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PERSPECTIVES ON THE IMPACT OF ADVANCED FOOTWEAR ON RUNNING PERFORMANCE AND INJURY: A REVIEW

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PERSPECTIVES ON THE IMPACT OF ADVANCED FOOTWEAR ON RUNNING PERFORMANCE AND INJURY: A REVIEW

ABSTRACT. This review explores the evolution of running from a basic survival skill to a complex sport, highlighting the significant role of advanced footwear in performance enhancement. Running economy, a key determinant of long-distance running success, is influenced by various external factors, including training methods and equipment, as well as individual attributes, such as biomechanics and cardiorespiratory capacity. Recent advancements in high-performance running shoes have shown promise in improving speed and efficiency, as evidenced by record-breaking performance. However, the potential impact of such shoes on natural running mechanics raises concerns regarding health and injury risks. This study examines the characteristics and effects of critical elements in advanced footwear, such as midsole foam and rigid plates to assess their advantages and disadvantages. The findings show that, although these shoes can temporarily enhance performance, proper training and conditioning are crucial for mitigating injury risks, particularly for untrained runners. The footwear industry must balance performance enhancement, injury prevention, and fairness in competition to ensure that technological advancements positively influence runners' health and performance.
KEY WORDS: running economy, shoes, midsole, biomechanics, carbon fiber plate

PERSPECTIVE LEGATE DE IMPACTUL ÎNCĂLȚĂMINTEI AVANSATE ASUPRA PERFORMANȚEI LA ALERGARE ȘI ASUPRA RISCULUI DE ACCIDENTARE: O TRECERE ÎN REVISTĂ

REZUMAT. Această trecere în revistă explorează evoluția alergării de la o abilitate de supraviețuire de bază la un sport complex, subliniind rolul semnificativ al încălțămintei avansate în îmbunătățirea performanței. Economia alergării, un factor cheie al succesului alergării pe distanțe lungi, este influențată de diverși factori externi, inclusiv de metodele și echipamentul de antrenament, precum și de atributele individuale, cum ar fi biomecanica și capacitatea cardiorespiratorie. Progresele recente în realizarea unor pantofi de alergare de înaltă performanță s-au dovedit a fi promițătoare în îmbunătățirea vitezei și eficienței, așa cum demonstrează performanțele record. Cu toate acestea, potențialul impact al unor astfel de pantofi asupra mecanicii naturale de alergare ridică îngrijorări cu privire la riscurile de sănătate și de accidentare. Acest studiu examinează caracteristicile și efectele elementelor critice din încălțămintea avansată, cum ar fi talpa intermediară din spumă și plăcile rigide, pentru a le evalua avantajele și dezavantajele. Descoperirile arată că, deși acești pantofi pot îmbunătăți temporar performanța, antrenamentul și condiționarea adecvate sunt cruciale pentru atenuarea riscurilor de accidentare, în special pentru alergătorii neantrenați. Industria de încălțăminte trebuie să echilibreze factori precum îmbunătățirea performanței, prevenirea accidentărilor și corectitudinea în competiție pentru a se asigura că progresele tehnologice influențează într-un mod pozitiv sănătatea și performanța alergătorilor.
CUVINTE CHEIE: economia alergării, pantofi, talpă intermediară, biomecanică, placă din fibră de carbon

PERSPECTIVES SUR L'IMPACT DES CHAUSSURES AVANCÉES SUR LES PERFORMANCES DE COURSE ET LE RISQUE DE BLESSURES : UNE REVUE

RÉSUMÉ. Cette revue explore l'évolution de la course à pied, d'une compétence de survie de base à un sport complexe, soulignant le rôle important des chaussures avancées dans l'amélioration des performances. L'économie de course, un facteur clé dans la réussite des courses de longue distance, est influencée par divers facteurs externes, notamment les méthodes et l'équipement d'entraînement, ainsi que par des attributs individuels tels que la biomécanique et la forme cardiorespiratoire. Les progrès récents dans le domaine des chaussures de course haute performance se sont révélés prometteurs en termes d'amélioration de la vitesse et de l'efficacité, comme le démontrent les performances record. Cependant, l'impact potentiel de telles chaussures sur la mécanique naturelle de course soulève des inquiétudes quant aux risques pour la santé et les blessures. Cette étude examine les caractéristiques et les effets des éléments critiques des chaussures avancées, tels que les semelles intermédiaires en mousse et les plaques rigides, afin d'évaluer leurs avantages et leurs inconvénients. Les résultats montrent que même si ces chaussures peuvent améliorer temporairement les performances, un entraînement et un conditionnement appropriés sont essentiels pour atténuer les risques de blessures, en particulier pour les coureurs non entraînés. L'industrie de la chaussure doit équilibrer des facteurs tels que l'amélioration des performances, la prévention des blessures et l'équité dans la compétition pour garantir que les avancées technologiques ont un impact positif sur la santé et les performances des coureurs.
MOTS CLÉS : économie de course, chaussures, semelle intermédiaire, biomécanique, plaque en fibre de carbone

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INTRODUCTION

Throughout human history, running has evolved from a necessity for survival to a pursuit that focuses on fitness and personal achievements. As running gains popularity, so does research aimed at improving speed and performance. Running economy (RE), a critical determinant of long-distance running performance, is influenced by various external factors, such as environmental conditions, training methods, and equipment, as well as individual physical attributes, including cardiorespiratory capacity, metabolism, biomechanics, and neuromuscular function [1, 2]. Historically, athletes have primarily emphasized internal factors, such as training techniques, to improve RE and speed. However, in recent times, a notable shift has occurred towards leveraging modern technology, especially “advanced footwear,” to optimize running performance, which has gained popularity among runners. Specifically, “high-performance running shoes” have emerged as a significant factor in enhancing long-distance running performance [2, 3].

While ancient runners ran barefoot, contemporary runners utilize shoes crafted from diverse materials, including soft compounds, high foam, and rigid plates [4-6]. Despite the recent emergence of advanced footwear, opinions and studies on its impact vary widely, with no clear consensus. Notably, high-performance running shoes have demonstrated the ability to enhance performance, as evidenced by athletes achieving world records while wearing them. Conversely, excessive technological advancements in running shoes may disrupt natural biomechanics and increase the risk of injury [7, 8]. Concerns have also arisen regarding the possibility of high-performance running shoes compromising the fairness of the sport, a fundamental principle in athletics [9].

Research on the effects of key elements in running shoes, such as midsole foam, cushioning, and rigid plates (e.g., carbon), on running performance has yielded inconsistent findings [4-6]. The rise of high-performance running shoes has reportedly led to faster performance times [9]. However, documentation is limited on whether these advancements contribute positively to overall runner health. Therefore, this study aims to comprehensively review the literature on the characteristics, advantages, and disadvantages of the main elements used in advanced footwear.

Shoe Mass

Shoe mass is a critical factor that influences RE [10]. Previous studies have indicated that increased shoe mass significantly decreases RE and overall performance, whereas lighter shoes are expected to enhance RE and performance by reducing muscle effort [2, 10]. Specifically, a 100 g increase in shoe mass raises oxygen consumption by approximately 1%, thereby diminishing RE [11, 12].

Accordingly, running barefoot has been suggested as more economical owing to the absence of shoe weight. Barefoot running can potentially enhance RE by allowing an acute transition from rearfoot strike to forefoot strike, increasing cadence, and minimizing vertical oscillations of the center of mass [6, 13, 14]. Greater plantar-flexed foot placement and increased stride frequency associated with barefoot running may facilitate a more effective recovery of elastic energy in tendons and muscles [13, 15]. Moreover, increased proprioception of the foot by running barefoot has been hypothesized to contribute to the above effects by allowing for the coordination and pre-activation of key running muscles [2, 9].

However, running barefoot does not necessarily optimize RE because the increased ankle joint contact forces and plantar flexor forces during transitions from rearfoot strike to forefoot strike can increase the risk of injury caused by abrupt changes in landing patterns. Furthermore, running with shoes tends to increase leg and ankle stiffness compared to barefoot running [16, 17]. Runners encounter various types of terrain that interact with the leg's spring-mass system, and invariant leg stiffness may decrease efficiency on uneven surfaces, highlighting the importance of stiffness. Notably, significant differences in RE between barefoot and shod running have been observed only when shoe weight exceeded 440 g [9, 10]. Thus, because appropriately weighted running shoes can actually promote more favorable RE compared to running barefoot, carefully integrating additional shoe elements is as crucial as minimizing shoe mass to avoid negative effects on RE [11].

Midsole Features (Stack Height and Cushioning)

Significant advancements have been made in cushioned running shoe design since the Onitsuka Tiger was introduced as the first cushioned running shoe in 1964, establishing cushioning as a fundamental element of modern footwear (Figure 1) [18]. Although cushioning can reduce elastic energy storage and recovery, thereby contributing to the generally lower net efficiency observed in shod running, increased cushioning does not always lead to decreased metabolic cost. In some cases, this may be considerably beneficial for running performance [19-21].

▲ Onitsuka Tiger running shoe in 1964 ▲ Nike zoomX (Braking sub 2 in 2019)

Figure 1. First cushioned running shoe vs modern running shoe
(Source: Onitsuka Co., Ltd & NIKE, Inc)

Advantages (Stack Height/Cushioning)

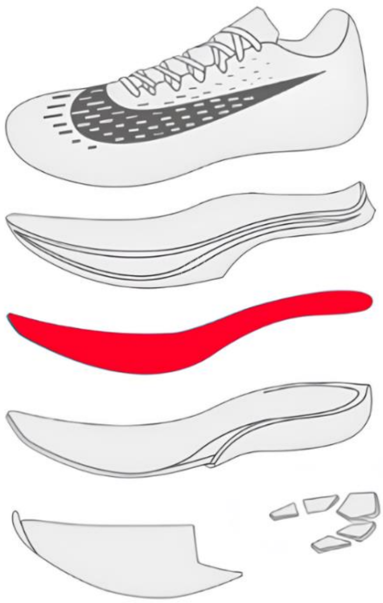

Figure 2. Shoe component (Source: NIKE, Inc)

Running shoes primarily consist of two components (Figure 2): the upper, which covers the foot, and the sole, which interacts with the ground [18]. The sole can be subdivided into the insole, midsole, and outsole, with research increasingly focusing on the midsole's role in cushioning [22]. The midsole is characterized by thickness and elasticity, including the materials used, each of which influences running performance (Figure 3) [18, 22].

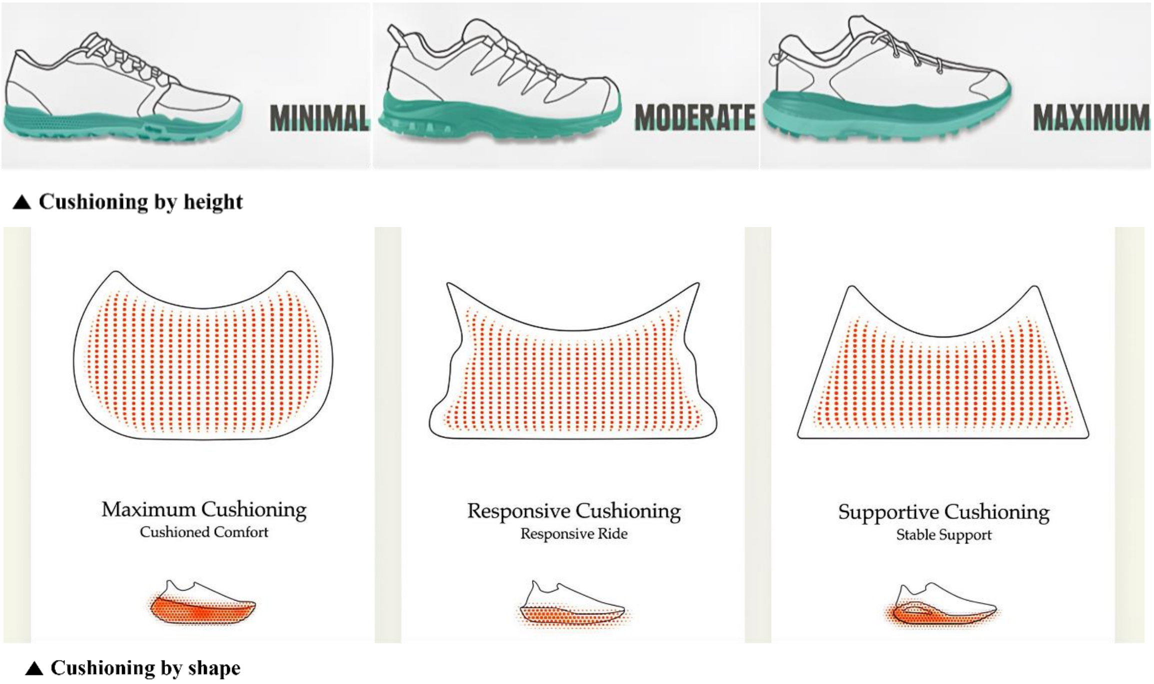

Figure 3. Types of cushioning (Source: Recreational Equipment, Inc & NIKE, Inc)

Thickness (stack height) (Figure 4): The thickness of the midsole, often referred to as stack height, influences ground contact time during a stride. A thicker midsole can extend ground contact time, affecting the ground reaction force-time curve and assisting in energy return timing [12]. Increased stack height can enhance athletes' effective limb length, potentially leading to longer strides during running [23]. Shoes with a greater stack height, particularly those incorporating carbon fiber or rigid plates, also exhibit increased curvature that can benefit RE [24].

Figure 4. Midsole stack height (Source: NIKE, Inc)

Elasticity (material) (Figure 5): Midsole elasticity pertains to the amount of energy the midsole returns with each step. The material used in its construction influences the cushioning and energy return properties of the midsole. Traditional materials include ethylene vinyl acetate and thermoplastic polyurethane, while recent advancements, such as polyether block amide, have introduced lighter, more resilient materials that enhance cushioning and energy return [23, 25, 26]. Research indicates that softer and more resilient midsoles can reduce oxygen consumption by up to 1% [27]. Conversely, poorly cushioned shoes may increase aerobic demand by approximately 2.8% compared to well-cushioned ones [28]. Furthermore, individuals wearing soft shoes have shown lower peak impact forces, longer times to peak force, and lower average loading rates of high-frequency signals than those wearing harder shoes, which might reduce the risk of injury [29].

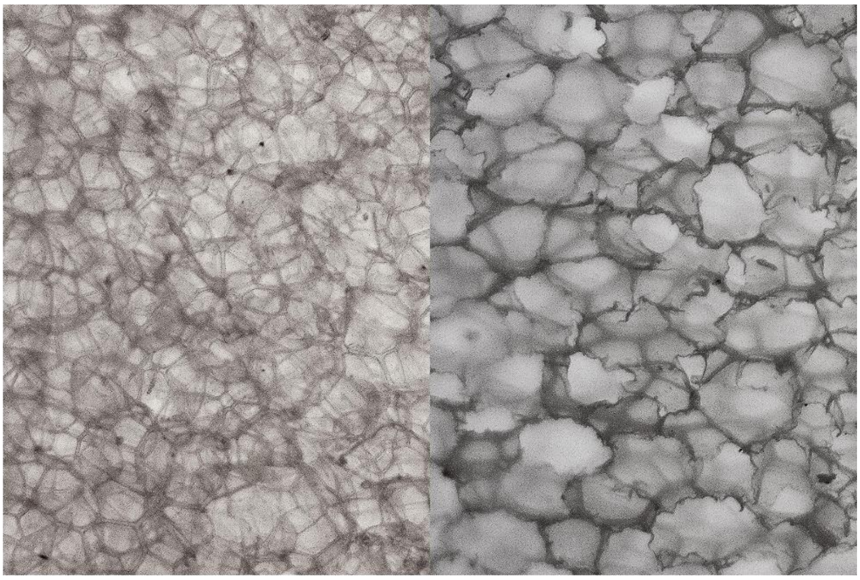

Figure 5. Midsole foam material characteristics (Source: RunRepeat.com)

Disadvantages (Stack Height/Cushioning)

Although midsole cushioning is crucial for absorbing impact, relieving joint pressure, and enhancing comfort, particularly on hard surfaces, some concerns have been expressed regarding the negative effects of excessive cushioning.

Increased body load: Although a thicker stack height can improve energy return, it may also increase the risk of injury by promoting a "heel strike" pattern that adds stress to the knee, potentially leading to knee pain or other injuries. Furthermore, increased joint load can contribute to overuse injuries, such as plantar fasciitis and stress fractures [29].

Impact on natural mechanics: The arch of the foot naturally absorbs shock during running, and foot muscles provide essential stability to maintain foot alignment during running. The prolonged use of highly cushioned footwear may lead to over-reliance on cushioning, causing muscle atrophy, weakness, and reduced activation, thus disrupting the function and natural mechanics of the foot and arch [19-21, 30, 31]. This may result in altered running patterns and an increased risk of injury, thereby increasing instability [32].

Decreased sensory feedback: Excessive cushioning can prevent the foot from receiving accurate sensory feedback from the ground and reduce the sensitivity of the plantar surface during running. This impairs proprioception, the body's ability to sense its own position and movement, which is essential for balance and coordination. This diminished sensory feedback can hinder the body's ability to adapt and respond to uneven terrain, potentially increasing the risk of falls and instability, and leading to injury [33].

Energy inefficiency: According to collision physics, excessive cushioning may increase the impact force on joints and tissues, leading to energy inefficiency. Shoes with excessive cushioning can distribute the body's propulsion forces throughout the shoe, leading to wasted power being transmitted between the foot and ground [10, 34]. Some studies have indicated that excessive cushioning can increase leg stiffness, which decreases perceived shock, but does not effectively reduce joint impact [10, 34]. Recent research suggests that optimal shoe cushioning characteristics (e.g., thickness) may vary depending on the runner's characteristics (e.g., body weight and composition). Specifically, several research findings show that greater cushioning can potentially provide more pronounced benefits for lighter runners [8, 35]. Thus, although cushioning enhances comfort and reduces perceived shock, excessive cushioning may compromise natural foot mechanics, reduce sensory feedback, and increase the risk of injury [10, 34].

Longitudinal Bending Stiffness (Carbon-Fiber Plate) (Figure 6)

Advantages (Performance)

High-performance running shoe development has been significantly advanced by the incorporation of embedded carbon fiber plates. These innovations have markedly affected athletics, leading to the breaking of multiple world records and prompting rule changes by the International Association of Athletics Federations [24].

The foot arch naturally functions as a spring, absorbing impact, while a stiff mid-foot plays a resilient energy-saving role, generating forward propulsion. Reduced arch stiffness diminishes energy return and, subsequently, running efficiency [36, 37]. Several studies have demonstrated that carbon fiber plates minimize energy loss by maintaining the foot's longitudinal bending stiffness, thereby limiting the angle and angular velocity of the metatarsophalangeal joint. Moreover, carbon plates have been linked to increased stride length and ground contact time, enhancing overall running efficiency and performance [38, 39].

Longitudinal bending stiffness, defined as the "resistance to bending around the mediolateral axis of the shoe," is an important factor in running footwear. Enhancing this stiffness reduces energy expenditure and improves RE by approximately 1–4%, as shown in experimental research [38, 40]. Carbon fiber plate effectiveness varies with factors such as location and shape, although most studies indicate that a bottom-loaded, full-length curved plate is the most effective. These plates have demonstrated their ability to significantly enhance marathon performance by increasing RE, thus enabling runners to cover greater distances within the same timeframe [41].

