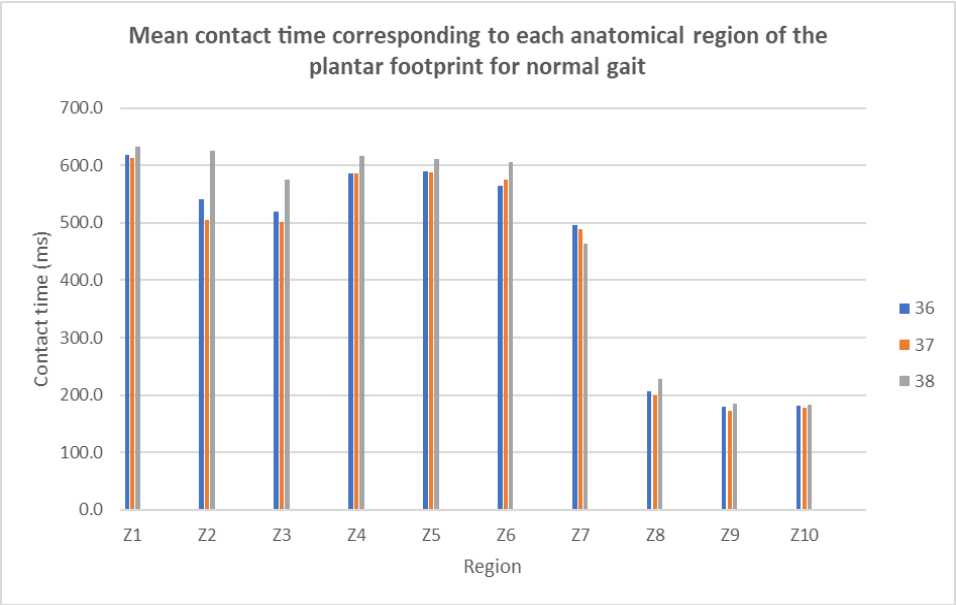


Figure 5. Mean contact time corresponding to each anatomical region of the plantar footprint for normal gait

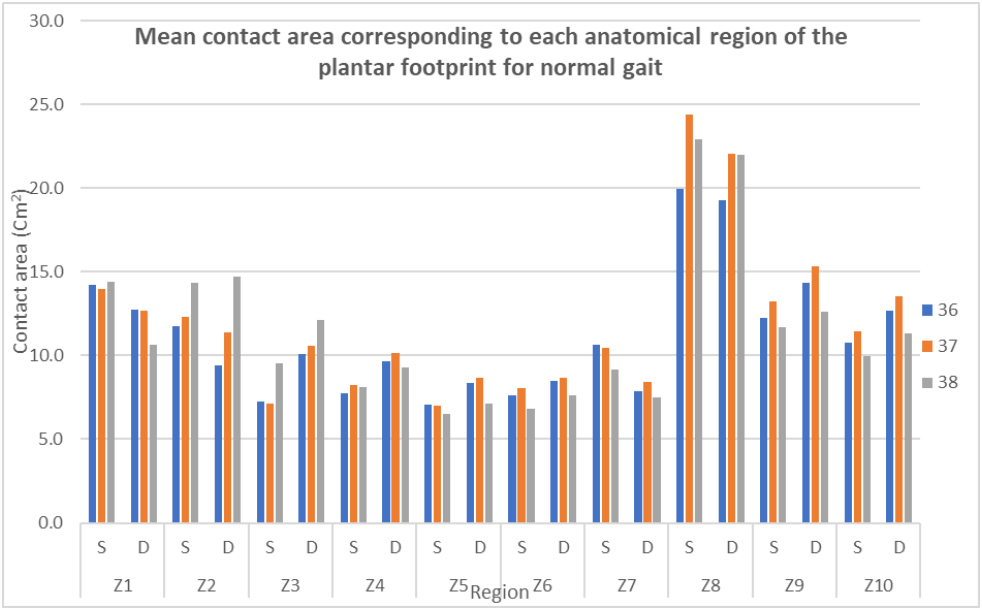


Figure 6. Mean contact area corresponding to each anatomical region of the plantar footprint for normal gait

Figures 7-10 represent the coefficients of variation of the studied biomechanical parameters graphically.

In the case of the group of subjects with size 36, the highest values of the coefficient of variation for force and pressure parameters are on Z2 (toe II-V) - 83%, Z7 (metatarsal V) - 74.8% and Z8 (midfoot) - 60.9%, while the lowest values are for the contact time parameter on the Z1 (toe I) -8.6% and Z4 (metatarsal II) - 9.5% regions.

The coefficient of variation with maximum value for the group of subjects with size 37 has the parameter force and pressure on the Z7 (metatarsal V) - 107.5%, Z3 (metatarsal I) - 89.9% and Z2 (toe II-V) - 75.3% regions, while the minimum values are observed for the contact time on Z1 (toe I) - 6.2%, Z4 (metatarsal II) - 6.9% and Z5 (metatarsal III) - 7.2%.

The highest values of the coefficient of variation for the group of subjects with size 38 in case of force and pressure are on Z2 (toe II-

V) - 113.2%, Z7 (metatarsal V) - 96.3% and Z8 (midfoot) -82.3%, while the lowest values are for the contact time parameter on Z1 (toe I) - 12.5%, Z2 (toe II-V) -10.5% and Z5 (metatarsal III) - 8.4%.

Regarding the contact surface, higher values of the coefficient of variation are detected in the case of subjects with size 38 on Z3 (metatarsal I) - 74.8%, Z2 (toe II-V), Z5 (metatarsal III) - 48.2% and Z7 (metatarsal V) - 48.8%. For the group of sizes 37 and 36, a minimum to medium dispersion over all 10 areas of the plantar footprint is highlighted.

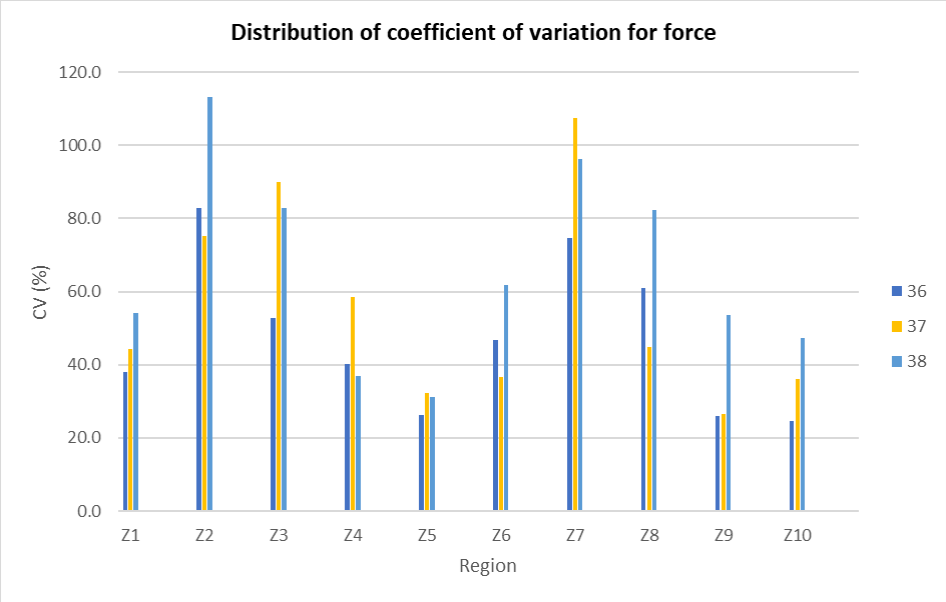


Figure 7. Distribution of coefficient of variation for force (normal gait)

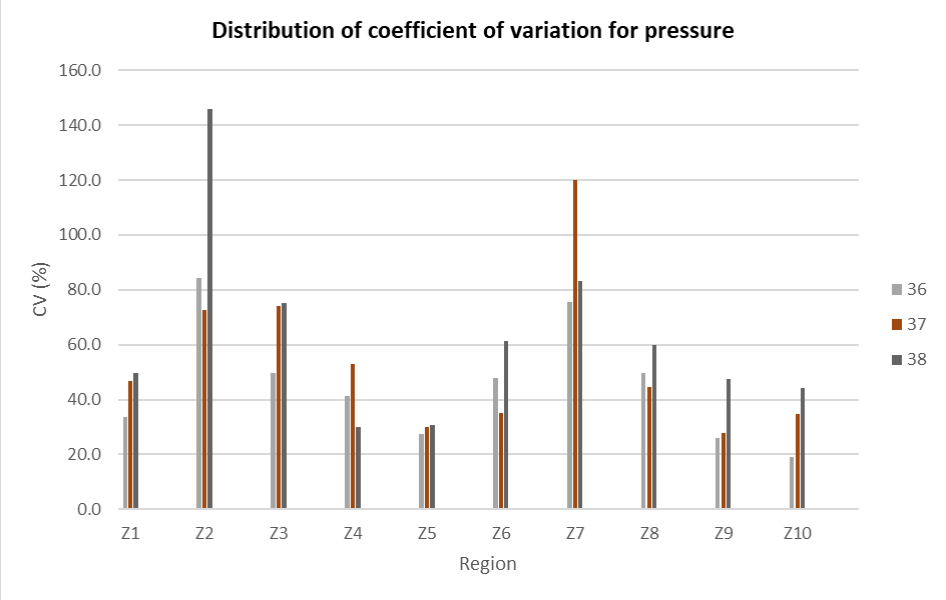


Figure 8. Distribution of coefficient of variation for pressure (normal gait)

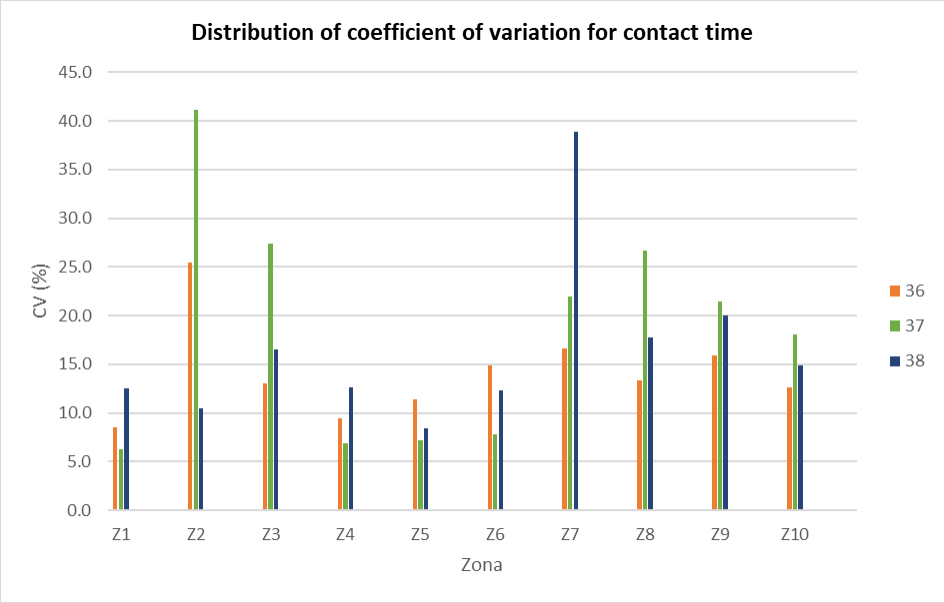


Figure 9. Distribution of coefficient of variation for contact time (normal gait)

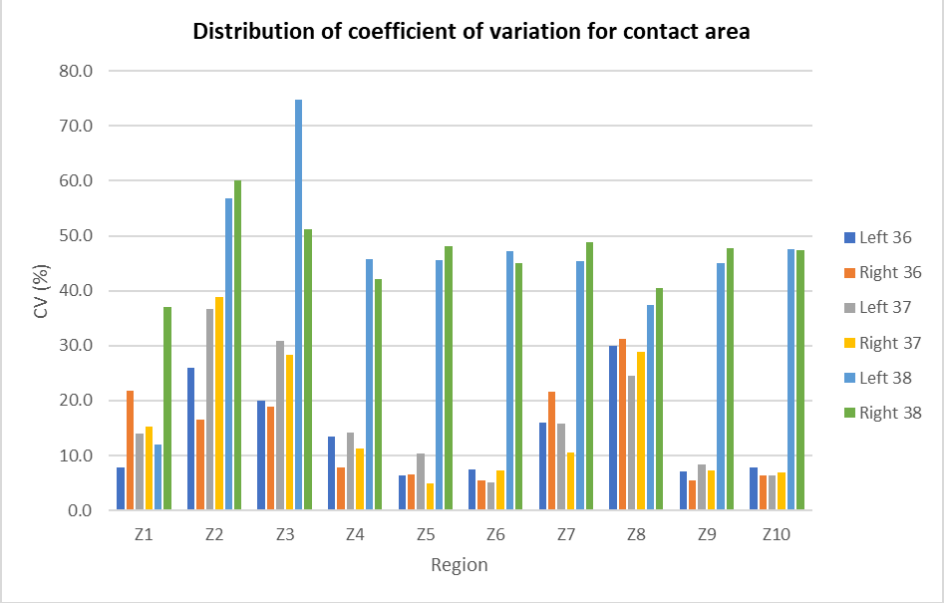


Figure 10. Distribution of coefficient of variation for contact area (normal gait)

CONCLUSIONS

The study evaluates the main variables in the biomechanical characterisation of gait – force, pressure, time and contact area. The research was performed based on the data collected from 32 healthy females, aged between 18 and 30 years, divided into three size groups – 36 (10 subjects), 37 (13 subjects), 38 (9 subjects).

