Addis Ababa University
Addis Ababa Institute of Technology
Center of Biomedical Engineering
School of Graduate Studies

Characterization and Efficiency Test of Affordable and Ecofriendly Sanitary Pad Made of Natural Fibers from Enset

By

Semira Abdela

In partial fulfillment of the requirements for the degree of Master of Science in Biomedical Engineering

Advisor: Professor Gyeong-Man Kim

Co-advisor: Dr. Dawit Assefa Haile

Mrs. Leelavathy Rajash (Msc.)

Dec, 2020

Addis Ababa University School of Graduate Studies

Certificate of Examination

This is to certify that the thesis prepared by **Semira Abdela** entitled: "**Characterization and Efficiency Test of Affordable and Ecofriendly Sanitary Pad Made of Natural Fibers from Enset"** submitted in partial fulfilment of the requirements for the degree of Master of Science in Biomedical Engineering (Biomedical instrumentation & imaging) complies with the regulations of the University and meets the accepted standards with respect to originality and quality. Signed by the examining committee.

Examiner:__________________Signature:__________________Date: ______________________

Examiner:_________________Signature: _________________Date: _____________________

Examiner:_________________Signature: _________________Date: _____________________

Examiner:_________________Signature: _________________Date: _____________________

____

Chief of department or Graduate program coordinator

Declaration

I, the undersigned, declare that this thesis and the work presented in it are my own and have been generated by me as the result of my own original research.

I confirm that:

- This work was done wholly or mainly while in candidature for a research degree at this University;
- Where any part of this thesis has previously been submitted for a degree or any other qualification at this University or any other institution, this has been clearly stated;
- Where I have quoted from the work of others, the source is always given. With the exception of such quotations, this thesis is entirely my own work;
- I have acknowledged all main sources of help;
- This work or any part of this work has not been published before submission;

Name: ________________________________

Signature: ______________________________

Date: _________________________________

This MSc. thesis has been submitted for examination with my approval as an advisor.

____

Professor Gyeong-Man Kim

Abstract

Sanitary pads are one of menstrual hygiene management (MHM) materials that are used by girls and women to absorb their menstruation. However, these products are mainly available in urban area and also expensive for the majority underprivileged girls of our country. Thus, most girls specially the rural girls are forced to use unhygienic and uncomfortable materials to deal with their period. Hence, these girls are forced to live stressful, uncomfortable and unsafe life. These result in a long chain of negative impacts on the health of our girls and women. On the other hand, the materials that are used to fabricate sanitary pads create environmental contamination during disposal.

This research aims at providing a better alternative to conventional sanitary pads using sustainable and convenient raw materials like cotton, Enset pulp and a bioplastic to make sanitary pads with a needed performance. By converting Enset fiber to pulp the major part of the sanitary pad, an absorbent core, is produced. Then, cotton fabric that is commonly known by the name of 'Nethla' is used as a top sheet during sample pad production and finally the bioplastic is used as the bottom layer to make sample sanitary pad.

Results showed that the sample sanitary pad meets all the required criteria such as absorbency, ability to withstand pressure after absorption, pH, wicking property, liquid striking property, fluid retention, disposability and physical parameters (i.e. pad length, width and thickness). Also the research revealed that the Enset pulp did not have antimicrobial activity. The cost estimation of the sample sanitary pad was done and the net cost for single pad production was found 0.85 birr.

As compared to conventional sanitary pads that are available in the local market, the pad designed in the current thesis is affordable, sustainable and ecofriendly with the potential to replace not only the pads that are imported from abroad but also the raw materials needed to produce them locally.

Key words:-Sanitary pad, Enset pulp, Cotton fabric, Bioplastic, MHM

Acknowledgements

Above all, my deepest gratitude goes to Allah for giving me the opportunity, courage, patience and health to get to the final part of my master thesis. I am very thankful for giving me a wonderful family and spectacular friends that supported me day in day out through the process of working on this master thesis. My parents and in general family deserve my intense and heartfelt gratitude for their support in each and every step of my life.

I would like to present my deepest gratitude to all the people and institutes that helped me to perform and write this master thesis paper. My main advisor, Professor Gyeong-Man Kim, for his advice, inspiration, encouragement and non-stop support throughout my thesis. He has been supportive since the days I began working on my thesis. I appreciate his critical comments, his vision for providing high quality works throughout my study period. I would like to extend my gratitude to my co-advisors Dr. Dawit Assefa and Mrs. Leelavathy Rajesh, for their continuous support, guidance, cooperation, encouragement, scholarly inputs. Their constant guidance, cooperation, motivation and support have always kept me going ahead. They all deserve my extreme thanks for all the support and assistance they have provided for me.

Special mention goes to Dr. Hana and Mr. Alemayehu (PhD student) from Addis Ababa University. It was an honor to work with highly educated and experienced professionals like you. I am really thankful for their guidance and generous contribution during my laboratory work. They had also assisted me in an enormous amount by their bright advice and opinion. Finally, my friends from Addis Ababa Institute of technology, Jimma Institute of technology post graduate classes and my co-workers have been amazingly support for me and I can’t thank them enough for their feedback, motivation and team spirit even though we were working on different areas.

Table of content

Contents

List of Figures

List of Tables

Acronyms

BMC	BioMed Central
CSA	Central Statistical Agency
FSH	Follicle Stimulating Hormone
GnRH	Gonadotropin-Releasing Hormone
LH	Luteinizing hormone
LMI	Low and Middle Income Country
LSR	Liquid to Solid Ratio
Mac	MacConkey Agar
MHM	Menstrual Hygiene Management
MSA	Mannitol Salt Agar
PMA	Performance Monitoring and Accountability
SAP	Super Absorbent Polymer
SNNPR	Southern Nations Nationalities and People's Region
SNV	Stichting Nederlands Vrijwilligers (Netherlands Development Organization)
TSS	Toxic Shock Syndrome
UNESCO	United Nations Education, Scientific and Cultural Organization
UNICEF	United Nations International Children's Emergency Fund
WHO	World Health Organization

Chapter One

1. Introduction

1.1 Background

According to the World Health Organization (WHO), a person aged 10–19 years is considered as an adolescent. The transition period between the childhood and adulthood is called adolescence which is marked with the growth and development of the child. During this period, physical, psychological, and biological development of the child occurs. This transition is recognized as a critical period in a girl's life cycle which requires special attention. Menarche is an important biological milestone in a woman's life as it is the onset of the reproductive phase of her life. The average age at menarche is mostly consistent across populations, which is, between 12 and 13 years of age. Unfortunately, due to lack of awareness about menstruation preparedness and management or due to shyness and embarrassment, the situation could be difficult for girls [1].

Menstruation is a natural process which is regulated by hormones; in this process, endometrium, lining of the uterus, gradually thickens and sheds off and causes bleeding that normally last for 3–5 days and occasionally up to 7 days. However, it is still a taboo in most societies as it is considered as curse and dirty. Menstruation wastes are the wastes that are generated by a female in her reproductive years. These wastes are produced during menstruation commonly known as menses, periods, or monthly bleeding. The menstrual cycle has three main phases, that is, follicular phase (proliferative), ovulation phase, and luteal phase (secretory) [1].

Around 52% of the total global populations are female. Out of these, 26% of the populations are on their reproductive age. Most women menstruate for two to seven days in each month [2].

Around 3000 days of menstruation occur in an average woman's lifetime. Hence, for all women and girls, menstruation is a natural monthly reality. During menstruation, girls and women face both practical and strategic gender problems. These have negative impacts on their personal lives and developmental opportunities; restrictions on work and mobility, increased fears and tensions, early marriage, early and premature childbirth and higher infant mortality, and potential vaginal infections resulting, in the worst case, infertility. In many cultures, the onset of menstruation means coming of age. Therefore, it has big consequences for young girls. Beside that, there is the hygiene concern and, if menstruation is not properly addressed, it can have horrific consequences. A menstrual hygiene is a barrier to women's health, participation and quality of life in the developing world society. Inadequate access to sanitation has been linked to school absenteeism, productivity declines, rashes and infections, seclusion and embarrassment. The subject continued to be a taboo in societies around the world [3].

