

## Article

# The Development and Consumer Acceptance of Shoe Prototypes with Midsoles Made from Mushroom Mycelium Composite

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**Abstract:** This research developed shoe soles using a biodegradable and renewable composite made of King Oyster mushroom mycelium. An exploratory approach was used to develop biodegradable shoe prototypes using the mushroom mycelium composite as the midsoles. An online survey was conducted to evaluate the consumer acceptance of the shoe prototypes and a wear test with undergraduate college students was conducted to evaluate the consumer acceptance, wearability, and comfort of the shoe prototype. The survey results indicated that consumers liked the new sustainable footwear and were likely to purchase it. Indian consumers liked the new shoes more and would be more willing to purchase the new shoes than the U.S. consumers. The young age group would be more willing to buy this sustainable shoe prototype than the old age group. The consumers who were frequent consumers of sustainable products, willing to pay more for an environmentally friendly product, and cared about the environment were more likely to purchase this sustainable shoe prototype. The wear test with a small sample of four college students had split opinions on the comfort and wearability of the shoes. Still, all of them liked the concept of shoe materials and biodegradable shoes made from renewable materials.

**Keywords:** mycelium; biodegradable; footwear; consumer



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## 1. Introduction

Over the past two decades, the globalization and industrialization of the apparel and footwear industry have led to the mass over-production, over-consumption and throw-away culture of cheap fashion items that we know as fast fashion today [1]. This production and consumption behavior has contributed to massive landfill waste in which textiles not only may take more than 200 years to decompose, but also generate greenhouse methane gas and toxic chemicals in the decomposition process to pollute groundwater and soil [2]. In fact, World Footwear reported that in 2022, 23.9 billion pairs of shoes were produced [3], and the U.S. Environmental Protection Agency estimated that over 9 million tons of clothing and footwear were landfilled in 2018 while less than 1.7 million tons were recycled [4].

However, consumers are becoming more aware of the environmental impacts related to their everyday purchasing decisions [5]. In response to this, companies are developing products made from safer materials with low environmental impacts and committing to social responsibility and transparency within their supply chains [6]. The global market size for sustainable footwear was valued at 8.88 billion U.S. dollars in 2022 and was expected to grow by a compounded annual growth rate of 5.3% in the next 8 years [7].

The purpose of this study was to develop shoe prototypes with midsoles made from mushroom mycelium composite and evaluate consumer acceptance of the shoe prototypes. The shoe midsoles were mushroom mycelium composite material developed in a previous study [8]. Other components such as the upper and outsole were also made from biodegradable materials from renewable resources, making them at least 90% biodegradable with the only non-biodegradable part being a foam insole inserted for comfort. Comfort is one of the most important features of footwear, but it is also a difficult attribute to define as the

perception of comfort is subjective and highly user dependent [9]. Perception of footwear comfort includes “pure comfort” such as good fitting, soft, flexible, and relaxing, and “thermal comfort” such as fresh, light and breathable [10]. Insole, as an important interface between the foot and footwear, can enhance footwear comfort by providing softness and cushioning [9,11]. The consumer acceptance of the biodegradable shoes made from renewable resources was evaluated by a survey and a wear test. While the consumer acceptance survey allowed the researchers to understand whether people thought sustainable shoes were needed and/or wanted in the market, the wear test helped the researchers understand if the shoes could be worn comfortably and if the shoe soles were durable enough to be walked on.

Currently, there are very few studies on the customer acceptance of mycelium-based materials, especially on the use of these materials for shoe applications. This research would provide a deeper understanding of how customers feel about wearable mycelium-based materials, particularly shoe soles, as well as a further exploration into the development of mycelium-based materials. This area is increasingly studied for its ecological benefits, easy accessibility, and cultivation.

## 2. Literature Review

### 2.1. Environmental Impact of Footwear

The environmental impacts of footwear are prevalent at each stage of the product lifecycle including the raw material extraction, product manufacturing, transportation, point of sale, consumer use, and disposal or end-of-use-phases [12]. Each stage of the product lifecycle has different and varying levels of environmental impacts such as CO<sub>2</sub> emission, chemical pollution, water use and pollution, energy use, and landfill waste [13]. In fact, the average shoe produces 30 pounds of carbon dioxide, and more than 20 billion pairs of shoes are produced each year [14]. These impacts also vary depending on the materials used to create the shoes. Common materials used for footwear include leather, canvas, polyurethane, polyvinyl chloride, vulcanized rubber, ethyl vinyl acetate, and other additional materials for shoelaces, eyelets etc. [15]. The manufacturing of these materials is responsible for the bulk of the impact on the environment because of the energy sources used to run the machinery and the chemical processes used to produce and preserve the materials.

There are now many tools that can be used to measure the impacts of footwear on the environment such as Life Cycle Assessment (LCA), Higg Material Sustainability Index (MSI), and Product Module (PM) tools [16,17]. Albers et al. used LCA to analyze the ecological impact of conventional shoes as well as shoes made from environmentally friendly materials like organic cotton, recycled materials, hemp, and jute [18]. This study found that materials production and assembly phase was responsible for about 90% of the environmental impacts in the entire life cycle of shoes [18]. They also found that the conventional shoes had a significantly higher ecological impact in eight of the ten impact categories than the shoes made from green materials including human toxicity potentials and global warming potentials [18].

Gottfridsson and Zhang investigated the environmental impacts of shoe consumption in Sweden from 2000 to 2010 using life cycle assessment, product flow analysis and material flow analysis [12]. In this study, researchers evaluated the impact of every material included in the study and determined the acidification, eutrophication, global warming, and photochemical ozone creation potential per one kilogram of each material. The results of this study found that leather had the most environmental impact in all four categories followed by rubber and plastic. Additionally, it was found that material production of shoes accounted for nearly 80% or greater of the total environmental impact for all four-impact categories in the lifecycle of shoes. Further, shoe consumption in Sweden increased by 20% from 2000 to 2010 with rubber and plastic shoes accounting for 36%, leather shoes 24%, and textile shoes 22% of the total consumption [12].

With similar consumption trends likely following suit across the globe, these conventional shoe materials would continue to have crucial environmental impacts and ultimately end up in landfill after a short period of time [19]. Once in the landfill, the shoes can shed toxic chemicals and contaminate the surrounding soils and drinking water, potentially harming humans living in the surrounding area [14].