Figure 6. Types of carbon fiber plate (Source: FootStore.au & Engineering.com)

Disadvantages (Injury)

Although some studies suggest that enhancing the longitudinal stiffness of shoes with carbon plates may improve RE, others present conflicting results, indicating that increased longitudinal bending stiffness alters running biomechanics without consistently affecting RE [41-43]. Thus, the physiological relationship between biomechanical changes induced by carbon plates and RE improvements remains unclear.

How effectively carbon plates can influence RE varies based on factors such as the plate's location, length, stiffness, shape, and a runner's individual characteristics, including speed [9, 44]. Specifically, which runners would benefit most from these plates has not been thoroughly investigated, and concerns have been raised that inappropriate use of carbon plates may increase injury risk [45]. For example, carbon plates tend to promote a longer stride, which is one factor that increases running speed [46]. Consequently, this may increase the risk of injury for novice runners who do not have the physical conditioning and strength to adequately control these factors. Despite their perceived advantages and disadvantages, no clear consensus has been reached on the use of embedded carbon fiber plates in footwear [47].

Many athletes adopt carbon fiber plate shoes without fully considering the potential risks, and instead focus primarily on their benefits. Therefore, comprehensive investigations into the impact of these shoes on foot health and injury prevention are crucial. Furthermore, research on carbon plates is needed that involves runners at various levels and under diverse environments and conditions, rather than studies conducted on a limited population or using a single intervention [48].

Sports Fairness

Critics of high-performance running shoes argue that they compromise the integrity of sports. When Eliud Kipchoge broke the "Marathon Sub 2" (Figure 1) barrier in October 2019, which had often been regarded as "the last barrier of modern athletics," it ushered in a new era in advanced athletic footwear and sparked ongoing debates about "technical doping" [49]. "Technical doping" refers to "the use of technological aids to gain a competitive advantage." In this context, high-performance running shoes, such as those with carbon fiber plates, have been primarily considered as "technological aids." These shoes are believed to enhance athletic performance beyond natural human capabilities and limitations [50]. However, technological advancements, including those in footwear, can positively enhance performance levels and unlock athletes' potential. Therefore, shoe development raises concerns about fairness in competition and remains a crucial issue that must be continuously addressed.

CONCLUSION

Running, often regarded as "one of the purest and simplest sports on the Earth," has become increasingly complex [51]. The ongoing research and development of advanced footwear are widely considered key factors in enhancing speed and performance. High-performance running shoes can provide significant temporary performance improvements. However, concerns persist regarding the potential health and injury risks they may pose by possibly having negative effects on an individual's natural running posture or pattern. Although the development of high-performance running shoes is essential, proper training for running is arguably of greater importance. Untrained runners who use these advanced shoes may inadvertently increase their risk of injury. Comprehensive training and conditioning are crucial to fully harness the benefits of high-performance running shoes and achieve optimal synergy between the runner's footwear and body.

The goal of shoe development is to optimize each component for human use, ensuring harmony and balance. To create high-quality products, the footwear industry must carefully consider factors such as "performance," "injury prevention," and "sports fairness." Therefore, critically evaluating the role of high-performance running shoes is crucial. Furthermore, ensuring that these shoes enhance performance while minimizing the risk of injury to runners is essential.

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THE FIVE-FACTOR MODEL OF SANDAL DESIGN

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THE FIVE-FACTOR MODEL OF SANDAL DESIGN

ABSTRACT. The growth of the sandal market in Thailand is on the decline, with purchase behavior changing among young consumers. As a result, the factors of sandal design are currently changing as well. The objective of this research was to study the factors of sandal design using a quantitative method. The data were collected from 400 Gen-Z consumers aged between 18-27 years old in Bangkok, Thailand, obtained by multi-stage sampling. A self-administered online survey questionnaire with a structured interview was used. The data were analyzed by exploratory factor analysis (EFA) and confirmatory factor analysis (CFA). The results revealed 5 factors of sandal design that meet the needs of Gen-Z consumers, i.e., aesthetic, functionality, symbolism, ergonomics, and innovation. Innovation was found to be the factor that most affected sandal design. According to the results, these factors can be applied to set a strategic plan for more efficient sandal design, which would be useful for product designers, manufacturers, and marketers of the sandal industry in Thailand.
KEY WORDS: sandal design, innovation, ergonomics, functionality, aesthetic, symbolism

MODELUL CELOR CINCI FACTORI APLICAT ÎN DESIGNUL SANDALELOR

REZUMAT. Dezvoltarea pieței de sandale din Thailanda cunoaște o scădere, comportamentul de cumpărare schimbându-se în rândul consumatorilor tineri. Drept urmare, și factorii care stau la baza designului sandalelor se schimbă în prezent. Obiectivul acestei cercetări a fost de a studia factorii care stau la baza designului sandalelor folosind o metodă cantitativă. S-au colectat date de la 400 de consumatori din generația Z (Gen-Z) cu vârsta cuprinsă între 18-27 de ani din Bangkok, Thailanda, obținute prin eșantionare în mai multe etape. S-a utilizat un chestionar online autoadministrat cu un interviu structurat. Datele au fost analizate prin analiză factorială exploratorie (EFA) și analiză factorială confirmativă (CFA). Rezultatele au evidențiat 5 factori ai designului sandalelor care răspund nevoilor consumatorilor Gen-Z, și anume estetică, funcționalitate, simbolism, ergonomie și inovație. Inovația s-a dovedit a fi factorul care a afectat cel mai mult designul sandalelor. Conform rezultatelor, acești factori pot fi aplicați pentru a stabili un plan strategic pentru un design mai eficient al sandalelor, care ar fi util pentru designerii de produse, producătorii și comercianții din industria de încălțăminte din Thailanda.
CUVINTE CHEIE: design sandale, inovație, ergonomie, funcționalitate, estetică, simbolism

LE MODÈLE À CINQ FACTEURS APPLIQUÉ À LA CONCEPTION DE SANDALES

RÉSUMÉ. Le développement du marché des sandales en Thaïlande connaît un déclin, le comportement d'achat des jeunes consommateurs étant en train de changer. En conséquence, les facteurs sous-jacents à la conception des sandales sont également en train de changer actuellement. L'objectif de cette recherche était d'étudier les facteurs sous-jacents à la conception des sandales en utilisant une méthode quantitative. Les données ont été collectées auprès de 400 consommateurs de la génération Z (Gen-Z) âgés de 18 à 27 ans à Bangkok, en Thaïlande, obtenues grâce à un échantillonnage à plusieurs degrés. Un questionnaire en ligne auto-administré avec un entretien structuré a été utilisé. Les données ont été analysées par analyse factorielle exploratoire (AFE) et analyse factorielle confirmatoire (AFC). Les résultats ont mis en évidence 5 facteurs de conception de sandales qui répondent aux besoins des consommateurs de la génération Z, à savoir l'esthétique, la fonctionnalité, le symbolisme, l'ergonomie et l'innovation. L'innovation s'est avérée être le facteur qui a le plus influencé la conception des sandales. Selon les résultats, ces facteurs peuvent être appliqués pour établir un plan stratégique pour une conception de sandales plus efficace, qui serait utile aux concepteurs de produits, aux fabricants et aux détaillants de l'industrie de la chaussure en Thaïlande.
MOTS CLÉS : conception de sandales, innovation, ergonomie, fonctionnalité, esthétique, symbolisme

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INTRODUCTION

Sandals are a product with high competition in terms of price, quality, and design. Because they are a fashion product, there are a large number of similar products in the same market [1]. In Thailand, the sandal market accounts for approximately 273 million USD, categorized into sandals of core brands at 60%, while sandals of minor/no brand, and multinational companies make up 40%. Despite intense competition, sandals are products with good profits when compared with other types of footwear. Therefore, many new brands are entering the sandal market, both Thai and international brands [2]. The supporting factors for the growth of the sandal industry include accepted product standards, cost advantage for internal acquisition of materials, quality, and experienced labor. Besides, Thailand also gets privileges from the Free Trade Area (FTA) with 16 ASEAN member countries, i.e., China, Japan, South Korea, Hong Kong, Australia, New Zealand, and Chile. These countries offer exemptions from import duties for Thailand in all items, i.e., rubber/plastic sandals, leather sandals, and those made of woven materials. Out of the total exports, 64% of sandals are exported from Thailand to the FTA's trading partners. According to rankings, Thailand is the 8th country in the world for sandal export, behind China, the EU, Vietnam, Turkey, the UK, Indonesia, and Brazil [3]. However, according to the 5-year retrospective data of sandal export from Thailand Textile Institute, it was found that the total export between 2019-2023 was equal to 110.7 (+9.2%), 86.8 (-20.0%), 89.8 (+3.5%), 93.2 (+3.8%), and 81.0 (-13.1%) million USD. More specifically, the export value in 2023 was lower than in 2020 during the COVID-19 outbreak [4]. Apparently, the growth rate of the Thai sandal market is declining continuously, partly due to economic conditions with a slow recovery rate because Thai consumers buy 0.7 pairs of sandals/per year on average [2]. Change in consumer behavior is also another reason for this incidence.

The purchase behavior of sandals has changed from the past. Market competition is higher because there are numerous brands in the sandal market, facilitating more opportunities for consumers to select their preferred sandals based on shapes, styles, brands, and colors; more varied distribution channels is another factor. Because of their characteristics as fragmented markets, small and international brands emerge, causing little or no brand loyalty among consumers [2]. Particularly, this is the era of rapid changes among consumers in terms of behavioral factors, needs, expectations, health concerns, and social aspects. Rapid changes due to several factors affecting purchase decisions involve more details. Consumers themselves also adapt to deal with changes in the world all the time. Therefore, consumers in this era mainly focus on value and new experiences.

Younger consumers are also paying attention to social and environmental sustainability as one of the principles for decision-making among the new generation [5]. This always results in consumer behavior change. Therefore, sandal design is necessary to meet this rapid change in order to increase more opportunities for access to each group of consumers. Product design is currently more important, with opportunities to connect with success in sandal design for distribution to the market. The product design process is a key part of the sustainable growth of the shoe industry [6] because consumers have changed their focus from price to impression with product shapes. It is no wonder why some companies rely on attractive product design as a key strategy for competitive advantage to create distinctiveness for their products and thus attract consumers [7, 8], as well as to standardize product assessment [9]. According to previous studies, the factors of product design were used to study consumer behavior [10-12], e.g., purchase decision, word of mouth [13], brand preference [9, 14], intention to use, and purchase [15]. Insightful studies on consumer behavior are usually found in research related to electronic equipment and office supplies. So far, however, there have been no studies focused on any factors that affect the purchase behavior of sandals.

The lower growth rate of the sandal market in Thailand and change in purchase behavior among young consumers impact the small entrepreneurs in Thailand who fail to adapt or understand consumer needs toward sandals at present and in the future. In addition, studies that aim to understand the factors of sandal design in Thailand are still quite limited. Therefore, the objective of this article was to study the factors of sandal design, which will be useful for product designers and entrepreneurs who can apply the factors obtained to design quality sandals for adapting to the trend of current and future consumer change. Other than this, the results of this research will generate advantages and increase opportunities for entrepreneurs of small and medium enterprises (SMEs), who can apply these design factors to create strengths and competitive advantages in the domestic market or to expand the export market to other countries in the future. That is because the sandal market is likely to increase further as sandals are a basic need in the daily lives of consumers of all groups, genders, and ages.

LITERATURE REVIEW

Characteristics of Shoe Design

The literature review of this study started with the application of a systematic review (SR) (Figure 1) to investigate sandal design characteristics. The review revealed that there have been no studies conducted specifically on the design of sandals. Therefore, studies on other types of shoes were used as the criteria instead, with the scope of the SR as follows: 1) the goal and the results of the SR were aimed at the investigation of shoe design characteristics; 2) only research articles were included, with the search conducted using Mendeley with the keywords for searching including " shoe" and "footwear;" 3) the articles were published and publicized in open access international journals with full text; 4) the articles were published in English only and publicized during 2019-2022 and were the most relevant articles, searched for from 4 to 18 January 2023 for the SR. Consequently, 28 articles met the selection criteria for the SR scope. Then, the relationships of these articles were examined in order to categorize the shoe design characteristics. Similar characteristics were used for the primary categorization, which resulted in a total of six categories, i.e., shoe characteristics, usage characteristics, material properties, manufacturing technology, foot proportions, and aesthetics.

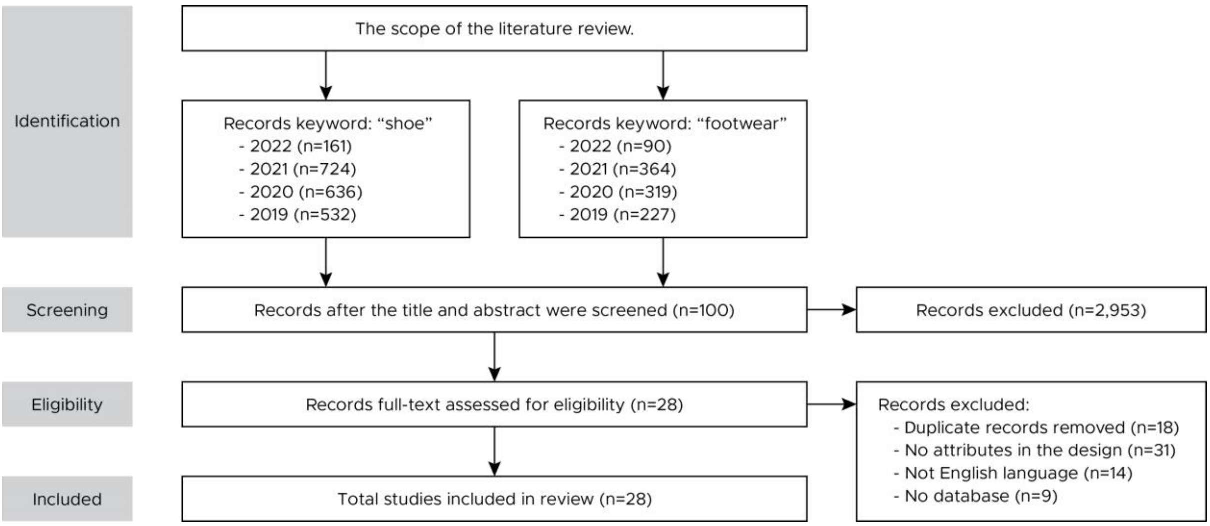

Figure 1. Schematic diagram on literature review process

Shoe Characteristics

Proper fit and comfort are the key characteristics that must be considered as they are significant for shoe design [16-26]. When considering proper fit, it was found that the lengths and widths of the designed shoes did not the fit foot proportions of the sample group [17, 19, 20, 25, 27]. For this reason, a new standard of shoes was set to fit their foot proportions [28], i.e., heel heights = 14-32 mm, midsoles = 10-15 mm, and the difference of thickness between forefoot and heel-to-toe drop = 4-12 mm. [30]. Regarding comfort, it was found that lightweight shoes with proper fit and soft insoles were generally comfortable. In fact, wearing comfort is not only influenced by shoe design but also the anatomical or physiological differences of each individual and their activities [18]. Foot shapes with suitable proportions will result in the proper fit and comfort of shoes.

Usage Characteristics

Shoes are indispensable to protect feet from injuries. Usage characteristics of shoes vary, depending on the age range of the users, i.e., children [24], middle-aged people, and older adults [17]. Healthy users require comfortable shoes that allow for efficient movements [17, 18, 23]. Patients need suitable shoes to facilitate walking [19, 25, 31]. Older adults need shoes that can enhance their safety while walking and prevent falls [27, 32]. Shoes that are easy to put on and take off and convenient for general users [16], including older adults and patients with gout, are necessary [17, 25]. Wearing durations are a risk factor of athlete's foot [33] and may possibly cause disorders of the muscular system, hip bone, knees, and feet [22]. Therefore, shoe maintenance, durability, and material selection for shoe manufacturing are highly required [16, 33, 34].

Material Properties

Properties of the materials for shoe manufacturing must also be considered. A shoe basically consists of two main parts, i.e., upper and sole. Flexible upper materials generate wearing comfort [18, 24]. However, a long duration of wearing may cause athlete's foot due to the conditions inside shoes, e.g., temperature, moisture, and ventilation. Therefore, the materials used must be capable of absorption or ventilation [18, 30, 33]. A shoe sole is divided into three parts, i.e., insole, midsole, and outsole. Soft and flexible midsoles reinforce wearing comfort [16, 18, 22, 36]. However, they should not be too soft because this can be harmful to body balance and increase the risk of falls. Thus, suitable insole thickness (10 mm) brings better body balance and reduces the risk of falls in older adults [17]. Adding flexible supportive materials for impact absorption of heels [16, 17, 37] helps to reinforce shoe heels, resulting in wearing comfort because high pressures usually occur at the heel while walking or standing [22]. These supportive materials can also relieve foot pain [36]. Midsoles reduce impacts while walking [17, 30, 38]. Impact absorption from shoes is mostly affected by the materials used, which can prevent injuries [26, 34]. Lastly, outsoles must prevent slipping [16, 18]. Therefore, the outsole pattern design must be seriously considered because it directly affects shoe adherence efficiency [17, 35]. Falls in older adults can be caused by inferior outsole materials [26, 27]. Furthermore, shoe material improvement and development should be eco-friendly [6].

Manufacturing Technology

This refers to the modern manufacturing technology [39] for manufacturing capabilities in industry and for commercial trade [6]. Shoe design should give consideration to innovation as well. That is because apart from quick prototype designs, it can also shorten the manufacturing process. There are two main types of technology and innovation development, i.e., 3D printing and 3D scanning. To describe, 3D printing is used for shoe prototype design [6, 16]. Supportive heel materials are made of thermoplastic polyurethane (TPU) for greater wearing comfort [37]. Orthopedic inserts can be used for pain relief [36]. Robots can be employed for the gluing process in shoe assembly [39]. As for 3D scanning, it is used to measure foot sizes of different proportions because it can generate the most reliable and precise data [28, 29]. However, technology and innovation development require close cooperation with related experienced agencies [6, 29].

Foot Proportions

Foot shapes generally change with age. Therefore, shoe sizes must be adjusted to suit and fit the foot proportions of users at all ages, i.e., children, adults, and older adults [28]. The differences in foot proportions must also be considered by sex in each particular region [29]; along with foot proportion measurement at four positions, i.e., foot length, foot width, heel width, [20, 28, 29], and instep height [29]. Simultaneously, foot arch types must not be neglected because this affects wearing comfort, with sensitivity of foot pain while walking or running [17, 18]. Furthermore, working in a standing position for a long duration will cause painful foot soles. The most common painful spots include the foot arch, forefoot, and heel [22].

Aesthetics

Currently, in addition to the shoes sold for foot protection, they can also be designed and developed into fashion products [16, 19, 24, 25]. Design is a crucial element in all businesses because it adds product value. Likewise, fashion design such as for shoes/footwear is a type of communication that requires creativity through the presentation methods for tangibility in the form of the products, i.e., applying inspiration or design concepts, forms, patterns, colors [16, 25, 40], packaging, tailoring [16], material selection, manufacturing processes, marketing, and the tastes/preferences of each gender [17, 33] in order to create unique identities that are distinct from the traditional ones. Creativity also includes the other clothing on the body with styles that perfectly match the fashion trends of a certain time and the stories or reflected emotions behind those shoes. These are all elements that are available to create positive feelings toward the designed shoes [6, 16].