Many girls and women have limited options for affordable menstrual management materials. Providing access to private facilities with water and low-cost menstrual management materials could reduce urogenital diseases. Specially, girls and women with disabilities and special needs face additional challenges regarding menstrual hygiene. They are highly affected with lack of access to sanitation materials to manage their period. Globally, 2.3 billion people lack basic sanitation services. In the least developed countries, only 27% of the population has a hand washing facility with water and soap at home. Therefore, managing periods at home is also a major challenge for women and adolescent girls who lack these basic facilities at home. According to WaterAid, one in three people lacks access to a decent toilet of their own, while one in nine is unable to obtain clean water near their home. A UNESCO report found that one in 10 girls in sub-Saharan Africa misses school during their monthly periods, while some simply drop out of school altogether [4]. This is one of the major reasons that limit the success of girls in social, economic and political arenas.

In some African countries, the onset of menstruation is viewed as a passage from one phase of life to the next. Girls are secluded from the society in the time of their menstruation. Specific huts or homes are set aside for women to stay in when they have their first period. They are joined only by their female family members and other women during this time. About half of the schools in low-income countries lack adequate drinking water and sanitation. Though keeping hygiene is crucial for girls and female teachers to manage their period. Inadequate hygienic facilities and menstrual protection materials make adolescent girls to miss 5 days of school in a month, which means 50 days a year. Because of all the difficulties regarding menstruation, around 23% of these girls actually drop out of school after they started menstruating [5].

In Ethiopia, there are 24.1 million women and girls in their reproductive age (15-49 years) all of whom have a need to manage their menstrual hygiene. There is no consistent and clear standard of what should or should not be used when it comes to menstrual hygiene management (MHM) products. The country has not defined and standardized quality control procedures for menstrual hygiene management practices or products. Hence, there are a number of MHM products in the local market without licensing. According to Performance Monitoring and Accountability (PMA) report of 2020, approximately 45% of women and girls aged between15-49 are using disposable sanitary pads, and 53% of women and girls are using cloths. The use of disposable sanitary pads is more common amongst adolescent girls as compared to adult women (49% for adolescent girls versus 24% of older women). The use of disposable sanitary pads amongst adolescent girls is higher in urban areas (85.9%) than in rural non-pastoralists (49%). However, taking into account both products and facility environment for MHM, the report found that only 28% of women in Ethiopia report having everything they need to manage their menstruation, with no variability across age [6].

The girls of Ethiopia experience shame, fear, decreased mobility, embarrassment and discomfort during menstruation. Also limited access to affordable and preferred MHM products carried on to be a monthly challenge for women and girls. Other studies have reported that 25% of girls in Ethiopia do not use any MHM products to manage their periods because they don't have anything to manage their period. So, they isolate themselves during menstruation. According to the study presented on BMC Public Health in 2014, only 25% of schoolgirls in the northeast part of Ethiopia had learned about menstruation and hygienic management in schools [7]. Further research is needed on the impact of menstrual hygiene practices on girls‟ and women's health and education. Qualitative studies with girls indicate that girls feel more comfortable when using better-quality menstrual products because they do not worry as much about leaks and stains [6].

The commercial market for menstrual hygiene products in Ethiopia was estimated at 230 million units in 2016 and growing at 15% volume and has the potential to grow to 7-9 billion annual units over time. The top two brands are Comfort which is imported from China and Eve which is owned by Chinese company and manufactured in Ethiopia. These sanitary pads cover nearly 90% of local market sales. Thirteen additional sanitary pad brands are also available in the market. The overall commercial disposable sanitary pad brands are dominated by imports of either finished products or the raw materials for domestic manufacturing. Reusable pads are also available in regional markets estimated at less than 0.5% of the total market volume in 2016, and are primarily manufactured by small enterprises and women groups. Over 90% of these reusable products are 100% subsidized and distributed by non-profit organizations to school girls and refugees [6].

The availability and use of commercial products varies significantly across rural and urban areas.

Despite 84% of Ethiopia's population living in rural areas, approximately 80% of the commercial market of disposable sanitary pads is limited to Addis Ababa, with limited to no coverage in rural areas [6]. Majority of disposable sanitary pads are distributed in major cities and larger regional towns targeting urban women with better income. Although some products are distributed directly from manufacturers and importers to supermarkets and pharmacy chains, the majority of disposable pads are distributed through highly disaggregated supply chains of fast moving consumer good dominated by Merkato wholesalers and dispersed retail outlets. Outlets in peri-urban and rural contexts that rarely stock these disposable pads cited that their customers had low awareness of or capacity to pay for such products. Ninety-nine percent of commercial MHM products in Ethiopia are reliant on importation, through either raw materials for country manufacturing or finished goods. Current macroeconomic conditions, including a declining currency value and import/export imbalance, impede local manufacturers and importers from accessing hard currencies [6].

Despite increasing innovation in the area of MHM, currently, the world is facing a very big problem of carbon footprint of feminine hygiene products as there is a huge amount of non-biodegradable material dumped in landfill, which releases harmful gasses into the atmosphere. In order to solve such problems, we need to focus on developing more sustainable products by choosing raw materials having low carbon footprint. In this regard, developing an affordable and ecofriendly sanitary pad helps our girls to live a better, safe and comfortable life while keeping their environmental hygiene intact. The current thesis study seeks to characterize and quantify properties of materials particularly Enset fiber that are highly available in Ethiopia for the production of the absorbent core, cotton for the top sheet and polylactic acid (PLA) film for barrier sheet of a sanitary pad in order to determine and characterize an alternative disposable sanitary pad.

1.2 Problem Statement

Majority of girls in developing communities like Ethiopia have been facing a lot of problems. One of their complex and challenging chapter of their life starts from their first menstruation cycles. Until today, most of these girls with limited financial resources are commonly using normal cloths which are found in households to deal with their menstruation. Sometimes they also use leaves and mattress stuffing. These girls usually have a few amounts of cloths to swap during their menstruation cycle. Thus, use of cloths won‟t be comfortable, safe, reliable and does not keep privacy. This could intern result in different personal hygiene problems and other health risks. The scarcity of clean water, difficulties to boil water and lack of soap in these poor communities make the problem of the girls even more pronounced. Most girls are absent from school or work in each month minimally 2-3 days. These girls are forced to live stressful, uncomfortable and unsafe life because of unreliable MHM product. Even if there are a number of imported and local disposable sanitary pads in the local market which make life easier during menstruation, however, these products are too expensive for the majority of the underprivileged girls. A poor menstrual hygiene lead to a healthy concern related to bacterial issues and this can result in a serious health problem. Moreover, most of the disposable sanitary pads are made of non-biodegradable materials which could induce an environmental contamination during disposal. These all problems have been big obstacles on the lives of our girls and women.

1.3 Objectives

1.3.1 General Objective

- ✓ To search out the applicability of Enset plant for sanitary pad production and characterizing a low cost and better ecofriendly sanitary pad.

1.3.2 Specific Objectives

- ✓ To propose affordable and ecofriendly disposable sanitary pad from locally available biodegradable materials;
- ✓ To change the Enset fiber into a pulp;

- ✓ To produce absorbent core from the Enset pulp;
- ✓ To test the quality of the sanitary pad layers regarding their intended purpose.
- ✓ To measure the feasibility of the final design using the standard design criteria of a commercial sanitary pad.

1.4 Significance of the Thesis

This thesis contributes a scientific input to the global scientific society and local manufacturers as well as for investors working on MHM specifically on sanitary pads. The study intended to introduce to the sanitary pad industry a new product that makes use of locally available raw materials: Inset pulp, cotton fabric and bio plastic. The raw materials for the proposed sanitary pad in this study are widely available in Ethiopia. This can play a great role in minimizing the scarce foreign currency required to import the raw materials from abroad. The raw materials have been characterized and their risk assessment has also been carried out in order to quantify the safety of a final design for the needed application. Affordability and eco-friendliness were also important requirements during the pad design. The study could also give good ground for other correlative or comparative researches in areas of MHM.