Due to the division of the plantar surface on 10 distinct regions, toe I (Z1), toe II-V (Z2), metatarsal I (Z3), metatarsal II (Z4), metatarsal III (Z5), metatarsal IV (Z6), metatarsal V (Z7), midfoot (Z8), medial heel (Z9), lateral heel (Z10), the more and less loaded zones in terms of the forces acting during normal walking are identified. The obtained data were centralised and analysed from a statistical point of view.

The plantar pressures recorded in dynamics highlight the first toe, metatarsal II-IV, lateral and medial heel as the most loaded regions of the plantar surface. There are statistically significant differences between the left and right foot for the contact area parameter for all size groups in all plantar regions except midfoot. The analysis of statistical indicators for force variation highlights a medium and large dispersion,

which describes the population as relatively homogeneous, and in some areas, even heterogeneous (CV is over 30%). It confirms that the forces generated during the impact with the ground vary from one subject to another, being a parameter influenced by many external and internal factors [38]. Considering the coefficient of variation for force and pressure variables, smaller distributions on the toe II-V, metatarsal I, V and midfoot regions are confirmed. In contrast, the areas with higher values of forces and pressures – toe I, metatarsal II-IV, medial and lateral heel have smaller distribution, nearby 30% – which characterise a moderately homogeneous population. In terms of time and contact area, the coefficient of variation highlights a small and medium spread of values, and the population is considered homogeneous.

Based on this research, the average model of foot loading for an extended target group was created to be further used in simulations of footwear behaviour in various loading conditions.

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ENZYMATIC ACTIVITY OF ALKALINE PROTEASE FROM *Bacillus cereus* TD5B AND ITS APPLICATION AS SHEEP SKIN DEHAIRING AGENT

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ENZYMATIC ACTIVITY OF ALKALINE PROTEASE FROM *Bacillus cereus* TD5B AND ITS APPLICATION AS SHEEP SKIN DEHAIRING AGENT

ABSTRACT. This study aims to determine the enzymatic activity of extracellular alkaline protease from *Bacillus cereus* TD5B and its potential application as a sheep skin dehairing agent. The *B. cereus* TD5B was screened for extracellular alkaline protease production on skim milk agar media, while its alkaline protease activity and the application were measured at 1%, 1.5%, and 2%. The application of alkaline protease from *B. cereus* TD5B as a sheep skin dehairing agent was observed through histological examination and physical properties measurement after chrome-tanning with lime and Na_2S as control. The study was conducted in a completely randomized design, and the quantitative data were analyzed using Duncan's Multiple Range Test. The results showed that a clear zone was seen surrounding *B. cereus,* indicating the bacteria's proteolytic activity. The protease activity measurement showed that 2% of alkaline protease had the highest enzymatic activity at 144.75 U/mL/min. The highest tensile strength of sheep leather was obtained after dehairing at 1% alkaline protease concentration (350.26 kg/cm^2), even though the highest elongation was obtained at 2% (34.92%). In contrast, different concentrations showed similar shrinkage temperatures at 90°C. This study concludes that the optimum alkaline protease concentration from *Bacillus cereus* TD5B as a sheep dehairing agent was 2%.

KEYWORDS: *Bacillus cereus* TD5B, dehairing, alkaline protease, sheep skin

ACTIVITATEA ENZIMATICĂ A PROTEAZEI ALCALINE DIN *Bacillus cereus* TD5B ŞI APLICAREA ACESTEIA PE PIELEA DE OAIE CA AGENT DE ÎNDEPĂRTARE A PĂRULUI

REZUMAT. Acest studiu are ca scop determinarea activității enzimatice a proteazei alcaline extracelulare din *Bacillus cereus* TD5B și a potențialei sale aplicații ca agent de îndepărtare a părului de pe pielea de oaie. S-a selectat *B. cereus* TD5B pentru producția de protează alcalină extracelulară pe mediu de agar din lapte degresat, măsurându-se activitatea proteazei alcaline și aplicarea acesteia în proporție de 1%, 1,5% și 2%. Aplicarea proteazei alcaline din *B. cereus* TD5B ca agent de îndepărtare a părului de pe pielea de oaie a fost observată prin examinarea histologică și s-au determinat proprietățile fizice după tăbăcirea în crom cu var și Na_2S ca martor. Studiul a fost realizat într-un design complet randomizat, iar datele cantitative au fost analizate folosind testul Duncan cu rază multiplă. Rezultatele au arătat că s-a văzut o zonă liberă în jurul *B. cereus*, indicând activitatea proteolitică a bacteriei. Măsurarea activității proteazei a arătat că proporția de 2% din proteaza alcalină a avut cea mai mare activitate enzimatică la 144,75 U/ml min. Cea mai mare rezistență la tracțiune a pielii de oaie a fost obținută după îndepărtarea părului folosind protează alcalină la o concentrație de 1% (350,26 kg/cm^2), chiar dacă alungirea cea mai mare a fost obținută la concentrația de 2% (34,92%). În schimb, concentrații diferite au arătat o temperatură de contracție similară la 90°C. Acest studiu concluzionează că concentrația optimă de protează alcalină din *B. cereus* TD5B ca agent de îndepărtare a părului de pe pielea de oaie a fost de 2%.

CUVINTE CHEIE: *Bacillus cereus* TD5B, agent de îndepărtare a părului, protează alcalină, piele de oaie

L'ACTIVITÉ ENZYMATIQUE DE LA PROTÉASE ALCALINE DE *Bacillus cereus* TD5B ET SON APPLICATION COMME AGENT D'ÉLIMINATION DES CHEVEUX POUR LA PEAU DE MOUTON

RÉSUMÉ. Cette étude vise à déterminer l'activité enzymatique de la protéase alcaline extracellulaire de *Bacillus cereus* TD5B et son application potentielle comme agent d'élimination des cheveux pour la peau de mouton. Le *B. cereus* TD5B a été sélectionné pour la production de protéase alcaline extracellulaire sur milieu gélose au lait écrémé, tandis que l'activité de la protéase alcaline et l'application ont été mesurées à 1%, 1,5% et 2%. L'application de protéase alcaline de *B. cereus* TD5B comme agent d'élimination des cheveux de la peau de mouton a été observée par examen histologique et les propriétés physiques ont été mesurés après tannage au chrome avec de la chaux et du Na_2S comme témoin. L'étude a été menée dans un plan complètement aléatoire et les données quantitatives ont été analysées à l'aide du test à plages multiples de Duncan. Les résultats ont montré qu'une zone claire était observée autour de *B. cereus*, indiquant l'activité protéolytique de la bactérie. La mesure de l'activité protéase a montré que 2% de la protéase alcaline avait l'activité enzymatique la plus élevée à 144,75 U/mL/min. La résistance à la traction la plus élevée du cuir de mouton a été obtenue après épilation à une concentration de protéase alcaline de 1% (350,26 kg/cm^2), même si l'allongement le plus élevé a été obtenu à 2% (34,92%). En revanche,

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différentes concentrations ont montré une température de retrait similaire à 90°C. Cette étude conclut que la concentration optimale de protéase alcaline de *B. cereus* TD5B en tant qu'agent d'élimination des cheveux des moutons était de 2%.
MOTS CLÉS : *Bacillus cereus* TD5B, agent d'élimination des cheveux, protéase alcaline, peau de mouton

INTRODUCTION

The tannery industry is an animal by-product processing industry that produces flexible and durable leather from livestock skins [1]. Due to the uniqueness and beauty of the leather, the natural product is favoured by consumers and preferred over synthetic materials [2]. However, the leather processing industries face challenges due to the generated pollution, which harms the environment. The commercial leather-making process involves sequential stages: pre-tanning, tanning, post-tanning, and finishing, which uses and expels chemicals. Among the pre-tanning stage operations, dehairing is an important step to remove hair, epidermis, non-collagenous proteins, and other cementing substances from the skin [3]. The conventional dehairing process uses saturated lime and sodium sulfide at high concentrations and contributes to 50-60% of the total dissolved solids and chemical and biochemical oxygen demand in the effluent [4].

The negative impacts of the leather processing waste on the environment and increased consumers' awareness encourage the industry to adopt cleaner processing methods. One of the more eco-friendly and sustainable approaches in leather processing is the use of enzymatic dehairing. Enzyme-based dehairing processes utilize proteolytic enzyme, or widely known as protease, which leads to a reduction of effluent load and toxicity. Also, improvement in leather quality is a viable alternative to the conventional chemical-based process [5].

Protease enzyme has represented about 60-65% of the total industrial enzyme market and could be obtained from various resources, such as animals, plants, and microorganisms [6]. Protease catalyzes the protein hydrolysis to polypeptides and oligopeptides to amino acids and is classified depending on the pH and their active site structure. The selection of enzyme sources plays a key role in obtaining desirable enzymes. Nowadays, *Bacillus* spp. strains are favored as a protease source due to their wide temperature and pH tolerance. Proteases from *Bacillus* spp. are widely used in food, pharmaceutical, detergent, leather industries, waste treatment, synthesis of oligopeptides [7, 8], and potential application for dehairing without affecting the quality of produced leather [9].

Bacillus cereus TD5B is protease-producing bacteria isolated from a farm area in Yogyakarta [10] and has shown increased enzymatic activity through ammonium sulfate purification [11]. Furthermore, *B. cereus* TD5B has also been shown to hydrolyze duck meat for angiotensin converting enzyme inhibitor production [12] and producing keratinase for poultry feather waste treatment [13]. In the present study, the enzymatic activity of extracellular alkaline protease from *B. cereus* TD5B and its application as sheep skin dehairing agents were observed to determine its potential to be utilized in the leather processing industry as an enzymatic dehairing agent.

EXPERIMENTAL

Materials and Methods

Bacterial Isolation, Medium, and Culture

The strain is obtained initially from a soil sample collected at ammonia high-emitted chicken hen production area in tropical country Indonesia. Soil samples (1.0 g) collected from various spots in a most odorous region were then suspended in 10 mL pure, sterile water and diluted appropriately. A portion of the cell suspension was spread on a 1/100 nutrient agar plate with a high concentration of $(NH_4)_2SO_4$ as an organic ammonium stressor (500 mg/L $(NH_4)_2SO_4$). Colonies appearing on the plate were then picked and purified. Each purified colony was

inoculated on an agar plate with and without ammonium stressor. Microorganisms displaying proper growth on the agar with $(NH_4)_2SO_4$ were selected as ammonium-responsive microorganisms. Isolates were then purified by plating on 1/100 nutrient broth (0.01% meat extract, 0.01% polypeptone, and 0.005% NaCl, pH-value adjusted 7.2) supplemented with 500 mg/L $(NH_4)_2SO_4$ and continued by incubation at 30^{o}sC for 48 h in aerobic condition.

Bacterial Screening

Colony from the selected strain was then identified based on the potency as proteolytic bacteria. The strains were screened for extracellular protease production using skim milk agar media containing (w/v): 0.5% peptone; 0.25% NaCl; 2% agar powder; 0.5% meat extract; and 1.5% skim milk, diluted on 100 mL distilled water. Positive results are shown in a clear zone of hydrolysis around the colonies [15]. Microorganisms showing a clear zone of skim hydrolyzed around their colonies were picked up for further identification, based on the morphological and molecular characteristics. Molecular characterization was further done by the 16S rRNA gene sequencing method.