## 2.2. Mushroom Mycelium Composites

Mushroom mycelium, more simply known as the roots of a mushroom, has been vastly studied in the last decade as a more ecological alternative to synthetic non-recyclable and non-biodegradable materials such as styrofoam and other plastic-based materials [20,21]. In the right conditions, the hyphae, small filament strands, grow in a natural lattice-like formation, acting as a natural glue that bonds its surroundings [22,23]. When heated at a certain temperature, the active fungi growth is halted, leaving a lightweight and low-density biocomposite material that has been experimented with purposes such as packaging, insulation, architecture, furniture and, more recently, clothing and footwear [21,24,25]. Mycelium-based materials can be an attractive alternative to plastic-based materials not only for their natural properties and biodegradability, but also because it is renewably sourced, low cost, and require very little energy or other inputs to be produced [26]. They are also non-allergenic, naturally flame-retardant, and static resistant, which makes them ideal for various consumer goods and applications [8].

Mushroom mycelium growth, like all living things, depends on certain nutrients. Cellulose-rich environments are ideal for fungi because fungi break cellulose down into glucose; so, oftentimes it is grown in substrates such as woodchips, straw or hemp [24]. Additionally, fungi require certain environmental conditions for growth. In a study by Silverman et al., the mycelium composites were grown in an environmental chamber at 25 °C and 65% humidity [8] while other studies have suggested a minimum of 90% humidity [24]. It is also important that the mycelium has sufficient airflow, otherwise, it will suffocate and die off. Sterilization is another crucial factor in the mycelium growth process because bad bacteria can infect the mycelium and prevent growth [24]. At the end of the growing process, the mycelium composites must be inoculated to kill off any living spawn and prevent unwanted growth of either the mycelium or bad bacteria [24].

## 2.3. Inoculation of Mushroom Mycelium

Sawdust spawn was traditionally used in mushroom cultivation due to its low cost and ease of preparation, however, liquid spawn has been gaining the interest of researchers and mushroom growers due to its ease of inoculation, fast colonization, and uniform distribution [27]. Many studies used the oyster mushroom (*Pleurotus ostreatus*) for its versatile capabilities [27–29] such as broad substrate adaptability, high yield, rapid growth, and easy cultivation [27]. For example, Zhang et al. aimed to discover whether the *Pleurotus ostreatus* mushroom liquid spawn had a comparable growth rate on blocks of lignocellulosic agro-waste blocks as on sawdust spawn blocks [27]. The three lignocellulosic agro-waste blocks used in the study consisted of loofah sponge, corncob, and sugarcane bagasse, as well as polyurethane foam (PUF) used as a supporting material. This study found that *P. ostreatus* showed the highest metabolic activity on the corncob block followed by the sugarcane bagasse, loofah, and lowest on the PUF. In terms of growth rate compared to the sawdust spawn block, the corncob, sugarcane bagasse, and loofah presented similar mycelium extension rates while the PUF did not. Ultimately, the corncob was found to be the best support for mycelial growth due to its low cost, ease of accessibility, similar growth rate and fruit yield compared to sawdust spawn blocks [27].

In Helberg et al.'s research, the oyster mushroom liquid spawn was also found to grow on knitted fabrics made from a combination of natural and synthetic materials, growing similarly on both materials [28]. Mycelium growth was optimal when dip-coated in a malt-extract agar medium on each side of the fabric, providing nutrients for the mycelium to feed on. This was particularly noticeable in the cotton and cotton/linen blend fabrics as they

absorbed significantly more agar than the acrylic and acrylic/wool blend. After 15 days, the cotton/linen blend knit was completely covered in mycelium and was estimated to have become a composite with a longer growth time [28]. These studies support the use of cellulosic agriculture waste and textile materials as a substrate for liquid spawn. This provides useful context for the study at hand as similar materials will be used.

#### 2.4. Mechanical and Moisture Characteristics of Mushroom Mycelium Composites

The mycelium composite's mechanical and moisture properties were related to fungal species and growth substrates. Tacer-Caba et al. found that mycelium composites developed from rapeseed substrate had higher compressive strength than those developed from oat husk substrate [30]. Mycelium composite developed from fungal cultures of *Trichoderma asperellum*, *Pleurotus ostreatus*, and *Ganoderma lucidum* on rapeseed substrates had a compressive resistance of 274.6 to 299.6 kPa [30]. Lingam et al. used oyster mushroom (*Pleurotus ostreatus*) species and juncao grass substrate to develop mycelium composite that had compressive strength of 78.34 kPa and flexural strength of 399.39 kPa [23]. Vasatko et al. developed a variety of mycelium composites using *Pleurotus ostreatus*, and *Ganoderma lucidum* species and different substrates such as beech sawdust, shredded newspaper. They shredded cardboard and conducted three-point flexural tests [31]. They found that maximum flexural stress ranged from 90 to 649 kPa and the maximum distance ranged from 1.64 to 4.52 mm [31]. The sample made from *Pleurotus ostreatus* and shredded newspaper substrate had the highest flexural strength of 649 kPa with a maximum distance of 3.65 mm [31]. The stiffness of mycelium composites can be adjusted by pressing. Appels et al. performed heat (150 °C) or cold (20 °C) pressing (<30 kN force for 20 min) on mycelium composites and found that heat pressing increased material homogeneity, strength, stiffness and changing the material from foam-like to cork and wood-like [32]. For mycelium composites made from *Pleurotus ostreatus* and rapeseed straw substrate, the stiffness (elastic modulus) increased from 2 MPa for non-pressed samples to 9 MPa and 97 MPa for cold-pressed and heat-pressed samples, respectively [32].

Most fungi are hydrophobic [30]. It was found that mycelium composites developed from beech sawdust inoculated with *Pleurotus ostreatus* were water repellent (water absorption coefficient less than 0.5). *Ganoderma lucidum* mycelium composite showed lower water absorption and were waterproof (water absorption coefficient less than 0.001) [31]. Appels et al. developed mycelium composites using *Trametes multicolor* and *Pleurotus ostreatus* and found that they have 3.15–8.22% and 7.57–11.63% weight increase in 60% relative humidity (RH) and 80% RH, respectively, at 40 °C [32]. It was also found that mycelium composites developed from nonwoven cotton fiber substrates showed a lower weight increase of 3.15–5.80% and 7.57–8.12% in 60% RH and 80% RH, respectively [31].

