Comparative study: Banana-polyester fiber with guava extract (GuaBaNIKA sock) as an alternative to cotton in prosthetic socks

Krisha Kate T. Tansiongco, Alexander L. Abellon, Iris Cecile M. Ambatali, Nicko Sean S. Cantiga and Marichelle A.de Castro, RN, CPO

Abstract

Introduction Skin problems are commonly reported by amputees due to perspiration discomfort inside the prosthesis. Cotton is commonly used in prosthetic socks but its properties are not ideal. This study compared the banana-polyester sock dyed with guava extract (GuaBaNIKA) and cotton socks in terms of air permeability, absorbency and antibacterial activity.

Methods This was a quantitative quasi-experimental study that compared GuaBaNIKA and cotton socks in terms of air permeability, absorbency and antibacterial activity using standard tests. Fibers from banana pseudostem were mixed with polyester, processed into yarn then fabric and dyed with guava leaf extract. Air permeability was analyzed using Mann-Whitney U Test and descriptive analysis was used for absorbency and antibacterial activity.

Results The mean air permeability for GuaBaNIKA was significantly higher than that of cotton (295.5 vs 112.7 $cm^3/s/cm^2$). The air permeability scores were higher in GuaBaNIKA in all 10 specimens tested. GuaBaNIKA absorbed water faster than cotton (< 1 vs > 60 seconds). Both GuaBaNIKA and cotton knit socks did not produce a zone of inhibition.

Conclusion GuaBaNIKA is more absorbent and permeable than cotton but did not exhibit antibacterial activity. GuaBaNIKA has the potential to be an alternative to cotton in prosthetic socks.

Keywords: Amputation stumps, prostheses and implants, thermal discomfort, prosthetic sock

Skin problems are commonly reported by amputees who use prostheses. Figures on the global incidence of dermatological problems caused by perspiration in the residual limb are not readily available.[1] There are studies which investigated the prevalence of skin problems due to perspiration discomfort. Muelenbelt found that among Dutch lower limb amputees, of the 82% who reported having skin problems, 32% were due to excessive sweating.[2] Another study found that the reduction in quality of life of 72% of their

Correspondence:
Marichelle A.de Castro, RN, CPO. Philippine School of Prosthetics and Orthotics, College of Allied Rehabilitation Sciences, University of the East Ramon Magsaysay Memorial Medical Center, 64 Aurora Boulevard, Barangay Doña Imelda, Quezon City; e-mail: madecastro@uerm.edu.ph

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participants was perspiration discomfort inside the prosthetic socket.[3] This affected the overall comfort of the amputees and might have added to the risk of damaging skin integrity resulting to temporary disuse of the device.[2]

Inappropriate ventilation within the socket contributes to majority of skin problems. A typical prosthesis has multiple layers that cover residual limbs. Prosthetic socks prevent air and moisture from causing skin irritations within such multi-layers.[4-7] Several options have been used to enhance the properties of this interface such as the use of aloe vera, mineral oil and vitamin E to promote skin health. However, these liners are costly. Enhancement with silver nanoparticles is now widely used as coating and finishing of liners and socks to obtain antibacterial property which also helps in addressing skin related problems caused by different bacteria.[8-10] However, despite its antibacterial property, it has been found that wash-out silver nanoparticles may cause harm.[11,12]

The Philippine School of Prosthetics and Orthotics uses prosthetic socks made from cotton. Cotton fabric has less absorbency and air permeability, and has the ability to retain moisture such as sweat, and oxygen that stimulate the growth and proliferation of bacteria.[13-17] This led the researchers to look for an alternative material that can be at par or even better in terms of antibacterial, air permeability and absorbency properties than cotton socks.

According to the Department of Agriculture, banana is the leading fruit grown in the Philippines.[18] Aside from being a source of food, natural fiber can also be obtained from the banana pseudo stem. It has been used in several countries to produce yarn, fertilizer, biochemicals, paper and handicraft due to its good properties.[19-21] Further-more, banana pseudostem fiber has been already proven to have excellent physical and chemical characteristics such as better fineness and spinnability than bamboo and ramie fiber, high moisture absorption, strength, lightweight, and is economical, which makes it a good material for producing textile products.[21-23] The use of guava leaf extract was incorporated in the study to inhibit the growth of bacteria as it has been proven to have an antibacterial effect in textile.[16,24-27] The purpose of the study was to compare the banana-polyester sock dyed with guava extract (GuaBaNIKA) and cotton socks in terms of air permeability, absorbency and antibacterial activity.