1.5 Scope and Delimitations of the Thesis

The main intent in this thesis was to research on the applicability of Enset, which is the most widely available plant in our country, for its use in sanitary pad production. The major quality control measurements were done on the final product. Issues of affordability and eco-friendliness were thoroughly investigated. Validation of the final design might require testing of the product on individual volunteers which might require a clinical trial. That part, however, was beyond the scope of the current study.

Chapter Two

2 Literature Review

2.1 Menstruation

Menstruation (a.k.a period) is a biological process that indicates the discharge of blood and mucosal tissue from the inner lining of the uterus through the vagina. About once a month, females who have gone through puberty will experience menstrual bleeding. This happens because the lining of the uterus has prepared itself for a possible pregnancy by becoming thicker and richer in blood vessels. If pregnancy does not occur, this thickened lining is shed accompanied by bleeding. Bleeding usually lasts for 3-8 days. For most women, menstruation happens in a fairly regular and predictable pattern. The length of time from the first day of one period to the first day of the next period normally ranges from 21-35 days [8]. The menstrual cycle is controlled by a complex interaction of hormones. These hormones are produced by pituitary gland**,** which promote ovulation and stimulate the uterus and breast to prepare for possible fertilization. The menstrual cycle includes several phases. The exact timing of the phases of the cycle is a little bit different for every woman and can change over time [9]. Table 1 shows the different phases of the menstrual cycle in women.

Table 1:Menstrual cycle

Menstrual cycle days (approximate)	**Events of the menstrual cycle**
Days 1-5	The first day of menstrual bleeding is considered Day 1 of the cycle. The period can last anywhere from 3 to 8 days, but 5 days is average. Bleeding is usually heaviest on the first 2 days.
Days 6-14	Once the bleeding stops, the uterine lining (also called the endometrium) begins to prepare for the possibility of a pregnancy. The uterine lining becomes thicker and enriched in blood and nutrients.

Day 14-25	Somewhere around day 14, an egg is released from one of the ovaries and begins its journey down the fallopian tubes to the uterus. If sperms are present in the fallopian tube at this time, fertilization can occur. In this case the fertilized egg will travel to the uterus and attempt to implant in the uterine wall.
Days 25-28	If the egg was not fertilized or implantation does not occur, hormonal changes signal the uterus to prepare to shed its lining, and the egg breaks down and is shed along with lining. The cycle begins again on Day 1 menstrual bleeding.

2.1.1 The Three Phases of Menstrual Cycle

A) Follicular Phase (before release of the egg)

This phase of the menstrual cycle occurs from approximately day 1-14. Day 1 is the first day of bright red bleeding, and the end of this phase is marked by ovulation. While menstrual bleeding does happen in the early part of this phase, the ovaries are simultaneously preparing to ovulate again. The pituitary gland (located at the base of the brain) releases a hormone called follicle stimulating hormone (FSH). This hormone causes several „follicles" to rise on the surface of the ovary. These fluid filled "bumps" each contain an egg. Eventually, one of these follicles becomes dominant and within it develops a single mature egg; the other follicles shrink back. If more than one follicle reaches maturity, this can lead to twins or more [9].

The maturing follicle produces the hormone estrogen, which increases over the follicular phase and peaks in the day or two prior to ovulation. The lining of the uterus (endometrium) becomes thicker and more enriched with blood in the second part of this phase (after menstruation is over), in response to increasing levels of estrogen. High levels of estrogen stimulate the production of gonadotropin-releasing hormone (GnRH), which in turn stimulates the pituitary gland to secrete luteinizing hormone (LH). On about day 12, surges in LH and FSH cause the egg to be released from the follicle. The surge in LH also causes a brief surge in testosterone, which increases sex drive, right at the most fertile time of the cycle [9].

B) Ovulatory Phase (egg release)

The release of the mature egg happens on about day 14 as a result of a surge in LH and FSH over the previous day. After release, the egg enters the fallopian tube where fertilization may take place, if sperms are present. If the egg is not fertilized, it disintegrates after about 24 hours. Once the egg is released, the follicle seals over and this is called the corpus luteum [9].

C) Luteal Phase (Days 14-28)

After the release of the egg, levels of FSH and LH decrease. The corpus luteum produces progesterone. If fertilization has occurred, the corpus luteum continues to produce progesterone which prevents the endometrial lining from being shed. If fertilization has not occurred, the corpus luteum disintegrates, which causes progesterone levels to drop and signals the endometrial lining to begin shedding [9].

2.2 Menstrual Hygiene Management

Menstrual hygiene management (MHM) is defined as materials that are used by women and adolescent girls to absorb or collect blood during the duration of menstruation. Menstruation necessitates the availability of material and resources to absorb menstrual blood which is important to facilitate a personal hygiene. Also, there is a need for a place to dispose waste MHM materials, ideally with adequate privacy. Women and girls in low income setting have low awareness about hygienic practices and appropriate materials for MHM practices. Type of absorbents used during menstruation are associated with negative clinical and psychosocial outcomes including reproductive and urinary tract infection, anemia, school absenteeism and social isolation [10].

In Ethiopia, like in many parts of the developing world, MHM is one of the critical challenges and a taboo topic for adolescent girls. This is largely due to lack of awareness as well as poor facilities to manage personal hygiene. According to UNICEF, more than half of primary schools in the country lack water supply and proper latrine facilities. The existing service facilities remain inadequate and are poorly managed [11].

A baseline study conducted by Stichting Nederlands Vrijwilligers (SNV) in four districts in Southern Ethiopia revealed that the school environment is not conducive especially for MHM. About 90% of the schools lack water supply, separate toilet for boys and girls and the existing toilets lack privacy. Moreover, the inquiry done by SNV in the same districts in 2009 on adolescent school girls showed that girls use unhygienic rags during menstrual period and have little knowledge on how to keep personal hygiene during menstruation. The study also revealed that menstruation is seen as a taboo by communities and school teachers. In addition, parents do not provide information and guidance on menstrual hygiene management which leaves school girls without assistance on how to manage their menstruation hygienically. The same study disclosed that 70% of adolescent school girls miss 2-3 school days each month, which in turn has a significant impact on their school performance [11].

Options for managing menstrual bleeding vary globally. Many studies indicate that women and girls have a strong preference for commercial products such as disposable sanitary pads. Commercial products, such as tampons and sanitary pads are widely used amongst adolescents in high income countries. However, in Low and Middle Income Countries (LMICs), commercial products may be less available and are often prohibitively expensive. The cost of commercial products prevents many women and girls in LMICs from using commercial products consistently. Some 70% of girls surveyed in a multi-country study in Ethiopia, Uganda, South Sudan, Tanzania, and Zimbabwe reported product affordability as the main reason for not using commercial sanitary pads [12].

A wide variety of reusable MHM products (both commercial and homemade) are used globally. Reusable products include sanitary pads, cloths/towels, leaves, newspaper, tissue paper, sponges and others. Girls who use reusable MHM materials report challenges accessing clean and comfortable absorbent cloth materials and using them comfortably and hygienically. Common complaints with reusable cloth MHM materials among girls and women are that they are often bulky, poorly absorbent, that they are prone to leakage, difficult to keep in place, and that they can cause chafing, pain or smell. In many cultures, tampon use is discouraged amongst young women due to concerns about blocking menstrual flow, misconceptions about tampon use leading to loss of virginity, lack of knowledge about the female reproductive tract and discomfort touching their own genitalia [12].

The girls in Control Program in Ethiopia, South Sudan, Tanzania, Uganda and Zimbabwe found that affordable and appropriate MHM materials were largely unavailable. Therefore, most girls use whatever material that they have at hand, including rags, cotton, sponges and goat skin. Despite the challenges associated with MHM materials, most girls and women have very less or no knowledge about reproductive tract infections caused due to ignorance of personal hygiene during menstruation time. Price and availability have been continued to be basic constraints for many girls and women regarding MHM products [12].