#### 2.5. The Application of Mushroom Mycelium for Shoe Soles

Using mushroom mycelium as an alternative to shoe soles would reduce the environmental impacts created of conventional shoe processes and reduce landfill waste during the end-of-use phase of the lifecycle. Several studies have examined the feasibility of using mycelium composites for footwear applications [8,33–35]. Research surrounding the use of mushroom mycelium as a natural and biodegradable alternative to footwear was thoroughly studied by Silverman et al. [8]. In their research, Silverman et al. found that the mycelium composites developed from King Oyster (*Pleurotus eryngii*) mushroom species had one of the highest densities and the highest compressive strength performance and would fulfill the compressive pressure requirements of shoe soles for the wearers [8]. In the material developed by Silverman et al., the King Oyster sawdust spawn substrate was mixed with flour, psyllium husk, chicken feathers (for protein and structure) and water before being placed into a mold. The mold was then placed in a controlled environmental chamber at 25 °C and 65% humidity for 14 days to allow—growth [8]. At the end of the growth process, the molds were then autoclaved at 90 °C for two hours to kill off any living spawn and halt the growth process [8]. While this study was successful in creating shoe

sole-shaped composites that can be used for footwear products, the initial prototype was impractical for actual use, as “the soles tend to break at the narrowest part if bent” [8]. Other studies developed a sandwich structure manufacturing process about composite parts patented by Ecovative (Green Island, NY, USA) with mycelium acting as a natural glue in the placement of traditional synthetic composites with natural resin as reinforcement to create the sole of an outdoor sandal [33–35].

## 2.6. Consumer Acceptance Evaluation Method

Qualitative analysis has often been used in consumer behavior research [36–38]. Content analysis and thematic analysis are two qualitative research approaches [39]. Content analysis is a systematic coding and categorizing approach to explore large amounts of texts “to determine trends and patterns of words used, their frequency, their relationships, and the structures and discourses of communication” [39]. Thematic analysis is a qualitative descriptive method by identifying, analyzing and reporting patterns of meaning (themes) in a data set [39–41]. These patterns can be found by the nature of keywords used by participants to interpret the inherent meanings of the data set [41]. Thematic analysis is flexible enough to analyze large and small data sets from a wide range of qualitative techniques such as case studies, interviews, focus groups and surveys [40].

Previous studies evaluating consumer acceptance of apparel products used questionnaire surveys including Likert scales and open-ended questions [42,43]. One study conducted a focus group which asked undergraduate students’ opinions on locally produced food and fibers and globally-sourced fiber and textiles [42]. A qualitative analysis was used in a descriptive manner to address the students’ opinions on locally-produced products and their acceptance of wool textiles through the lens of social, economic, and environmental dimensions [42]. A 5-point Likert scale was used for the questionnaire survey along with open-ended questions to gauge their interest in local farming practices and willingness to pay comparable or premium process for locally produced textiles, as well as opinions and attitudes regarding the three pillars of sustainability e.g., equity, economy, and environment [42].

Another study conducted a wear test to evaluate the acceptance and comfort of two types of products made from bio-based materials: shoes and a coat [43]. For the shoe wear test, the participants viewed the shoes while remaining seated to give initial thoughts on the shoe’s appearance, and then walked on the hard floor, carpet, and stairs, and answer questions related to the fit and comfort of the shoes [43]. Once completing the wear test, the participants were given information on the sustainability and environmentally friendly materials used in the shoes and coat and answered “follow-up” questions that were based on a 5-point Likert scale [43]. The participants found the products to be wearable, versatile, and practical and were willing to buy products made from these environmentally friendly materials but would prefer a different style as they considered the shoes not to be “fashionable”. There was also not a high willingness to pay more for these sustainable products even though there was a general interest in buying sustainable apparel and footwear products [43].

## 2.7. Market Potential

In 2022, the global market size for sustainable footwear was valued at 8.88 billion U.S. dollars and was expected to grow by a compounded annual growth rate (CAGR) of 5.3% from 2023 to 2031 to reach \$14.13 billion U.S. dollars in 2031 [7]. Growing consumer awareness and concern for the environment contributed to the increased sustainable footwear demand [44], and younger consumers such as Gen-Z and millennials are more aware of sustainability and prioritize it than the previous generations [7]. The revenue share of the men’s sustainable footwear segment was 54.0% in 2022, which was bigger than the combined revenue share of women’s and children’s sustainable footwear segments [32]. North America is the most significant market for sustainable footwear with a CAGR of

5.2% [7], while the Asia-Pacific region has a lot of room for growth [7] with a CAGR of 6.8% [44].

### 3. Materials and Methods

#### 3.1. Development of Shoe Soles and Shoe Prototypes

An exploratory approach was taken to develop the shoe soles and shoe prototype for this study. As the material process used for this study had previously been developed in a previous study [8], the goal for this study was to research product development strategies that best suited the material in its application for shoe midsoles. In the researchers' previous shoe prototype development [45], the mycelium composite midsole thickness was 1.4 cm. The thin midsole in the sandal prototype [45] was found to be fragile, which was evidenced by the breakage observed when attempting to bend the sole. It was also found that increasing the thickness of the mycelium composite would make it less likely to break and have a higher compressive resistance. Since mycelium composite was not appropriate for the shoe design with thin sole, the researchers determined that a platform-style shoe with a thick sole would be suited for the material due to its inflexible nature during wear and its greater potential for compression performance. Following the material development method from the previous study [8], the researchers began by creating a mold of platform-style sole that would be used to shape the mycelium material. The thickness of the shoe sole can be determined by the depth of the mold. Once the mold was finished, the remainder of the process was carried out by mixing the ingredients (King Oyster sawdust spawn substrate, flour, psyllium husk, chicken feathers and water) used to create the material, placing the ingredients into the mold (the thickness of ingredients in the mold also determined the thickness of sole), covering the top with plastic wrap, and placing in a temperature-controlled chamber set at 25 °C and 80% relative humidity for 14 days. The midsoles were then removed from mold and placed in a heated chamber at 90 °C for 2 h to kill any living spawn [8]. The thickness of the mycelium composite midsoles was 2.3 cm. A creative design process was then used to fashion the sole into an espadrille-style platform shoe by using double contour espadrilles rope made from recycled canvas and jute thread as the shoe sole. Cotton fabric was used as the upper cover for the shoes.