Based on the investigation on the shoe design characteristics of all six categories related to usage characteristics and shoe components for wearing comfort; along with the study of Lamb and Kallal [41], who suggested a consumer model with three needs: Functional, Expressive, and Aesthetic (FEA), this model leads to the various design criteria for consumers and focuses on consumer needs in order to be developed further into a conceptual framework of clothing design. Similarly, Orzada and Kallal [42] suggested that the FEA model is flexible as it can also be applied to clothing products or all types of fashion products. Tian *et al*. [43] applied the concept of the FEA model as a conceptual framework of the design for Chinese older adults based on three factors, i.e., older adults, footwear, and the usage scenario. They mainly considered the needs and the usage situations of the sample as a guideline along with the rules for setting product design, which finally affected the product shapes and forms. Based on the SR and the results of all the research studies as stated, they were implemented for determining the conceptual framework sandal design with three key components, i.e., consumers (functional, aesthetics, and symbolism), feet in terms of the shapes with suitable proportions (ergonomics), and sandals (structure, properties, and manufacturing technology). These three components are fully required for innovation creation. To apply the conceptual framework as aforementioned, the designers must have flexible ideas in order to combine all of the components appropriately at the design step.

Product Design Dimensions

During the past several years, the word "design" has been defined in various ways, starting from a determination to solve problems and to meet consumer needs according to user-based viewpoints [44-46], with the objective to achieve the normative roles of design [47]. Regarding the factors of industrial product design, Homburg *et al*. [13] stated that product design is a source of competitive advantages for companies. They also suggested the conceptual framework as a factor of product design in three aspects, i.e., aesthetics, functionality, and symbolism. Moreover, they examined the effects of these factors in the designed products on purchase intention and word of mouth. The results indicated that these three factors had both direct and indirect positive influences on purchase intention and word of mouth through attitudes toward brands. Later on, Candi *et al*. [10] applied the factors from the study of Homburg *et al*. [13] to investigate consumer behavior. These three factors also had influences on the behavioral responses of consumers. The results imply that product designers should prioritize aesthetic and symbolic elements instead of merely functional ones. In contrast, Moon *et al*. [11] and Jindal *et al*. [12] suggested the related factors of product design (aesthetics/form, features/function, and ergonomics) without symbolism but with ergonomics because companies compete for user safety as they regard users and the central role of safety as priorities. Gilal *et al*. [14] elucidated that companies view product design as essential for competitiveness and as a standard for performance assessment. They also suggested a model of the factors of product design by combining the results of all of the research studies above into a model with four aspects, i.e., aesthetic, functional, reflective, and ergonomic. The results revealed obsessive passion is influenced by the factors "aesthetic" and "reflective" whereas "functional" and "ergonomics" influenced harmonious passion. Furthermore, Adulyanukosol and Silpcharu [6] pointed out that product design is a vital part of the sustainable growth in the shoe industry. Undoubtedly, they studied the strategies of shoe design for the Thai shoe industry and found that innovation directly influenced shoe design and that design should always consider innovation so that the designed products can remain in the market share over a long period of time. Hence, based on all of these previous studies, this research relied on five components, i.e., aesthetics, functionality, symbolism, ergonomics, and innovation, as the conceptual framework for this research implementation.

Aesthetics

This refers to consumer responses that arise from the perceived physical appearances and beauty of objects [48, 49]. Emotional reactions may be caused by the holistic form of a product, or they may be responses to individual design characteristics [50, 51]. Consumer behavioral responses are related to product design, and the product form of exterior design is the most basic characteristic that motivates consumer responses [48]. Product design aesthetics can also affect emotional responses [52, 53].

Functionality

This component/factor reflects consumer responses arising from product characteristics assessment by usage [54]. They can be assessed with no need to rely on physical appearances [13, 55, 56]. The assessment eventually motivates intellectual responses [54] and includes perceived product characteristics, durability, quality, price, reliability, and technical complication [57]. Primarily, usage value means the utility or rationality of the product. Therefore, product value can be judged by a rational as well as an intellectual appeal to consumers [58-60].

Symbolism

This is perception of the form of products that implies the self-respect and social significance of the consumers [57, 61-63]. Reflective responses occur with consumers who feel attached to products, including their attachment to places or some certain periods of time [54, 64, 65]. Additionally, consumer behavioral responses in terms of motivation are not only caused by product forms or characteristics but also from symbolic connections when compared with the products themselves [51, 66]. Symbolism is thus a key factor of product design because it cannot be inclusive through aesthetic, functionality, and ergonomics only [63, 67]. Moreover, symbolism may be as important as functionality because it usually reveals the consumers' desire to present their personal images to society [13, 61, 68, 69].

Ergonomics

This is the perceived usage regarding convenience and safety. This factor is accepted as noteworthy because companies compete for the higher levels of convenience of product usage [11]. Aesthetic and functional product design will be useless unless there are the responses of the user experience, e.g., usage, convenience, and safety [11, 70]. According to the anthropological data, product sizes hugely influence the perceived convenience and suitability for physical products [71]. Product design based on physiological principles can reduce the uncomfortable feelings of users, and thus it will pave a way toward successful product development [72]. More than this, product convenience also has considerable influence on usage intention [73].

Innovation

Innovation development requires knowledge of science and technology, and the innovation creation process requires internal and external knowledge transfer by connecting the factors of marketing and the factors of science and technology [74]. Design-driven innovation can enhance competitiveness and competitive advantages, create product distinctiveness, and prolong useful life [6, 75]. Such innovation is unlike other types of innovation, e.g., technological innovation that mainly focuses on product development or consumer-oriented marketing innovation. On the contrary, design innovation focuses on the reasons for usage rather than what products are or how to use them [76].

Theory of Planned Behavior

Usage Intention

This refers to the willingness of individuals to behave in a certain way. Intention occurs prior to actions, according to the theory of planned behavior (TPB) to explain events that occur before attitudes, subjective norms, and perceived behavioral control. TPB is often used to explain/describe intention directly [77]. Usage intention refers to the willingness or likelihood to use products or services. It is equipped for understanding behavior and for predicting the future actions of consumers, which brings about the success of products in the market [78].

Purchase Intention

This is the act of attempting to purchase products or services. There are several factors affecting purchase intention, e.g., attitudes, perceived behavioral control [79], risk propensity [80], and price [81]. Purchase intention always comes after usage intention [15], although there might be potential intervening factors during purchase intention prior to purchase decision, i.e., attitudes of others and situational considerations [82].

RESEARCH METHODOLOGY

The research was implemented by using a quantitative method (a survey), with the principal subjects as follows.

Sandal Selection Criteria

1) Para rubber sandals or plastic sandals were used because of their highest export proportion (up to 92.4% of total sandal export) [3]. The clog style was selected because of the free design of their physical features, with quite high distinction for users. 2) They were unisex sandals for males, females, and LGBTQ+ so that data collection by the questionnaire would be inclusive among consumers with different needs [83]. 3) The samples were familiar with the product [84]. The selection criteria were used as a guideline for QFD sandal design [85]. Therefore, the newly designed sandals from this guideline were used as the representatives for data collection (Figure 2).

Figure 2. The sandal style is indicative of the process of gathering data

Population and Sample

In this study, the population was selected from Gen Z consumers, born during 1997-2009 [5]. This population group has emerged as the largest generation with supreme financial power in history. According to World Data Lab, it is expected that Gen Z will be the only generational grouping with a population of 2 billion (25% of the world population). It is also expected that the population of Gen Z in 2034 in Asia Pacific will become the supportive group for total household expenses, which amount to over 3 trillion USD. The report of NIQ Spend Z shows that the population of Gen Z in Thailand is the group with the largest strategic spending behavior in Asia. Thus, it is certain that this population has a strong influence on the altered perspectives of retailers in Thailand, resulting in major changes in consumer trends and market dynamics [86]. The sample in this study consisted of 400 consumers between 18-27 years of age in Thailand, with 95% confidence [87]. They were obtained using multi-stage sampling.

Instrument

A self-administered online survey questionnaire with a structured interview was used, under the title “The Factors of Sandal Design.” The questionnaire was divided into 2 parts, i.e., 1) 8 checklist questions about general data and consumer behavior, and 2) consumer opinions for evaluation in 5 aspects, i.e., aesthetic, functional, symbolism, ergonomics, and innovation. Each aspect contained 10 questions, a total of 50 questions. All questions were developed from a literature review. A 5-point rating scale was used [88], ranging from 5 (totally agree) to 1 (slightly agree). Content validity was tested by 3 experts, with an index of item objective congruence (IOC) = 0.67-1.00 (> 0.50) [89]. All questions contained content validity. Reliability was tested in the tryout group, consisting of 30 samples. The test revealed Cronbach’ s alpha coefficient [90] = 0.932 (>0.70) [91]. Therefore, the questionnaire was reliable. It was also approved by the Human Research Ethics Committee, King Mongkut’s Institute of Technology Ladkrabang (KMITL), in Thailand. The project code was EC-KMITL_66_088, approved on 7 August 2023.

Data Collection

The data in this study were collected by a face-to-face survey. To clarify, there were discussions between the researcher and the respondents using Google Forms. The duration for the data collection was between June and August 2024.

Data Analysis

The analysis was divided into 3 parts as follows: 1) general data and consumer behavior were analyzed by a descriptive statistic, i.e., percentage; 2) the factors of sandal design were analyzed by exploratory factor analysis (EFA) using SPSS; 3) confirmatory factor analysis (CFA) was used to analyze the first-order, followed by AMOS to analyze the second-order.

RESULTS

General Data and Consumer Behavior

According to 400 samples between 1 8 - 27 years of age, general data revealed that 201 or most of them were males (50.25%), age 22.005 years on average. 294 (73.50%) graduated with a bachelor’s degree. 261 (65.25%) used clog-style sandals. 284 (62.00%) wore sandals for over 2 hours on average. As for consumer behavior, 104 samples (26.00%), or most of them bought a pair of sandals in 1-3 months on average. 203 (50.75%) sometimes studied information and properties of sandals before their purchases. 173 (43.25%) perceived that brand affected usage and purchase.

Exploratory Factor Analysis (EFA)

Adequacy

Adequacy was examined by considering Kaiser-Meyer-Olkin (KMO), equal to 0.958 (KMO > 0.50); (Table 1) or the measure of sampling adequacy (MSA), which was equal to 0.916-0.978 (MSA > 0.50) [92].

Correlation

Correlation was examined by considering Bartlett's test, with the significance value (sig.) = 0.000 (sig. < 0.05) [92]. It can be concluded that this dataset was adequate for the factor analysis technique (Table 1).

Table 1: KMO and Bartlett's Test

Kaiser-Meyer-Olkin Measure of Sampling Adequacy		0.958
	Approx. Chi-Square	15275.828
	df	1225
	Sig.	0.000

Communality

Communality was equal to 0.451-0.776 (Communality > 0.40) [92]. It can be concluded that the observed variables could be assembled as a cluster in the factors.

Factor Analysis

Factor analysis by principal component analysis (PCA) was based on factor extraction criteria; 5 factors were set for their size. Varimax orthogonal factor rotation was used, along with the selection criteria of observed variables, with factor loading > 0.50. Out of the 50 observed variables, 45 passed the criteria (Table 2).

According to the analysis of 5 factors and 45 variables, Factor 1: Aesthetic consisted of 11 observed variables (Aes1, Aes3, Aes8, Aes6, Aes2, Aes4, Aes9, Sym1, Sym2, Sym3, Aes10) with factor loading = 0.505-0.720 and 13.92% variance. Factor 2: Innovation consisted of 9 observed variables (Inn8, Inn5, Inn4, Inn7, Inn10, Inn6, Inn9, Inn3, Inn1), with factor loading = 0.510-0.709 and 12.77% variance. Factor 3: Functional consisted of 9 observed variables (Fun9, Fun5, Fun6, Fun3, Fun4, Fun8, Fun7, Fun10, Fun2) with factor loading = 0.555-0.705 and 12.60% variance. Factor 4: Symbolism consisted of 7 observed variables (Sym7, Sym10, Sym9, Sym8, Erg3, Sym6, Sym4), with factor loading = 0.506-0.827 and 12.30% variance. Factor 5: Ergonomics consisted of 9 observed variables (Erg2, Erg4, Erg1, Erg7, Erg5, Erg9, Erg8, Aes5, Erg6), with factor loading = 0.516-0.630 and 10.57% variance. According to all 5 factors, it can be concluded that the accumulated variance was equal to 62.16%, which was over 60% [92].

Table 2: Rotated component matrix

Code	Variables	Component					Communality
		1	2	3	4	5	
Aes1	The sandal has a visually striking style.	0.720					0.587
Aes3	The sandal is compatible with other clothing accessories.	0.717					0.596
Aes8	The sandal has a beautiful overall shape and proportions.	0.679					0.588
Aes6	The sandal is beautifully colored.	0.675					0.540
Aes2	The sandal is unique.	0.664					0.563
Aes4	The sandal attracts attention.	0.618					0.517
Aes9	The sandals complement one's sense of style.	0.617					0.652
Sym1	The sandals allow you to communicate with others.	0.574					0.582
Sym2	The sandal has the ability to make a strong impression on people.	0.525					0.559
Sym3	The sandals make me proud to own them.	0.519					0.596
Aes10	The sandal has a beautiful texture.	0.505					0.577
Inn8	The sandal can use environmentally friendly materials.		0.709				0.665
Inn5	The sandal uses modern production technologies.		0.676				0.679
Inn4	The sandal can develop materials to make them more comfortable.		0.659				0.653
Inn7	The sandal can develop the bottom sole to provide more traction.		0.658				0.671
Inn10	The sandal can be manufactured using 3D printing technology.		0.646				0.655
Inn6	The sandal uses a material with high elastic properties.		0.638				0.686
Inn9	The sandal can use an environmentally friendly manufacturing.		0.618				0.619
Inn3	The sandal has a strong assembly.		0.606				0.646
Inn1	The sandal has standards in production.		0.510				0.551

Code	Variables	Component 1	2	3	4	5	Communality
Fun9	The sandal is waterproof.			0.705			0.661
Fun5	The sandal improves walking efficiency.			0.694			0.665
Fun6	The sandal is simple to put on or take off.			0.687			0.637
Fun3	The sandal is a good fit to wear.			0.682			0.631
Fun4	The sandal is durable.			0.675			0.621
Fun8	The sandal is simple to clean.			0.673			0.633
Fun7	The sandal is lightweight.			0.663			0.641
Fun10	The sandal is breathable and does not get damp.			0.607			0.555
Fun2	The sandal is versatile and suitable for various events.			0.555			0.664
Sym7	The sandal can create stories to share with others.				0.827		0.776
Sym10	The sandal establishes a distinctive image.				0.802		0.693
Sym9	The sandal helps to differentiate yourself from others.				0.792		0.716
Sym8	The sandal can boost your personality and make you look good.				0.791		0.735
Erg3	The sandal has a heel strap to suit a wide range of activities.				0.711		0.616
Sym6	The sandal aligns with the prevailing societal trend.				0.518		0.608
Sym4	The sandals are stylish in accordance with current fashion trends.				0.506		0.553
Erg2	The sandals increase safety while walking.					0.630	0.664
Erg4	The sandal has arch support.					0.595	0.643
Erg1	The sandal seems to be comfortable to wear.					0.584	0.652
Erg7	The sandal has a soft and elastic midsole.					0.572	0.710
Erg5	The sandal upper is soft and elastic.					0.567	0.698
Erg9	The sandal has an outsole for traction.					0.534	0.666
Erg8	The sandal has heel support to help reduce impact.					0.530	0.644
Aes5	The sandal employs a proper design concept.					0.518	0.528
Erg6	The sandal fits snugly and does not discomfort the foot.					0.516	0.664
							Total
	Sum of Squares Loadings (Eigenvalue)	6.961	6.385	6.302	6.149	5.284	31.081
	Percentage of Trace	13.922	12.769	12.604	12.299	10.567	62.161

Confirmatory Factor Analysis (CFA)

Measurement Model

For the examination of 5 measurement models for the observed variables, including aesthetic, innovation, functional, symbolism, and ergonomics, the models were adjusted by removing inadequate observed variables. Modification indices were used to bring the goodness-of-fit index (GFI) between the adjusted model and empirical data. The criteria for GFI consideration = χ^2/ df < 3.00 [93], *p* > 0.05, CFI > 0.96, TLI > 0.96, RMSEA < 0.07 in case of over 250 samples and less than 12 observed variables [92]. According to 45 observed variables that passed EFA analysis criteria, only 20 observed variables remained after all 5 measurement models of the observed variables had been examined and GFI was considered. In detail, the *aesthetic* measurement model was measured by 4 observed variables, i.e., Aes1, Aes8, Aes2, and Aes4 (Standardized factor loading = 0.689-0.754). The innovation measurement model was measured by 4 observed variables, i.e., Inn8, Inn4, Inn5, and Inn7 (Standardized factor loading = 0.707-0.865). The functional measurement model was measured by 4 observed variables, i.e., Fun5, Fun3, Fun4, and Fun10 (Standardized factor loading = 0.603-0.817). The symbolism measurement model was measured by 4 observed variables, i.e., Sym10, Sym9, Sym8, and Sym4 (Standardized factor loading = 0.623-0.902). The ergonomics measurement model was measured by 4 observed variables, i.e., Erg2, Erg4, Erg1, Erg7 (Standardized factor loading = 0.771-0.834) (Figure 3).