Methods

The researchers used a quantitative quasi-experimental design to fulfill the objectives of the study and consisted only of material testing. The study used sabá pseudo-stem as a raw material for GuaBaNIKA socks as it was the type of banana available in the private farmstead and according to a previous study, banana pseudo-stem can be used in producing fabric regardless of its type. Knitted socks that were 100% cotton was used as the comparator.

The production of GuaBaNIKA sock comprised seven different stages and it lasted for about 3 to 4 weeks. The researchers harvested the raw banana pseudo-stem and guava leaves from a private farmstead in Quezon City. The pseudo-stem was cut, and the outer layer and the center were removed as they could not be processed into fibers. It was divided into four one-meter long portions and put in a clean plastic bag to protect the pseudo-stem as moisture could make them vulnerable to pathogens. The guava leaves were placed in a separate plastic bag. The collected raw materials were sent within 24 hours to maintain their freshness to the Philippine Textile Research Institute (PTRI) of the Department of Science and Technology.

At the PTRI, the banana pseudo-stem underwent decortication to extract banana fiber (Figure 1), after which it underwent spinning to convert fibers into yarn. In the process of spinning, polyester was blended with the banana fiber to achieve a ratio of 80:20 (Figure 2). The yarn underwent a knitting process where it was turned into fabric called sock knit. During the dyeing process, the sock knit was cleaned by bleaching. Mordant was applied for the guava leaf extract --- which had been previously made by boiling the leaves for one hour --- to adhere to the sock knit. The sample was dipped and stirred in the guava leaf extract for another hour. The sock knit was hanged to dry and brought to the PTRI Testing Services Division to determine absorbency and air permeability and to the Industrial Technology Development Institute (ITDI) Standard Testing Division for the anti-bacterial test.

The banana-polyester sock knit with guava leaf extract (GuaBaNIKA) and the 100% cotton samples were cut according to the specified American Society for Testing and Materials (ASTM), American Association of Textile Chemists and Colorists (AATCC), and US Pharmacopeia (USP) dimensions and those required by ITDI and Technical Services Division. Sample size for each property was guided by

Figure 1. Banana fiber after decortication

Figure 2. Polyester-banana thread

related existing studies and supported by a manual of standard tests. According to Selvi 10 specimens were needed for testing air permeability, and five for testing absorbency. One specimen was needed for testing antibacterial activity.[28-31] Researchers were able to obtain the desired number of specimens and with the proper dimensions for both GuaBaNIKA and cotton sock knit.

The experimental and control samples underwent three different tests as follows:

Air permeability (ASTM D737). Test samples were placed into the machine. Air flow was set at 200 Pa and calibrated until the green light appeared. This was done at 21°C since simulation of the socket environment was not feasible. The test was repeated 10 times using different sections of the fabric to ensure that the results represented the whole sample.[32] The rate of air flow passing perpendicularly through the area under pressure was measured and recorded in SI units as $cm^3/s/cm^2$ and in inch-pound units as $ft^3/min/ft^2$ rounded to three decimal places. The average of all the samples was taken as the result for air permeability.[32]

Absorbency (AATCC 79). The test samples were examined in a standard atmosphere having a relative humidity of 65 ± 2% at 21 ± 1°C (70 ± 2°F) as required by the standard test with overhead lighting to know the end point of the test. The sample was mounted on the embroidery hoop to prevent wrinkles from forming and without deforming the structure of the fabric. The burette's stopcock was placed on 9.5 ± 1.0 mm from embroidery hoop in order to prevent mechanical force from acting on the sample. After setting up the fabric, distilled water was dropped from the burette as was required by the standard test (Figure 3). According to previous studies, this solution could simulate human perspiration.[28,33] The time when the reflection of the water was no longer seen was measured through observation by trained staff. The average time of the five samples was considered as the absorbency of the material. The shorter the time, the more absorbent the fabric is.[28]