#### 3.2. Consumer Acceptance Survey

The researchers conducted an online survey to understand consumer acceptance of a biodegradable shoe. As this is a new product, the data gathered from the survey is primary research on the consumer acceptance of the prototypes developed in this research. The researchers put the picture of shoe prototypes and a detailed description of the mushroom mycelium composite midsole and other natural, biodegradable components in the shoe prototypes in the survey. The research also involves both qualitative and quantitative research methods. The qualitative research methods that were used in the survey included open ended questions asking for the participants' opinion on the product, features they look for in shoes, as well as any additional comments they may have in which they were asked to type their response in a text box. The quantitative methods used in this research include 5-point Likert Scale (1 = most like or very likely, 3 = neutral, 5 = most dislike or very unlikely) questions, and multiple-choice questions. The survey was conducted online via Qualtrics. Amazon Mturk was used to recruit participants and each participant was compensated \$1 for participating in the study. The survey protocol was approved by the university's Institutional Review Board (IRB) prior to the data collection.

In the survey, data was collected from a relatively small number of participants that did not include large amounts of texts. The researchers used a thematic analysis approach instead of other methods, e.g., content analysis, to analyze the data because of the smaller data set and the focus on higher level themes and patterns within the data.

### 3.3. Wear Test

In order to understand the wearability (fit and ease of walking [46]) and comfort of the shoe prototypes, the researchers conducted a human subject wear test and created a post-study survey for the participants to fill out. A convenience sample was used for the test. The researchers recruited four female college students who wear size 6.5 to 7 shoes to participate in the study. Each participant was provided with a pair of new socks for hygienic and safety purposes. The subjects were then asked to walk with the shoes on in a straight line then up and down a set of stairs and back to the starting point. The subjects then completed a survey that gauged their opinion of the shoes in terms of attractiveness, fit, comfort, and ease of walking. The survey had a 5-point Likert Scale (1 being the lowest and 5 being the highest) questions, as well as written responses, and open-ended questions asking for participants' willingness to pay for the shoes, comments on the shoe's material make-up and style, words or phrases used to describe the material and attractiveness of the shoes, as well as comments on the comfort and ease of walking of the shoes after performing the wear test. Upon completion of the wear test and survey, each participant was compensated with a \$20 gift card. The wear test protocol was approved by the university's Institutional Review Board (IRB) prior to the data collection.

## 4. Results and Discussion

### 4.1. Shoe Prototypes

The mushroom mycelium composites were used as the midsoles of the shoe prototypes. With an understanding of the mushroom mycelium composite's performance of their inflexible nature and their good compressive resistance during wear [8], it was determined that a wedge and platform-style shoe with a thick sole would be suited for the material. Upon researching various shoe styles, the researchers selected an Espadrille design for its aesthetics. This design choice also facilitated easy slipping on and off. The mycelium composite midsoles were wrapped with double contour rope made from recycled natural fiber textiles and jute thread as the shoe outsoles. Using a cotton fabric as the upper, the Espadrille platform-style slip-on shoe prototypes were created as in Figure 1. The researchers also inserted foam insoles to increase softness and add cushioning for comfort. The foam insoles were the only non-biodegradable parts in the shoe prototype. At the end of the useful time of the shoes, the consumers can easily remove the foam insoles and place the rest of shoes in a composting bin for a complete biodegradation.



**Figure 1.** Shoe prototypes with mushroom mycelium composite as midsole ((left): shoe prototype; (right): the mycelium composite midsole).

### 4.2. Consumer Acceptance Survey Results

In this study, there were 243 total participants who validly completed the consumer acceptance survey. Among these participants, 190 were from the USA, 50 from India, one from was Ireland, one was from Singapore, and one person did not disclose their

country. There were 127 males, 114 females, and two persons did not disclose their gender. Four participants (1.6%) were between 18–25 years old, 100 participants (41.2%) were between 25–35 years old, 93 participants (38.3%) were between 35–50 years old, and 46 participants (18.9%) were older than 50 years. The survey used a 5-point Likert scale (1 = Strongly agree and 5 = Strongly disagree) for agreement with the statements as well as multiple choice and short answer questions. For the results to be meaningful, countries and third or unspecified genders with few respondents were excluded from the analyses of country and gender comparison. Additionally, the age group 18–25 had fewer than 5 respondents and therefore was combined with the age group 25–35.

#### 4.2.1. Consumers' Willingness to Purchase This Sustainable Footwear

A summary of the statistical results on important preference and purchase questions can be seen in Table 1. The participants liked the new sustainable footwear (Question 1 in Table 1,  $M = 2.41$ ;  $SD = 1.17$ ) and were likely to purchase it if price were not a factor (Question 8 in Table 1,  $M = 2.70$ ;  $SD = 1.29$ ); both null hypotheses of Mean = 3 (neutral) were rejected. Indian consumers significantly liked the product more and were more likely to purchase the product than the U.S. consumers (The null hypotheses of India mean = USA mean for both questions 1 and 8 were rejected). This result does not support the most significant market for sustainable footwear would be in North America [7], but supports the Asia-Pacific region which has the highest potential sustainable footwear market growth [7]. There was no significant difference between males and females on both questions of “like the product” and “likely to purchase it” (The null hypotheses of Male mean = Female mean for both questions were not rejected). This result does not support Grand View Research's conclusion that the main market share segments of sustainable footwear would be in men's footwear [32]. A probable reason is that the shoe prototype (as in Figure 1) is for women. A one-way between-age groups ANOVA was conducted to explore the effect of age groups on the likelihood of consumers purchasing the new product if the price were not a factor (Question 8 in Table 1). There was a statistically significant difference among three groups, i.e., 18–35, 35–50, and 50+ ( $p < 0.05$ ). An LSD post hoc test comparison indicated that the mean score of the age group 18–35 ( $M = 2.45$ ;  $SD = 1.31$ ) differed significantly with age groups 35–50 ( $M = 2.86$ ;  $SD = 1.19$ ) and 50+ ( $M = 2.93$ ;  $SD = 1.40$ ), however, age group 35–50 did not significantly differ from age group 50+. If price were not a factor, the youngest age group would be more willing to purchase the new product than older age groups. This finding supports that younger consumers are more aware of sustainability and prioritize it over the previous generations [7].