2.3 Sanitary Pad

Sanitary pads are one of the medical products that are worn by women in any situation where it is necessary to absorb flow of blood or fluid from the vagina. It is mostly preferred MHM product by the girls and women due to its comfort. The affordability, fluid absorbency, health risk and environmental concerns are the major questions that have been raised by the users. Conventional sanitary pads that are available in the market comprise of multilayered structure in which each layer has specific functions to perform. It consists of three main layers the top sheet, absorbent core and barrier sheet [13].

- ✓ **Top sheet (Acquisition layer)**:

It is designed to transfer fluid quickly from the top sheet to secondary layers. The top sheet contains thermoplastic fibers to prevent capillary collapse of this layer, and small amount of hydrophilic absorbent fiber to allow fluid to absorb. A commonly available top sheet material is made up of polypropylene fiber.

- ✓ **Absorbent core**:

It is interposed between top sheet and barrier layer and its main function is to absorb and retain the fluid. Moreover, to have comfort, absorbent core need to be thin, soft and pliable. The core was made up of wood pulp traditionally but there is constant effort to replace it by air laid wood pulp and Super Absorbent Polymer (SAP) to improve its absorption efficiency. SAP turns the absorbed liquid into a jelly-like state so that it would not retract back. Chlorine-bleached Kraft or sulphate pulp is used by manufacturers to produce fluff pulp for this layer. But this procedure is leading the end product to have a harsh full fragrance of chemicals that could damage the users‟ health.

- ✓ **Barrier sheet**:

It seals the fluid from staining or leakages. It is a breathable but fluid impermeable film made up of polyethylene. Few components of sanitary pad will disintegrate and be attacked by the bacteria in a public or private sewage disposal system but polyethylene or polymeric films used as a barrier sheet remain intact as this polymer is inert and not broken down by bacteria and thus pollutes the environment.

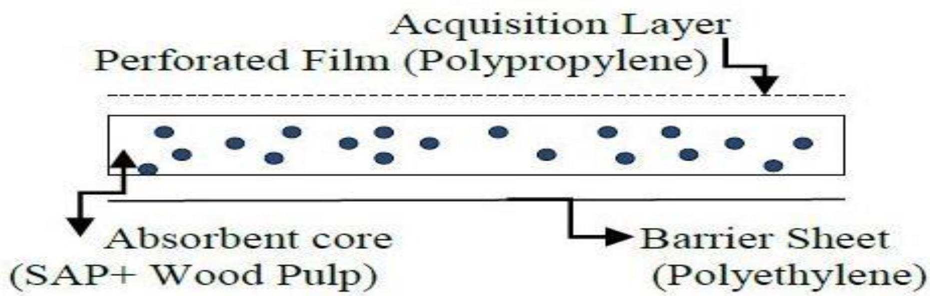


Figure 1:Conventional structure and materials used in sanitary pads [13].

Chapter Three

3. Menstrual Hygiene Management

The preference of MHM is based on personal choice, cultural acceptability, economic status, and availability in local market. The choice of absorbents varies among rural and urban women and girls. In rural areas, the most preferred absorbents are reusable cloth pads and women in urban areas prefer to use commercial sanitary pads. Different MHM used by women and girls are discussed below [1].

3.1 Natural and Homemade Materials

This MHM system is a very common way of menstrual management in low income countries. Natural materials such as leaves have been used by girls in rural and remote area. This way of management is more ancient and backward one. It has high risk for contamination and uterine track infections. The other common way of menstrual MHM is a homemade material like rag.
Studies showed that this MHM is used by about 65% of schoolgirls of Ethiopia in rural places.

3.2 Reusable and Washable Cloth Pads

These may be sustainable sanitary options especially for low income people but it must be hygienically washed and dried in the sunlight. The sun's heat is a main sterilization mechanism for such products. Drying these cloth pads under sun will sterilizes them for future use. These cloth pads are reusable, so they are cost-effective, easily available, and ecofriendly. They also need to be stored in a clean dry place for reuse to avoid contamination. The major challenge with these products is the availability of clean water and detergent to wash them and to keep the instructed sterilization mechanism under a direct sun light as well.

3.3 Commercial Sanitary Pads

These are easily available at many shops, supermarkets, pharmacies or online markets. Most of the time their availability is restricted to urban and pre urban areas. They are expensive, nonreusable and not very environment-friendly compared to cloth pads. The cotton used in many commercial sanitary pad manufacturing process is not 100% natural and may contain pesticides. Also during bleaching process, different hazardous chemicals are used. Nevertheless, many deodorized and non-deodorized sanitary products are available in the market made of synthetic fiber rayon. These deodorized products contain chemicals like organochlorines, which have antibacterial activity. Due to their chemical composition, these products when buried in the soil they kill the soils microflora and delay the process of decomposition. Nowadays, some sanitary pads are being produced from bamboo fiber, banana fiber, hyacinth and other non-wood materials in some countries. These raw materials are considered as better resources to meet the major gaps in the sanitary pad industry including affordability and environmental impact.

3.4 Tampons

These are the type of absorbents that provide internal protection. These require plugging of soft materials (cotton) which is inserted into the vagina to absorb the menstrual flow before it leaves the body. They are expensive and not easily degradable. Nowadays, sea sponge tampons are available in the markets which are a natural alternative to synthetic tampons. Also there are reusable tampons, which are washable, made up of natural materials like bamboo, wool, cotton, or hemp. Unwillingness and negative thinking of most society to insert an object into female gentile organ is another major challenge on the use of such MHM products.

3.5 Menstrual Cups

These are considered newer technologies for poor women and girls and an alternative to sanitary pads and tampons. They are like cups made of medical grade silicone rubber which makes the cup easy to fold and get inserted into the vagina to collect menstrual blood. They can be worn up to 6–12 hours depending on the amount of menstrual flow and hence need to be removed and emptied less frequently. They have to be washed by a hot water carefully in order to be sterilized. They are reusable and environment-friendly as well as cost-effective alternatives. The same as tampon, the major limitation of these materials is their utilization technique. Most societies do not accept insertion of an object in their reproductive organs. Addressing the correct sterilization instruction is also the other challenge for the users.

3.6 Historical Development of Menstrual Hygienic Management

In the 1800s, women and girls used homemade menstrual management alternatives in their underwear that were made of cloth of flannel or woven fabric and commonly called “the rag”.

However, healthy concerns about inadequate cleaning of these reusable products triggered emergence of a new menstrual hygiene management market. Between 1854 and 1915, twenty patents were taken out for menstrual products, including the first menstrual cups which were made up of aluminium or hard rubber, rubber pants that were underwear lined with rubber, and Lister's towels which were the first disposable pads [14].

By 1870, period pants made of rubber were marketed door to door. The first commercial products available for a mainstream audience came in the 1890s with the products such as menstrual tools, including "Ladies Elastic Doily Belt" (a silk and elastic belt to which you'd attach a pad) and "Antiseptic and Absorbent Pad". "Lister's Towel" Johnson & Johnson's sanitary napkins were said to be the first commercially available disposable sanitary protection products for women in the United States. While inventors were beginning to see the need for these products, moral taboos around menstruation meant consumers were still hesitant to be seen purchasing them. Case in point: the commercial failure of Lister Towels, the first disposal pad made of gauze and cotton, which first hit the market in 1896 [14].

During the First World War (WWI), nurses noticed that cellulose was much more effective at absorbing blood compared to cloth bandages. This inspired the first cellulose Kotex sanitary pad, made from surplus high-absorption bandages, which was first sold in 1918 [14].

By 1921, Kotex had become the first successfully mass-marketed sanitary pad. In addition to providing the innovation for a product that would change the MHM options available to women, the war caused another major shift in women's lives: they were now needed to contribute to factory production in a way they had never been before. Through bathroom redesign, factory employers during WWII encouraged women to use menstrual products in order to "toughen up" and continue to work during their monthly bleeding. The beginning of mainstreaming period products meant women could take more control of their autonomy, allowing them to work and participate in activities outside of the home in a way they hadn't been able to before [14].