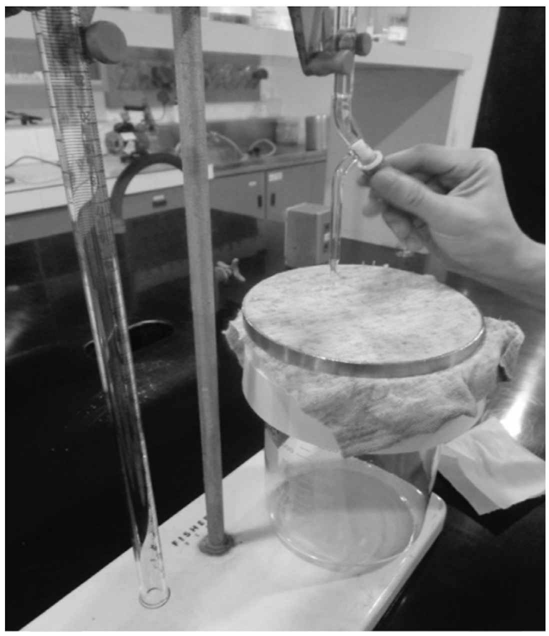

Figure 3. Absorbency test of GuaBaNIKA sock knit

Antibacterial (USP 30-NF 25). The standard test assessed the antibacterial activity of the textile samples. Test samples were challenged with gram positive *Staphylococcus* aureus, one of the common pathogenic bacteria causing skin problems in residual limbs. The organism was inoculated into 10 mL tryptic soy broth and incubated overnight at 35°C. The agar plates were prepared by adjusting the overnight culture based on the turbidity to be comparable with the standard of McFarland. A 200-uL bacterial suspension was placed in a sterile Petri dish then 15-20 mL Mueller-Hinton agar was added; it was agitated until it was mixed well and allowed to solidify. A disc filter paper with samples was placed to the agar plates and incubated at 35°C.[34,35]

Reactivity and inhibitory activity, as measured through the zone of inhibition were rated. The reactivity rating was as follows: no zone of inhibition (0); slight zone of inhibition under the specimen, exact measurement was not specified (1); zone of inhibition limited under the specimen, exact measurement was not specified (2); zone of inhibition 5-10 mm from the specimen (3); and zone of inhibition > 10mm from the specimen (4). The inhibitory rating used was complete +++, partial ++, slight +, and negative (-).[34]

Mann-Whitney U test using Microsoft Excel 2017 was done to test the difference in air permeability between two independent samples gained from GuaBaNIKA and cotton socks as researchers could not meet the assumptions for a parametric test. The significance level was set as $p = 0.05$, with a confidence interval of 95%. Descriptive analysis was used to analyze the difference in absorbency and antibacterial properties of GuaBaNIKA and cotton socks as researchers did not meet the required sample for both parametric and non-parametric tests.

Results

Researchers were able to obtain enough samples with the prescribed size and dimension for both GuaBaNIKA and cotton sock knit. The mean air permeability for GuaBaNIKA (made from single yarn) was 295.5 $cm^3/s/cm^2$, higher than cotton made from multiple yarns (112.7 $cm^3/s/cm^2$). The difference was significant ($p < 0.001$). The air permeability scores were higher in all 10 specimens of GuaBaNIKA tested. GuaBaNIKA absorbed water in less than one second in five samples tested compared with more than 60 seconds for the cotton knit sock. Both GuaBaNIKA and cotton knit sock did not produce a zone of inhibition (reactivity 0, inhibition (-)). Both materials did not exhibit any bacteriostatic activity.

Discussion

According to Mansor, the ability of water vapor and air to pass through fabric is an important property in clothing as water mimics perspiration. With these two properties, comfort among wearers can be determined through standard testing. Similar with lower limb prosthetic users, good air flow and regulation of perspiration are factors in determining comfort among amputees and prevent skin irritations.[36]

In this study, a blend of banana-polyester was used to create new sock knit. These two raw materials are known for their good material properties such as high moisture absorbency and air permeability due to their porous structure. After analyzing the results, researchers found out that GuaBaNIKA sock knit absorbs moisture faster than cotton with a 60-second difference, implying that GuaBaNIKA is more absorbent than cotton. This may have been due to the knitting structure of the fabric, where GuaBaNIKA was made with only a single yarn unlike cotton which was made from multiple yarns. The result of the study was similar with that of Alay and Yilmaz where cotton was considered one of the least absorbent among different types of fabric tested.[37] However, different test methods were used to assess water absorption. Despite being more absorbent than cotton, it is important to test the overall moisture management of GuaBaNIKA sock knit to ensure that the ability to manage perspiration is mimicked.[37]

Air permeability enables the material to transport moisture vapor from the skin to the outside environment. This is important as it will help the prosthetic users to properly regulate the heat due to the compromised thermoregulation mechanism caused by the absence of some part of their limb. Sock knit with excellent air permeability has the potential to improve the breathability effect or the ventilation within the socket.[38] As the results show, GuaBaNIKA sock had significantly higher air permeability than cotton. Therefore, GuaBaNIKA sock can possibly facilitate adequate heat transmission and add comfort to the user. However, according to the previous studies, structural factors of the fiber can influence the air permeability result.[38,39] Therefore, it might have affected the result of the study as the samples were made with different knitted structures. GuaBaNIKA sock was only made with single yarn unlike the cotton sock that was made with multiple yarns.