A vast majority of the participants selected “Eco-friendly/sustainable” (122 participants, 50.2%) or “biodegradability” (82 participants, 33.7%) as the feature that they like the most about this new product. “Style” was selected by 146 participants (60.1%) as the feature that they liked the least about this new product. If this product were available in other styles (Question 9 in Table 1), 57 participants (23.5%) would be “very likely” (score = 1 in the 5-point Likert scale) and 103 participants (42.4%) would be “moderately likely” (score = 2 in the 5-point Likert scale) to purchase this product if it were available in other styles. People were likely to purchase the product if other styles were available (null hypotheses of Mean = 3 were rejected for Question 9 in Table 1).

The participants would be willing to buy this product over a product that is not sustainable (Question 24 in Table 1,  $M = 2.64$ ;  $SD = 1.06$ ); null hypotheses of Mean = 3 (neutral) were rejected. An independent samples *t*-test was conducted to compare the means between males and females to determine whether the means were significantly different from each other in relation to whether they would be willing to buy this product over a product that is not sustainable. There was not a significant difference ( $p = 0.24$ ) between males ( $M = 2.65$ ;  $SD = 1.10$ ) and females ( $M = 2.61$ ;  $SD = 1.00$ ). Further, a one-way between-age groups ANOVA was conducted to explore the impact of age groups on the willingness to buy this product over a product that is not sustainable. There was a statistically significant difference among three groups, i.e., 18–35, 35–50, and 50+, ( $p < 0.05$ ). An LSD post hoc

test comparison indicated that the mean score of age group 18–35 ( $M = 2.47$ ;  $SD = 1.02$ ) differed significantly with age group 50+ ( $M = 2.93$ ;  $SD = 1.24$ ), however, neither age group 18–35 nor age group 50+ differed significantly with age group 35–50 ( $M = 2.69$ ;  $SD = 0.98$ ). These results showed the youngest age group would be more willing to buy this product over a product that is not sustainable than the oldest age group, supporting the findings in [7].

**Table 1.** Statistical results of participants' opinion and purchase intention of the new product.

| Questions                                                                                                       |           |       | Test                       | N   | M $\pm$ SD      | p-Values                                                | Post-Hoc                        |
|-----------------------------------------------------------------------------------------------------------------|-----------|-------|----------------------------|-----|-----------------|---------------------------------------------------------|---------------------------------|
| 1. Based on appearance and description, how much do you like or dislike this new product?                       | Total     |       | One sample t-test          | 243 | 2.41 $\pm$ 1.17 | H0: Mean = 3, $p < 0.05$ (reject H0)                    |                                 |
|                                                                                                                 | Countries | India | Independent samples t-test | 50  | 1.70 $\pm$ 0.71 | H0: India mean = USA mean, $p < 0.05$ (reject H0)       |                                 |
|                                                                                                                 |           | USA   |                            | 190 | 2.60 $\pm$ 1.20 |                                                         |                                 |
|                                                                                                                 | Gender    | M     | Independent samples t-test | 127 | 2.44 $\pm$ 1.19 | H0: Male mean = Female mean, $p = 0.63$ (not reject H0) |                                 |
|                                                                                                                 |           | F     |                            | 114 | 2.37 $\pm$ 1.15 |                                                         |                                 |
| 8. If price were not a factor, how likely or unlikely would you be to buy this new product?                     | Total     |       | One sample t-test          | 243 | 2.70 $\pm$ 1.29 | H0: Mean = 3, $p < 0.05$ (reject H0)                    |                                 |
|                                                                                                                 | Countries | India | Independent samples t-test | 50  | 1.62 $\pm$ 0.75 | H0: India mean = USA mean, $p < 0.05$ (reject H0)       |                                 |
|                                                                                                                 |           | USA   |                            | 190 | 2.98 $\pm$ 1.27 |                                                         |                                 |
|                                                                                                                 | Gender    | M     | Independent samples t-test | 127 | 2.74 $\pm$ 1.24 | H0: Male mean = Female mean, $p = 0.52$ (not reject H0) |                                 |
|                                                                                                                 |           | F     |                            | 114 | 2.64 $\pm$ 1.25 |                                                         |                                 |
| 9. If this product were available in other styles, how likely or unlikely would you be to buy this new product? | Age       | 18–35 | One-way ANOVA              | 104 | 2.45 $\pm$ 1.31 | Between groups: $p < 0.05$                              | 18–35 < (35–50 = 50+)           |
|                                                                                                                 |           | 35–50 |                            | 93  | 2.86 $\pm$ 1.19 |                                                         |                                 |
|                                                                                                                 |           | 50+   |                            | 46  | 2.93 $\pm$ 1.40 |                                                         |                                 |
|                                                                                                                 | Total     |       | One sample t-test          | 243 | 2.40 $\pm$ 1.24 | H0: Mean = 3, $p < 0.05$ (reject H0)                    |                                 |
|                                                                                                                 |           |       |                            |     |                 |                                                         |                                 |
| 24. Would you be willing to buy this product over a product that is not sustainable?                            | Total     |       | One sample t-test          | 243 | 2.64 $\pm$ 1.06 | H0: Mean = 3, $p < 0.05$ (reject H0)                    |                                 |
|                                                                                                                 | Gender    | M     | Independent samples t-test | 127 | 2.65 $\pm$ 1.10 | H0: Male mean = Female mean, $p = 0.24$ (not reject H0) |                                 |
|                                                                                                                 |           | F     |                            | 114 | 2.61 $\pm$ 1.00 |                                                         |                                 |
|                                                                                                                 | Age       | 18–35 | One-way ANOVA              | 104 | 2.47 $\pm$ 1.02 | Between groups: $p < 0.05$                              | (18–35 = 35–50) < (35–50 = 50+) |
|                                                                                                                 |           | 35–50 |                            | 93  | 2.69 $\pm$ 0.98 |                                                         |                                 |
|                                                                                                                 |           | 50+   |                            | 46  | 2.93 $\pm$ 1.23 |                                                         |                                 |

Note: 5-point Likert scale: 1 = most like or very likely, 3 = neutral, 5 = most dislike or very unlikely.