While homemade menstrual rags were still in use throughout Europe until the 1940s, the 1930s brought a surge of ingenuity in period product offerings modern disposable tampons, which were patented in 1933 under the name of "Tampax". Due to hygiene concerns about the proximity of pads to fecal bacteria, tampons were generally concerned a healthier alternative by the medical community. Medical and marketing interviews found that most women did not return to pads once they had learned how to insert tampons correctly. But many communities were hesitant to embrace tampons because of moral concerns about virginity, masturbation, and its potential to act as contraception. Due to this, manufacturers continued innovations in pads industries. Mary Beatrice Davidson Kenner, a female African-American inventor, patented the sanitary belt in 1956, the first product featuring an adhesive to keep the pad in place [14].

In 1927, Johnson & Johnson hired pioneering psychologist Lillian Gilbreth, to conduct a study on merchandising the sanitary pad. She interviewed thousands of women across the country, answering questions about size and fit (they tended to be too large with inflexible edges) and preferences (most women wanted smaller, more discreet packaging). She inspired a new wave of very successful advertisement campaigns focused on allowing girls to maintain their innocence, so to speak, by separating menstruation from sex and reproduction. The campaign presented period products as allowing girls to participate in sports and recreational activities, helping to reinforce the idea of adolescent girls. This strategy was also used by tampon campaigns hoping to overcome the moral concerns people still had about them [14].

Later, an adhesive strip was placed on the bottom of the pad for attachment to the saddle of the panty, and this became a flavoured method with women. The first beltless pads came out in 1972, inspiring variations like heavy flow, light flow, and mini-pads. The belted sanitary pad quickly disappeared during the early 1980s. Creative modifications to period products continued into the age of peace, love, rock and roll. In the 1980s, versions of modern maxi pads and pads with wings hit the market [14].

Tampons continued to increase in popularity. But a massive health concern about them made news when over 5,000 cases of Toxic Shock Syndrome (TSS) were reported between 1979 and 1996. Most of the cases were linked to a specific tampon brand and specific materials which are now no longer on the market. While these health scares did not discourage women from using the products, they brought to light a lack of government regulation over the safety and composition of menstrual products. This lead to more focus on more “natural” alternatives [14].

In 1956, Leona Chalmers updated the menstrual cup, using softer materials to make a product more like what we use today. The first menstrual cups were made of aluminum or hard rubber; now, they are typically made of a better material which is from silicone [14].

Some more extreme options were presented, including powder that could be inserted into the vagina, which was meant to neutralize the pH of period blood and prevent bacterial growth.
While these more creative measures didn't take off, reusable menstrual cups, period sponges, and biodegradable options became more popular throughout the 1970s as second-wave feminist and environmentalist movements grew. Mini-pads were a huge success when they hit the market, even inspiring fan letters from women who finally felt comfortable. As the feminist movement pushed women to become comfortable with their bodies, free bleeding was adopted by women who resented the fact that they were expected to hide and feel ashamed of their periods (though it was hardly mainstream) [14].

The most revolutionary development in period management came in 1971, when a women's self-help clinic introduced the "extraction method". This invention came out of research on safe abortions. Women used a suction device to evacuate all the contents of the uterus, shortening periods from around 5 days to just a few minutes. The procedure was seen as a blessing for athletes and people with especially painful periods, and the inventors patented safer and more effective tools throughout the 1970s. In spite of the benefits, research into the safety of this procedure was restricted, partly because of its association with early abortions. The method required a doctor to perform the procedure, making it potentially costly. This plus the lack of medical data investigating potential long-term effects prevented it from becoming mainstream [14].

Today, there are a plethora of options for managing periods, from period panties to menstrual cups, organic pads and tampons. As of 2000, over 80% of women used tampons, with pads and panty liners close behind. Even the cloth options from the 1800s are making an updated comeback, with more and more options for anti-microbial period panties and reusable pads in the market [14].
As concern about the environmental impact of disposable products grows, many are returning to reusable organic methods, like the menstrual sea sponge and silicone cups (though both have been associated with cases of TSS). As girls and women are learning more about the different MHM options, they will be able to take their health into their own hands. Hence, women have always

been intimately involved with the development of period products; female entrepreneurship continues to grow in this market. Products and advertisement campaigns are also shifting to focus on all bodies that get periods [14].

From early on, the expectation was that by hiding their menstruation, women were seen as more feminine, hygienic, and capable. Strategies based on fear of “discovery” continue to be employed by marketers today, from odorized products to silent and discreet packaging. But these advertisements have also shifted towards a more feminist message, portraying tampons as liberating, allowing women to take control of their bodies and participate in areas of society that didn’t welcome them before. History shows us that advances in menstrual technologies have had significant impacts on women’s health and personal and professional freedoms. From patents to pilots, menstrual technologies have been opening doors for women throughout history [14].

Over the last twenty years, the sanitary pad industry has advanced by leaps and bounds. The days of bulky belts and diaper like thicker products had gone. With the invention of more absorbent materials and better designs, pads are more comfortable and practical than ever. The invention of „wings‟ keeps pads in place in the underwear, and the invention of „scented pads‟ reduces odour. Sanitary pads are the most widely used form of menstrual management, but they are still overpriced, particularly in developing countries [14].

Chapter Four

4. Material Composition

Materials which are used in feminine hygiene products, are derived from natural resources mostly petroleum based which cannot be reused or compost. At the same time, over-exploitation of these resources have to be stopped otherwise nothing will be left for our future generation. We have to find an alternative raw material that is sustainable in nature, without compromising on the functional requirement of the product. Beside this the major problem regarding sanitary pads is the cost, which is the basic issue for the users especially in low income countries such as Ethiopia. The current thesis work intends to make affordable, quality and eco-friendly sanitary pads that can be available to girls and women in developing countries using locally available raw materials. The major raw materials that are used to develop the final sanitary pad are cotton fabric, pulp from Enset fiber and bio-plastic of PLA. The behavior of the raw materials and their availability in Ethiopia will be explained in detailed in this chapter.

4.1 Cotton Material

Cotton, which is a comfortable, absorbent, biodegradable fiber, is the base fiber in the nonwovens. Cotton fiber is one of the oldest fibers, which is much familiar to human beings and widely used for numerous purposes. It is predominantly composed of cellulose along with hemicellulose while there are certain non-cellulosic matters attached and present in cotton fiber [15].

Cotton fabrics are the most commonly used types of fabrics in the world. This textile is chemically organic, which means that it does not contain any synthetic compounds. Cotton fabrics are derived from the fibers surrounding the seeds of cotton plants, which emerge in a round, fluffy formation once the seeds are mature [15].

Approximately 75% of the world’s clothing products contain at least some amount of cotton. Therefore, cotton is the most widely used textile fiber in the world. This fabric is used to make bathrobes, bathmats, towels, bed sheets, blankets, and duvets. Manufacturers may even use cotton to make curtains, wall-hangings, and other types of home decorations. It is also a good option for formal and business wear. In addition to this, cotton is use to make medical supplies, industrial thread and tarps. Generally, cotton can be used to make practically any type of textile for consumer or industrial use [15].

Ethiopia is one of the African countries that produce and export cotton. There is a long tradition of cotton cultivation with an estimated area of 2.6 million hectares suitable for cultivation; of these 65% is found in 38 high potential cotton producing areas and the remaining 0.9 million hectares or 35% is found in 75 medium potential districts of the total land under cotton cultivation; 33% is cultivated by small holders, 45% by private farms and 22% are state owned [16]. Cotton is a common type of fiber in Ethiopia. It has been used to make different clothes.
Even the cultural cloth of the country which is known as 'Thbeb' is made using cotton. So it is highly available, commonly used and conventional material for different cultural and modern textiles. Hence, in this research cotton is used to prepare the top sheet of the sanitary pad.

Cotton is a soft, absorbent, highly moisture wicking and breathable natural fiber, making it the perfect fiber for clothing and undergarments worn close to the skin. Cotton is non-allergenic, unlike synthetic fibers. Cotton, due to its unique fiber structure, breathes better and is more comfortable than oil-based synthetic fabrics. It is one of the easiest fabrics to dye due to its natural whiteness and high rate of absorbency [17].