Furthermore, existing studies mentioned that bacterial growth is also a problem among prosthetic users due to the moist warm environment inside the socket. Hence, material with an antibacterial property could be advantageous. In this study, researchers used guava leaf extract similar with other studies, however the process of extraction and application (dye technique) to the sock knit was different and might have affected the outcome of the test.[24,26] After analyzing the results, researchers found out that although GuaBaNIKA sock knit was dyed with guava leaf extract, it was still not able to inhibit growth of *Staphylococcus aureus*. This implies that there is no difference between GuaBaNIKA and cotton sock knit in terms of antibacterial activity. Instead of the dyeing technique, researchers recommend the use of the printing method as used in other studies.

Aside from good air permeability and absorbency, there are other properties that a prosthetic sock should have for it to be used on actual patients. These include wash and dry, wickability, abrasion resistance, elongation, tensile strength and friction coefficient. Previous studies examined the duration of the effectiveness of the antibacterial property of a fabric. The bacterial reductions were measured after 0, 5, 20 and 50 wash cycles.[40,41] In another study, prosthetic sock was evaluated to measure its capillary pressure and permeability referred to as wickability; it is an important property as it mimics the rate at which the sweat is absorbed by the prosthetic sock and the rate it evaporates which in turn provides comfort.[33,6] Another study evaluated the ability of prosthetic sock to resist friction referred to as durability or abrasion resistance; it mimics the friction inside the socket which causes wear and tear thus a high value indicates more durability.[42,43] Moreover, a study evaluated the elongation and tensile strength of yarn by compression, twisting, bending and friction; the property mimics the stress forces applied on the fabric when used.[44] Lastly, the friction coefficient of fabric was computed in a study to assess its smoothness which relates to skin comfort inside the socket.[45]

To be able to recommend the use of GuaBaNIKA sock as an alternative to cotton, further material testing such as wash and dry, wickability, abrasion resistance, friction coefficient and elongation and tensile strength as well as changes in some methods are needed. The use of an industrial type of machinery is recommended to reduce the bias for the set parameters as the fabric structure influenced the results. In addition, due to the poor results of antibacterial testing the researchers recommend that future researchers consider using printing and pad-dry methods to incorporate the guava leaf extract into the fabric. Increasing the degumming solution is also recommended as this will improve the fineness of the fabric which is important for the texture of prosthetic sock.

In order to make the GuaBaNIKA sock feasible, researchers used banana fiber in combination with polyester, thus another trial must be made wherein the banana fiber is blended to another natural fiber to produce an eco-friendly fabric. In addition, GuaBaNIKA sock was only made with single yarn due to the availability of machinery which influenced the result of the study. Comparing different yarn counts is recommended. Simulating the environment of the prosthesis and the residuum is also important before testing it on humans to know the potential residual limb reactions and to ensure the patient's safety. Furthermore, setting a standard value of material properties for prosthetic socks is important due to limited resources regarding its use. This can be done by comparing the different varieties of prosthetic socks available including GuaBaNIKA sock.

Results showed that GuabaNIKA sock made from single yarn had higher air permeability and absorbency compared to cotton sock which was made from multiple yarns. These results indicate that yarn count may influence the properties of a sock knit. The fewer the yarn count, the more porous the fabric is which makes it to be permeable and absorbent. However, structure of the fabric is only one of the factors affecting its properties. Properties of the raw materials used might have also influenced the sock knit properties, wherein banana was proven to have good absorbency and air permeability properties and cotton was one of the least natural fibers in terms of those properties. However, it is not possible to determine whether the yarn count alone or the combination of the yarn count and the raw material properties led to results of the study. On the other hand, there was no zone of inhibition seen on the two samples during testing. This might be due to the dyeing process used for GuaBaNIKA sock. To finally prove that the GuaBaNIKA can be an alternative to cotton sock, further material testing and change in knitting structure should be done.

GuaBaNIKA is more absorbent and permeable than cotton but did not exhibit antibacterial activity using the dye method to incorporate the guava extract. GuaBaNIKA has the potential to be an alternative to cotton in prosthetic socks depending on the results of further testing.

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