Table 3: Model's goodness-of-fit indexes (measurement model)

Model-fit Criterion	Acceptable Level* [92]	Model Level				
		Aesthetic	Innovation	Functional	Symbolism	Ergonomics
χ^2		1.710	5.100	3.302	5.195	4.914
df		2	2	2	2	2
χ^2/df	< 3.00 [93]	0.855	2.550	1.651	2.597	2.457
p-value	> 0.05 [92]	0.425	0.078	0.192	0.074	0.086
CFI	> 0.96 [92]	1.000	0.996	0.998	0.996	0.996
TLI	> 0.96 [92]	1.002	0.988	0.994	0.988	0.989
RMSEA	< 0.07 [92]	0.000	0.062	0.040	0.063	0.060

Note: *The sample size was more than 250 people, and the number of observational variables was less than 12, χ^2 = Chi-square, df = Degrees of Freedom, χ^2/df = Relative Chi-square, CFI = Comparative Fit Index, TLI = Tucker Lewis Index, RMSEA = Root Mean Square Error of Approximation

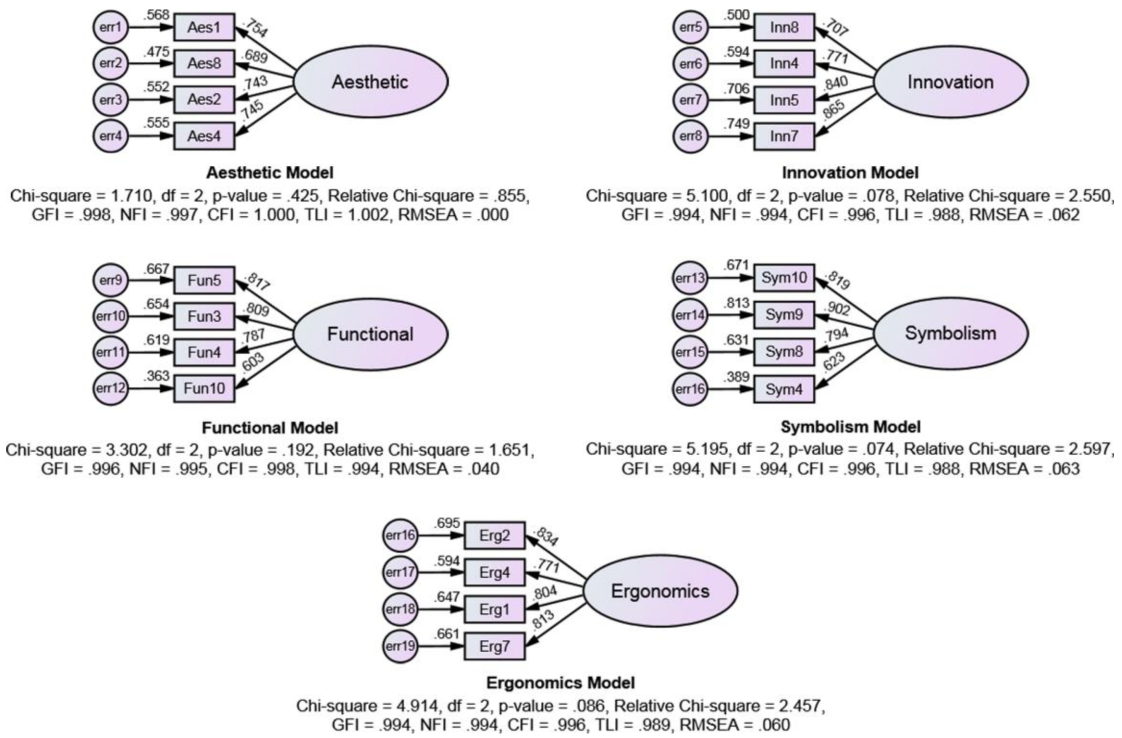

Figure 3. Analyzing the five latent variable measurement models

First-order CFA (F-CFA)

For the CFA of the first-order in all 5 observed variables, GFI was obtained as follows, i.e., χ^2= 340.452, df = 160, p < 0.001, χ^2/df = 2.128, GFI = 0.924, NFI = 0.928, CFI = 0.961, TLI = 0.953, RMSEA = 0.053 (Figure 3). It was found that GFI met the criteria (Table 4). The examination of convergent validity included convergent reliability (CR) examination, i.e., CR $_{\text{Aesthetic}}$ = 0.860, CR $_{\text{Innovation}}$ = 0.875, CR $_{\text{Functional}}$ = 0.844, CR $_{\text{Symbolism}}$ = 0.869, CR $_{\text{Ergonomics}}$ = 0.881; and analysis of average variance extracted (AVE), i.e., AVE $_{\textit{Aesthetic}}$ = 0.534, AVE $_{\text{Innovation}}$ = 0.638, AVE $_{\text{Functional}}$ = 0.577, AVE $_{\text{Symbolism}}$ = 0.628, AVE $_{\text{Ergonomics}}$ = 0.649. It was found that CRs > 0.70 and AVEs > 0.50, which met the criteria [92]. Thus, it can be concluded that each observed variable contained convergent reliability, which led to further analysis in the next step.

Second-order CFA (S-CFA)

For CFA of the second-order in the factors of sandal design, GFI was obtained as follows, i.e., χ^2= 392.320, df = 162, p < 0.001, χ^2/df = 2.422, GFI = 0.912, NFI = 0.918, CFI = 0.950, TLI = 0.941, RMSEA = 0.060 (Figure 4). It was found that GFI met the criteria (Table 4). Standardized factor loading of all variables contained a statistical significance of 0.001 ($p < 0.001$). It can be concluded that there were 5 factors for sandal design, arranged respectively as follows. Innovation (Standardized factor loading = 0.894) was measured by 4 observed variables, i.e., Inn7, Inn5, Inn4, Inn8 (Standardized factor loading = 0.723-0.860) Functional (Standardized factor loading = 0.857) was measured by 4 observed variables, i.e., Fun5, Fun3, Fun4, Fun10 (Standardized factor loading = 0.629-0.823). Ergonomics (Standardized factor loading = 0.850) was measured by 4 observed variables, i.e., Erg7, Erg2, Erg1, Erg4 (Standardized factor loading = 0.778-0.827). Aesthetics (Standardized factor loading = 0.568) was measured by 4 observed variables, i.e., Aes4, Aes2, Aes1, and Aes8 (Standardized factor loading = 0.710-0.750). Symbolism (Standardized factor loading = 0.533) was measured by 4 observed variables, i.e., Sym9, Sym10, Sym8, Sym4 (Standardized factor loading = 0.637-0.895) (Table 5).

Table 4: Model's goodness-of-fit indexes

Model-fit Criterion	Acceptable Level	Model Level	
		F-CFA	S-CFA
χ^2		340.452	392.320
df		160	162
p-value	Significant *p*-values expected [92]	< 0.001	< 0.001
χ^2/df	< 3.00 [93]	2.128	2.422
GFI	> 0.90 [94]	0.924	0.912
NFI	> 0.90 [94]	0.928	0.918
CFI	> 0.94 [92]	0.961	0.950
TLI	> 0.94 [92]	0.953	0.941
RMSEA	< 0.07 [92]	0.053	0.060

Note: χ^2 = Chi-square, df = Degrees of Freedom, χ^2/df = Relative Chi-square, GFI = Goodness of Fit Index, NFI = Normed Fit Index, CFI = Comparative Fit Index, TLI = Tucker Lewis Index, RMSEA = Root Mean Square Error of Approximation, F-CFA = First-order Confirmatory Factor Analysis, S-CFA = Second-order Confirmatory Factor Analysis

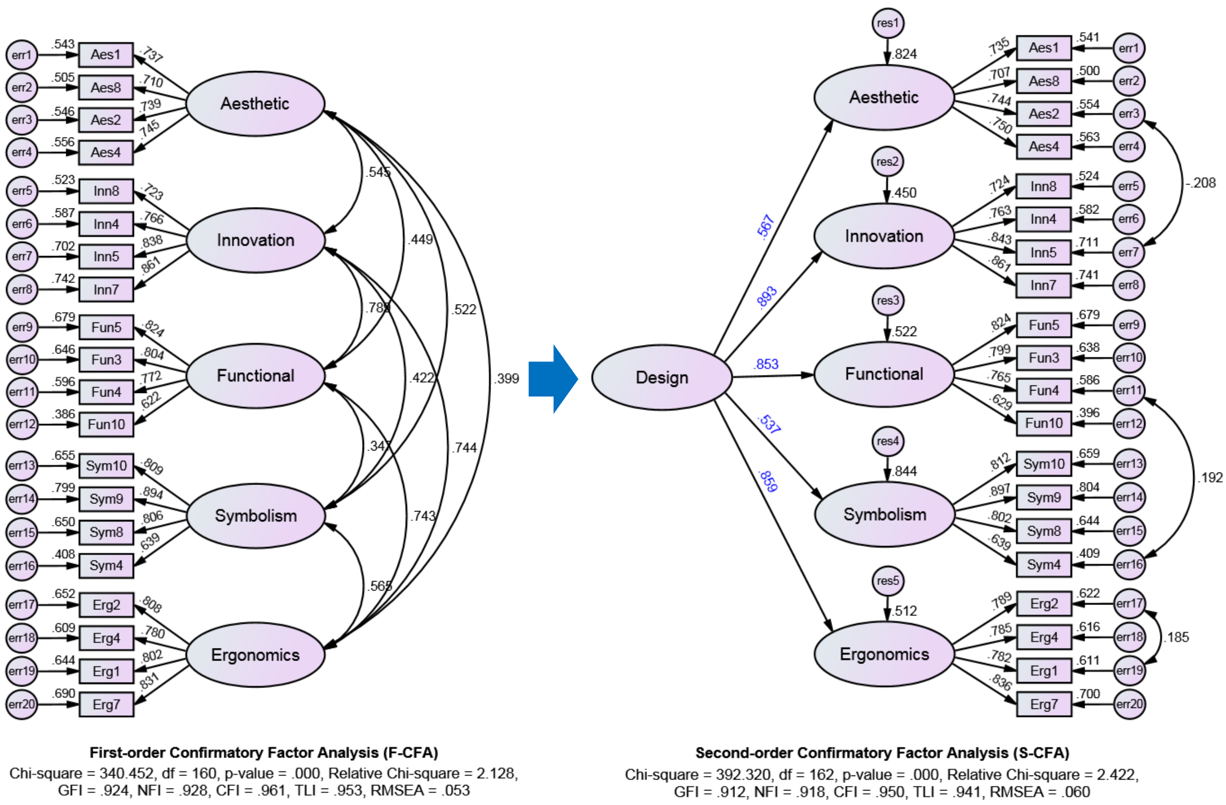

Figure 4. The final model features standardized path coefficients and factor loadings

Table 5: The resulting model's standardized regression weights and squared multiple correlation estimations

Path		Items		β	S.E.	C.R.	R^2	p
Design	--->	Innovation		0.893			0.798	
Design	--->	Aesthetic		0.567	0.063	9.012	0.322	***
Design	--->	Functional		0.853	0.069	13.061	0.727	***
Design	--->	Symbolism		0.537	0.072	9.505	0.288	***
Design	--->	Ergonomics		0.859	0.069	14.077	0.738	***
Aesthetic	--->	Aes4	The sandal attracts attention.	0.750			0.563	
Aesthetic	--->	Aes2	The sandal is unique.	0.744	0.072	13.538	0.554	***
Aesthetic	--->	Aes1	The sandal has a visually striking style.	0.735	0.072	13.385	0.541	***
Aesthetic	--->	Aes8	The sandal has a beautiful overall shape and proportions.	0.707	0.076	12.916	0.500	***
Innovation	--->	Inn7	The sandal can develop the bottom sole to provide more traction.	0.861			0.741	
Innovation	--->	Inn4	The sandal can develop materials to make them more comfortable.	0.763	0.050	17.835	0.582	***
Innovation	--->	Inn5	The sandal uses modern production technologies.	0.843	0.046	20.798	0.711	***
Innovation	--->	Inn8	The sandal can use environmentally friendly materials.	0.724	0.053	16.531	0.524	***
Functional	--->	Fun4	The sandal is durable.	0.765			0.586	
Functional	--->	Fun3	The sandal is a good fit to wear.	0.799	0.061	16.044	0.638	***
Functional	--->	Fun5	The sandal improves walking efficiency.	0.824	0.061	16.562	0.679	***
Functional	--->	Fun10	The sandal is breathable and does not get damp.	0.629	0.069	12.356	0.396	***
Symbolism	--->	Sym9	The sandal helps to differentiate yourself from others.	0.897			0.804	
Symbolism	--->	Sym10	The sandal establishes a distinctive image.	0.812	0.045	19.778	0.659	***
Symbolism	--->	Sym8	The sandal can boost your personality and make you look good.	0.802	0.045	19.456	0.644	***
Symbolism	--->	Sym4	The sandals are stylish in accordance with current fashion trends.	0.639	0.047	14.188	0.409	***
Ergonomics	--->	Erg7	The sandal has a soft and elastic midsole.	0.836			0.700	
Ergonomics	--->	Erg4	The sandal has arch support.	0.785	0.051	17.544	0.616	***
Ergonomics	--->	Erg1	The sandal seems to be comfortable to wear.	0.782	0.053	17.091	0.611	***
Ergonomics	--->	Erg2	The sandals increase safety while walking.	0.789	0.052	17.317	0.622	***

Note: β = Standardized Beta Coefficients, S.E. = Standard Error, C.R. = Critical Ratio, R^2 = Squared Multiple Correlation, *** $p < 0.001$

DISCUSSION

According to the CFA of the first-order and the second-order in the model with 5 factors and 20 variables (Figure 5) , GFI was found to meet the criteria. The results revealed that all 5 factors are necessary for sandal design, and can be discussed respectively by the effect size of each factor as follows.

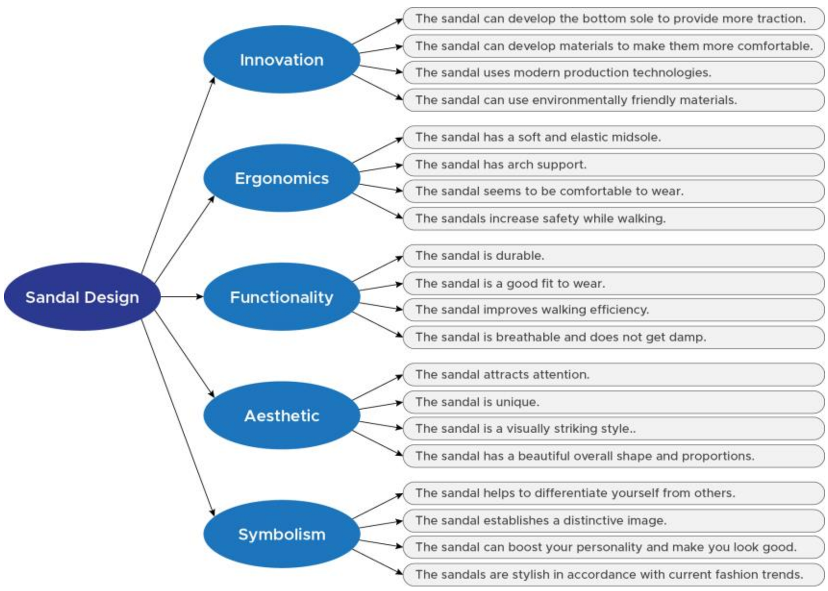

Figure 5. The five-factor model of sandal design

Innovation

Designers must pay attention to the development of materials, manufacturing technology, and knowledge of science, as well as technology as they are all indispensable for innovation development [74]. Sandal design requires updated materials and technology to create prototypes of fashion innovative products, which are necessary for value-added and prolonging product life cycles [95, 96]. Therefore, manufacturing technology should be developed regularly, e.g., material development for more comfortable wear or outsole development for durability and more efficient adherence to the ground [16, 17, 35]. Nonetheless, the development of materials and manufacturing technology for modern shoes still requires environmental concern for sustainability in future sandal industry [97, 98].

Ergonomics

Designers must care about the convenience and safety of users [11]. Ergonomics is a factor affecting the usage and purchase decision of sandals [15]. Wearing shoes that fail to meet ergonomics principles can affect consumer health, particularly foot pain and foot disorders [99]. These problems definitely affect users' feelings negatively. Therefore, caring about ergonomics for users directly affects consumers because they connect directly with their shoes. The midsole is also a key component that designers must consider as a major part affecting the user body. Soft and elastic materials should be used, with wide space for the forefeet to facilitate the natural movement of toes. What is more, shoe soles should be thick enough to reduce impacts around foot soles and heels while walking. Arch support is also required in order to spread body pressure throughout the soles [17, 30, 38].

Functionality

Designers must pay attention to perceived usefulness, perceived comfort, and perceived ease of use. Furthermore, functionality also includes perceived product characteristics, e.g., durability, quality, reliability, technical complexity [14], good ventilation, and lack of moisture [30, 33]. This factor refers to the basic needs of users that designers must keep in mind. It is also a user-centered concept [100]. Users need fit and comfort from wearing shoes because fit is a key factor in perceived comfort [17, 18, 101, 102]. Also, these two feelings affect the ability to wear, body balance, and movement efficiency [103].

Aesthetics

Designers must pay attention to the visual perception of the beauty of sandals. The beauty of clothing mainly arises from applied design principles and compositions to create aesthetics as intrinsic beauty according to user perception. Product beauty design is related to the intrinsic creativity and artistic abilities of designers. Aesthetics emerges from appropriate features for new products [96], usually represented through shapes and forms of eye-catching, distinctive, and attractive products [41]. Aesthetics, perceived by user satisfaction, originates from contact with physical features of products, i.e., the eyes or skin, which motivate feelings inside users [13, 52, 104]. These features must represent beauty and distinction, affecting consumer motivation in terms of their purchase decisions [7, 102, 105-107].

Symbolism

Designers must communicate the meanings of products through their styles and symbolism in order to create a proper understanding of those meanings through the shapes and forms of sandals. Symbols/symbolic meanings will be created into identity or be used to enhance images so that users will understand and take interpreted meanings from product forms for their purchase decisions [13, 14]. Sandals are regarded as a fashion product that helps improve personalities and represent the "self" of users. Anyway, the marketing strategies and styles of fashion products are usually adjusted with time. Therefore, sandal design requires studies on the tendency of future fashion [108, 109] so as to design sandals with modern styles that follow fashion trends and enhance user-distinctive images [6].

CONCLUSIONS

The objective of this research was to study the factors of sandal design in Thailand's market. The 5 factors affecting sandal design can meet consumer needs as users. To illustrate, "Factor 1: Innovation" requires the study and development of materials and manufacturing technology to be up-to-date. These innovations can increase the comfort and safety of users. "Factor 2: Ergonomics" must give precedence to the appropriate body sizes of users. It should give the feeling of more comfort when wearing and support positive effects on their health. "Factor 3: Functionality" must focus on comfort wear, related to quality material selection. "Factor 4: Aesthetics" must be concerned about intrinsic values through visual and physical contact. "Factor 5: Symbolism" must consider communication through the shapes and forms of sandals. Designers must interpret the meanings they want to communicate to users through sandal features.

These 5 factors will pave the way to sustainable development in the sandal fashion industry of Thailand's market. Kotler *et al.* [5] stated that young generations are usually interested in social responsibility and environmental sustainability, which are key aspects of their decision-making, particularly Gen Z and Gen Y consumers. These factors also bring innovative ideas for sandal design that gives priority to feedback from consumers so that designers can understand and set efficient guidelines for new product design [110-113]. Creativity is a key part of the future success of the sandal industry [114]. Therefore, design is the beginning of innovation from efficiency improvement to meet user needs and to expand market share by prolonging product life cycle for opportunities to make worthy profits for entrepreneurs and manufacturers [115].

Comfortable and modern sandal design requires the skills and experiences of designers. They must embrace comprehension of design principles and the tendency of fashion trends to be able to transfer inspirations and ideas/concepts into desirably designed sandals. Cooperation with external agencies is also required, e.g., shoe factories (for marketing data, technology, and innovations) and hospitals (for data on foot ergonomics). By doing so, designers can extend the scope of their knowledge for broader perspectives, using the capabilities of data analysis for a better understanding of consumer needs, e.g., foot shapes, foot structures, materials, accessories, manufacturing equipment, and QC to follow design outlines. These goals should be implemented under the common goals, i.e., to be worn with appropriateness and beauty, to enhance personalities, and to meet the needs of consumers in the new era.

LIMITATIONS AND FUTURE RESEARCH

This study is necessary to create value for sandals through design that relies on feedback from consumers in order to apply sandal design to Thailand's market as a significant product for the national economy. Even so, two limitations in this study should be addressed, which could be used to guide related studies and research in the future. For the first limitation, the samples consisted of Gen-Z consumers only, a group of consumers having grown up in the era where the Internet is a major trend. Undoubtedly, they can quickly adapt to new technology, and thus they are viewed as a key market for sandal brands. Future research should focus on other consumer groups, such as older adults, because the size of this group of people keeps increasing. As for the last limitation, the study results of consumer behavior revealed that brands affected the usage and purchase of sandals, according to opinions from most consumers. This implied that they still viewed sandal brands as essential. Therefore, future research should study and examine how these 5 factors of sandal design can affect consumer usage and purchase through their attitudes toward brands.