4.2 Enset Plant

Enset is a monocarpic, tall, perennial herbaceous plant. It belongs to the order Scitamineae, family Musaceae, and genus Ensete. It is commonly called false banana for its close resemblance to large thick, single-stemmed banana plant (*Musa* sp.). Enset plant has an underground stem structure known as corm and bundle of leaves like a banana plant. However, it does not bear edible fruits and it is not categorized as common banana plant (genus *Musa*) [18].

Enset is usually larger than a banana plant. It reaches up to 13 meters with a pseudostem up to one meter in diameter and dilates at the base to a circumference of 1.5 to 3.0 m and length of 2 to 5m. The leaves are more erect than that of a banana plant. It has the shape of a lance head and maybe 4 to 6 m long and nearly 0.6 to 0.9 m wide. The plant has an adventitious root system, an underground stem structure known as corm. The corms are 0.7-1.8 m long and 1.5-2.5 m in diameter at maturity. The above ground part of Enset pseudostem is formed by a bundle of clasping and overlapping leaf sheaths. The proportion of the different components of the Enset plant (% dry matter) was reported as lamina and midribs of leaves 15-17%, leaf sheaths 45-51%, stalk 9-11% and corm 26-29% but a higher variation range was reported among different varieties and age of the plant [18].

As the plant grows older and matures, an inflorescence grows at the apex and a stalk develops along the inner part of the pseudostem, and the flower emerges at the top and drops out. The pseudostem and leaf midribs colors vary but most are light green with variegated brown patches. Enset is cultivated in south-western part of Ethiopia and covers considerable land area within the private holdings with an estimated area over 300,000 hectares in the highlands (1100-3000 m above sea level) of central, southern and southwestern parts. An average temperature 10-21 ^{O}C and rainfall of 1100-1500mm per annum are conducive for the growth of the plant. It grows well in most sufficiently fertile and well-drained soil types [18].

Enset is a drought-resistant plant; failure of rain can only stop the growth but not kill the plant, as it has a large accumulation of moisture in its pseudostem. As a result, famine rarely occurs in areas where Enset is widely grown. Enset leaves are fed to cattles during the dry season. It is also being used as an ornamental plant in Ethiopia and elsewhere [18].

Enset plant grows in domestic as well as in wild forms. The domesticated Enset is mainly propagated vegetatively from suckers whereas most wild plants are produced from seeds, and the species appears to have an outcrossing reproductive system. This plant occurs in sub-Saharan Africa and grows wild in many countries in Central and Eastern Africa including Ethiopia, Congo, Mozambique, Uganda, Tanzania and Zambia. In Ethiopia, wild Enset occurs in the highlands in the southwestern part whereas the cultivated Enset grows in a wider area comprising the central, southern and southwestern parts of Ethiopia, but mainly at higher altitudes ranging from 1500 to 3100m. Enset is presently the main crop of a sustainable indigenous African system, which ensures food security and it is well known for its drought resistance. In Ethiopia alone, more than 20% of the total populations, concentrated in the highlands of southern Ethiopia, depend upon Enset. Besides its use as a source of copious quantities of carbohydraterich food, Enset is also utilized for fiber production, animal forage, construction materials, as an ornamental, and for its medicinal values, with a demonstrated antimicrobial activity against viral, bacterial, fungal and nematodal diseases of humans [19].

Ensete ventricosum fiber is a plant fiber extracted from the pseudostem and leaf parts of the Enset plant. Decortication of the pseudostem (leaf sheaths) of Ensete ventricosum provides starchy pulp .which along with the corm is processed and used as a food product, and a fiber as a byproduct. The extracted fibers are then sun dried and used, in rural areas, to make sacks, bags, ropes, cordage, mats, sieves and tying materials for construction (in place of nails). These fibers are very long, often cut to 1-2m during extraction but can be extended to 6m or more depending upon the height of the pseudostem, the method of extraction and the intended end use. It is also strong and flexible enough to be used for many applications [19].

Additionally, there is enormous potential to extract and utilize fibers from the leafstalk (midrib) and fallen-sheath parts of this plant which are commonly used for animal feed, compost, fuel (firewood) and landfills. However, for the best of our knowledge, if not at all, little attempts were made to systematically investigate the properties of these fibers and their potential for textile and technical applications. In this thesis work, efforts have been exerted to study the applicability of Enset pulp which is produced from the Enset fiber for sanitary pad production.

According to the Ethiopian Central Statistics Authority (CSA) data, around 2.27% of area under major crops cultivation in Ethiopia is covered by private Enset plantation. SNNPR and Oromia regions are the two major Enset growing regions in Ethiopia. SNNPR produces over 65% of Enset production in Ethiopia. In these regions, Enset is cultivated mainly for a starchy food and livestock feed. In addition, every part of Enset plant is thoroughly utilized in one way or another. Sidama, Arsi, Gedio, Keffa, Jimma, Guji, Gurage, Kembata, Hadiya, Kefa, and related ethnic groups are the main Enset producing zones in Ethiopia [18].

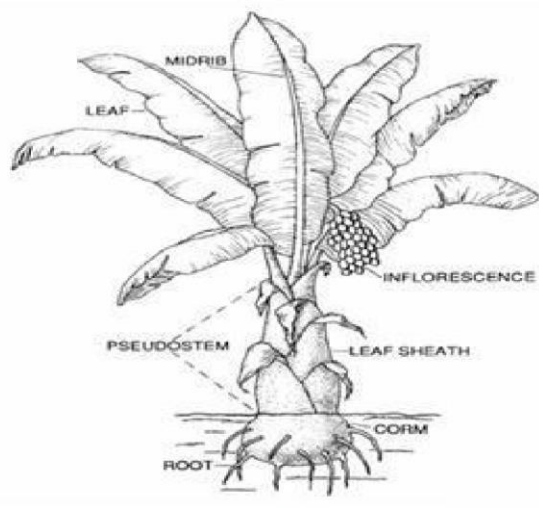


Figure 2:Enset plant [20]. Figure 3:Part of Enset plant [20].

A picture of the Enset plant and its different parts are depicted in Fig. 2 and Fig. 3 respectively. Harvesting of Enset includes cutting the leaf sheaths of the pseudostem into pieces, scraping the leaf sheaths pulp (parenchymatous tissue) from the cut pieces, pulverizing the corm, mixing the pulverized corm with the scraped leaf sheaths pulp and fermenting the mixture for a period 2 to 6 months. Kocho is the main food product obtained by fermenting the mixture. Part of the starchy liquid called "bulla" obtained by squeezing the mixture can be consumed after it is allowed to settle for 4 to 5 hours or more resulting in thick paste. The freshly cooked corm is locally called "Amicho" and can be consumed in a similar way as Irish potato. Thus, the plant is considered as a field bank of the food. The pseudostem, corm, and stalk of inflorescence constitute the most important source of food for humans, whereas the whole parts of the plant except the roots are used to feed livestock. The pseudostem, the main food source, is rich in soluble carbohydrates (80%) from this the largest proportion is starch (65%) but has low protein content (4%) [18].

Different types of residues are disposed of commonly during food preparation of Enset. The fiber, the leaf and inflorescence stalk are the main solid residues which are not utilized for Enset based foods preparation. The fiber bundle, with a hair-like structure, locally called "Kacha" is collected after scraping of the leaf sheath and leaf bases around the pseudostem. Over centuries the Enset fibers have been extracted from the leaves of this plant as major material for the weaving, ropes and cord production, as well as for baskets production. Enset fiber obtained from the leaf sheaths has an excellent structure, and its strength is equivalent to the fiber of abaca, a world-class fiber crop [18]. This high quality fiber can be used for the production of specialty papers, such as currency notes, tea bags, etc. that require the use of long and high strength fibers. Enset fiber can also be used for the production of high quality papers and packaging or to supplement short and inferior fibers in the pulp and paper industry. Additionally, its biodegradability and recyclability as well as mechanical behavior makes it comfortable for the production of bags, ropes, cordage, mats, construction material, textile industry, packaging and so on [21].