Observation of the Strain Morphology

The morphological characteristic was observed by scanning electron microscopy (SEM) [14]. The SEM sample was prepared by transferring the biomass of selected microbial strain harvested after 48 h incubation to a clean Eppendorf tube containing approximately 1.5 mL of 3.5% glutaraldehyde solution. Then, the culture was incubated for 4 h at room temperature, followed by a wash with phosphate buffer (100 mM, pH 7.2). The culture is dehydrated through a series of 50% to 100% ethanol solutions. The filter was mounted on the stub, coated with gold, and examined under a scanning electron microscope (JEOL JSM-6510LA, Hitachi Limited, Japan).

Identification of 16S rRNA Gene Sequencing and Phylogenetic Analysis

The molecular characteristics were done by the 16S rRNA gene sequencing method. The 16S rRNA was amplified by PCR using universal primers. The purified PCR product was then sequenced using BigDye Terminator v3.1 Cycle Sequencing Kit from Applied Biosystems, USA with the ABI Prism 310 Genetic Analyzer (Applied Biosystems) and analyzed using the BLAST version 2.2.18 (BLASTN) to compare with the public database of DDBJ (http://blast.ddbj.nig.ac.jp). Molecular taxonomy, sequencing, and phylogenetic analysis of DNA were isolated from the biomass selected bacteria harvested at 48 h. Genomic DNA of the bacterium was extracted by standard methods. The PCR was carried out to amplify about 1500 bp fragment of the 16S rRNA gene using primers designed based on the conserved region of the 16S rRNA gene for bacteria. A combination of forward primers 16S forward (5-AGAGTTTGATCCTGGCTCAG-3) and 16S reverse (5-GGYTACCTTGTTACGACTT-3) was applied to amplify the 16S rRNA sequence of bacteria. The PCR was performed using PCR thermal cycler (Applied Biosystem, USA). The PCR conditions and the methodology for sequencing were followed as per procedure [10]. The purified DNA was sequenced using a DNA analyzer (Applied Biosystems), and the sequences were aligned and assembled using the sequencher 4.7 program (GENE CODES). The 16S rRNA partial gene sequence similarities were studied using the National Center for Biotechnology Information-BLAST search. The high similarity sequences deposited in the DNA database and isolates' identities were calculated by the highest score (> 98%). The phylogenetic tree was constructed with a neighbor-joining algorithm method performed using Clustal W and viewed using FigTree v1.4.0.

Bacterial Growth and Cultivation

The selected isolate was first cultivated into pre-culture by incubating the isolate on pH 7.0 stock solution (1 g meat extract, 1 g biological peptone, 0.5 g NaCl, and 70 ml distilled water) for 24-h 27°C with continuous

shaking (120 rpm). The culture media for *Bacillus cereus* TD5B protease production was composed of 1 g meat extract, 1 g peptone, 0.5 mL NaCl, 2 g skim milk agar, and distilled water reached 100 mL. The culture solution was set at pH 7.2 and inoculated with 1 mL pre-culture and incubated on a rotary shaker (120 rpm) for 24-h at 27°C. The culture was centrifuged at 6000 rpm (4°C) for 10 minutes, and the supernatant was used for proteolytic activity assay.

Enzyme Assay

The supernatant (3 ml) was mixed with 1 ml of casein dissolved in 0.2 M phosphate buffer (pH 8.0) and was incubated at 37°C for 30 min. The reaction was stopped by the addition of 5 ml of 5% trichloroacetic acid. The blank was also prepared by adding TCA before the enzyme addition and incubated at the same condition. The sample test and the blank test solutions were then filtered through a Whatman No. 1 filter paper. For 1.5 ml of the filtrate, 5 ml of 0.4 M Na_2CO_3 and 1 ml of 0.5 N Folin Ciocalteu reagent were added and mixed thoroughly. The absorbance was measured at 578 nm by the UV Visible spectrophotometer. One unit of protease activity is defined as the amount of enzyme which liberated 1 µmol of tyrosine per min at 37°C.

Sheep Skin Dehairing Application

Wet salted sheep skins were used for the dehairing application. Before dehairing, the sheep skins were cut into 10 x 10 cm, washed, and soaked by water and 0.5% (w/v) detergent for 30 min in a mini cylindrical rotating drum. Alkaline protease enzyme was then added at 1%, 1.5%, and 2% (w/v) and left for 18-h at room temperature and then dehaired by rubbing. Depilated sheep skins were cut at 0.75 x 0.5 cm for histological examination, while the rest were processed into leather for physical properties measurement.

Leather Processing

The dehaired sheep skin was processed into the leather by chrome tanning (8%) for 60 to 120 min, followed by bating for seven times with 1% (w/v) formic acid and 1.75% (w/v) sodium bicarbonate for 15 minutes each, re-tanning with 150% (w/v) water, 0.5% formic acid, and 0.3% wetting agent for 30 to 60 min, and washing with 200% (w/v) water and 0.5% (w/v) formic acid for 20 min.

Histological Examination

Dehaired sheep skin pelts were cut into 0.75 x 0.5 cm, washed, and fixed in 10% formic acid (w/v) to be used as a sample. To analyze the histology feature, samples were then embedded in paraffin block with haematoxylin and eosin (H&E) staining [17].

Leather Physical Properties Measurement

The physical measurement of this study has included tensile strength, elongation, and shrinkage temperature. The tensile strength and elongation of sheep leather were measured as per standard International Union for Physical testing for Leather IUP methods EN ISO 3376 (IULTCS/IUP 6, 2011) [18] and EN ISO 17236 (IULTCS/IUP 43, 2016) [19]. The tanned leather's shrinkage temperature was analyzed following ISO 3380:2015 (IULTCS/IUP 16) [20]. The leather samples were all completely vertically immersed in glycerine at 20±2°C, and the heating rate was 2±0.2°C·min^{1}.

Statistical Analysis

The study was conducted in a completely randomized design. All the experiments were carried out in triplicates, and the mean ± standard deviation has been plotted. The bacterial screening and histological examination were analyzed descriptively. Other quantitative data were analyzed statistically using Duncan's Multiple Range Test (DMRT) with the significant value set at $P \leq 0.05$.

RESULTS AND DISCUSSIONS

Screening *Bacillus cereus* TD5B

B. cereus TD5B was isolated from soil at odorous layer hen farm in Yogyakarta, Indonesia [10]. The strain was initially plated on Skim Milk Agar (SMA) at pH 7.2. Growing

on SMA medium for 24-h at 30°C has shown a clear zone formation surrounding the colonies (Figure 1). The formation of a clear zone indicates the strain's proteolytic activity, while its activity on pH 7.2 indicates alkaline protease production by the bacteria.

The formation of a clear zone in SMA medium was due to the skim milk protein hydrolysis, which has been catalyzed by the bacteria's extracellular protease. Thus, a clear zone would be formed surrounding the bacteria colony. The clear zone formation on SMA medium has been a widely utilized method to determine bacterial screening for proteolytic activity, especially for *Bacillus* strain [9]. *Bacillus* strains have been known to possess the alkaline proteolytic activity and are described in many papers for their applications, mainly directed to detergents [22] and the tannery industry [23]. The study by Kasana and Yadaf [24] also used this method to screen alkaline protease production of psychotropic *Exiguobacterium* sp. SPKB5, while [25] used the clear zone formation method to determine de-hairing protease production on *B. cereus* strain AT from cow dung. The clear zone formation in the SMA medium in this study confirmed that *B. cereus* TD5B could produce an alkaline protease enzyme.

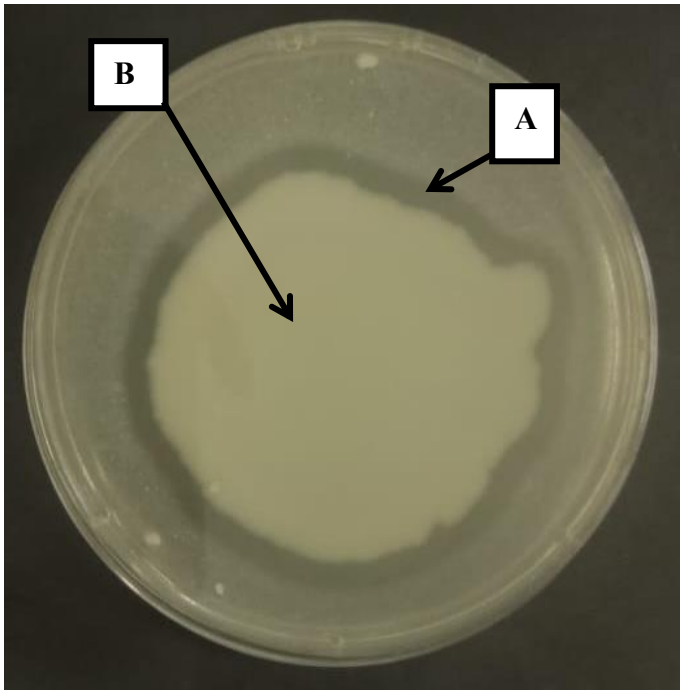

Figure 1. Proteolytic activity of *B. cereus* TD5B on SMA medium. A = clear zone; B = bacteria colony

Identification and Characterization of *Bacillus cereus* TD5B

Scanning Electron Microscope (SEM) was used to identify the strain's morphological properties (Figure 2). The strain was found to be aerobic, motile, spore-forming, and rod-shaped. The 16S rRNA partial gene sequence of strain TD5B showed sequence similarity with the published 16S rRNA gene sequences of *B. cereus*. The phylogenetic tree (Figure 3) was constructed by the neighbor-joining method using Clustal W software [21].

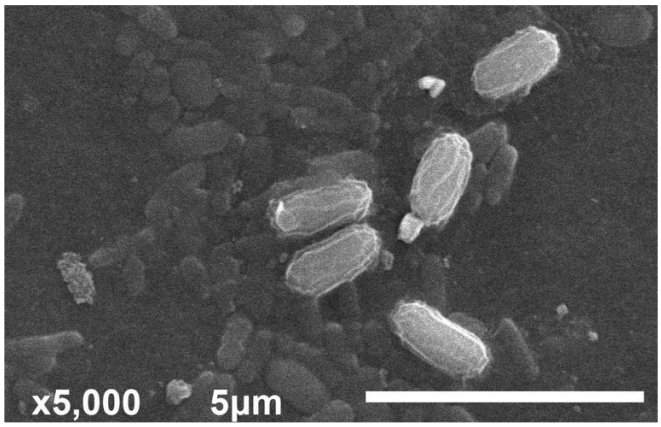

Figure 2. SEM image of *B. cereus* TD5B

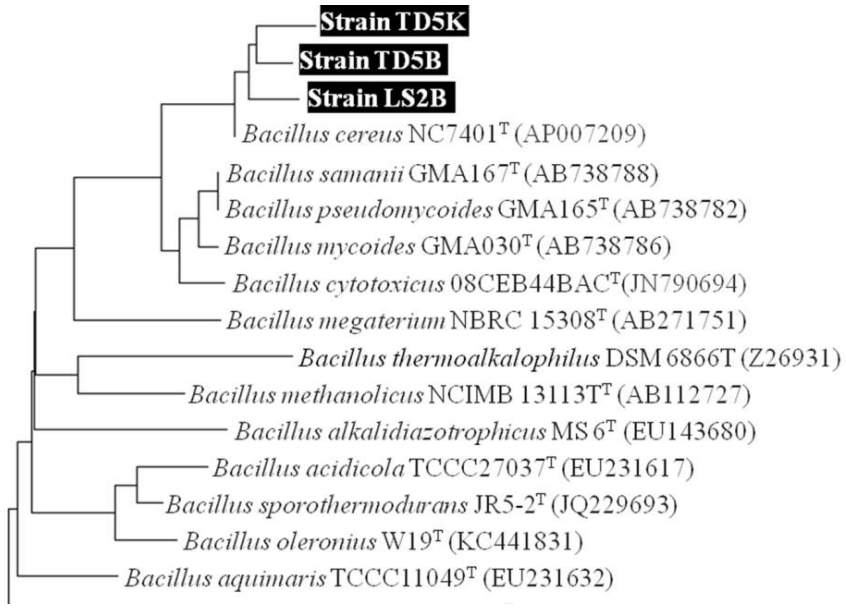

Figure 3. The relationships between *Bacillus cereus* TD5B and members of *Bacillus* strains on rooted neighbor-joining tree based on 16S rRNA sequences

Enzymatic Activity

The extracellular alkaline protease of *B. cereus* TD5B was extracted and measured for its proteolytic activity under different concentration levels (1%, 1.5%, and 2%). The different concentration levels measurement was aimed to understand its activity before applying it for sheep skin dehairing. The result of alkaline protease activity of *B. cereus* TD5B measurement at different concentration levels in this study is presented in Figure 4.