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THE ANTIOXIDANT EFFECT OF COLLAGEN HYDROLYSATE ON IMPROVING LIGHTFASTNESS AND MECHANICAL PROPERTIES OF THE GRANOFIN EASY F90-MIMOSA-TANNED LEATHER

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THE ANTIOXIDANT EFFECT OF COLLAGEN HYDROLYSATE ON IMPROVING LIGHTFASTNESS AND MECHANICAL PROPERTIES OF THE GRANOFIN EASY F90-MIMOSA-TANNED LEATHER

ABSTRACT. The effect of antioxidants on the properties of Granofin easy-F90-mimosa-tanned leather is explored in the present paper. The fresh bovine hides were prepared through soaking, liming, de-liming, and bating processes before being tanned with Granofin Easy-F90 and mimosa. Granofin easy-F90 (G) and mimosa (M) were used as cross-linking agents and collagen hydrolysate (C) was used as an antioxidant. The molecular structure, lightfastness, mechanical properties, morphology, and shrinkage temperature (Ts) of leather were measured using Attenuated total reflectance Fourier Transform Infrared Spectroscopy (ATR-FTIR), Xenotest Alpha and Beta LM, tensile strength testing machine, Scanning Electron Microscope (SEM) and a leather shrinkage temperature tester, respectively. The results indicated that the lightfastness, shrinkage temperature, tear strength, tensile strength, and elongation at the break of the sample treated with collagen hydrolysate were improved. The Granofin easy-F90-mimosa-collagen hydrolysate (GMC) tanned leather sample offered a lightfastness, shrinkage temperature, tear strength, tensile strength, and elongation at break of 4, 95°C, 37.8N/mm, 25N/mm^2, 42%, and the Granofin easy-F90-mimosa-tanned leather sample gave 3-4, 91.5°C, 30.5 N/mm, 24.2 N/mm^2, 44.6%, respectively. Considering these results, it is proved that collagen hydrolysate had a positive impact on leather properties.

KEY WORDS: hydrolyzed collagen, F90, antioxidant, lightfastness

EFECTUL ANTIOXIDANT AL HIDROLIZATULUI DE COLAGEN ASUPRA ÎMBUNĂTĂȚIRII REZISTENȚEI LA LUMINĂ ȘI A PROPRIETĂȚILOR MECANICE ALE PIELII TĂBĂCITE CU GRANOFIN EASY F90 ȘI MIMOSA

REZUMAT. În lucrarea de față se explorează efectul antioxidanților asupra proprietăților pielii tăbăcite cu Granofin Easy F90 și mimosa. Pielea proaspătă de bovine a fost pregătită prin procese de înmuiere, alcalinizare, decalcifiere și sămăluire înainte de a fi tăbăcită cu Granofin Easy F90 și mimosa. Granofin Easy F90 (G) și mimosa (M) au fost folosite ca agenți de reticulare, iar hidrolizatul de colagen (C) a fost utilizat ca antioxidant. S-au măsurat structura moleculară, rezistența la lumină, proprietățile mecanice, morfologia și temperatura de contracție (Ts) ale pielii folosind Spectroscopia în infraroșu cu reflectanță totală atenuată (ATR-FTIR), Xenotest Alpha și Beta LM, un dispozitiv de testare a rezistenței la rupere, un microscop electronic de scanare (SEM) și un tester pentru temperatura de contracție a pielii. Rezultatele au indicat că rezistența la lumină, temperatura de contracție, rezistența la sfâșiere, rezistența la rupere și alungirea la rupere ale probei tratate cu hidrolizat de colagen au fost îmbunătățite. Pentru proba de piele tăbăcită cu Granofin Easy F90, mimosa și hidrolizat de colagen (GMC) s-au obținut valori de 4, 95°C, 37,8 N/mm, 25 N/mm², 42% pentru rezistența la lumină, temperatura de contracție, rezistența la sfâșiere, rezistența la rupere, respectiv alungirea la rupere, în timp ce proba de piele tăbăcită cu Granofin Easy F90 și mimosa a avut valori de 3-4, 91,5°C, 30,5 N/mm, 24,2 N/mm², respectiv 44,6%. Având în vedere aceste rezultate, s-a demonstrat că hidrolizatul de colagen a avut un impact pozitiv asupra proprietăților pielii.

CUVINTE-CHEIE: colagen hidrolizat, F90, antioxidant, rezistență la lumină

L'EFFET ANTIOXYDANT DE L'HYDROLYSAT DE COLLAGÈNE SUR L'AMÉLIORATION DE LA SOLIDITÉ À LA LUMIÈRE ET DES PROPRIÉTÉS MÉCANIQUES DU CUIR TANNÉ AU GRANOFIN EASY F90 ET MIMOSA

RÉSUMÉ. L'effet des antioxydants sur les propriétés du cuir tanné au Granofin Easy-F90 et mimosa est exploré dans cet article. Les peaux bovines fraîches ont été préparées par des procédés de trempage, de pelanage, de déchaulage et de confitage avant d'être tannées avec Granofin Easy-F90 et mimosa. Le Granofin Easy-F90 (G) et le mimosa (M) ont été utilisés comme agents réticulants et l'hydrolysat de collagène (C) a été utilisé comme antioxydant. La structure moléculaire, la solidité à la lumière, les propriétés mécaniques, la morphologie et la température de retrait (Ts) du cuir ont été mesurées à l'aide de la spectroscopie infrarouge à transformée de Fourier - réflectance totale atténuée (IRTF-ATR), du Xenotest Alpha et Beta LM, d'une machine d'essai de résistance à la traction, d'un microscope électronique à balayage (MEB) et respectivement d'un testeur de température de retrait du cuir. Les résultats ont montré que la solidité à la lumière, la température de retrait, la résistance à la déchirure, la résistance à la traction et l'allongement à la rupture de l'échantillon traité avec l'hydrolysat de collagène étaient améliorés. L'échantillon de cuir tanné au Granofin Easy-F90-mimosa-hydrolysat de collagène (GMC) a offert une solidité à la lumière, une température de retrait, une résistance à la déchirure, une résistance à la traction et un allongement à la rupture de 4, 95°C, 37.8N/mm, 25N/mm^2, 42%, tandis que l'échantillon de cuir tanné au Granofin Easy-F90-mimosa a donné respectivement 3-4, 91.5°C, 30.5N/mm, 24.2N/mm^2, 44.6%. Considérant ces résultats, il est prouvé que l'hydrolysat de collagène a eu un impact positif sur les propriétés du cuir.

MOTS-CLÉS : collagène hydrolysé, F90, antioxydant, solidité à la lumière

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INTRODUCTION

Since prehistoric times, leather has been a valuable material [1]. Leather is obtained from skin/hide through a series of processing stages such as soaking, unhairing, liming, de-liming, bating and, tanning. When exposed to the environment, including UV light, leather can undergo oxidation, resulting in the formation of free radicals that are reactive due to the presence of unpaired electrons [2, 3], leading to a reduction of the light fastness of leather and other physical-mechanical properties.

Vegetable-tanned leather is friendly to the environment; however, properties like shrinkage temperature (Ts), tear strength, tensile strength, and light fastness are reported to be poor [4]. When vegetable-tanned leather is combined with strong cross-linking agents, leather with enhanced properties is produced [5].

Granofin Easy F-90, an organically based tanning agent made of sodium p-((4,6-dichloro 1,3,5-triaz-2-yl) amino) benzene sulphonate, can be utilized as a cross-linking substance in leather processing [5]. The chemistry behind the reaction of F-90 with the collagen matrix is that the two chlorine atoms in F90 combine with the collagen matrix's attached amino groups to create covalent connecting bonds [6]. One of the chlorine atoms is hydrolyzed in water to form HCl, which drops the pH from 8 to 5 leading to the promotion of the sulfonate group's interaction with the collagen matrix's positively charged amine groups.

Additional crosslinkings are generated when F90 is re-tanned with mimosa, which induces an integrative tanning effect that causes a cross-linking bond formation between the amine of the collagen matrix, its carboxylic and hydroxyl groups. These cross-linking connections are formed across the collagen and the NH_2 group of the sulphonate benzene in the F90.

Despite the integrative cross-linking developed between F90 and mimosa, which leads to enhanced physical properties, the leather is still reported to have poor light fastness [7, 8]. With low light fastness, the resulting leather is prone to fading, leading to a reduction in the strength and lifetime of the leather [9]. Therefore, to lengthen the lifetime of the resulting leather, it is a recommended practice to use materials with antioxidant properties that can enhance the lightfastness and physical properties of leather.

Recently, various antioxidants have been reported to be active radical scavengers that provide a protective environment to products in textiles, leather, and other industries that are prone to the fading process [10]. It is accepted that collagen hydrolysate (C), a low molecular weight protein (1–30 kDa) with good biocompatibility and low antigenicity, can be used as an antioxidant [11, 12]. The availability of the aromatic amino acids and the histidine in the collagen hydrolysate which are hydrophobic amino acids gives the collagen hydrolysate properties of working as an antioxidant [12]. Various studies have worked on the antioxidant impact of collagen hydrolysate on human skin [5, 12, 13]. Nevertheless, there are no studies regarding the antioxidant effect on lightfastness and related leather properties through the application of collagen hydrolysate alone or in combination with other tanning agents on the F90-mimosa-tanned leather. Therefore, in this study, it is interesting to know whether the lightfastness could be improved by incorporating collagen hydrolysate in the F90-mimosa-tanned leather.

EXPERIMENTAL

Materials and Methods

Materials

Bovine hides were used in the tanning processes. Industrially produced, commercially available products were utilized as tanning agents in the present study. These include Borron A, Borron T, Preventol ZL, Oropon, and Erhavit MB from TFL, Lipoderm Licker A1, Decaltal ES FL, and Granofin Easy F-90 from Stahl, Burtral 30 WB from Buckman, Merpin 8020 from Carpetex, Mimosa tannin from Silvachimica S.r.l. Other chemicals and reagents used were provided by various suppliers and were of analytical standard.

Preparation of Materials and the Tanning Process

The raw fresh hide from bovine was processed following the stages indicated in Figure 1 before the tanning process. The chemicals used in this process were commercial grade, where F-90 was supplied by Stahl. The weight of the chemicals used in the main tanning was determined based on the weight of the limed pelt. Fresh hides were prepared and processed as per Yu *et al*. [14] with some modifications as presented in Tables 1 and 2.

Figure 1. Stages involved in processing the rawhide before the tanning process [14]

Analysis of GM and GMC Leather Samples' Physical and Mechanical Properties

The shrinkage temperature (Ts) was examined by a shrinkage tester (Heidolph MR 3001 K, SKU: RBN 22734) as per the official method (ASTM D6076-18 (2013)). From the leather sample, a thin strip measuring 50 by 10 mm was taken off and suspended in the water. The bath's temperature was raised by 2 degrees Celsius each minute, and the temperature of the first definite shrinkage was recorded. The tensile strength and elongation at break were performed using the tensile strength testing machine as per standard methods (DIN EN ISO 3376:2002(E) IULTCS/IUP6) using a LLOYD instrument (Erichsen Prüftechnik Wuppertal). Measurements of single-edge tear strength were determined as per DIN EN ISO 3377-1:2002 (E) IULTCS/IUP 40. Three trials were carried out per sample and the average value was calculated.

Fourier Transform InfraRed (FTIR) Analysis of GM and GMC Leather Samples

ATR-FTIR spectroscopy technique was applied to study the molecular changes of sample GM and GMC. The spectra were obtained at a wave number ranging from 400–4500 cm^{-1}, a resolution of 4 cm^{-1}, and 16 scans. To record spectra, a Nicolet iZ10, which is an extension of the Nicolet iN10 IR microscope, was used.

Scanning Electron Microscopy (SEM) Analysis of GM and GMC Leather Samples

Field Emission Scanning Electron Microscopy (FE-SEM Thermo Fisher FEI Quanta 250 FEG) was utilized to examine the leather samples' surface morphology. Samples from official sampling positions were used to create the experimental leather samples. Before being loaded into a sample holder, samples were immediately sliced into specimens of equal thickness and coated with gold. Using the SEM set at 100x magnification levels and an accelerating voltage of 10 kV, the micrographs for the cross-section were produced.

Colorfastness to Artificial Light by Xenon Arc Fading Lamp Test

The lightfastness measurements of the leather samples were tested for normal light and hot light as per the testing standard methods ISO 105-B02:2014 and DIN EN ISO 105-B06:2020 through subjecting at reflectance measurements using Xenotest Alpha and Beta LM, respectively. Together with a set of reference materials, a leather sample to be tested was subjected to artificial light from the Xenon arc fading lamp under controlled conditions. The test specimen's color change was compared to the reference materials to determine the color's fastness to light. The light fastness results were evaluated as per standard DIN EN 20105-A02. The ISO blue wool scale, which ranges from 1 to 8 along with an intermediate, served as the reference materials for ISO 105-B02 and its corresponding test procedures. Blue wool 1 indicates the lowest color fastness and 8 the highest. Nine levels, each occurring in two grey fields with their corresponding contrast, were chosen for the greyscale. As per DIN EN ISO 20105-A02: A grey scale for evaluating the color changes, nine possible values are considered including 5, 4-5, 4, 3-4, 3, 2-3, 2, 1-2, and 1. Grade 1 indicates a significant visual change (lowest rating) and Grade 5 indicates no visual color change (highest rating). The exposed portion of a sample was compared to an unexposed reference sample for the visual inspections.

Table 1: Soaking, liming, deliming, and bating

Process	%	Product	Temp	Runtime	pH	Comment
Dirt soak	150	Water, drain	25	20'		
	150	Water	25	20'		
	0.1	Borron A, drain				Wetting, dispersing & emulsifying agent
Main soak	400	Water				
	0.2	Sodium Dimethyl 68 Dithiocarbamate (Preventol Z-L)				Bactericidal
	0.5	MgO (Merpin 8020 90)				Basifying agent
	0.2	Borron T			9.5	Degreasing agent
Liming	80	Water	20			
	1	Erhavit MB				sulphide-free liming agent
	0.1	$Ca(OH)_2$ (Lime)		20'	12	
	1	NaHS		30'		
	1	Na_2S		60'		2'/1'/run/stop
	1	Na_2S		60'		To complete hair removal
	0.5	Na_2S				
	1	$Ca(OH)_2$ (Lime)		45'		
	30	Water				
	1	$Ca(OH)_2$ (Lime)	20			
	0.1	Borron A		90'		
		Drain				
	150	Water, Flesh, split, weigh	25	15'		Wash 2 times
Delime	100	Water	25			
	2	Decaltal ES-N liquid (carboxylic acid esters)				
	0.05	Borron A				
	0.05	Borron T		60'	8	
Bating	0.6	Protease enzyme (Oropon ∞), wash		45'	8	

Color Index Measurements for Leathers Tanned with F90-Mimosa (GM) and F90-Mimosa-Collagen Hydrolysate (GMC)

Color measurements were performed using the Digi Eye color imaging system (Digi Eye, VeriVide Ltd, Great Britain), which consists of a digital camera and an illumination box with diffuse illuminant D65. The system was calibrated using digitizer calibration charts. Regarding the digital imaging techniques, the reference and tested leather sample's color difference was computed through the calculated CIELab values. The colorfastness grade was calculated according to the DIN EN ISO 105-A05 standard. In the CIE Lab color space coordinates, the color of the leather was represented by ΔL (Luminosity). This measures whether the sample is lighter (high L) or dark (low L). This shows no color information but only how light or dark the sample is. The coordinates (Δa and Δb), Δa represents redness or greenness, and Δb denotes yellowness or blueness. The color change or chromatic aberration (ΔE) between the light-subjected and un-subjected samples was used to measure the specimen's luminosity. ΔE was calculated using Equation 1 [15].

$$\Delta E = \sqrt{\Delta a^2 + \Delta b^2 + \Delta L^2} \quad (1)$$

L represents the difference between light and dark. a represents the difference between green (-a) and red (+a), and b represents the difference between yellow (+b) and blue (-b). A positive ΔL increment indicates that the color of the composite is lighter, while negative ΔL indicates that the color of the sample is dark after being exposed to light.

L, a, and b represent the difference between light and dark, -a (green) and red (+a), -b (blue) and +b (yellow), respectively. When ΔL is positive, the color of the material is lighter, while the negative value represents the darkness of the sample after exposure to light.

Table 2: Tanning, re-tanning, dyeing

Process	%	Dilution	Product	Temp	Time	pH	Comment
Tanning	80		Water				
	10		sodium p-((4,6-dichloro 1,3,5-triaz-2-yl) amino) benzene sulphonate (Granofin Easy F-90)	55	o. n	6	
	0.1	1:10	Burtol 30 WB				Fungicide, in hot water
	150		Water, drain, Samm, shave				Wash 2 times
Re-tanning	100		Water	40	40'		
	15		Mimosa			3.6-3.8	
	1		Tamol (naphthalene sulfonic acid)		60'		% based on mimosa weight
	50		Water		o. n	5.7	o.n. (overnight)
	5		Collagen hydrolysate		o. n	5.7	
Fatliquoring	4		Lipoderm liquor A1 (sulphited esters)		o. n	4.0-4.5	
	2		Ensul AM 90				
	100		Water, drain	25			Wash
Dying	100		Water	25			
	1		Dye (Avacor Brown MRZ)				Leave till penetration
Fixation	1.5	1:5	formic acid, drain		60'	3.5-3.6	3x @ 10+ 30
	200		Water		20'		
Top dying	1		Dye (Avacor Brown MRZ)				
Fixation	1.5	1:5	Formic acid, drain, wash, toggle		60'		3x @ 10+ 30

RESULTS AND DISCUSSIONS

Physical and Mechanical Properties for F90-Mimosa (GM) and F90-Mimosa-Collagen Hydrolysate (GMC) Tanned Leather

Figure 2 provides a schematic comparison between the physical properties of GM and GMC-tanned leather.

From the results, tear and tensile strength for the sample treated with collagen hydrolysate were higher than that without collagen hydrolysate. The increase was caused by stabilizing function through covalent intramolecular crosslinkers [16] of collagen hydrolysate functional groups, leather matrix, F-90, and mimosa. The results were in line with the physical requirements for shoe-upper leather [17].

The application of collagen hydrolysate reduces the elongation at break. However, the decrease was still above the physical standard requirements for shoe upper leather [16]. The applied collagen hydrolysate positively affected the fullness of leather and prevented over-elongation. These results show a similar trend to the study reported by Afşar *et al*. [18] regarding the impact of collagen hydrolysate on the physical properties of leather when it was used during the re-tanning process.

The shrinkage temperature for sample GMC was higher as compared to that of GM (Figure 2). The formation of the hydrogen bonding network and electrostatic interaction of collagen hydrolysate, leather matrix, and other tanning agents resulted in the higher shrinkage temperature [16]. The physical properties of the leather where the collagen hydrolysate was applied and its antioxidant capacity are reported to be related [16]. The antioxidant capacity of collagen hydrolysate is influenced by the available functional groups, such as hydrophobic amino acids in the peptide, which can stabilize free radicals through the donation of electrons or absorbing the free radicals electrons to reduce their reactivity [12]. The same functional groups play a role in improving other related leather properties [16]. Hence, collagen hydrolysate has a double impact as an antioxidant in improving light fastness and mechanical/physical properties of leather.