4.3 Plastics

Plastics are organic polymers, which can be processed in various different ways. Their technical properties, such as formability, hardness, elasticity, rigidity, heat resistance and chemical resistance, can be varied across a wide range by selecting the correct raw materials, manufacturing process, and additives. Plastics are lighter and more economical than many other materials. For these reasons, plus their extreme versatility and excellent process ability, they are the material of choice in many industrial and commercial applications. Since the widespread availability of petroleum at the beginning of the 20th century, most traditional plastics have been produced using petroleum [22].

Basically, plastic or polymer products differ in whether they are structural polymers or functional polymers. Structural polymers are those that are used in industrial applications, i. e. what we commonly call plastics. Functional polymers, however, are used for non-material applications. This may be, for example, the use as a paper additive, adhesives, coating resins, thickeners, flocculants, concrete additives and much more. The statistics shows that approximately 235 million tons of plastics are produced annually, worldwide. Its applications are not only in packaging (40%), construction materials (20%), their utility includes for agriculture, aerospace, automobile, sports, domestic, and household equipment of all types [22].

Plastics have been incredibly useful to us in various ways for our lives. However, their overuse has been causing our planet many environmental problems such as pollution, degradation, and cancer. In recent decades, the plastic industry and the academic community have been together looking for new raw materials to replace the petrochemical polymers, which are produced from nonrenewable resources [23].

4.3.1 Bioplastics

Bioplastics are mainly two types of plastic: compostable plastics and bio-based plastics. The compostable plastics are made up of renewable and non-renewable resources whereas bio-based plastics are made up of renewable resources. There have been various researches on bioplastics. Biodegradation is the chemical process in which the material itself decomposes into the nature. The plastic which is made from bio based substance is known as bio-based plastic and the plastic which can be decomposed by natural organism is called biodegradable plastic. The fossil fuel plastics are bio degradable, when it is combined with bio based substance and forces them to decompose [24].

Bioplastics are new generation of plastics which are biodegradable and compostable. They are manufactured generally from renewable raw materials like starch from e.g. corn, potato, or plants as a whole are used as a feedstock for bioplastics to get starch, cellulose, lactic acid etc. which are not hazardous in production materials, so it blends harmlessly with soil and then decompose back into carbon dioxide. Some bioplastics can break down in a matter of weeks. The most familiar bioplastics are made from natural materials such as corn starch and sold under such names as EverCorn™ and NatureWorks with a distinct emphasis on environmental credentials.
Some bioplastics look virtually indistinguishable from traditional petrochemical plastics [24].

4.3.2 PLA

Polylactic acid (PLA) is one of commonly used bio-plastics. It has been known since 1845 but not commercialized until early 1990. PLA belongs to the family of aliphatic polyesters with the basic constitutional unit lactic acid. The monomer lactic acid is the hydroxyl carboxylic acid which can be obtained via bacterial fermentation from corn (starch) or sugars obtained from renewable resources. Although other renewable resources can be used, corn has the advantage of providing a high quality feedstock for fermentation which results in a high-purity lactic acid, which is required for an efficient synthetic process. L-lactic acid or D-lactic acid is obtained depending on the microbial strain used during the fermentation process. PLA is a biocompatible and biodegradable material that has numerous applications in sustainable plastic products along with ease of disposability [20].

PLA is a commercially interesting polymer as it shares some similarities with hydrocarbon polymers. It has many unique characteristics, including good transparency, glossy appearance, high rigidity, and ability to tolerate various types of processing conditions. Major manufacturers of PLA in the world are Toray (Ecodear™), NatureWorks and MiniFibers [20].

PLA looks and behaves like polyethylene and polypropylene and is now widely used for food containers. According to NatureWorks, making PLA saves two thirds the energy you need to make traditional plastics. Unlike traditional plastics and biodegradable plastics, bioplastics generally do not produce a net increase in carbon dioxide gas when they break down (because the plants that were used to make them absorbed the same amount of carbon dioxide to begin with). PLA, for example, produces almost 70% less greenhouse gases when it degrades in landfills [20].

PLA is widely used in many day to day applications since it is fully biodegradable and biocompatible which makes this fiber attractive and suitable for medical applications like wound dressing. The fiber is also useful as an eco- and people-friendly alternative to existing textile fibers for industrial and consumer apparel applications such as outdoor furniture, automotive interior fabrics, active wear, shoe linings, and disposable products like diapers and wipes, either at 100% or in blends with natural fibers such as cotton. It has been also used in food packing (including food trays, tableware such as plates and cutlery, water bottles, candy wraps, cups, etc.). PLA production requires less energy per kg as compared to other polymer bioplastics such as polyethylene terphalet (PET) and polypropylene (PP) (42 MJ/kg for PLA as compared to 73 MJ/kg for PP and 80 MJ/kg for PET) [25].

4.3.3 PLA Film for Sanitary Pad Production

The conventional sanitary pads consist of polypropylene nonwoven clad and polyethylene film. These polymers have been big obstacles of a disposable hygienic materials sustainable development. The whole world has disposed a huge amount of sanitary pads every day, these sanitary towels once embedded underground almost cannot decomposed forever; since, the most part of sanitary pads are made up of a plastic which require several years to degrade [26].

By replacing these inert raw materials with PLA, we can improve the production process, energy consumption, and environmental pollution. So that the transformation to PLA based material will be helpful to decrease the burden of our environment which improve environmental sustainability.

PLA is majorly produced from agricultural crops through fermentation and polymerization science and technologies. The commonly known raw materials for PLA production are corn starch, cassava starch, cottonseed hulls, jerusalem artichokes, corn cobs, cornstalk, beet molasses, wheat bran, rye flour, sweet sorghum, sugarcane press mud, cassava, barley starch, cellulose, carrot processing waste, molasses spent wash, corn fiber hydrolysates, banana peel and potato starch [26]. Ethiopia is one of the countries which is rich and suitable for these agricultural products.

Chapter Five

5 Methodology

Sanitary pad comprises of multilayered structure in which each layer has a specific function to perform. Predominantly, it consists of three main layers:

- The top sheet: is designed to transfer fluid quickly from the top sheet to the secondary layer.
- The absorbent core: is interposed between top sheet and barrier layer and its main function is to absorb and retain the fluid as much.
- The bottom layer: seals the fluid from staining or leakage.

Accordingly, the current thesis research passed through the three main phases in order to accomplish the final design of the proposed MHM product. The methodology utilized in the current research is similar to the procedures utilized in previous literatures [27-29]. The overall process has been described in the following sub sections.

5.1 Phase One: Pulp Production

A. Raw Materials

The samples of fibers were collected from a household Enset plantation located in Wolkite, Gurage zone, Ethiopia. The pulping mechanism used in this study was a soda pulping. Hence, the major material used was a laboratory grade sodium hydroxide, which is bought from chemical shop around Cherkos in Addis Ababa, Ethiopia. Also distilled water was used as a solvent during pulping process. The three materials are depicted in Fig. 4, 5 and 6 respectively.

Figure 4:Enset fiber

Figure 5:NaOH

Figure 6:Distill water

B. Experimental Design

- **Pulp Preparation**: this was done using soda pulping. There were five main parameters in the pulp production process, i.e., time, temperature, concentration of NaOH, liquid to solid ratio (LSR) and mass of fiber. These parameters were specified by reviewing different literatures and those were recommended for Enset fiber pulping [18]. Thus, we made two samples in cylindrical and conical biker with the same experimental parameters as follow:
    - ✓ Time= 90min
    - ✓ Temperature= 140^{o}C
    - ✓ Concentration of 98% NaOH= 17%
    - ✓ LSR= 30:1
    - ✓ Fiber mass= 15g
- **Solution Preparation:** The collected fibrous materials were washed and sun-dried. Prior to pulping, the fiber threads were cut to average size of 5 mm. In order to extract the final pulp material, the following procedures were utilized.