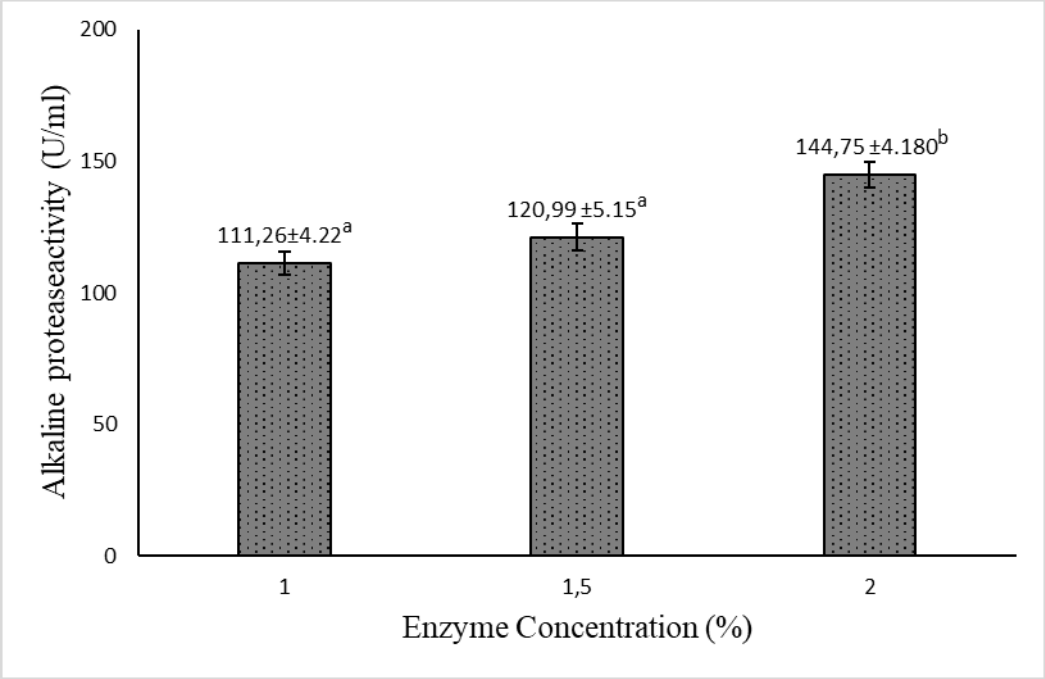

Figure 4. Alkaline protease activity of *B. cereus* TD5B

The results showed that alkaline protease of *B. cereus* TD5B concentration positively correlates with enzymatic activity; higher alkaline protease concentration application has shown higher enzymatic activity. In this study, we found that 1% alkaline protease of *B. cereus* TD5B had enzymatic activity at 111±4.22 U/ml, while at 1.5% and 2% concentration the enzymatic activity was at 120.99±5.15 U/ml and 144.75±4.80 U/ml, respectively. The enzymatic activity of alkaline protease from *B. cereus* TD5B in this study was higher compared to crude alkaline protease from *Bacillus* sp. SB12, which was at 114 U/mg [9].

In this study, the alkaline protease from *B. cereus* TD5B was produced at 27°C and pH 7.2. At a similar temperature, another researcher [24] showed that the alkaline protease activity of *Streptomyces* sp. Al-Dhabi-82 was at 48±2.8 U/ml, significantly lower than *B. cereus* TD58 in all different concentration levels in this study. Research has shown that the microbial enzymatic activity is affected by various factors, such as temperature, pH, fermentation period, carbon and nitrogen source, and used substrates [9, 25, 26]. Investigations on the effect of temperature revealed that 37°C was the optimum value for maximum protease production by *Bacillus* species [27].

Furthermore, research on *Bacillus licheniformis* RKK-04 [28] and *Bacillus subtilis* RTSBA6 [29] showed that both strains had a protease thermal stability range of 25°C to 50°C. Aside from pH and temperature, the media's carbon and nitrogen sources also affect alkaline protease activity [25, 30]. However, the study on different environmental conditions towards protease production of *B. cereus* TD5B has not been done in this study. Thus, an approach to further optimize the proteolytic activity of *B. cereus* is possible by modifying the environmental condition of the media.

Enzymatic Sheep Skin Dehairing Application

The histological examination of dehaired sheep skin was observed using a photomicrograph (Figure 5).

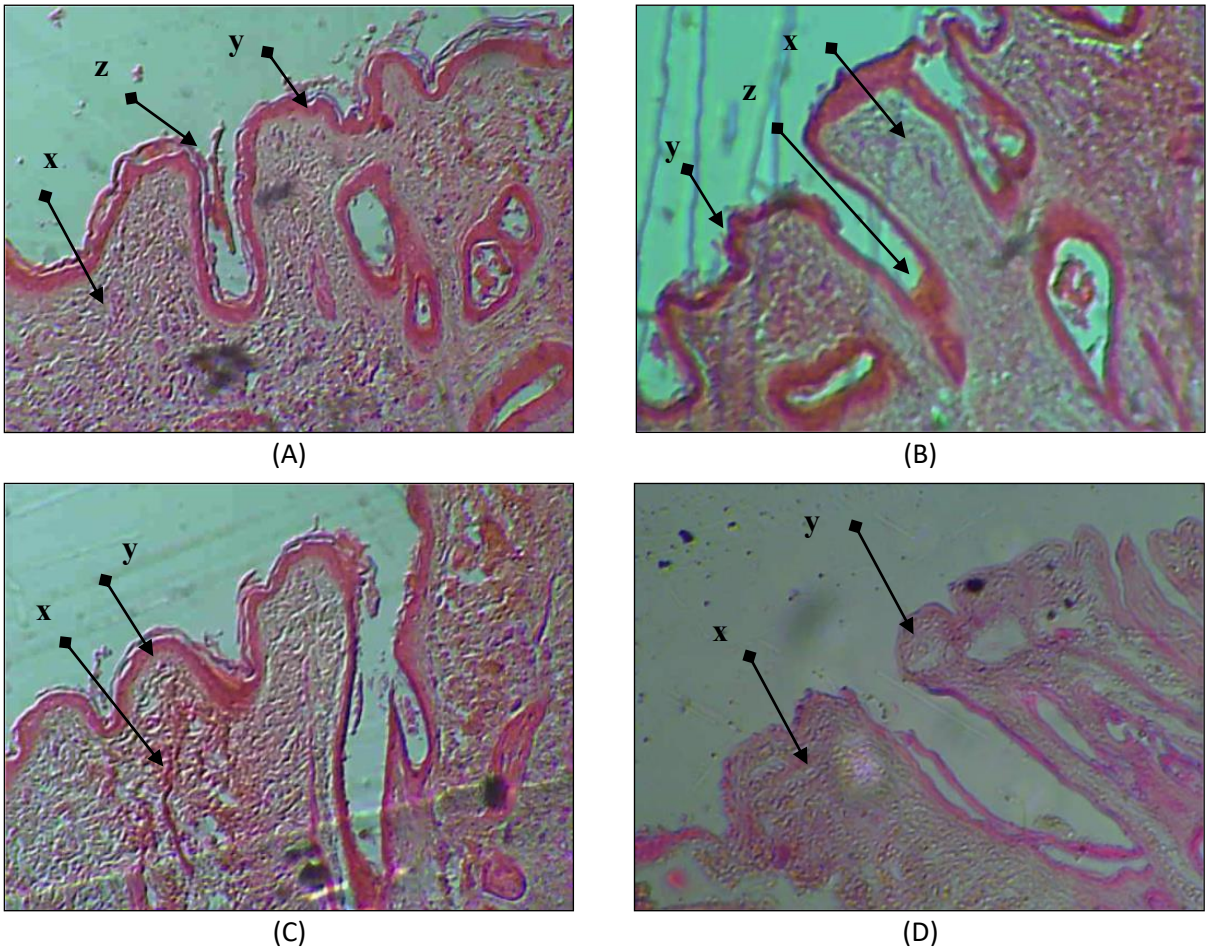

Figure 5. Histological examination of dehaired sheep skin. A = 1% alkaline protease; B = 1.5% alkaline protease; C = 2% alkaline protease; D = lime and Na_2S; x = dermal papillae; y = reticular papillae; z = hair.

The dehairing process aims to remove the skin epidermis and hair by removing epidermal keratins without damaging the dermal collagen fibers. The result showed that protease *B. cereus* TD5B has a non-collagenolytic effect on the hide and a non-keratinolytic effect on the hair. Other research [31] showed that dehairing proteases result in the degradation of the cells in the Malpighi's layer and the hair bulb's basal cells. In Figure 5, it can be seen that alkaline protease of *B. cereus* TD5B at all concentration levels did less damage to the sheep skin than the usage of lime and Na_2S. Other reports showed that proteolytic enzymes destroyed the soft keratin tissues during dehairing, which is sufficient to remove the hair without damaging the collagen dermal fibers [32]. It showed that the enzymatic dehairing of alkaline protease from *B. cereus* TD5B yields better sheep skin quality than lime and Na_2S to be further processed into leather. However, the histological examination showed that enzymatic dehairing of sheep skin at 1% and 1.5% concentration level in this study still left several hairs intact to the skin. In comparison, at 2% concentration levels, the sheep hair was fully dehaired from the skin.

Leather Physical Properties

The physical properties of enzymatic dehaired sheep skin by using alkaline protease from *B. cereus* TD5B at different concentration levels (P1 = 1%; P2 = 1.5%; and P3 = 2%) was observed and compared to the conventional dehairing by using lime and Na_2S (P0) to understand the potential application of *B. cereus* TD5B in the leather industry. In this study, sheep leather's physical properties were observed by measuring the tensile strength, elongation, and shrinkage temperature. Different alkaline protease concentration levels in this study showed significant differences ($P<0.05$) in the tensile

strength (Figure 6). The highest tensile strength was found on 1% alkaline protease dehairing, which was at 34.35±0.33 N/mm^2. The tensile strength measurement also showed that enzymatic dehairing of sheep leather by using *B. cereus* TD5B yields better tensile strength than the conventional dehairing, except at a 1.5% concentration level.

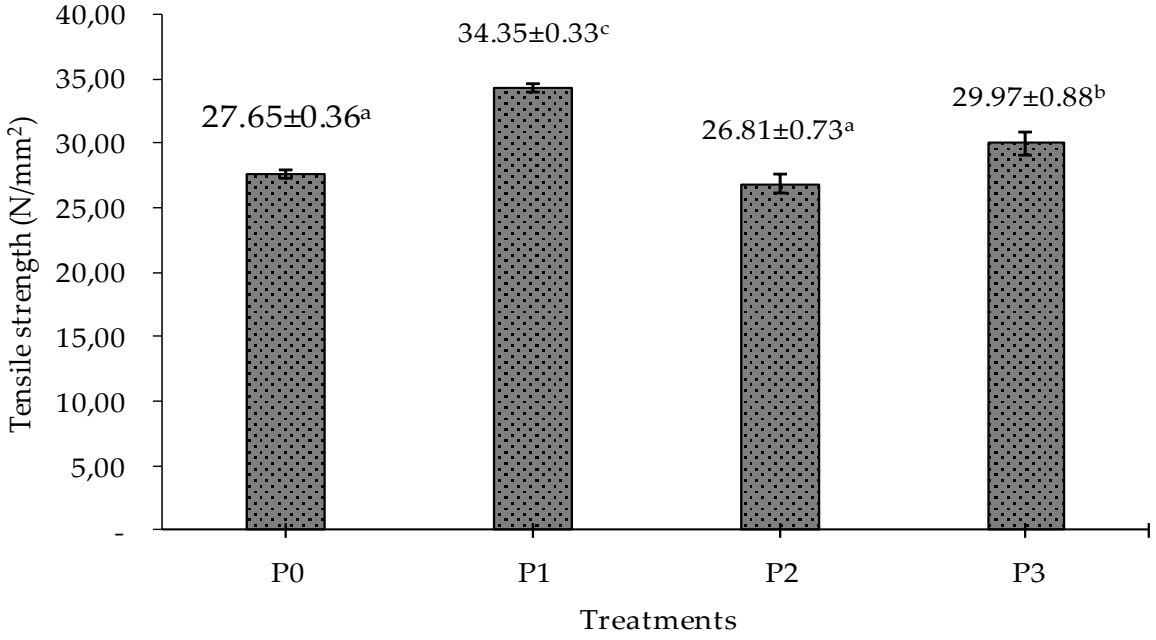

Figure 6. Tensile strength of sheep leather dehaired with different agents. P0 = 0.5% lime and 3% Na_2S; P1 = 1% alkaline protease; P2 = 1.5% alkaline protease; P3 = 2% alkaline protease. Different superscripts indicate significant difference (P<0.05).