To assess the significance of variations, a Welch Two Sample t-test on two variables was used for the properties of GM and GMC-tanned leather. The dataset comprises four pairs of values for these properties. The results of the t-test demonstrate a p-value of 0.9207 and a t-value of -0.10379 with six degrees of freedom (df = 5.9986). The alternative hypothesis that the true difference in means is not equal to zero serves to conduct the test. The 95% confidence interval for the difference in means ranges from -55.29598 to 50.79598. Furthermore, the sample estimations indicate that GM's mean is 49.95 and GMC's is 47.70. Given the high p-value, there is no statistically significant difference between the means of GMC and GM.

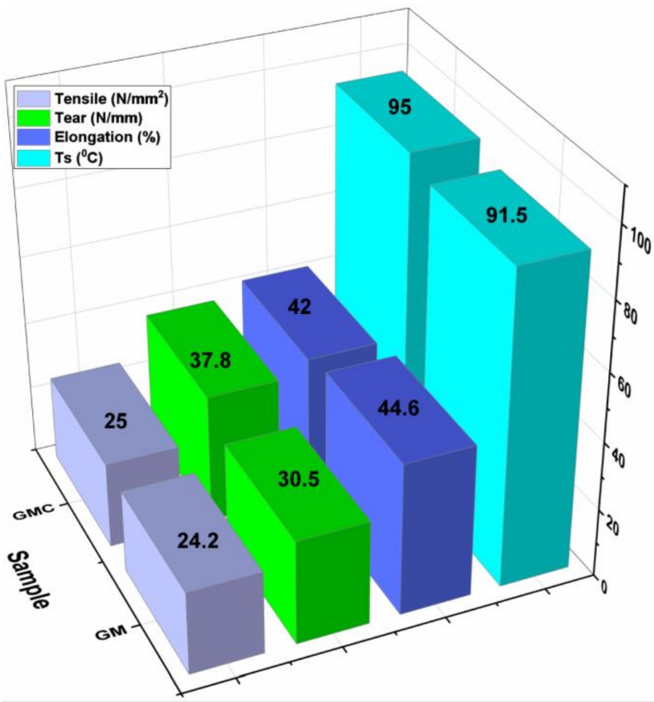

Figure 2. Properties of leather tanned with F90-mimosa (GM) and F90-mimosa-collagen hydrolysate (GMC)

Fourier Transform InfraRed (FTIR) of GM and GMC Leather Samples

The effective incorporation of collagen hydrolysate into the GM was verified by FTIR analysis, and the results are shown in Figure 3. The characteristic absorption bands at 3003, 2923, 1630, 1541, and 1234 cm^{-1} were observed in the FTIR spectra of GM and GMC. These were Amide A bands, observed at 3003 cm^{-1}, which represent the hydrogen bonding caused by N-H attached to a carbonyl group of the peptide chain[19]. The amide band B, due to CH_2 stretching, was observed at 2923 cm^{-1}. The amide band I, which represents the secondary structure of the protein, was seen at 1630 cm^{-1}. This is caused by hydrogen bonding due to the stretching of N-H and C=O. Amide II and III due to N-H bending vibration coupled with C-N and C-H stretching vibrations were found at 1541 and 1234 cm^{-1}, respectively. The absorption ratio between amide I and II, or 1451 $cm^{-1,}$ and amide III, which is equivalent to 1, confirms the existence of the triple helical structure of collagen [3]. The band observed at wavenumber 2853 cm^{-1} was influenced by the lipids from the fatliquors used during the tanning process.

A shift in the peak intensity of the absorbance was observed, and there was no shift in the wave number of the amide bands. The peak intensity for sample GMC increased as compared to GM. In FTIR, a higher peak intensity always indicates a higher concentration of the molecular bond's functional groups per unit volume [20]. The dispersion theory states that the square effective charge of the moving atom and the number of oscillators per unit volume are proportional to the absorption band's intensity [21]. The effective charge is influenced by structural changes and therefore, any changes in the peaks of the absorbance intensity indeed indicate structural changes.

FTIR of the tanned leather mostly displays the absorption band for collagen, therefore, a re-tanning of sample GM with collagen hydrolysate (which has the same composition as that of collagen) did not shift the band's wave number; rather, it only maximized the peak intensity of the spectra. The spectra exhibited features whose intensity changed after the addition of collagen hydrolysate, indicating a strong influence in defining the structure of the resulting leather.

The amide A's intensity change was associated with both intramolecular and intermolecular hydrogen bonds, indicating that a peptide's NH group should form the hydrogen bond [11]. The study's findings showed that the leather treated with collagen hydrolysate had a stronger hydrogen bond than the untreated leather. The outcomes demonstrated that following the addition of collagen hydrolysate, the leather's chemical characteristics were unaltered.

Concerning the influence of the functional groups on color fastness to light, collagen hydrolysate can penetrate inside the collagen fibers of leather due to its lower molecular weight [16]. Having the reactive amino, carboxyl, and hydroxyl groups (the functional groups), it can interact with leather collagen and other used tanning agents through hydrophobic, hydrogen, Van der Waals forces, and electrovalent bonds [22]. The peptides present in collagen hydrolysates function as electron donors to break down chain reactions in the leather matrix by reacting with free radicals to create more stable products [23]. The stable product, when exposed to light, will not be significantly affected by light, hence pronouncing the improved lightfastness.

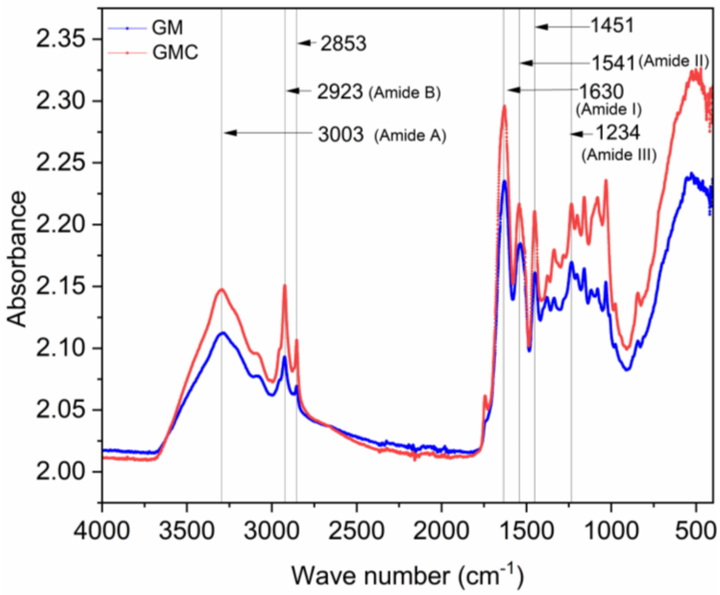

Figure 3. The FTIR spectra of GM and GMC

Scanning Electron Microscopy (SEM) for GM and GMC-tanned Leather Samples

The morphological structures of samples GM and GMC are shown in Figure 4. Scanning electron micrograph (SEM) analysis has been performed to investigate the fiber structure of the tanned leathers. Before the addition of collagen hydrolysate, the fiber bundles of F90-mimosa-tanned leather (GM) were tightly and closely packed (Figure 4a). After the addition of collagen hydrolysate, the fiber bundles of the tanned leather (GMC) were loosened, well separated, and opened (Figure 4b) due to the inside penetration of the collagen hydrolysate, which was also advantageous to the additional sites and the infiltration of dye. The opening of the fiber bundles was due to the interaction of collagen hydrolysate with F-90, mimosa, and leather collagen [22]. As an antioxidant, the opening of the fiber bundles improved the transfer of electrons to free radicals, leading to a stabilized structure of the leather matrix.

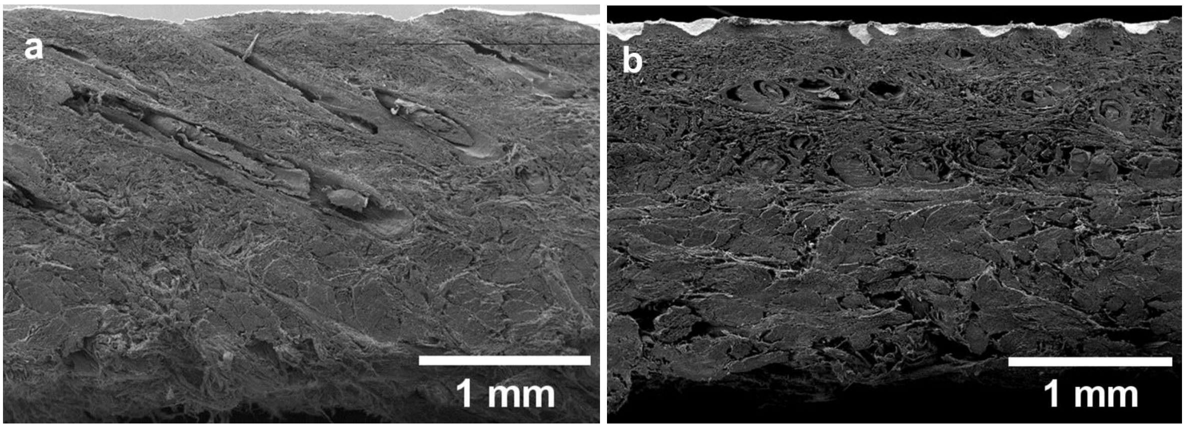

Figure 4. SEM images of (a) F90-mimosa and (b) F90-mimosa-collagen hydrolysate tanned leather

Colorfastness Test to Artificial Light by Xenon Arc Fading Lamp Test

The leathers tanned with GM and GMC show greater differences in their light fastness when exposed to UV light and hot light, as shown in Table 3. GMC had better lightfastness as compared to GM. This is due to the impact of collagen hydrolysate, which has an antioxidant effect on tanned leather.

Many studies indicate that most of the polymer's photodegradation routes are oxidative [3]. Auto-oxidation in leather is a process that is primarily triggered by UV radiations that are high in energy. Environmental pollutants or chemicals that function as radical initiators catalyze this process by splitting into free radicals when exposed to high-energy radiations. Since free radicals are so reactive, they react with oxygen present in the air to generate peroxide radicals. These peroxide radicals react with organic components of leather such as fat liquor, colorants, or dyes, tanning agents, and collagen leading to the deterioration/fading of the material [24].

Collagen hydrolysate neutralizes the propagation action leading to the prevention of the photodegradation process. The antioxidant mechanism of collagen hydrolysate can be attributed to its hydrophobic amino acids and aromatic side chains, which act as radical scavengers, neutralizing free radicals generated by UV exposure. This process likely stabilizes the leather matrix, reducing the degradation of colorants and structural proteins under UV light.

Table 3: Lightfastness for leathers tanned with F90-mimosa (GM) and F90-mimosa-collagen hydrolysate (GMC)

Sample	Blue scale	Greyscale
GM	3-4	1-2
GMC	4	3

Color Index Measurements for Leathers Tanned with F90-Mimosa (GM) and F90-Mimosa-Collagen Hydrolysate (GMC)

The images of the leathers processed with (GMC) and without collagen hydrolysate (GM) are presented in Figure 5 for visual assessment only and the dye used for both samples was Avacor Brown MRZ.

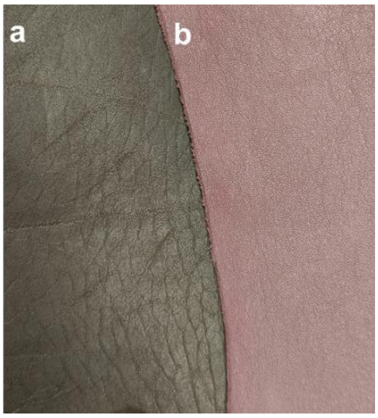

Figure 5. Image of leather tanned with (a) F90-mimosa-collagen hydrolysate and (b) F90-mimosa

For the color index measurement, the color changes or chromatic aberration (ΔE) of leather samples are shown in Figure 6. For all leather kinds, good color resistance to fading under hot or normal light is required [25]. The resistance to yellowing can be investigated by the change of chromatic aberration (ΔE) [28]. By comparing the ΔE values for GM which are 3.56 and 7.81 (normal and hot light exposure, respectively) and for GMC which are 1.55 and 3.38 (normal and hot light exposure, respectively), the values were a bit lower for the sample GMC, confirming that it is more resistant to yellowing than GM [7, 26]. This also implies that, when GM and GMC are exposed to light, GM will be affected (prone to yellowing) more than GMC. The greater resistance to the yellowing of the GMC sample was influenced by the incorporation of collagen hydrolysate (an antioxidant) and it confirms that GM and GMC exhibited differences in their light fastnesses. So here, we can pronounce that F90-mimosa-collagen hydrolysate (GMC) tanned leather has higher light fastness properties than F90-mimosa (GM).

Looking at the ΔL, Δa, and Δb values for samples GM and GMC, it is experimentally determined that the two samples do not match in color. Considering the ΔL, it is evident that sample GM is lighter than sample GMC, which was dark in color. The greater lightness of sample GM was influenced by serious photodegradation and photooxidation [27], leading to the disorientation of the structural network of the leather. Chroma values (Δa and Δb) in GM were higher than in GMC, suggesting that GM underwent a considerable yellowing upon exposure to light. The addition of collagen hydrolysate may have brought about these variations between GM and GMC. ΔE value is the total color difference that represents the distance of a line between the sample and the standard. Comparing the ΔE value, GM has a higher value than GMC, where the lower the value of ΔE of a sample implies the closer the sample is to the standard and the less the change in color after exposure to UV light [28].

To evaluate the significance of differences between the color index values (ΔL, Δa, Δb, ΔE) of GM and GMC tanned leather, the Welch Two Sample t-test on two variables was conducted. The dataset comprises four pairs of values for the samples. For normal light, the t-test results indicate a t-value of 0.57723 with 10.313 degrees of freedom, and the p-value was found to be 0.5762. The 95% confidence interval for the difference in means ranges from -6.094725 to 10.380440, and the mean of GM was found to be 5.101429, while the mean of GMC was 2.958571. The result indicates no significant difference between the two sample means, as the p-value exceeds the common significance threshold (0.05). For hot light, the test results show a t-value of 0.83435 with 10.343 degrees of freedom and a p-value of 0.4229. The 95% confidence interval for the difference in means ranges from -5.207864 to 11.487864. The mean of GM was found to be 6.375714, while the mean of GMC was 3.235714. Since the p-value is greater than the typical significance level of 0.05, the result suggests no statistically significant difference between the means of the two samples.

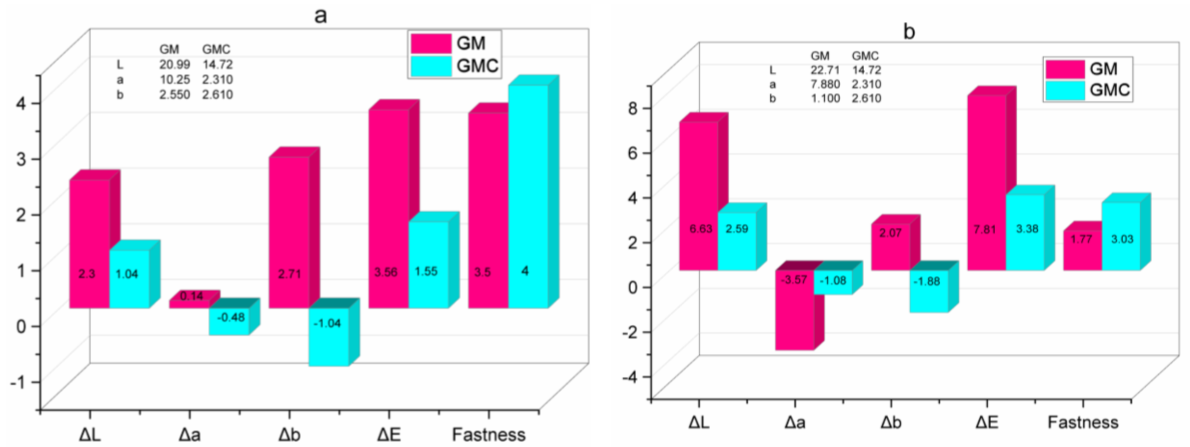

Figure 6. Color index measurements of (a) normal light and (b) hot light for leathers tanned with F90-mimosa (GM) and F90-mimosa-collagen hydrolysate (GMC)

CONCLUSIONS

The application of collagen hydrolysate as an antioxidant in the F90-mimosa-tanned leather improved the lightfastness and the physical-mechanical properties. The morphological changes also occurred after the addition of the antioxidant. Possibly, the cross-linking between collagen hydrolysate, F90, and mimosa occurred as expected. As an antioxidant, collagen hydrolysate may be applied as an effective stabilizer in the photofading process of leather and for industrial applications, the enhanced lightfastness observed in GMC-treated leather suggests its potential for high-end applications such as automotive or outdoor leather goods where prolonged exposure to sunlight is expected. The darkening effect observed in sample GMC after the introduction of collagen hydrolysate could be of advantage for leather intended to be resistant to UV light however, this effect is of disadvantage if the material was intended to maintain the color of the dye used (lighter color). Hence, to maintain the color of the dye used after the application of collagen hydrolysate while improving the lightfastness of the material, further study needs to be carried out.

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EUROPEAN RESEARCH AREA

COTANCE NEWSLETTERS

Starting with January 2019, the COTANCE Council has issued 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/leather/newsletter, and were also published in the 2019-2024 issues of *Leather and Footwear Journal*. Newsletter 12 of 2024 and 1 & 2 of 2025 are given below.

NEWS 12/2024

Double-Face Leather: Simple, Warm, Sustainable

Do you think leather isn’t suitable for winter? Then you haven’t heard of double-face leather! It’s one of the warmest and most natural solutions for the season. Made primarily from sheepskin, it combines two faces in one garment: soft wool on the inside for warmth and supple leather on the outside for protection.

In the coldest northern regions, people rely on double-face coats, hats, gloves, and boots for their unmatched warmth and resilience to extreme temperatures and conditions. With double-face leather, you’ll stay cosy, comfortable, and protected—and we guarantee that you’ll truly enjoy winter, perhaps for the first time.

 

What is Double-Face Leather ?

Double-face leather is a natural material crafted from lamb or sheepskin, where the wool remains attached to the leather during the tanning process. This creates a garment that provides both insulation and protection in one piece, eliminating the need for additional linings. The result is an incredibly functional and versatile material that keeps you warm in the harshest conditions.

The Advantages of Double-Face Leather

1. Warm:
    - The wool interior provides natural warmth, while the leather exterior shields against wind, snow, and rain.
2. Simple:
    - Double-face leather garments are a timeless investment, built to last for decades and easy to care for. Unlike fast fashion, a quality sheepskin coat can endure over 50 years, combining style, durability, and low maintenance.
3. Sustainable:
    - Double-face leather is sustainable because it upcycles meat industry byproducts into high-quality, durable, and warm garments, reducing waste that would otherwise go to landfills.

 

Simple, Warm, Sustainable

Double-face on frosty, cold and windy days – no more cold ears, feet or hands – enjoy the time outside, whether you commute to work by train or bus, or go sledding with your children. With double-face leather, nature makes it easy for us to stay warm and be sustainable!

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Festive Leather Treasures: Perfect Gifts for December | **COTANCE** **[Newsletter 5/2023]**
Leather for Christmas? - Of course! | **COTANCE** **[Newsletter 8/2022]**
Go for Slow Fashion - choose leather! | **COTANCE** **[Newsletter 1/2022]**

NEWS 01/2025

Leather Biodegradability: Another Reason to Embrace Leather

We often hear about massive floating "islands" of plastic polluting our oceans. But have you ever wondered why leather is never part of that conversation?