#### 4.2.2. Factors Associated with Consumers' Willingness to Purchase This Sustainable Footwear

Bivariate correlations were conducted to measure the extent to which scores on two variables (i.e., previous purchasing behavior and willingness to buy this product) change together. Chi-square tests were conducted to find whether two nominal variables (i.e., previous purchasing behavior and willingness to buy this product) were related. The results of these tests further narrowed down who the consumers were for this new product and can be seen in Table 2.

First, there was a moderate and significant relationship between consumers who purchase sustainable products (Q16) and the likelihood to buy this new product if price were not a factor (Q8) ( $r = 0.46$ ,  $p < 0.001$ ) such that consumers who more frequently purchased sustainable products were more likely to buy this new product if price were not a factor. A Chi-square test found a statistically significant association between these questions (Q8 and Q16) as well ( $X^2 = 67.56$ ,  $p < 0.001$ ). There was a moderate and significant relationship between consumers who purchase sustainable products (Q16) and willingness to buy this product over a product that is not sustainable (Q24) ( $r = 0.44$ ,  $p < 0.001$ ) such that consumers who more frequently purchased sustainable products were more willing to buy this product over one that is not sustainable. A Chi-square test also finds a statistically significant association between these factors ( $X^2 = 75.60$ ,  $p < 0.001$ ). These results suggested that those who were frequent consumers of sustainable products would be very likely to purchase this sustainable shoe, especially over products that are not sustainable.

**Table 2.** Results of bivariate correlation and Chi-square.

| No. | Questions                                                                                                    |                                                |                                               |                                                |                                                |                                                |                                                |
|-----|--------------------------------------------------------------------------------------------------------------|------------------------------------------------|-----------------------------------------------|------------------------------------------------|------------------------------------------------|------------------------------------------------|------------------------------------------------|
| Q8  | If price were not a factor, how likely or unlikely would you be to buy this new product?                     |                                                |                                               |                                                |                                                |                                                |                                                |
| Q9  | If this product were available in other styles, how likely or unlikely would you be to buy this new product? |                                                |                                               |                                                |                                                |                                                |                                                |
| Q16 | How frequently do you purchase sustainable products?                                                         |                                                |                                               |                                                |                                                |                                                |                                                |
| Q20 | How much do you care about your impact on the environment?                                                   |                                                |                                               |                                                |                                                |                                                |                                                |
| Q22 | How important is it to you that your shoes are sustainable?                                                  |                                                |                                               |                                                |                                                |                                                |                                                |
| Q23 | Are you willing to pay more for an environmentally friendly product?                                         |                                                |                                               |                                                |                                                |                                                |                                                |
| Q24 | Would you be willing to buy this product over a product that is not sustainable?                             |                                                |                                               |                                                |                                                |                                                |                                                |
|     | Q8                                                                                                           | Q9                                             | Q16                                           | Q20                                            | Q22                                            | Q23                                            | Q24                                            |
| Q8  |                                                                                                              |                                                | $r = 0.46$<br>$p < 0.001$<br>$\chi^2 = 67.56$ | $r = 0.51$<br>$p < 0.001$<br>$\chi^2 = 116.54$ | $r = 0.64$<br>$p < 0.001$<br>$\chi^2 = 186.01$ |                                                |                                                |
| Q9  |                                                                                                              |                                                |                                               | $r = 0.50$<br>$p < 0.001$<br>$\chi^2 = 105.63$ | $r = 0.60$<br>$p < 0.001$<br>$\chi^2 = 150.42$ | $r = 0.55$<br>$p < 0.001$<br>$\chi^2 = 125.06$ |                                                |
| Q16 | $r = 0.46$<br>$p < 0.001$<br>$\chi^2 = 67.56$                                                                |                                                |                                               |                                                |                                                |                                                | $r = 0.44$<br>$p < 0.001$<br>$\chi^2 = 75.60$  |
| Q20 | $r = 0.51$<br>$p < 0.001$<br>$\chi^2 = 116.54$                                                               | $r = 0.50$<br>$p < 0.001$<br>$\chi^2 = 105.63$ |                                               |                                                |                                                |                                                | $r = 0.57$<br>$p < 0.001$<br>$\chi^2 = 154.12$ |
| Q22 | $r = 0.64$<br>$p < 0.001$<br>$\chi^2 = 186.01$                                                               | $r = 0.60$<br>$p < 0.001$<br>$\chi^2 = 150.42$ |                                               |                                                |                                                |                                                | $r = 0.62$<br>$p < 0.001$<br>$\chi^2 = 194.14$ |
| Q23 |                                                                                                              | $r = 0.55$<br>$p < 0.001$<br>$\chi^2 = 125.06$ |                                               |                                                |                                                |                                                |                                                |
| Q24 |                                                                                                              |                                                | $r = 0.44$<br>$p < 0.001$<br>$\chi^2 = 75.60$ | $r = 0.57$<br>$p < 0.001$<br>$\chi^2 = 154.12$ | $r = 0.62$<br>$p < 0.001$<br>$\chi^2 = 194.14$ |                                                |                                                |

Second, there was a strong and significant relationship between willingness to pay more for an environmentally friendly product (Q23) and likelihood to buy this new product if it were available in other styles (Q9) ( $r = 0.55$ ,  $p < 0.001$ ) such that consumers who were willing to pay more for an environmentally friendly product were also very likely to buy this new product if it were available in other styles. A Chi-square test found a statistically significant association between these factors as well ( $\chi^2 = 125.06$ ,  $p < 0.001$ ). This result suggested that those who were willing to pay more for an environmentally friendly product would be more likely to purchase this sustainable shoe.