The elongation at break measurement of sheep leather in this study showed a significant difference between each treatment (P<0.05), with the enzymatic dehairing of sheep skin, showed higher elongation compared to conventional dehairing except at 1.5% alkaline protease concentration (Figure 7). Research has shown that enzymatic dehairing using alkaline protease from *Bacillus* strain produced leather with better tensile strength and elongation, which was 28±6 N/mm^2 39±1.3%, respectively, on goat leather [9]. Other research [33] showed that goat dehairing by alkaline protease yields leather with elongation at 49.01±2.61% and tensile strength at 25.78±1.02 N/mm^2, both being higher compared to the conventional dehairing by using lime and sulfide. In addition, other research on goat skin dehairing by using bacterial alkaline protease also showed similar results [34].

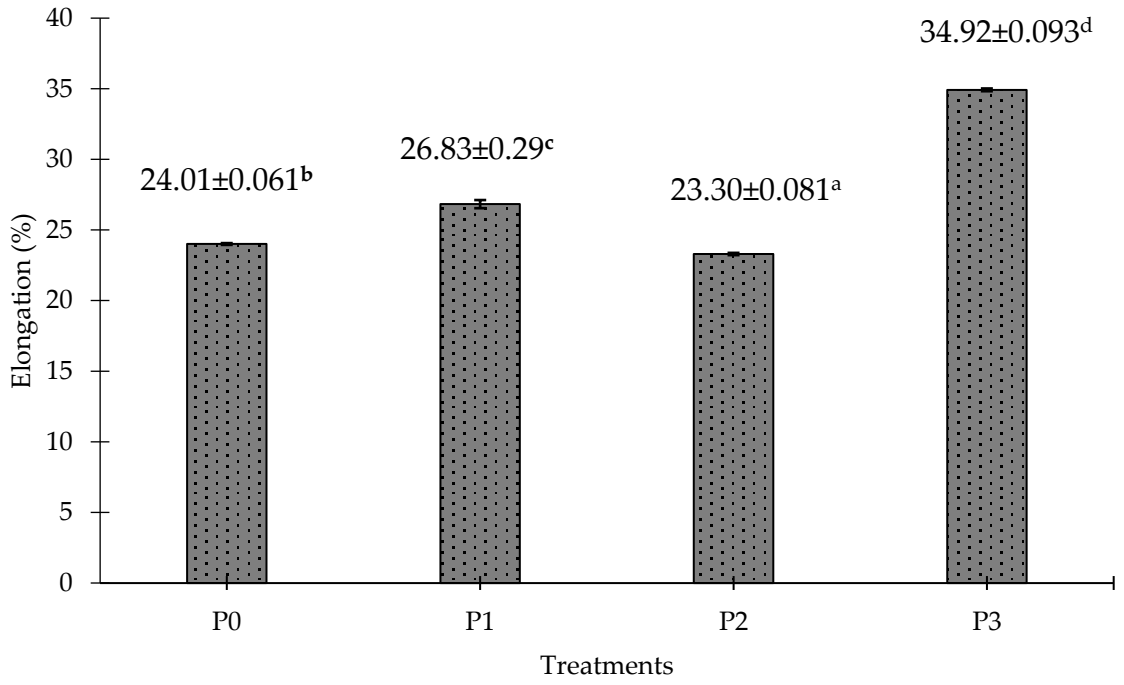

Figure 7. Elongation of sheep leather dehaired with agents. P0 = 0.5% lime and 3% Na_2S; P1 = 1% alkaline protease; P2 = 1.5% alkaline protease; P3 = 2% alkaline protease. Different superscripts indicate significant difference ($P<0.05$).

This study's shrinkage temperature measurement showed similar results between leather with conventional dehairing and enzymatic dehairing at different alkaline protease concentration levels. In the process of leather tanning, the fibers were strengthened by chemical cross-linking bonds formation among molecular collagen chains [35]. Tanned leather's shrinkage temperature is an important index for hydrothermal stability, especially for leather intended for outwear manufacturing subjected to hot temperature. Research showed that the shrinkage temperature of sheep skin tanned using syntan containing active chlorine group was 81.6°C, lower than found in this study [36]. Another research found that the use of epoxy resin as a sole tanning agent showed leather shrinkage temperature at 85°C [37]. In this study, the tanning of sheep skin was done using chrome, and the obtained shrinkage temperature was found at 90°C. This showed the enzymatic dehairing of sheep skin by using alkaline protease from *B. cereus* TD5B yield matching the shrinkage temperature to that of conventionally dehaired leather.

CONCLUSIONS

The extracellular alkaline protease enzyme from *Bacillus cereus* TD5B was detected and showed the potential to be used as an alternative for lime-sulfide dehairing for sheep skin. The optimum alkaline protease concentration of *B. cereus* TD5B was found at the highest concentration of the study, which was at 2%, thus indicating better dehairing at a higher concentration.

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EFFECT OF BADMINTON SHOE SOLE ON THE LUNGE SKILL PERFORMANCE: IN THE VIEWPOINT OF COORDINATION

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EFFECT OF BADMINTON SHOE'S SOLE ON THE LUNGE SKILL PERFORMANCE: IN THE VIEWPOINT OF COORDINATION

ABSTRACT. Badminton lunge requires rapid coordination between the knee and ankle joints and it is accompanied by fast contact between the shoe's sole and the floor. Phase angle analysis is a protocol with high resolution and relating to the coordination, but how the shoe's sole would affect the lunge performance was not clear in terms of coordination. Thereby, the aim of this study was to applied phase angle analysis to insight the lunge process, then to disclose the effect of badminton shoe's sole on the lunge skill performance. Eleven elite badminton players performed five left-forward maximum lunge trials with wearing Rounded Heel Shoe (RHS), Flattened Heel Shoe (FHS), and Standard Heel Shoes (SHS). The motion capturing system was used to measure the knee and ankle kinematics information. The Phase Angle (PA), continuous relative phase (CRP) and variability of continuous relative phase (VCRP) between the knee and ankle joints were then calculated for both forward lunge phase and recovery phase in each of the three shoes. Current findings indicated that players wearing RHS had certain advantages on better movement coordination than other shoes, as indicated by better PA and CRP. The findings of this study would be helpful to understand the coordination of badminton lunges and explain the synergy between the lower extremity ankle and knee joint to minimize the possibility of injury in badminton. Furthermore, the coordination between the knee and ankle joints was greatly affected by the structure of the shoe heel design.

KEY WORDS: phase angle, kinematics, coupling angle, lunging, footwear, badminton shoe

INFLUENȚA TĂLPII PANTOFILOR DE BADMINTON ASUPRA EXECUTĂRII FANDĂRILOR ÎN CEEA CE PRIVEȘTE COORDONAREA

REZUMAT. Fandările în badminton necesită o coordonare rapidă între articulațiile genunchiului și ale gleznei, însoțită de un contact rapid între talpa pantofului și podea. Analiza unghiului de fază este un protocol de înaltă rezoluție care se referă la coordonare, dar nu este clar modul în care talpa pantofului afectează executarea fandării în ceea ce privește coordonarea. Prin urmare, scopul acestui studiu a fost de a aplica analiza unghiului de fază pentru a studia procesul de executare a fandării, apoi de a dezvălui influența tălpii pantofului de badminton asupra executării fandării. Unsprezece jucători de badminton de elită au executat cinci fandări cu extensie maximă, cu piciorul stâng înainte, purtând pantofi cu toc rotunjit (RHS), pantofi cu toc aplatizat (FHS) și pantofi cu toc standard (SHS). Sistemul de captare a mișcării a fost utilizat pentru a măsura datele cinematice ale genunchiului și ale gleznei. Unghiul de fază (PA), faza relativă continuă (CRP) și variabilitatea fazei relative continue (VCRP) între articulațiile genunchiului și ale gleznei au fost apoi calculate atât pentru faza de fandare înainte, cât și pentru faza de recuperare, pentru fiecare dintre cele trei tipuri de pantofi. Descoperirile actuale au indicat faptul că jucătorii care au purtat pantofii tip RHS au avut anumite avantaje în ceea ce privește o mai bună coordonare a mișcării decât cei care au purtat alt tip de pantofi, după cum indică valorile PA și CRP mai bune. Rezultatele acestui studiu ar fi utile pentru a înțelege coordonarea fandărilor în badminton și pentru a explica sinergia dintre extremitatea inferioară a gleznei și articulația genunchiului pentru a reduce la minim posibilitatea rănirii practicând badminton. În plus, coordonarea dintre articulațiile genunchiului și ale gleznei a fost foarte afectată de designul tocului pantofului.

CUVINTE CHEIE: unghi de fază, cinematică, unghi de cuplare, fandare, încălțăminte, pantof de badminton

L'EFFET DE LA SEMELLE DE LA CHAUSSURE DE BADMINTON SUR L'EXÉCUTION DE LA FENTE, EN TERMES DE COORDINATION

RÉSUMÉ. La fente de badminton nécessite une coordination rapide entre les articulations du genou et de la cheville et s'accompagne d'un contact rapide entre la semelle de la chaussure et le sol. L'analyse de l'angle de phase est un protocole à haute résolution et relatif à la coordination, mais la façon dont la semelle de la chaussure affecte l'exécution de la fente n'est pas claire en termes de coordination. Ainsi, le but de cette étude était d'appliquer une analyse d'angle de phase pour comprendre le processus de fente, puis de révéler l'effet de la semelle de la chaussure de badminton sur l'exécution de la fente. Onze joueurs de badminton d'élite ont effectué cinq extensions maximales avec leur pied gauche en avant, en portant des chaussures à talons arrondis (RHS), des chaussures à talons plats (FHS) et des chaussures à talons standard (SHS). Le système de capture de mouvement a été utilisé pour mesurer les informations cinématiques du genou et de la cheville. L'angle de phase (PA), la phase relative continue (CRP) et la variabilité de la phase relative continue (VCRP) entre les articulations du genou et de la cheville ont ensuite été calculés pour la phase de fente avant et la phase de récupération pour chacun des

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trois types de chaussures. Les résultats actuels ont indiqué que les joueurs portant des chaussures type RHS avaient certains avantages sur une meilleure coordination des mouvements en comparaison avec les autres types de chaussures, comme indiqué par de meilleures valeurs PA et CRP. Les résultats de cette étude seraient utiles pour comprendre la coordination des fentes de badminton et expliquer la synergie entre l'extrémité inférieure de la cheville et l'articulation du genou afin de minimiser la possibilité de blessure en jouant au badminton. De plus, la coordination entre les articulations du genou et de la cheville était grandement affectée par la structure de la conception du talon de la chaussure.
MOTS CLÉS : angle de phase, cinématique, angle d'accouplement, fente, chaussure, chaussure de badminton

INTRODUCTION

Badminton is considered as one of the fastest racket sports in the world [1], which requires excellent strength, dynamic balance, quick response and body coordination [2, 3]. Lunge is a frequently executed footwork in badminton, which consists of simultaneously stretch and retraction of the hip, knee, and ankle joints through muscular strength and power [4]. This movement requires a high level of coordination in a very short time between points [2, 5]. During lunges, badminton players may be exposed to the strenuous impacts, accounting for more likelihood of badminton injury [6]. Studying joint contact can predict injury in badminton [7].

To date, research has reported that the knee and ankle joints were the most frequently injured joints in badminton players [12, 13]. Reeves *et al*. [12] concluded that the knee could be exposed to higher risk of injuries whilst performing strenuous turns or cuts that predominantly occur in the frontal and transverse planes instead of the sagittal plane alone. The authors suggested that studying sport specific movements could better analyze the underlying mechanisms of lower limb injury. Huang *et al*. [14] maximized the jerk motion of badminton players using an injury mechanism model and they found that professional badminton players showed a large knee joint torque in both sagittal and frontal planes. According to the study of Herbaut *et al*. [13], the greater the degree of ankle inversion, the more likelihood of ankle sprain injury can be found. Wang *et al*. [15] reported that the net joint torque was closely related to the co-contraction levels between agonist and antagonist muscles during isokinetic ankle dorsiflexion.