One possible explanation: **leather is a natural, biodegradable material**. Unlike plastic, which lingers in the environment for centuries, leather naturally breaks down at the end of its life.

When produced using **natural or biobased tanning agents and biodegradable additives**, leather can decompose in industrial composting in as little as **20 days** *(as highlighted in Karl Flowers' article, "Opportunities at Leather's End-of-Life," ILM, Sep-Oct 2024)*. That's a timeframe comparable to vegetable waste, which takes **5–30 days**!

Let's be clear: **all materials eventually biodegrade, but what sets leather apart is its ability to decompose quickly (20–60 days) and safely for the environment, transforming—under the right conditions—into compost that** enriches the soil with vital nutrients.

This unique feature makes leather not only a valuable part of the circular economy, but also one of the most sustainable fashion materials.

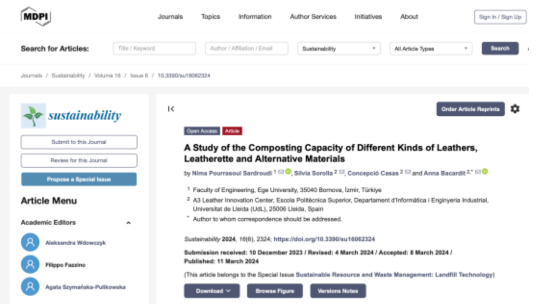
And that's just one of many reasons to choose leather!

***Biodegradability** refers to the process by which organic materials are broken down by microorganisms into simpler components like carbon dioxide, water, and ammonia.*

***Compostability,** a measure of biodegradation, refers to the ability of a material to break down into biomass without releasing harmful or toxic substances—provided it does not contain hazardous components that persist after decomposition.*

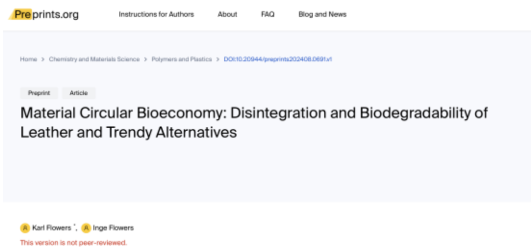
Any leather can be composted but the speed of degradation and environmental impact depends on the tanning chemistry used.

Producing *fully biodegradable* leather requires advanced technological solutions, and the industry is making incredible strides in this area. But even conventionally produced European leather demonstrates the ability to decompose naturally, and **here are the studies to back it up.**



"A Study of the Composting Capacity of Different Kinds of Leathers, Leatherette, and Alternatives" (A3 Leather Innovation Center, Ege University, Universitat de Lleida)

The study demonstrated that genuine leather, especially alginate-treated, **fully degrades within 21–25 days**, with wet-blue leather degrading in 31–35 days. Alternatives like leatherette, Piñatex®, and Desserto® showed no degradation after 90 days, underscoring leather's superior biodegradability compared to synthetic and plant-based substitutes.



"Material Circular Bioeconomy: Disintegration and Biodegradability of Leather and Trendy Alternatives" (Karl & Inge Flowers, Authenticae Limited)

Vegetable-tanned **leather compost promoted 74% more plant growth** and proved suitable for agriculture, showcasing leather's capacity to enrich soils. Meanwhile, most *fake leather* alternatives showed poor biodegradability, raising significant waste concerns at the end of their life.

[Compost-Leather-Able II Project (INESCOP, IVACE & ERDF)]

This study demonstrated that **all five tested leather types**, featuring various tannages and finishes, **exhibited high biodegradability and compostability** under lab conditions. However, polymeric finishes sometimes degraded slower than leather, leaving residual fractions in compost.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Assessment of the Biodegradability and Compostability of Finished Leathers: Analysis Using Spectroscopy and Thermal Methods

by Alberto Vico [1,*], Maria I. Maestre-Lopez [2], Francisca Arán-Ais [1], Elena Orgilés-Calpena [1], Marcelo Bertazzo [1] and Frutos C. Marhuenda-Egea [2,*]

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(This article belongs to the Section Biobased and Biodegradable Polymers)

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[“Assessment of the Biodegradability and Compostability of Finished Leathers” (INESCOP & University of Alicante)]

These findings underscore the potential of eco-friendly finishes to reduce the environmental footprint of leather production, promoting sustainability and further aligning leather with circular economy goals. Bio-based finishes showed strong biodegradability, while traditional finishes exhibited moderate levels. Notably, **some finishes enhanced plant growth during composting, highlighting leather's potential for eco-friendly practices in production.**

These studies prove that leather is one of the most ecologically responsible materials in the fashion industry. It manages the balancing act of being durable and yet biodegradable.

With its ability to “transform waste into beauty”, support closed-loop production cycles, and naturally return to the environment at the end of its service life, **leather stands out as one of the most sustainable materials available**. Its unique properties make it a crucial ally in achieving the goals of the EU Green Deal, supporting the success of key regulations like the Ecodesign, Waste Framework & Green Claims Directives.

So, as you consider your next purchase, remember: choosing leather is choosing a material that supports the planet—from cradle to grave.

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"A Study of the Composting Capacity of Different Kinds of Leathers, Leatherette and Alternative Materials", Sardroudi, Nima Pourrasoul, Sílvia Sorolla, Concepció Casas, and Anna Bacardit. 2024. Sustainability 16, no. 6: 2324. https://doi.org/10.3390/su16062324

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Is leather Biodegradable? | Nera tanning l Article

NEWS 02/2025

Women in Tanneries: Special Womens' 2nd Edition

March is all about celebrating women—their strength, their ambition, and their impact. After the overwhelming success of our March 2024 edition, we knew we had to make this a tradition. This year, we're back, diving deeper into the untold stories of the incredible women working in the European leather industry. From breaking barriers to mastering the craft, their journeys are as bold and resilient as the leather they help create.

The second edition of our special newsletter will feature three women from Italy, Spain, and Portugal, each representing a different age group, job role, and career journey. Their stories highlight passion, resilience, and opportunity, proving that the leather industry is full of possibilities for those ready to challenge conventions.

By sharing their experiences, COTANCE hopes to inspire more women to explore careers in this evolving sector—one where talent, skill, and determination matter more than ever.

Coming from a family of pioneers in the leather industry, **Barbara Mastrotto** began her career at 22, working in accounting and logistics before joining the Automotive Division of Rino Mastrotto in 2004. Now Head of the Automotive & Mobility Business Unit, she champions meritocracy, ethical leadership, and sustainability, striving to balance its environmental, social, and economic pillars.

At just 24 years old, **Laura Castro Gonçalves** has been part of A. Castro & Filhos for four years, gaining experience in various roles. With a degree in Marketing Management, she now leads chemicals and commercial operations, focusing on innovative and sustainable solutions for the leather industry.

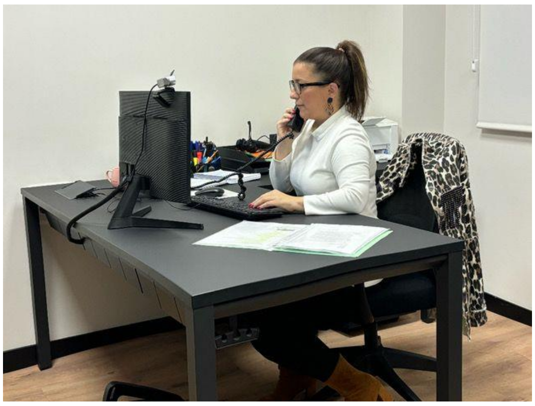
As HR Manager at INCUSA, **Irene Tarazona** is dedicated to creating a workplace where talent thrives. She actively supports women in the leather industry, ensuring equal opportunities for training and leadership. By bridging the gender gap, she helps make tanneries a more inclusive and rewarding place to work.

- **Your Journey into Leather: What inspired you to join the leather industry? Was it a deliberate choice, or did you discover your passion for leather along the way?**

Irene: *"I have always found it a fascinating sector because it is related to the world of fashion, which I am passionate about. I found myself in an unknown sector that attracted me from the very first moment and that was completely different from my previous professional experiences".*

Barbara: *"For me it was a simple and almost obvious choice. I have always heard about leather in my family and the passion for this particular product was passed on to me by my dad who is in love with leather, with the ever-evolving technology needed to process it, and with the importance of tanning in enhancing a by-product of slaughtering from the food industry. I was very happy when he asked me to join the company to bring my own contribution, and it was in the automotive world that I found myself".*

Laura: *"I entered the leather industry almost by chance. After university, I started working in the family business and, over time, I realized how challenging and fascinating this sector was. Today, I love what I do and know that it is a demanding field, requiring dedication, knowledge, and constant innovation. It is an industry full of creativity and challenges".*



Irene at her workplace at *INCUSA* in Spain

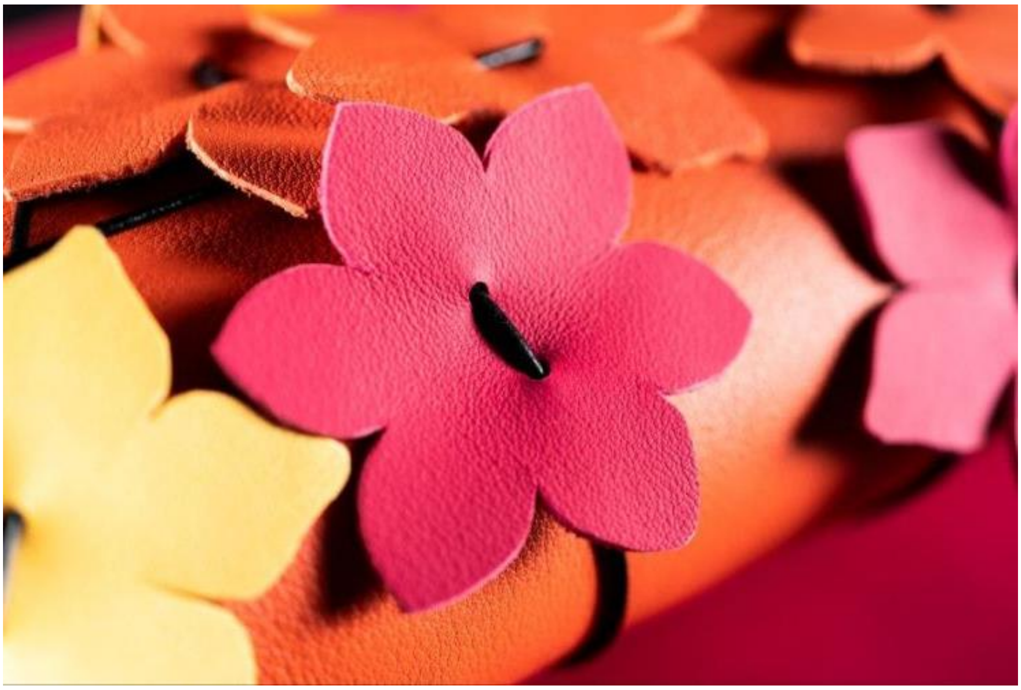
Laura operates a finishing machine to inspect and treat leather at *A. Castro & Filhos* in Portugal

- **Breaking Stereotypes: The leather industry has traditionally been male-dominated. Have you encountered challenges as a woman in this sector? How have you overcome them?**

Irene: *"Yes, I found myself at a very young age in a mostly male sector, but that helped me to reinvent myself, to set goals and objectives at a professional level, as well as to develop new skills that have made me grow personally and professionally."*

Barbara: "*The leather industry is a male-dominated world indeed. I have been lucky, however, because the industry I supervise is international, and I have been able to deal from the very beginning with markets such as the United States, which was more advanced in this sense, even 20 years ago, having women in leadership roles. The Italian experience, on the other hand, was initially a bit more close-minded, but with determination, professionalism, and pragmatism it was possible to handle even some less comfy situations."*

Laura: "*The leather industry has traditionally been male-dominated, but that has never been an obstacle for me. I work with many women, and I feel that we have an equal place alongside men, with the same opportunities to grow and innovate. I believe and know that knowledge, dedication, and results are what truly matter, and that is what allows us to establish our place in the industry."*



- **The Beauty of Leather: What aspects of leather do you think deserve more recognition, especially among younger consumers?**

Laura: *"Leather is a timeless and natural material that carries the history of our ancestors, reflecting generations of knowledge and craftsmanship. Behind every piece lies hard work, dedication, and skill, transforming raw material into something truly unique. Its exceptional durability allows it to last for generations without losing its quality or charm. Moreover, leather stands out for its endless creative possibilities—offering a wide range of designs, colors, and finishes—while maintaining its authentic and sustainable character."*

Barbara: *"Innovative, sustainable, Circular, Zero waist approach, uniqueness, high performance, durability, heritage, animal well-fair ... I would say all of these are features that young consumers highly appreciate. The challenge this material often faces with young people and the final market in general is getting known for what it genuinely is. It is up to us to improve in communicating and providing facts that support the value of it."*

- **Work-Life Balance & Passion: What do you love most about working in this industry? How does your job balance technical skills, creativity, and tradition?**

Laura: *"What fascinates me most about this industry is the perfect balance between tradition, technical expertise, and creativity. Leather carries centuries of history while offering endless possibilities for innovation. In my work, precision and attention to detail go hand in hand with the freedom to create and reinvent, making each day dynamic and inspiring".*

- **A Message to Young Women: Many young women may not consider a career in tanneries. What would you say to those who are curious but unsure about entering this industry?**

Barbara: *"Tannery is a challenging but at the same time fascinating industry. It can open up opportunities in different markets and roles: fashion, interiors, automotive.... and it requires different skills ranging from technical expertise to creativity .... It 'is an industry that is thrilling. The world of* *tanning has mellowed, and new generations have helped make it less male-oriented. There is more of a preference for teamwork, and female input is appreciated."*

The conclusion is clear: European tanneries are not just places of opportunity for women; it is a sector where they are already making significant impacts and leading change. By highlighting their achievements maybe we inspire more women to join this exciting and evolving world of leather.

Read the full interviews at euroleather.com

edited by

COTANCE

In collaboration with

Acexpiel - UNIC - APIC

You want to know more:
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IULTCS NEWSLETTER

IULTCS Newsleather
Stay curious, informed and connected

Edition 3, 2024

Welcome

This is the third edition of our scientific newsletter, dedicated to providing the latest updates on research, regulatory developments, technology, and standard methods in the leather industry.

In this issue, we are starting a series of publications about the use of patents in the leather industry. We will review two old patents that shaped the leather industry.

Patents are a complex subject, involving the interplay of technology, science, art, and legal expertise. The process of obtaining a patent is intricate and often requires the expertise of a patent attorney for the submission, interaction with the patent examiner, and defense of the patent. The patent process varies across different countries, resulting in situations where patents may be granted in some regions but not in others.

Thank you for joining us on this journey. We look forward to your feedback and contributions in future editions.

Please share your comments and suggestions to secretary@iultcs.org

Wishing you all a Happy New Year! Keep Tanning!

Kind regards,
Dr. Luis A. Zugno, editor

Traditionally, leather technology has been kept as a trade secret, with recipes and formulations guarded closely by the Master Tanner. Often, the chemicals were coded, and only handwritten formulations existed. Tanneries were tightly closed industries. However, with the advent of the industrial revolution, tanneries had to become more transparent, requiring the disclosure of chemicals and formulations. This shift created an opportunity to use patents to protect intellectual property. Today, both trade secrets and patents continue to play a crucial role in the leather industry.

A **patent** is a special legal protection for inventors. It gives them the exclusive right to use, make, and sell their invention for a set period, usually 20 years. This means no one else can use or copy their invention without permission.

Patents encourage inventors to create new things by ensuring they can benefit from their hard work. To get a patent, inventors must describe their invention in detail so others can understand how it works. This sharing of knowledge helps inspire more new ideas and inventions.

In simple terms, a **patent** is like a reward for inventors that also helps spread new knowledge and technology.

Patents play a crucial role in innovation by:

1. **Protection of Intellectual Property**: Patents safeguard inventors from unauthorized use of their inventions, ensuring they can control and monetize their innovations.
2. **Incentive for Innovation**: By granting exclusive rights to profit from inventions, patents provide a strong incentive for investing time and resources in research and development.
3. **Promotion of Knowledge Sharing**: The requirement for public disclosure of patented inventions fosters knowledge dissemination, which can inspire further innovation and development in related fields.
4. **Economic Growth**: Patents drive economic growth by encouraging the commercialization of new technologies, leading to the creation of new products, services, and industries.

While patents provide significant advantages, they also come with certain challenges:

1. **Cost**: The process of obtaining and maintaining a patent can be expensive, including application fees, legal fees, and maintenance fees. In the United States the total cost for the life of the patent is estimated in 100,000 dollars.
2. **Time-Consuming**: The patent examination process can be lengthy, often taking several years to complete. In most countries patents are valid for 20 years.
3. **Enforcement**: Enforcing patent rights can be complex and costly, particularly in cases of international infringement.

In this newsletter we will review 2 important and historical United States patents on the leather industry:

1. The two-batch system for chrome tanning patented in the United States by Schultz on January 8, 1884, next month completing 141 years. The two patents "Tawing Hides and Skins" describe the use of bichromate of potash (potassium bichromate) being reduced by sodium sulfite or sodium thiosulfate. Patents: US291784A and US291785.

Schultz patents were challenged by Zahn citing prior art. The New Jersey court said that the process is not entirely new or original and that similar patents existed at the time of Schultz's patent. This video has a great representation of the patent dispute: https://bit.ly/409Q5w7

2. Dr. Otto Rohm patented in 1908 the invention of a bating process using extract of the pancreas of animals and a mixture of salts of alkali and ammonia. This new bating method served as a replacement for the traditional use of dog dung in the bating process. The most known product of this patent (now expired) is called Oropon® and is still being used today. Patent US886,411. The German patent was issued on June 7, 1907: DE200519C https://patents.google.com/patent/DE200519C/en

The patent when issued became a public document and can be accessible easily. At the end of this newsletter, we have the complete text of these patents. The old patents are simple and very objective; today are more complex.

We will continue our discussion on patents and how to make searches in the future issues of Newsleathers.

IULTCS **Newsleather**

Stay curious, informed and connected

Edition 4, 2025

Welcome

This is the fourth edition of our scientific newsletter, dedicated to providing the latest updates on research, regulatory developments, technology, and standard methods in the leather industry.

In this issue, we have a peer review article on a LCA (Life Cycle Assessment) of the leather industry published at Discover Sustainability. The work was compiled by Leather Naturally and Spin 360. Our Sustainability Committee Chair Kim Sena and I are co-authors of the paper.

The paper can be downloaded through the link or QR Code below.

Please share your comments and suggestions to secretary@iultcs.org

Kind regards,
Dr. Luis A. Zugno, editor

Sustainability – *Kim Sena*

Message from Kim Sena, IUS Chair

Sustainability is an unavoidable topic in the modern world. Humanity and its supply chains must adjust to the reality that the balance between the resources we use and the ability of Earth to regenerate them is clearly negative. As part of very relevant value chains, the leather industry has been going through a surge of new data and information on its externalities. Nevertheless, it has long needed comprehensive and up-to-date studies on the environmental impact of leather production. Different studies have been published in the past, but mainly due to the lack of comprehensiveness failed to represent the entire leather segment.