Third, there were strong and significant relationships between how important it is to the consumer that their shoes are sustainable (Q22) and the likelihood of buying this new product if price were not a factor (Q8), provided it were available in other styles (Q9), as well as a willingness to buy this product over a product that is not sustainable (Q24) such that consumers who find it very important that their shoes are sustainable are more likely to buy this new product if price were not a factor ( $r = 0.64$ ,  $p < 0.001$ ), buy this product if it were available in other styles ( $r = 0.60$ ,  $p < 0.001$ ), and be willing to buy this product over a product that is not sustainable ( $r = 0.62$ ,  $p < 0.001$ ). Chi-square tests found statistically significant associations between the importance of having sustainable shoes

and the likelihood of buying this new product if price were not a factor ( $X^2 = 186.01$ ,  $p < 0.001$ ), likelihood of buying this new product if it were available in other styles ( $X^2 = 150.2$ ,  $p < 0.001$ ), and willingness to buy this product over ones that are not sustainable ( $X^2 = 194.14$ ,  $p < 0.001$ ). These results suggested that consumers who found it important that their shoes are sustainable, again, would be very likely to purchase this sustainable shoe, especially over products that are not sustainable.

Last, there were strong and significant relationships between how much the respondents care about their impact on the environment (Q20) and the likelihood of buying this new product if price were not a factor (Q8), if it were available in other styles (Q9), as well as willingness to buy this product over a product that is not sustainable (Q24), such that consumers who care about their impact on the environment were more likely to buy this new product if price were not a factor ( $r = 0.51$ ,  $p < 0.001$ ) if the product were available in other styles ( $r = 0.50$ ,  $p < 0.001$ ), and be willing to buy this product over a product that is not sustainable ( $r = 0.57$ ,  $p < 0.001$ ). Chi-square tests found statistically significant associations between how much the respondents care about their impact on the environment and likelihood of buying this new product if price were not a factor ( $X^2 = 116.54$ ,  $p < 0.001$ ), likelihood of buying this new product if it were available in other styles ( $X^2 = 105.63$ ,  $p < 0.001$ ), and willingness to buy this product over ones that are not sustainable ( $X^2 = 154.12$ ,  $p < 0.001$ ). These results suggested that consumers who cared about the environment would be more likely to purchase this sustainable shoe.

#### 4.2.3. Qualitative Thematic Analysis

A thematic analysis of the written response question in the consumer opinion segment, “Please provide your reaction to the material make-up of the shoe”, shows two prominent themes of strengths and two prominent themes of concerns with the product, as in Table 3. Table 3 provides sample quotations from participants, and comments like these occur frequently. These themes of strengths (e.g., environmentally friendly) and concerns (e.g., style) parallel with the responses to the questions on what the participants like the most and least of the shoe prototype.

**Table 3.** Prominent themes of strengths and concerns with the shoe sole material and shoe product.

| Theme    |                          | Sample Quotations                                                                                                                                    |
|----------|--------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------|
| Strength | Innovation               | "I think it is very creative!"                                                                                                                       |
|          |                          | "Something new. I like it."                                                                                                                          |
|          | Environmentally friendly | "I found it very interesting that shoes could be made from materials like that."                                                                     |
|          |                          | "I think it's a very interesting concept and is something that could be very possible for the future because we need more biodegradable things too." |
|          |                          | "The material is really unique and environmentally friendly!"                                                                                        |
|          |                          | "I was surprised that this combination of ingredients could be used. I think it is an interesting combination and like that it is eco-friendly."     |
| Concern  | Durability               | "It's interesting and seems plausible and eco-friendly, for sure."                                                                                   |
|          |                          | "I think it is great that they found a way to make a biodegradable shoe."                                                                            |
|          |                          | "I wonder how durable the material is for prolonged wear."                                                                                           |
|          |                          | "I thought that it would disintegrate as I walked."                                                                                                  |
|          | Style                    | "I'd have concerns about the longevity of the material"                                                                                              |
|          |                          | "How long you can wear them without breaking down?"                                                                                                  |
|          |                          | "But the style and looks should be improved."                                                                                                        |
|          |                          | "The only thing is it doesn't quite look stylish."                                                                                                   |
|          |                          | "They're not very fashionable."                                                                                                                      |

A thematic analysis of the written response in the previous purchasing decisions segment, “What do you like/dislike about other footwear brands/products that you have previously purchased?”, shows two prominent themes of what respondents like/dislike in other footwear brands. The first theme is the durability of the shoe. Respondents commented that they like the durability of a shoe and dislike when shoes are not durable. For example, respondents made comments that addressed this such as:

*"They fall apart way too quickly."*

*"For some brand I like the time they last and durability."*

*"They don't hold up well and I have to replace them."*

*"My main problem is durability."*

This was a shared theme with the respondent's reaction to the material make-up of this shoe prototype. Another theme that was commonly mentioned was comfort. Many participants mentioned that shoes were only comfortable for a short period, need more support for the foot arch, or cause pain from chaffing or blisters. Others mentioned that they disliked having to compromise comfort for style. This correlated closely with the features that respondents looked for in shoes that they could not find and made interesting suggestions for what to consider in further product development.

Additionally, a thematic analysis of "What features do you look for in shoes that you can't currently find?" showed overarching themes of comfort and style, oftentimes connected together. There were also many comments around comfort in relation to fit such as people with wide feet, certain illnesses and disabilities, or not being able to find small/large enough sizes that are comfortable. For example, respondents made comments such as:

*"I have a hard time finding shoes with style that are comfortable to wear."*

*"A pair that looks good with various types of outfits for various functions, but also comfortable and supportive."*

*"Comfort and style, cute and comfortable."*

*"I have very wide feet, so finding them with stylish lines is usually difficult."*

#### 4.3. Wear Test Results

The wear test survey used a 5-point Likert Scale (1 being the lowest and 5 being the highest) questions. The first section of the wear test survey gauged the respondent's initial reaction to the product concept and their opinion on the shoe's material make-up and style. The initial reaction to the concept of the shoe was very optimistic with all four respondents answering that their initial reaction was 'Extremely positive'. When asked whether they thought the upper material, insole, and midsole was suitable for footwear, the respondents answered that each component was somewhat to very suitable for footwear (upper material:  $M = 4.5$ ,  $SD = 0.577$ ; insole:  $M = 4.25$ ,  $SD = 0.5$ ; midsole:  $M = 4.75$ ,  $SD = 0.5$ ). The respondents would buy these shoes if a different design or style made from the same materials ( $M = 4.75$ ,  $SD = 0.5$ ). The respondents were then asked to comment on whether they would buy the shoes based on their opinion of the shoe's material make-up and style and the responses were the following:

*"I would buy them based on how they look."*

*"I prefer shoes that have a back to them."*

*"My skinny feet walk right out of these kinds of shoes."*

The respondents liked the overall look of the shoe but would prefer it to be designed more for everyday wear. Respondents were then asked to use 3 to 6 words or phrases to describe the outsole, midsole, insole materials as well as the overall shoe style and quality. This helped understand how the respondents perceived the quality of the shoes before wearing them. The most frequent responses to these questions were words such as sturdy, in-style, thick, comfortable, and durable. Based on these responses, the participants perceived the shoes as good quality and stylish.

In the next section of the wear test, the participants were then asked to put on the shoes and sit (before walking), walk on flat ground (10 paces forward and 10 paces back) and walk a few stairs up and back down. They were asked to answer how well the shoes fit, how comfortable the shoes felt, and how comfortable the upper materials and shoe soles were after each step. The results are in Table 4. Before and after walking, the participants

were asked whether they would buy the shoes. The results of this question were the same before and after walking: varied with respondents answering definitely not, probably not, neither, and definitely yes, respectively for each ( $M = 2.75$ ,  $SD = 1.71$ ). However, every respondent said that they would definitely buy the shoes if a different design or style, made from the same materials.

**Table 4.** The results of wear test while seated and walking.

| Questions                              | Put on Shoes While Seated (before Walking) | Walk on Flat Ground | Walk Up and Down a Set of Stairs |
|----------------------------------------|--------------------------------------------|---------------------|----------------------------------|
| How well the shoes fit                 | $2.33 \pm 1.16$                            | $3.00 \pm 1.41$     | $2.75 \pm 1.26$                  |
| How comfortable the shoes felt         | $2.67 \pm 1.53$                            | $3.25 \pm 2.06$     | $3.00 \pm 1.83$                  |
| How comfortable the upper material     | $4.00 \pm 1.00$                            | $4.00 \pm 1.41$     | $3.75 \pm 1.89$                  |
| How comfortable the soles of the shoes | $3.00 \pm 1.73$                            | $3.50 \pm 1.73$     | $3.75 \pm 1.89$                  |

Note: 5-point Likert scale: 1 = the lowest, 3 = neutral, 5 = the highest.

In the last section of the wear test, the researchers asked the respondents to comment on the comfort and wearability of the shoes and, again, there were split opinions with two respondents saying that the shoes were comfortable but would prefer a different style so that the shoes were more secure on the foot. The other two respondents said that the shoes were uncomfortable and hard and would not be good for walking in for long periods of time. The average purchase price the respondents said they would be willing to pay for the shoes was \$37.50.

After four participants completed the wear tests, the midsole made from mushroom mycelium composite did not break, indicating the biocomposite's good temporary durability for shoe soles if it was thick. If the style and fit met consumers' needs, the consumers were willing to buy shoes with midsoles made from mushroom mycelium composite that is biodegradable.

## 5. Conclusions

In this study, the researchers developed mushroom mycelium composite and used it as the midsole to develop a pair of biodegradable shoe prototypes. The consumer acceptance of the biodegradable shoes was favorable as participants in the consumer acceptance survey liked the shoe prototypes and were likely to purchase it. Specifically, participants like the eco-friendly and biodegradable nature of the product and show a willingness to choose this product over an unsustainable option. It was found that Indian consumers significantly more liked this sustainable shoe prototype and were more likely to purchase it than the U.S. consumers. The youngest age group (18–35 years old) would be more willing to buy this sustainable shoe prototype over a product that is not sustainable than the oldest age group (50+ years old). The consumers who were frequent consumers of sustainable products, willing to pay more for an environmentally friendly product and cared about the environment were more likely to purchase this sustainable shoe prototype. These findings aligned with the Straits Research's report that consciousness of consumers toward sustainability was the driving force of the demand for environmentally friendly footwear across the globe [7].

Further, the importance of style, durability and comfort showed to be a significant factor. This has implications for a gap in the market for footwear that is stylish, lasting and comfortable. The demand for these features also aligns with research from Straits Research [7], proving that the samples in this survey accurately represent demands from the market. However, while the respondents have shown a demand for style, durability and comfort, they also showed concern for style and durability in the shoe prototypes. Style of the shoe prototypes was the feature that most of the survey participants liked the

least. However, consumers were willing to buy shoes with midsole made from mycelium composite if other styles that met their needs were available in the market.

The wear test with a small sample of four college students had split opinions on the comfort and wearability of the shoes: two respondents said that the shoes were comfortable but would prefer a different style while the other two respondents said that the shoes were uncomfortable. All of the four wear test participants liked a great deal of the concept of shoe materials and biodegradable shoes made from renewable materials.

The insufficient turnout of the 18–25 age group in the consumer acceptance survey and the small number of four college students in the wear test provided limitations of this study. The concept of sustainability is recognized more by younger generations such as the Gen-Z and Millennials [7]. Future research should aim to collect more data from the 18–25 age group which would allow researchers to have a more accurate knowledge of the target market of the sustainable shoes.

There were a few other limitations in the wear test. The participants wore the shoe prototypes for a limited time with limited movement. The wear test only evaluated the participants' perceived comfort through the survey. There are objective parameters related to footwear comfort such as softness, thermal comfort, flexibility, weight, damping capability, heel-zone impact absorption, and plantar pressure distribution [9]. The participants only wore the shoe prototypes with midsoles made from mycelium composites in the wear test without wearing control shoe prototypes with midsoles made from traditional midsole materials. For example, Lo et al. compared their custom-fabricated shoe insoles with traditional EVA foam insoles and tested plantar pressure distribution and muscle activity in addition to the perceived comfort scale [11]. Future research should increase the walking time in the wear test, incorporate the assessment of the objective parameters, and include control shoe prototypes with midsoles made from traditional materials.

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