In addition, Phomsoupha *et al*. [3] suggested that badminton sports required high performance of badminton shoes especially during the landing phase of a lunge. Appropriate shoes would improve the performance and attenuate impact forces effectively during a lunge. For instance, Kesilmiş *et al*. [16] found that the athletes wearing Kangoo Jump Shoes can improve dynamic balance and muscle strength at ankle joint. Similarly, changing the heel curvature design in badminton shoes could reduce ground reaction forces and knee moments during lunges, implying a lower risk of joint injury [6]. As the key interface between foot and ground, the shoe features would influence movement coordination during various sports.

Normally, although we could know how the lunge performed through kinematic in a joint, we lack details such as correlation within lower limb joints. Badminton lunge requires rapid coordination between the knee and ankle joints and it is accompanied by fast contact between the shoe's sole and the floor. Since coordination is considered as important to maintain the appropriate relationship between joint movements and muscle contractions, it ensures the efficiency of sport activities [8, 9]. Movement coordination is described as the capability to complete a series of actions accurately and smoothly, which is usually assessed by the continuous relative phase [10, 11]. Therefore, to reduce the injury potential to joints and muscles during badminton exercises, it seems insightful to evaluate the coordination during extreme lunge to establish theoretical framework for badminton athletes. Unfortunately, how the shoe's sole would affect the lunge performance was not clear in terms of coordination.

Hence, the present study was aimed to apply phase angle analysis to insight the lunge

process, then to disclose the effect of badminton shoe's sole on the lunge skill performance. Based on the existing literature, we hypothesized that different shoe soles would affect the coordination of the knee and ankle joints during lunge, especially during initial impact phase.

METHODS

Participants

Eleven male elite badminton players participated in this study with the mean age of 20.6 ± 0.7 years, mean body height of 156.0 ± 6.0 cm, mean body weight of 70.9 ± 5.9 kg, and mean year of playing experience of 8.4 ± 1.4 years. All participants were right-handed and had experience of national game participation. They reported no lower limb injuries for at least six months prior to the test. Participants signed the written consent and all the procedures were confirmed with the principles of the Helsinki Declaration.

Footwear Conditions

Three identical pairs of badminton shoes with different modifications of heel shape were built for this study (Figure 1): Rounded Heel Shoe (RHS), Flattened Heel Shoe (FHS), and Standard Heel Shoe (SHS). As aligned with the previous study [6], the RHS was modified with the 5-mm extension at the tip of the posterior heel with reference to the original professional badminton shoe model (Li Ning SAGA, Beijing, China). The FHS had a flat edge on the posterior heel. And the SHS was the original specification available in the market without any modification, which was used as a reference shoe condition for this study.

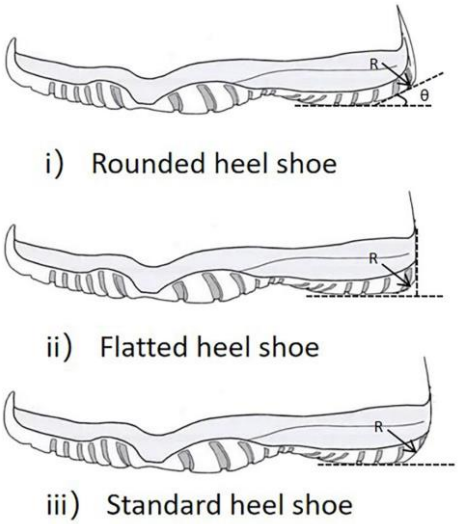

Figure 1. Footwear structure. (i) Rounded Heel Shoe, (ii) Flattened Heel Shoe, and (iii) Standard Heel Shoe

Kinematics Measurement

The lower limb kinematics data were obtained using an infrared motion system at 200 Hz. Since left-forward direction was considered as a key direction in the badminton lunge study for its higher landing impact [3, 4, 17], the lunging leg (i.e., right leg) information during maximum-effort lunge toward the left-forward direction were selected to assess the lower limb coordination. The cameras were arranged in a circle manner to capture all the marker trajectories during the entire lunge landing.

The athletes were asked to warm up and stretch in the test zone whilst wearing experimental shoes. Following the standard static and dynamic calibrations as specified from the manufacturer, the camera lens distortion was minimized for actual data collection. Then, the participants were instructed to perform five left-forward lunge trials with maximum-effort wearing each type of shoe in a randomized manner. The task was the lunge to the 45-degree toward the left from the individual starting position and then hit the suspended target. A complete test cycle was from initial heel contact, hitting the shuttlecock, and then recovery back to the original starting position.

Data Processing

The marker trajectories were filtered by a fourth-order low-pass Butterworth with a cut-off frequency at 6 Hz. Then, the data were normalized to 101 points with quintuple spline procedure. The ankle and knee angles were calculated and then determined the vector angles (θ) with respect to the horizontal in the sagittal plane for further analysis [18].

$$\theta_{\text{centered}}(t_i) = \theta(t_i) - \min(\theta(t)) - \frac{\max(\theta(t)) - \min(\theta(t))}{2} \quad (1)$$

$$\zeta(\mathrm{t}) = \theta_{centered}(t) + iH(t) \quad (2)$$

$$\varphi(t_i) = \tan^{-1}\left(\frac{H(t_i)}{\theta_{centered}(t_i)}\right) \quad (3)$$

$$CRP_{(1-2)}(t_i) = \varphi_1(t_i) - \varphi_2(t_i) \quad (4)$$

where $\theta_{\text{centered}}(t_i)$ and $\theta(t_i)$ represent the zero-centered and original Euler angles at each time point (t_i); min(θ(*t*)) and max(θ(*t*)) are the minimum and maximum values over these 100 points, respectively; H(*t*) of $\theta_{\text{centered}}(t_i)$ represents the Hilbert transform imaginary part of the analytic signal ξ(t); $\varphi_1(t_i)$ and $\varphi_2(t_i)$ serve as the phase angles of the proximal joint and the distal joint, respectively.

Firstly, the vector angles of each selected joints were transformed to the zero baseline (Eq. 1). Secondly, each zero-centered set of data was put into an analytic signal (ξ(*t*)) by Hilbert transform and obtained the imaginary part (H(t_i)) (Eq. 2) [20]. Thirdly, the phase angle (φ(t_i)) at each time point was calculated by substituting the required data into the formula (Eq. 3). Finally, continuous relative phase by subtracting the phase angles between the two joints (Eq. 4).

The CRP usually ranged between -180 and 180 degrees. Perfect in-phase indicated a value of 0 degree, representing the two joints rotated in the same direction; while perfect anti-phase was 180 degrees, representing the two joints rotating in opposite directions. Furthermore, the CRP between 0 and 180 degrees was classified as out-phase [11]. The phase of CRP showed the correlation between joint angles and velocities, providing a basis for assessing coordination of limb [10].

In this study, continuous relative phase (CRP) and variability of CRP (VCRP) were also calculated to identify the coordination between two adjacent joints. For CRP, the joint data were processed through Hilbert transform introduced by Lamb and Stöckl [19] to quantify the coordination without any artificial interference. The four main formulas were calculated as follows to determine CRP [11, 19, 20].

Additionally, the variability of continuous relative phase (VCRP) was evaluated as the between-stride standard deviation for a single subject within the 101 data points, which aimed to evaluate the variability within joints [11]. The VCRP was considered as a valuable index to evaluate the motor coordination. The high value indicated a poor degree of coordination between the two joints [11].

Statistical Analysis

At first, since lunge movement would be finished in a very short time, both knee and ankle joint were in a status of flexion, the ankle plantar flexion and knee flexion were the target for further analysis.

All the CRP and VCRP data were averaged across groups. As for time series variables, GROUP ANALYSIS was performed with Model Statistic Procedure, which showed macro variations between different conditions in the lunge tasks [11]. Independent samples T-test indicated obvious exploring variation to explore detailed inter-group differences. We obtained 101 significant or insignificant results through statistical analysis in each group of time series data, and then accumulated the percentage of points (%P) to demonstrate the results of group analysis. Paired Student T-tests (ES＞0.8) were performed to assess the

credibility of the shoe comparison [4]. All statistical analysis was performed using SPSS (v22.0, IBM, USA) with a significance level at 0.05.

RESULTS

Phase Angle (PA) Variables

The PA of ankle was indicated in Figure 2. In terms of lunging forward, ankle joint plantar flexed slightly faster when wearing RSH and FSH since 30%GC; while plantar flexion of ankle with FSH was relatively higher than RSH since 48%GC (Figure 2a). No significant differences were found for lunging backward (Figure 2b), as well as both lunging forward and backward in knee joint (Figure 2c, d).

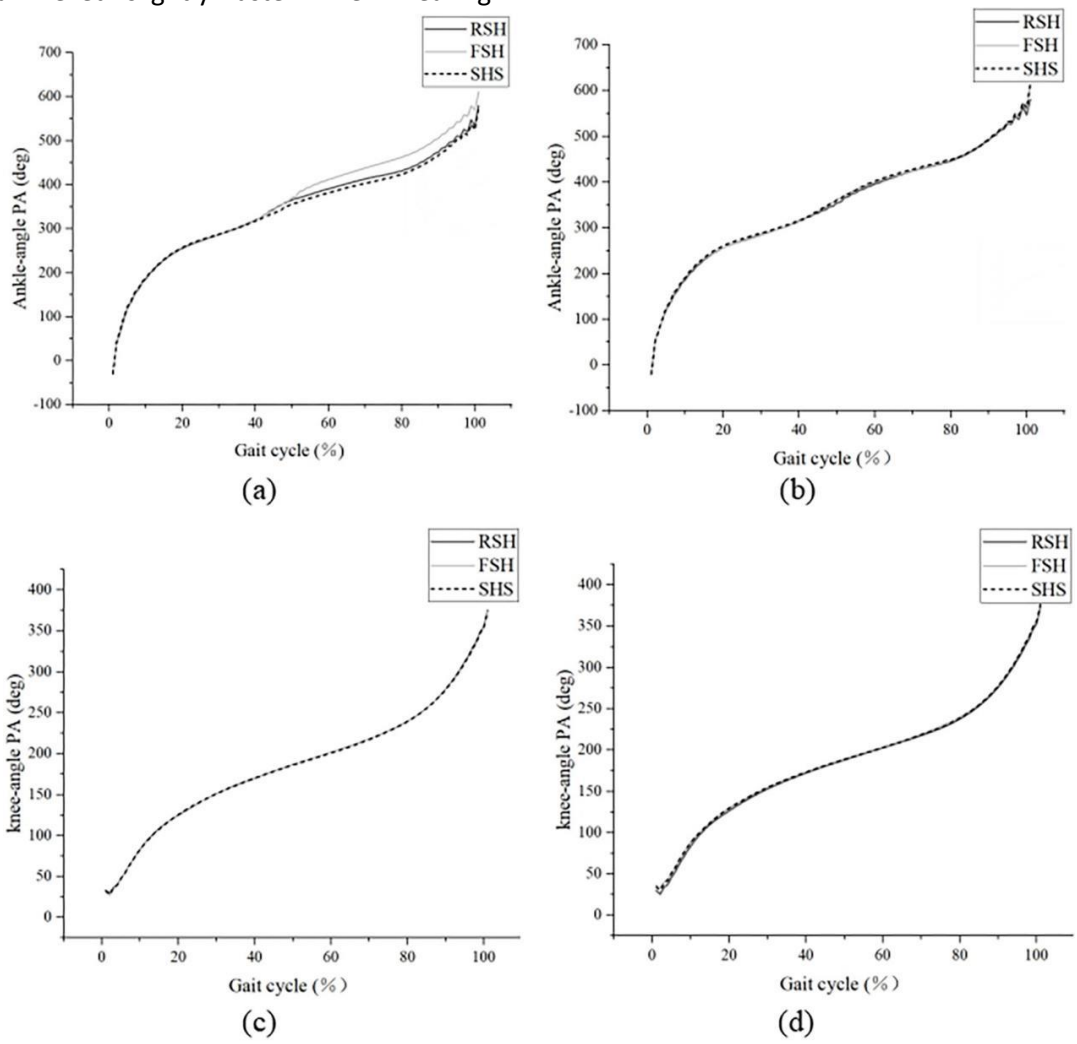

Figure 2. Phase angle (PA) curves for rounded heel shoe (RSH), flattened heel shoe (FHS), and standard heel shoe (SHS) over the gait cycle. Gait cycle (GC) duration was taken as the time interval between two successive heel strikes of one leg; (a) and (b) are about ankle angle of forward and backward respectively, (c) and (d) are about knee angle of forward and backward respectively.