This paper addresses these gaps by conducting an extensive Life Cycle Assessment (LCA) using modern methodologies and data from 56 studies across 16 facilities in 11 countries. The study covers various types of leather, such as automotive, shoe, upholstery, and goods, providing a global perspective. Key findings highlight that the farming stage significantly impacts most environmental categories, and there's a need for better data on raw materials and processing. On the other hand, some environmental impacts were lower than previously thought, providing some important insights. This research is crucial for leather manufacturers, as it identifies areas for improvement and highlights data gaps that, if addressed, could lead to more reliable and useful LCA results. The insights gained can guide the industry towards more environmentally friendly production methods, continuously positioning leather as a responsible material alternative for the future.

The paper can be downloaded here: https://rdcu.be/d9fe0

IULTCS **Newsleather**

Stay curious, informed and connected

Edition 5, 2025

Welcome

This is the fifth edition of our scientific newsletter, dedicated to providing the latest updates on research, regulatory developments, technology, and standard methods in the leather industry.

NOTE: This newsletter is in English, Spanish and Portuguese. One version after the other.

In this issue, we are excited to feature an exclusive interview with an expert in the field of collagen. We are honored to have Mr. Serhat Ugur Başyiğit as our first interviewee. Mr. Serhat began his career in the leather industry before transitioning to focus on the production of high-quality collagen products. Today, he manufactures collagen products in Türkiye, exporting them worldwide. In this interview, Mr. Serhat will share valuable information on the classification of collagen products and provide insights into the close relationship between the leather industry and the collagen market.

Please share your comments and suggestions to secretary@iultcs.org

Kind regards,
Dr. Luis A. Zugno, editor

IULTCS INTERVIEW

Lifeline: Serhat Ugur Başyiğit holds a degree in Leather Engineering from Ege University in Türkiye, with over 30 years of experience in the leather and collagen industries. His career has focused on pioneering sustainable and innovative uses for the hides and skins, with a particular emphasis on developing high-quality gelatin and collagen products for food, pharmaceutical, and industrial applications. As the founder of Gelner Gıda A.Ş. and Lucas Ingredients, he has spearheaded initiatives that bridge the gap between traditional leather processing and modern collagen applications. have 9 Patent applications and Industrial designs with his brother Servet Başyiğit.

IULTCS Question 1: When we say that hides are converted to collagen, what does this mean? What are the typical product categories?

Serhat: The transformation of raw materials can be classified within a value pyramid framework, starting with the base using leather by-products (trimming scraps, shavings, sanding dust, etc.). The other pyramid levels use hides and skins. This pyramid is structured as follows in the Figure 1 and detailed on the Table 1:

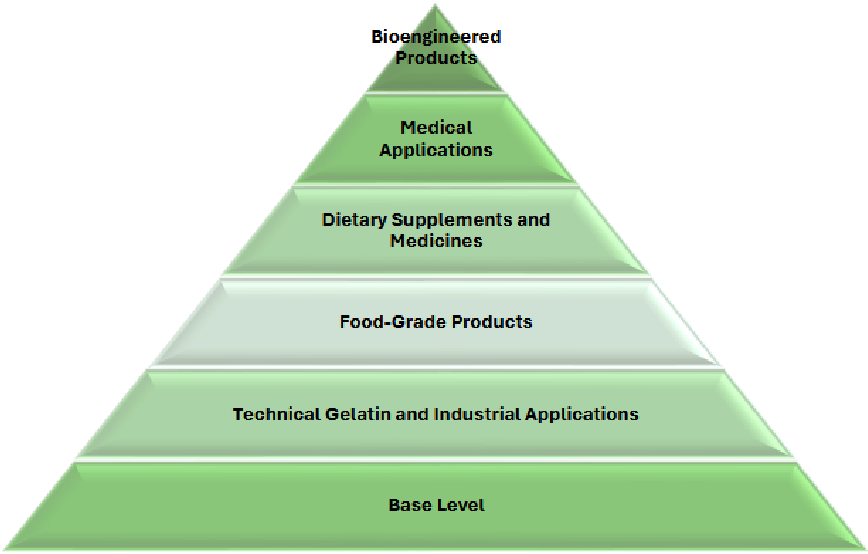

Fig. 1 Value pyramid for leather byproducts and collagen. As production volumes decrease while ascending the pyramid, the added value and need for specialized knowledge increase. This underscores the strategic importance of collagen-based products in the global economy

Level	Products	Details
Base Level – Uses leather by-products	Organic fertilizers and animal feeds	High in volume, low in added value, includes organic fertilizers with high nitrogen content and animal feeds (fish and poultry feeds)
Technical Gelatin and Industrial Applications	Gelatin derivatives, adhesives, technical products	Not suitable for human consumption, sourced from tannery by-products
Food-Grade Products	Gelatin, functional collagen	Intended for food use, produced to high-quality standards suitable for human consumption
Dietary Supplements and Medicines	Collagen peptides, hard and soft capsules	High-value products used in sports nutrition and health supplements
Medical Applications	Bioactive collagen peptides, wound dressings, medical-grade gelatin	
Bioengineering Products	Artificial human skin, bio-inks, vaccine stabilizers	Derived from ultra-pure collagen

Table 1: Details of the value pyramid

IULTCS Question 2: Today it is estimated that 300 million cow hides are produced/year and 15 to 20% are used for collagen. In your opinion is this a good approximation?

Answer Serhat: This estimate is accurate for the pre-COVID era, as gelatin manufacturers primarily relied on by-products from the leather industry, such as trimmings and splits from hides processed for leather. This accounted for approximately 15-20% of the total hide production.

However, the COVID-19 pandemic brought about an unprecedented shift. Leather experienced its greatest downturn in history as demand for leather goods plummeted during global lockdowns. Many raw hides were discarded due to lack of demand, while prices for hides fell significantly.

In contrast, the dietary supplement sector, including collagen peptides, experienced explosive growth as consumers focused more on nutrition and health. This shift dramatically increased the demand for collagen-based products. The abundance of raw hides post-COVID allowed manufacturers to expand beyond by-products and process entire hides for gelatin and collagen production. This also encouraged new entrants to invest in large-scale facilities for collagen production.

In the coming years, the demand for leather goods is expected to rebound, driven by trends such as the renewed interest in natural materials. This poses a potential challenge for the new collagen and gelatin producers who have become heavily reliant on hides as their primary raw material. Balancing the demand for leather and collagen products will be critical for the sustainability of both industries. Currently, it is estimated that between 25% and 30% of hides are processed into collagen.

Collagen is a broad term that encompasses various food-grade products, including both gelatin and hydrolyzed collagen peptides.

IULTCS Question 3: What is the future of the collagen market? Is there potential to double or triple collagen production?

Answer Serhat: As highlighted in the value pyramid discussed earlier, collagen's applications are becoming increasingly diverse and evolving towards higher value-added products. This trend is expected to shape the future of the collagen market in several ways.

In summary:

• The future growth of lower-value products will be closely tied to the leather industry and its raw material supply. An increase in the production volumes of relatively inexpensive gelatin and collagen products would be a clear indicator of a struggling leather industry

• In Türkiye, Latin America and Asia a more sustainable and competitive model is emerging, driven by efforts centered around large-scale bovine leather tanneries. These models involve facilities where the by-product of one process serves as the raw material for another. This integrated approach is proving to be a more resilient investment strategy, with potential for long-term success

• High-value applications, particularly in bioengineering and medical fields, are likely to expand rapidly due to innovation and increasing demand for advanced materials

• The overall market could see substantial growth, with potential for doubling or tripling production in certain segments, particularly those that leverage cutting-edge technologies

• Today South America accounts for 35-40% of the total collagen market followed by Asia with 25-30% and Türkiye with 5-10%

Thus, the collagen market's future will depend on balancing traditional uses with emerging high-value applications, each influenced by different market forces and technological drivers.

IULTCS Question 4: Please explain the trend and factors that influence collagen prices?

Answer Serhat: The collagen market prices have decreased significantly since 2019. Figure 2 illustrates the price changes.

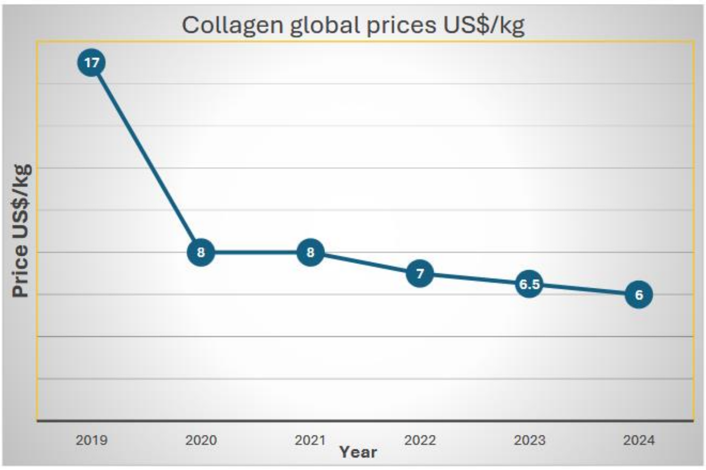

Figure 2: Collagen prices from 2019 to 2024 (US$/kg)

The main factors contributing for recent price reduction are:

• Post-COVID raw material surplus: the pandemic resulted in an oversupply of raw hides as the leather industry slowed down.

• Increased production capacity: new investments, especially in South America, Asia, and Türkiye, have led to a surge in collagen production

• Market Competition: The rapid growth of the collagen market attracted many new entrants, intensifying competition and driving prices down

While demand for collagen products, especially in supplements, has risen, the oversupply and expanding production capabilities have kept prices low. This trend highlights the complex dynamics of the collagen market, where lower prices do not necessarily reflect a lack of demand but rather a shift in supply and competition.

Collagen prices are subject to significant fluctuations, driven by a complex interplay of supply, demand, and external market factors. These fluctuations can be better understood by considering the following elements in Table 2:

Factor	Impact
Raw Material Availability	High leather demand reduces hides for collagen, increasing prices. During downturns, hide availability increases, leading to price drops
Geopolitical and Economic Factors	Global events like pandemics and trade restrictions impact raw material availability and pricing. COVID-19 caused logistics disruptions and a surge in demand for health products
Technological Advances and Production Costs	Advances in extraction and processing methods can influence costs. Innovations require significant investment, causing short-term price hikes but stabilizing prices over time
Shifts in Market Demand	Popularity of collagen in supplements, foods, and cosmetics creates new markets with higher profit margins, increasing competition for raw materials and price volatility
Sustainability Trends	Pressure for sustainable sourcing adds complexity to the supply chain. Compliance with environmental regulations and certification drives up production costs
Regional Differences	Production and demand vary by region. Asia and South America are major hubs due to abundant raw materials and lower labor costs. Regional disruptions can cause localized price spikes
Rising Customer Awareness in Supplements	Consumer awareness of collagen's health benefits has grown, leading to demand for high-quality, branded products, which command premium prices

Table 2: Factors that impact the collagen prices

Collagen prices are influenced by a delicate balance between supply chain dynamics, technological advancements, sustainability pressures, and evolving consumer demands. Rising awareness among supplement consumers has added a premium to high-value collagen products, further contributing to price fluctuations. Long-term stability in the collagen market will depend on addressing these challenges while maintaining sustainable practices and innovation.

IULTCS Question 5: You actively participate in Food Additives fairs like the one in Frankfurt in November 2024. What are the trends for the future of collagen-based products?

Answer Serhat: Humans are inherently complex, and this complexity is also reflected in industry trends. In the collagen sector, we observe a parallel to the so-called “vegan movement” in the leather industry. Fortunately, unlike in the leather industry, where plastics are often proposed as alternatives, the collagen industry has avoided such environmentally problematic suggestions. Instead, plant-based amino acid blends are being marketed as "vegan collagen." However, these products lack hydroxyproline, a key amino acid unique to animal-derived collagen, making their claims of being collagen substitutes scientifically unfounded. This raises questions about transparency and consumer trust.

Combining this observation with insights into industry trends we have them summarized in Table 3:

Category	Details
Clean Label and Sustainability	Collagen remains a leading clean label ingredient, derived naturally and fitting consumer demands for minimal processing. True collagen products maintain a distinct advantage due to their unique amino acid profile, particularly hydroxyproline, essential for skin and joint health
Halal and Kosher Certification	Growing consumer demand for certified Halal and Kosher products has pushed manufacturers to invest in these certifications. This inclusivity broadens market reach and aligns with ethical and sustainable sourcing practices
Functional Foods and Beauty Products	Collagen is increasingly being incorporated into functional foods and beauty products. These innovations cater to health-conscious and beauty-focused consumers, driving strong growth in supplements, beverages, and anti-aging solutions
Medical and Pharmaceutical Applications	The healthcare sector continues to innovate with collagen, particularly in regenerative medicine, wound care, and bioengineering. High-value applications such as bioactive peptides and medical-grade gelatin are key growth areas
Marine and Alternative Collagen Sources	Sustainability efforts have driven interest in marine collagen and other alternative sources, which diversify supply and offer unique properties such as enhanced solubility and bioavailability
Personalized Nutrition and Advanced Delivery Formats	Personalized collagen products tailored to specific health needs are becoming more popular. Innovative formats like gummies, effervescent tablets, and liquid shots cater to consumer demand for convenience

Table 3: Collagen industry trends with details

The future of the collagen market lies in balancing scientific integrity, consumer trends, and sustainable practices. While "vegan collagen" claims may attempt to capitalize on market demand, the scientific advantages of authentic animal-derived collagen remain unmatched. Coupled with Halal and Kosher certifications, clean-label trends, and advanced medical applications, true collagen products are well-positioned for long-term success. Manufacturers who focus on innovation, transparency, and sustainability will lead this evolving market.

IULTCS Question 6: Many tanneries split the hide on lime and use the split for collagen products, while the grain is used for leather products. Other tanneries take the whole hide, remove the hair, and sell it for collagen. In your opinion, will this model continue in the future?

Answer Serhat: The current model of splitting hides in lime and utilizing the splits for collagen while reserving the grain layer for leather products is efficient and has been widely adopted due to its ability to maximize resource utilization. However, whether this model continues in the future will depend on several key factors listed on Table 4:

Category	Details
Economic Dynamics	If demand for leather rebounds, tanneries may prioritize grain layers, reducing splits for collagen production, pushing collagen manufacturers to explore alternative raw materials
Technological Advances	Advances in collagen extraction may allow processing the entire hide, challenging the split-and-grain model
Sustainability Trends	Push for sustainable practices could favor models using the entire hide, reducing waste, improving efficiency
Collagen Market Growth	Growing collagen demand in foods, supplements, medical applications may shift balance towards collagen production
Regulatory and Market Pressures	Stricter regulations on waste management and sustainable sourcing may encourage integrated models

Table 4: Factors that affect the splitting the hides in lime and using the splits for collagen

In my opinion, while the split-and-grain model has been effective, I believe the future lies in integrated systems that balance leather and collagen production. Models where the by-product of one process becomes the input for another, as pioneered in Türkiye and adopted in parts of South America and Asia, represent a more sustainable and competitive approach.

However, if leather demand continues to grow, particularly with trends favoring natural and sustainable materials, collagen producers may face challenges in securing sufficient raw materials. In this scenario, the current model will likely continue, but with adaptations to ensure that both industries coexist and thrive sustainably.

Closing comments from **Serhat**:

I would like to extend my sincere gratitude to the readers of the IULTCS Newsletter for taking the time to explore the evolving world of collagen and its connection with the leather industry. The insights and trends shared here reflect a shared commitment to sustainability, innovation, and collaboration.

As a professional dedicated to advancing these industries, I welcome your thoughts, questions, and ideas. Please do not hesitate to reach out to me for further discussion or collaboration. Together, we can continue to shape the future of these interconnected sectors.

Thank you once again for your interest and support. I look forward to engaging with you in the future!

Serhat Ugur Başyiğit

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NEWS RELEASE FROM THE IULTCS

February 21, 2025

Winners of Three 2025 IUR Research Grants Announced

The Executive Committee of the IULTCS is pleased to announce the winners of the 2025 IUR research grants to be awarded to two young scientists, under the age of 35. The monetary awards help support the work of young talent in the leather sector.

This is the tenth year of the grants which have been generously supported by the industry. The Selection Committee of the IULTCS Research Commission (IUR), chaired by Dr. Volker Rabe, is pleased to announce the following recipients:

Basic Leather Research Grant 2025

Mr. Zoheb Akhter from LASRA, New Zealand. The title of his project is **"Alkaline Hydrolysis of Zeolite and Chrome Shavings: Investigating the fate of their hydrolysate and Undigested Materials"**.

Project's main objective is to hydrolyse Shavings (zeolith and chrome tanned) to providing insight into the purity of the hydrolysates, particularly in terms of organic and inorganic content. Furthermore, studying the fate of chrome and zeolites during hydrolysis will reveal the extent to which these tanning agents remain bound to the collagen matrix or are released for assessing the implications of tanning agents on the hydrolysis process.

Professor Mike Redwood Sustainability/Environmental Grant 2025

Dr. Yudan Yi from Jiaxing University, China **"A cationic amphiphilic acrylic copolymer for metal-free eco-leather production: Integration of retanning and fatliquoring"**.

The general objective is to develop a cationic amphiphilic copolymer with retanning and fatliquoring dual function, which can be utilized in post-tanning process to produce eco-friendly metal-free leather with high performance and the ability to save leather chemicals, reduce the discharge into wastewater, and shorten the processing time.

Leather Machinery/Equipment Grant 2025

Will not be awarded this year

Dr. Volker Rabe congratulates the winners and thanks all participants who submitted proposals. He emphasizes the strong innovative power and talent of the industry. He also acknowledges the contributions of the reviewers and the generous support of the sponsors Tyson Leather (basic leather research) and Leather Naturally (sustainability/environment).

The IULTCS looks forward to the valuable insights from these projects and wishes the award winners continued success in further developing industry knowledge.

NEWS RELEASE FROM THE IULTCS

03 March 2025

Leather Technology Self-Study Modules Available to Download

The loss of much tradition-based training in leather technology - such as the impending closure of ICLT – is a matter of concern and can have serious effects that extend across the global leather sector. Nevertheless, in line with the shift toward distance learning, there are two existing and updated studies available (free of charge) to help address these eventualities and minimise the impact of such closures.

The author of these studies is Richard Daniels who hast brought his vast wealth of knowledge and experience from a lifetime working in the global leather industry together and has spent many, many months creating these studies for the benefit of the industry.

The first is entitled **"Leather: AN INTRODUCTION"**, providing information for people who need background information on the subject, or simply want a clear understanding for general interest.

The second, entitled "**Leather: AN OVERVIEW OF MANUFACTURE"**, is a more advanced study in 10-sections, and intended to support those who wish to become leather technicians.

These are designed for individual study and self-training, but they are also viewed within formal education as supports at introductory and intermediate levels respectively.

Moreover, they are suited for reference purposes, and as part of distance learning packages. As two complementary volumes, they comprise around 45,000 words, enhanced with more than 450 images and industrial photographs. Using a format that combines concise text with supporting images, these studies are designed for clear understanding.

This information is available for use, **including in-house training**, or dissemination by any company or organisation which wishes to promote better leather-related understanding. All of the content is available free of any charge.

Approved and reviewed by IULTCS, SLTC, ALCA, COTANCE and UNIDO, these studies are now available for download via their respective web sites.

INSTRUCTIONS FOR AUTHORS

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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).

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