CRP Outcomes

According to Figure 3a, there were noticeable changes in CRP trajectories of Knee-Ankle coupling at gait cycle among three kinds of tested shoes. When wearing RHS to perform lunging forward movement, a faster ankle plantar flexion than knee flexion was found since 30%GC; while similar relation was found in FHS since 60%GC. But there were few differences between SHS and RSH during recovery phase of lunge (Figure 3b).

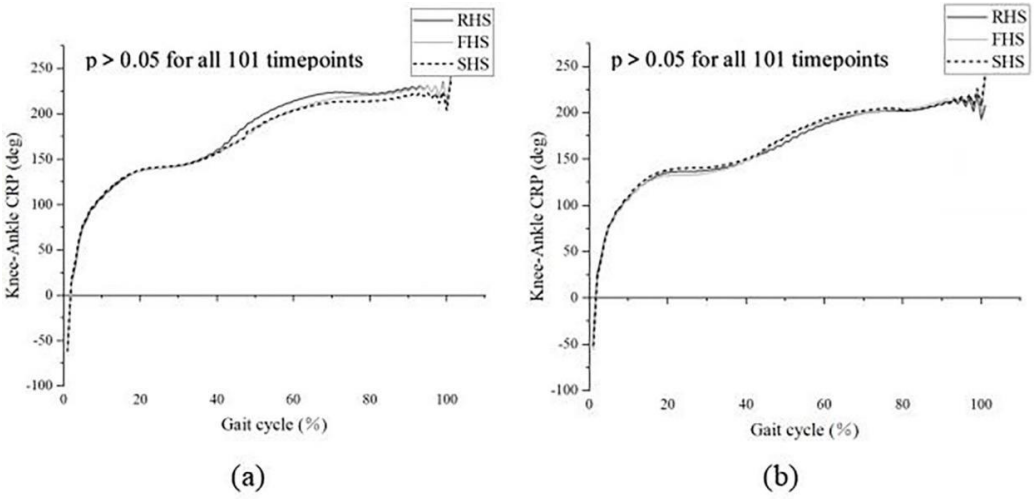

Figure 3. Continuous relative phase (CRP) curves of forward lunge (a) and recovery back to starting position (b) for rounded heel shoe (RSH), flattened heel shoe (FHS), and standard heel shoe (SHS) over the gait cycle. Gait cycle (GC) duration was taken as the time interval between two successive heel strikes of one leg

VCRP Outcomes

In terms of lunge forward, mean VCRP was 12.1 for RHS, 13.4 for FHS and 11.7 for SHS; while those in recovery phase was 10.7, 7.3 and 10.6. There was small significance between footwear during forward lunge for all coupling joints (%P=4 for RHS v.s. FHS, %P=8 for RHS v.s. SHS and %P=12 for FHS v.s. SHS). Meanwhile, the significance of VCRP was also small during recovery backward (%P=4 for RHS v.s. FHS, %P=0 for RHS v.s. SHS and %P=14 for FHS v.s. SHS).

DISCUSSION

The present study evaluated the influence of different shoe heel design (RHS, FHS and SHS) on the movement coordination during the entire lunge movement (forward and recovery backward phases). Through the analysis of higher order variables (PA, CRP and VCRP), the current findings indicated that players wearing RHS had certain advantages on better movement coordination than other shoes, as indicated by better PA and CRP. The findings of this study would be helpful to understand the coordination of badminton lunges and explain the synergy between the lower extremity ankle and knee joint to minimize the possibility of injury in badminton.

Ankle and Knee function during fast lunge could be determined by push-off, initial-contact and foot-flat phases. One interesting phenomenon is that only small variations exist in ankle PA in initial contact of lunge forward. This variation could be comprehended as that the FHS had an apparent pivot point than RHS, and this structure would assist fast ankle plantar flexing. It was also the reason resulting the variations in CRP values. But when considering VCRP, we found that FHS had a higher value than RHS, indicating that coordination was relatively poor. Meanwhile, Kuntze [4] suggested that a peak ground reaction force would be generated while initial contacting and the poor coordination would contribute to a high injury risk. We also found that an earlier ankle plantar flexion occurred in RHS, which implied an earlier forefoot contact and thereby reducing the overall impulse generated in loading response stage [11].

In viewpoint of CRP, a faster initial contact of ankle increased the relative rotation between ankle and knee. The faster relative rotation implies a higher sensitivity of lower limb performance. Sensitivity of lower limbs was highly related with the muscle contraction and relaxation processes, which also reflects the effective movement coordination [4, 15]. Muscle contraction and relaxation are the key processes to movement

control of badminton lunge, including the posture, velocity and cushioning for ground reaction forces. Therefore, achieving high sensitivity and coordination of lower limb by using different footwear could be beneficial for safety and efficiency in badminton lunge. Our findings about how footwear influences coordination were also consistent with another previous study [21], which suggested the footwear recommendations for RHS, followed by FHS and SHS. Thereby, RHS was a superior choice for lunge movement.

Some experimental limitations should be considered when interpreting our data. First, only left-forward lunge was tested in this study, different lunge directions may induce different coordination strategies. Second, the extreme lunge (i.e., maximum-effort and intensity) was investigated but we did not compare different lunge distances and movement intensities, which may show distinct lunge steps and movement controls. That requires a Hilbert transformation to eliminate the movement coordination. Future investigations should be carried out by comparing different lunge intensities before a viable conclusion about coordination of badminton lunge can be made.

CONCLUSIONS

Initial contact is the critical phase when investigating badminton lunge. Participants wearing shoes with rounded heel design altered the landing impacts at initial contact. Furthermore, the coordination between the knee and ankle joints was greatly affected by the structure of the shoe heel design. The findings from this study indicate that improving the heel curvature of badminton shoes could be one plausible method to improve movement coordination in badminton.

Acknowledgements

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EUROPEAN RESEARCH AREA

COTANCE NEWSLETTERS

Starting with January 2019, the COTANCE Council will issue a monthly ***COTANCE Newsletter*** with the purpose of **promoting an improved image of leather** to relevant decision makers and domestic stakeholders including Members of the European and National Parliament, Governmental authorities, Ministerial officers, Customers of the leather industry, Brands, Retail chains, Relevant NGOs, Designers, etc. The monthly newsletters present topics that tell the truth about a controversial aspect or a fact that is not well known by the general public to bring about a better understanding of leather and the European leather industry, as well as a positive predisposition to legislate in favor of the leather industry. The newsletters are available in seven languages at https://www.euroleather.com/index.php/newsletter, and were also published in the 2019 and 2020 issues of *Leather and Footwear Journal*. Newsletters 4, 5 and 6 of 2021 are given below.

NEWS 4/2021

The beauty of Imperfections

Nature is “naturally” perfect. The patterns on the surface of leaves, trees, insect wings or fruits are always fascinating, especially when magnified.

However, nature can do even better; nature repairs. If a tissue is damaged, whether by an insect bite, a scratch or an infection, the injuries heal.

Yet sometimes scars occur.

Manure marks

We all know it. The scar on your knee from falling off a scooter or the small mark on your arm after a hot burn from the iron. The older we get, the more “memories” such as these mark our skin.

Animals are also injured, stung, chafed or sunburned. These injuries heal just like ours and leave scars. After the animal hide has been tanned, these long-healed injuries are of course still there and visible on the leather as small or large marks.

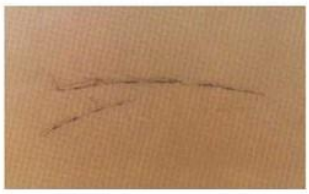
Growth marks

Pictures: Gmelich + Söhne GmbH

Yet, illogical as it seems, people who buy leather, and who perhaps see holes in their jeans as cool and fashionable or enjoy a “used look”, perceive these scars as defects. For this reason, leathers are often sanded and given a finish so that the natural skin, with its unique individual characteristics, becomes a flawless, uniform material, like synthetic materials from industrial production.

Healed scars

Dung marks



Pics: FAIR project

Scratch scars

But leather only becomes truly beautiful with the small flaws, scars and colour differences, because only then can we see that it comes from nature itself, without loss in function or quality.

Let's accept nature as it is! Let's enjoy the natural qualities of leather!

edited by COTANCE

in collaboration with VDL

NEWS 5/2021

European Leather: Fashionable, Sustainable… Unique!

In December 2020, COTANCE and IndustriAll-Europe, the European labour trade union, officially presented the new Social and Environmental Report of the European tanning industry to a wide audience of stakeholders.

The report was developed and published in the framework of a dedicated EU Social Dialogue Project (SER2020), that started in 2019.

The aim of the project was to illustrate the outstanding progress made by the sector in the areas of social footprint, environmental footprint and ethics since the previous exercise in 2012.

The work started with an intensive survey amongst EU tanneries: 37 social indicators, such as contract type, age brackets, education, length of service, and 39 environmental parameters (chemicals, energy and water consumption, waste generation, removal of pollutants…) were monitored and analyzed over a 3 years reference period (2016-2018).

The exercise was challenging but very stimulating, evidencing the incredible variety of leather production segments across the 11 countries involved.

The European tanning industry offers continuous employment contracts, solid guarantees of transparent relationships, an inclusive working environment and the chance to collaborate with amazing creative industries, like fashion, design and automotive.

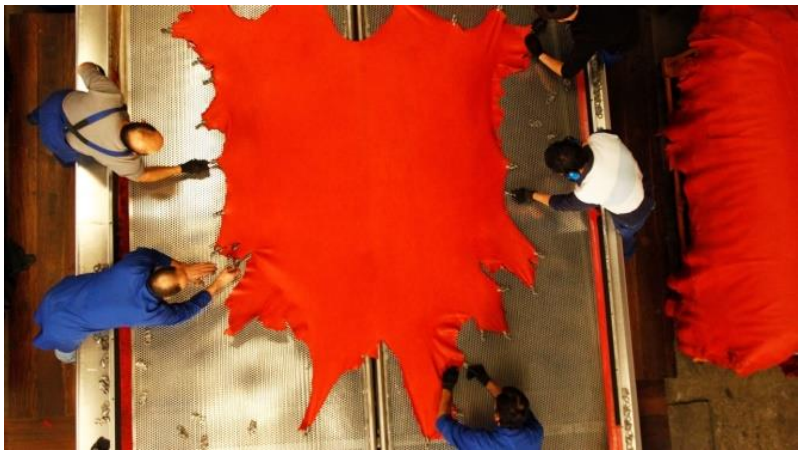
These conditions are the base for high staff retention and for an important increase in skills levels. Environmental performance has also shown considerable progress: circularity, efficient trend in resources consumption, removal of water pollutants, environmental investments are all elements that define a virtuous industry that aims at continuously reducing its environmental impact.

Despite the numerous attacks and an unjustified bad reputation, our sector can be proud of its contribution to the most ambitious targets set by UN Agenda 2030.

Times are difficult, but the industry's commitment towards sustainability is stronger than ever.

For the future European Tanners will continue to focus on due diligence, safety, and the key ethical aspects regarding traceability & transparency.

Therefore, we can say loudly that European Leather …is good for you and good for the planet!



edited by COTANCE in collaboration with UNIC ITALIAN TANNERIES

NEWS 6/2021

Outside the Box: Leather's Charm in Interior Architecture & Design

Leather has been part of our lives for centuries. We are no stranger to leather bags, shoes, or belts, among others, but let's not forget that, thanks to its unique scent, textures and patina, leather also has **prestige in interior design and architecture**.

Photographer : David Cleveland. Designed by Rundell Associates & Bill Amberg Studio. Featuring leather Kipling colour biscuit by Tenerias Omega, S.A. - Courtesy by Tenerias Omega S.A, Navarra, Spain.

Enhancing homes, offices, hotels or restaurants, leather has recovered the glamour of its past and today it is a key contender when we look at the latest trends in interior design. The **British Chesterfield sofa** is one of the most recognisable pieces of furniture in the world. Dating back to the 1800s, its luxury leather, deep buttoning, low back, and classic charm, are a perfect example of

interior ornamentation that is very much in vogue today. But let's go back further in time, when leather was an option chosen by many European castle owners in place of wooden floorings. Even Pope Julius III enjoyed the beauty of gilded leather walls. Our ancestors saw the **versatility of leather and played with the endless possibilities it offered**.


Courtesy of St. Vincents concept store, Antwerp

Thanks to its longevity, all these applications are available to us. **Leather wears and ages well**, and its versatility allows it to be applied in countless spaces and places, adding a touch of luxury. Today leather offers a wide variety of options for contemporary interiors ranging from traditional aesthetics to innovative designs.

Beautiful, durable and low maintenance, it is becoming the "*material par excellence*" for a number of interior designers and architects. Bold or subtle accents throughout the home or office, the options are endless. Sumptuous leather wall tiles with 3D textures like geometric tessellations or gilded leather add a style statement.


Traynham Club Chair by Moore & Giles, featuring leather Botany, Wet Green tannage by Tenerias Omega, S.A.
Courtesy by Tenerias Omega S.A, Navarra, Spain.


Courtesy of St. Vincents concept store, Antwerp

Leather sofas, rugs or even headboards are **bold statements**, irrespective of your sense of fashion design – bohemian chic, minimalist, traditional, eclectic, contemporary or modern. Other options are also available, such as ottomans, lounge chairs, coffee tables or even curtains. Leather door and cabinet door panelling is also an attractive way of **adding leather accents to the different spaces of a home or an office**.

Still asking why leather?

No other material has the same appeal as leather. The look, feel, fragrance, and texture of leather is unique. It has both a masculine and feminine personality depending on the colour, the texture and the design of the piece you wish to put into your home. It is low maintenance and easily cleaned with a damp cloth. It is extremely versatile, blending in with any style of décor while adding unique aesthetics. Leather is an extremely durable natural material that ages well and endures regular wear and tear.

Imitations will never give you the innate properties that nature offers!

edited by COTANCE

in collaboration with CURTIDORES ESPAÑOLES SPANISH TANNERS

News Release from the IULTCS

09 April 2021

XXXVI IULTCS Congress and 5th World Leather Congress becoming HYBRID events

Africa Leather and Leather Products Institute (ALLPI), in conjunction with the Government of Ethiopia, is excited to announce that the 36th International Union of Leather Technologists and Chemists Societies (IULTCS) Congress, and the 5th World Leather Congress (WLC) are becoming HYBRID events, to offer participants the choice of how they prefer to attend these important international congresses. Both events will be held in Addis Ababa, Ethiopia from 01- 05 November 2021.

With the backdrop of mounting COVID-19 pandemic-related restrictions, the hybrid mode will allow all those who are not able to attend in person, to be able to participate from the comfort of their own workplace or home, from anywhere in the world.

The video recordings from the congresses will also be made available on an online platform for 30 days, to ensure that all the conference registrants can access the presentation materials of speakers, researchers and sponsors without being constrained by time zones and/or internet connectivity problems at the time of the events.

The two Congresses (XXXVI IULTCS and 5th WLC) are expected to leave delegates with great insights and informative actions that delegates could use in their respective institutions and/or enterprises.

Registration for the congresses has commenced and a new registration fee structure for remote registrations is in place – with the ability to 'upgrade' to in person attendance if travel restrictions allow. Abstract submission is open until 31 August 2021 – with the option to submit to present a remote paper, allowing current global research to be shared, even if the presenter cannot be in attendance.

The link https://www.iultcs2021africa.org/home will provide more information on registration and guidelines for submission of Abstracts.

There are also opportunities to support these high-profile, globally attended events by becoming sponsors, as it is critical to our industry that we continue to share our knowledge, research and best practice – various packages are available to suit all budgets.

Summary Information:
5th World Leather Congress: 01 November 2021
XXXVI IULTCS Congress: 03 - 05 November 2021
Venue: Ethiopian Skylight Hotel, Addis Ababa, Ethiopia
Working Language: English
ALLPI Website: https://www.allpi.int

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AICC
ASSOCIAZIONE ITALIANA DEI CHIMICI DEL CUOIO

III IULTCS EUROCONGRESS VICENZA 2022

The Italian Leather Chemists Association (A.I.C.C.) is pleased to inform you that Vicenza and the Leather District of Arzignano have been selected as the location for the III IULTCS EuroCongress 2022.

Vicenza, a beautiful little city in the Venetian Region, is famous thanks to the villas and works of the ancient architect and artist, Andrea Palladio (1508-1580), and for the tanning and gold industries.

The Congress will take place from the evening of the 18th September 2022, with the Opening Ceremony, till the afternoon of the 20th September 2022 with the Closing Ceremony.

These dates have been selected in cooperation with UNIC, the Italian National Union of Tanning Industry, to be close to the Lineapelle Leather Fair and to avoid overlaps.

The Congress will be held at the Vicenza Convention Center and a visit to the Leather District of Arzignano will be planned.

Link to the presentation of the territory: Vicenza

A.I.C.C. is pleased to invite you to participate to this important Event, of international value, which will host interesting technical and scientific works about the tanning sector.

All future information will be available on a dedicated website, which A.I.C.C. is preparing; this will be constantly updated during the planning of the Event.

GIANCARLO LOVATO APPOINTED PRESIDENT OF THE III IULTCS EUROCONGRESS VICENZA 2022

The Italian Leather Chemists Association (**AICC**) is pleased to inform you that its Board of Directors has elected **Dr. Giancarlo Lovato** as President of the Organizing Committee of the **III IULTCS EuroCongress Vicenza 2022**.

The III IULTCS EuroCongress, in which the latest technical and scientific findings in the tanning sector will be presented, will be held in Vicenza and in the Tanning District of Arzignano from 18th till 20th September 2022. The date was chosen in collaboration with UNIC – Concerie Italiane to have a synergistic effect with the LINEAPELLE fair.

Giancarlo Lovato is currently also the Secretary of AICC. He works at Corichem Srl as Manager of R&D Leather Chemicals. He has also worked as R&D Manager and Product Manager at other companies in the chemical-tanning sector such as TFL, Chimes (now part of GSC Group) and Chemipal. He is the author of numerous discoveries, patents and technical publications in the Leather Chemicals industry, in Beamhouse, Wet-end and Finishing.

The whole AICC congratulates Giancarlo Lovato for this new important assignment.

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The scientific papers should be presented for publishing in English only. The text of the article should be clear and precise, as short as possible to make it understandable. As a rule, the paper should not exceed fifteen pages, including figures, drawings and tables. The paper should be divided into heads and chapters in a logical sequence. Manuscripts must meet high scientific and technical standards. All manuscripts must be typewritten using MS Office facilities, single spaced on white A4 standard paper (210 x 297 mm) in 11-point Times New Roman (TNR) font.

Paper Format

Title. Title (Centered, 12 pt. TNR font) should be short and informative. It should describe the contents fully but concisely without the use of abbreviations.

Authors. The complete, unabbreviated names should be given (Centered, 10 pt. TNR font), along with the affiliation (institution), city, country and email address (Centered, 9 pt. TNR font). The author to whom the correspondence should be addressed should be indicated, as well as email and full postal address.

Abstract: A short abstract in a single paragraph of no more than 200-250 words must accompany each manuscript (8 pt. TNR font). The abstract should briefly describe the content and results of the paper and should not contain any references.

Keywords. Authors should give 3-5 keywords.

Text

Introduction. Should include the aims of the study and results from previous notable studies.

Materials and Methods. Experimental methods should be described clearly and briefly.

Results and Discussions. This section may be separated into two parts. Unnecessary repetition should be avoided.

Conclusions. The general results of the research are discussed in this section.

Acknowledgements. Should be as short as possible.

References. Must be numbered in the paper, and listed in the order in which they appear.

Diagrams, Figures and Photographs should be constructed so as to be easy to understand and should be named "Figures"; their titles should be given below the Figure itself. The figures should be placed immediately near (after or before) the reference that is being made to them in the text. Figures should be referred to by numbers, and not by the expressions “below” or “above”. The number of figures should be kept to minimum (maximum 10 figures per paper).

Tables. Should be numbered consecutively throughout the paper. Their titles must be centered at the top of the tables (12 pt. TNR font). The tables text should be 9 pt. TNR font. Their dimensions should correspond to the format of the Journal page. Tables will hold only the horizontal lines defining the row heading and the final table line. The tables should be placed immediately near (after or before) the reference that is being made to them in the text. Tables should be referred to by numbers, and not by the expressions "below" or "above". The measure units (expressed in International Measuring Systems) must be explicitly presented.

Formulas, Equations and Chemical Reactions should be numbered by Arabic numbers in round brackets, in order of appearance, and should be centered. The literal part of formulas should be in Italics. Formulas should be referred to by Arabic numbers in round brackets.

Nomenclature. Should be adequate and consistent throughout the paper, should conform as much as possible to the rules for Chemistry nomenclature. It is preferable to use the name of the substances instead of the chemical formulas in the text.

References should be numbered consecutively throughout the paper in order of citation in square brackets; the references should list recent literature also. Footnotes are not allowed. If the cited literature is in other language than English, the English translation of the title should be provided, followed by the original language in round brackets. Example: Handbook of Chemical Engineer (in Romanian), vol. 2, Technical Press, Bucharest, 1951, 87.

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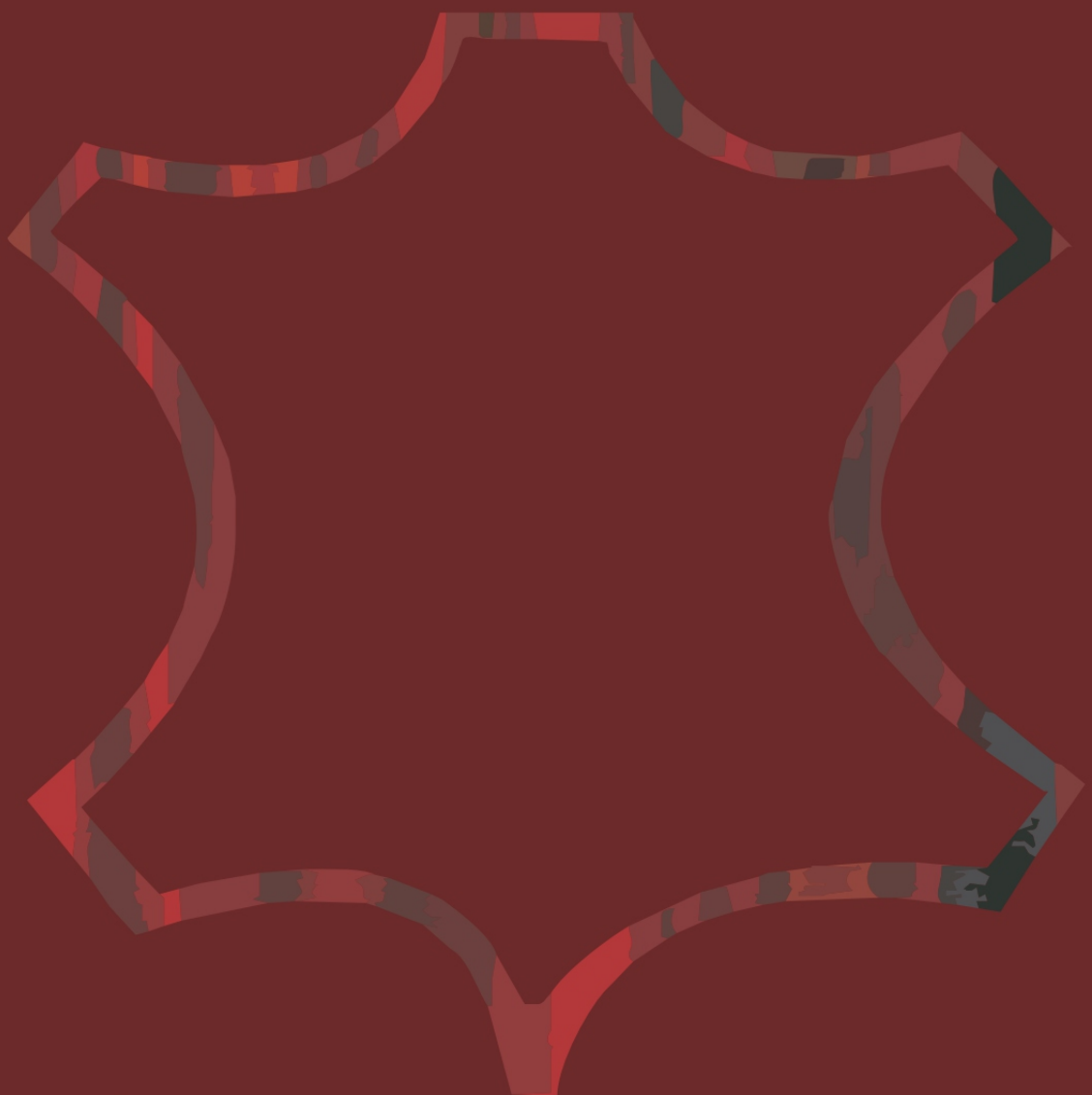

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