1. First, the raw materials were measured, which were needed to make the solution. The mass of the fiber was 15g, while the LSR was 30:1. The amount of water was 15x30 = 450 ml. Subsequently, a 17% NaOH solution was prepared, as also depicted in Fig. 7, 8 and 9 the remain mass is the mass of the paper used to hold the sample.

Figure 7:Mass of Enset Fiber.

Figure 8:Mass of NaOH .

Figure 9:NaOH solution granule.

2. After the solution is prepared, the fiber is put inside. And we make sure all of the fibers get wet. Covering the biker with aluminium foil, the sample is put into an autoclave for 90 min at 140^{o}C as shown in Fig. 10 and 11 [18].

Figure 10:Mixture of Enset fiber and NaOH.

Figure 11:Steam Autoclave.

3. Once the sample is taken out of the autoclave, it will be left for about 3 minutes to cool down. Then it is washed by tap water on 1.8mm and 0.8mm sieve for two hours to get rid of the NaOH. Then the pulp is taken into an oven for 24 hours on 80^{o}C in order to dry it (see also Fig. 12 and 13).

Figure 12:Autoclaved mixture.

Figure 13:Enset pulp.

4. The dry mass of the pulp yield is then measured from the two samples. Those were 8.5 and 8.1 grams. Finally, the pulp is blended by conventional coffee blender for 2-3 minutes within 30 seconds interval until the needed texture was attained. Figure 14 presents the blended pulp.

Figure 14:Blended Enset pulp .

5.1.1 Evaluation of the Enset Pulp

5.1.1.1 Antimicrobial Activity

This property is one of the very essential characteristics for sanitary and textile products. Bacteria are living organisms that are abundantly found as part of a human skin flora and are the common cause of infection. In this thesis, an assessment of antibacterial activity of Enset pulp was performed against the two common residents of the human skin. These are Staphyloccus Aures (gram positive) and Escherichia coli (gram negative) bacteria. At this stage, three main issues were testified:

A. Whether the Enset pulp has antibacterial property or not?

B. Whether Enset pulp facilitates bacterial growth or not?

C. Whether sterilization of Enset pulp prior to sanitary pad production is obligatory or not?

In order to test these conditions, four test scenarios were prepared for both bacterial cells:

1. Sterilize pulp + pathogen
2. Sterilize pulp + no pathogen
3. Non sterilize pulp + pathogen
4. Non sterilize pulp + no pathogen

Numbers 1&3 were used to justify antibacterial activity of Enset pulp and the other two conditions (2&4) were used to understand the characteristics of the pulp against bacterial growth; at the same time the effect of sterilization of Enset pulp was assessed. Some amounts of the pulp were sterilized by using steam autoclave at 120^{o}C for 20 minutes. MacConkey Agar (Mac) plate for E. Coli and

Mannitol salt agar (MSA) plate for Staphyloccus were prepared. The suspended bacterial culture was shaked at 180 rpm to ensure prolific bacterial reproduction and avoid the bacterial settlement on the bottom part of the containing tube. The steps are depicted in Fig. 15, 16 and 17.

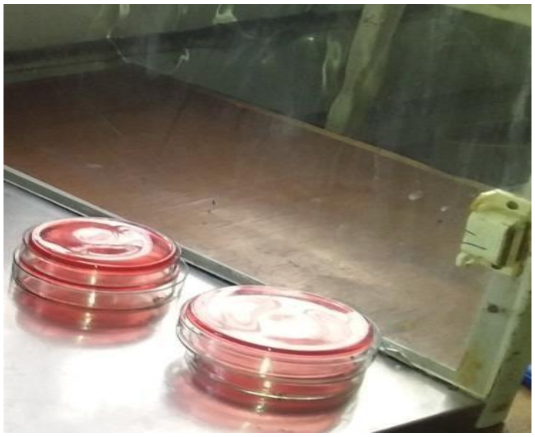
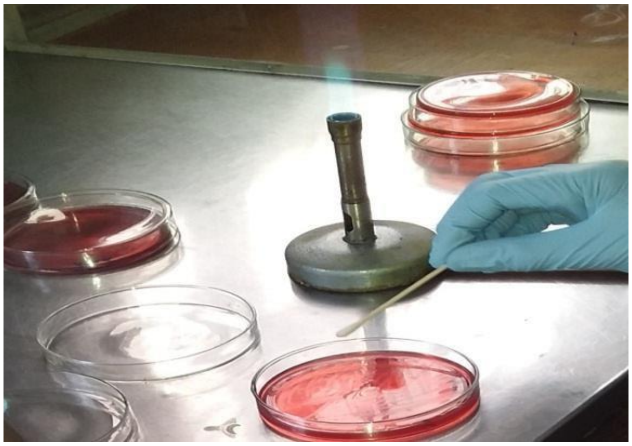


Figure 15:Sterilized Enset pulp and bacterial culture . Figure 16:Mac & MSA Plates.

Figure 17:Shaking of bacterial culture.

The inoculated bacterial culture is then transferred to Mac & MSA agar plate (see also Fig. 16) and it was spread uniformly throughout the surface using a sterilize cotton swab. Then the tiny piece of specimen was tap directly on to each agar plate using a sterile forceps. Finally, Petri plates were closed and stored upside down in incubator for 48 hours at 37^{o}C. The steps are summarized in picture format in Fig. 18, 19, 20 and 21.



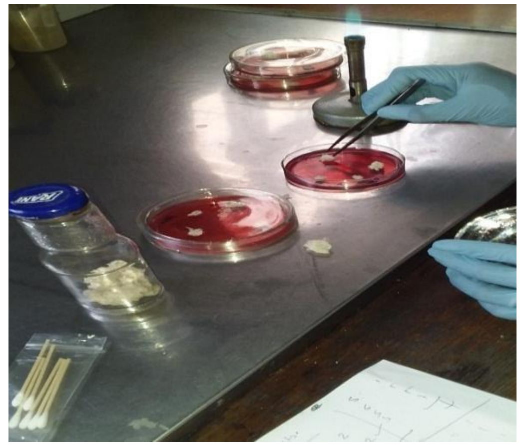


Figure 18:Transferring bacteria culture to agar plate. Figure 19:Taping specimens on a plate.

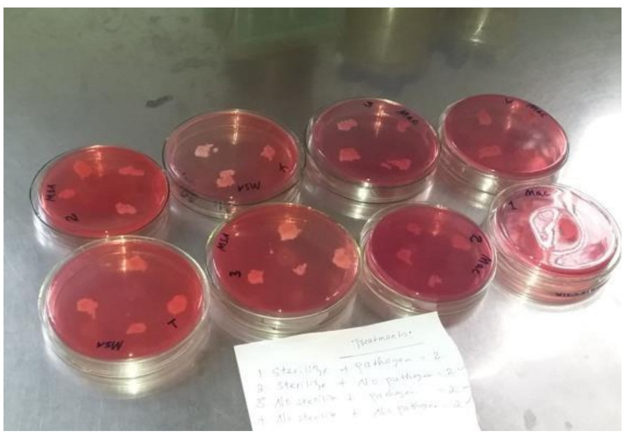


Figure 20:Mac & MSA plates with specimens. Figure 21:Photo of Petri dishes in incubator.

5.1.1.2 pH Value

The other essential parameter that we need to consider is pH value. The sanitary pad shall be free from acidic and alkaline materials to prevent any toxicological problems such as itching, irritation and other skin infections during use. Hence, the pH value of Enset pulp is measured using a pH meter. Before measuring the pH value of the pulp, the pH meter itself had to be calibrated. Consequently, 7 gram of pulp was immersed in a 400ml of distilled water and manually shacked and stirred until it is disintegrated completely. Then the electrode of the pH meter was inserted into a biker and the measurement was recorded. In order to reduce errors, the measurement was done three times within 15 minutes interval. Figure 22 presents the process during the pH value reading.

Figure 22:Photo during pH value reading.

5.1.1.3 Absorbency Test

A sample holder was prepared from copper wire in order to put the pulp during the test procedure. The sample holder has a length of 8cm, width of 4 cm and a depth of 4cm. Then, one gram of pulp was measured and placed in the sample holder (see also Fig. 23).

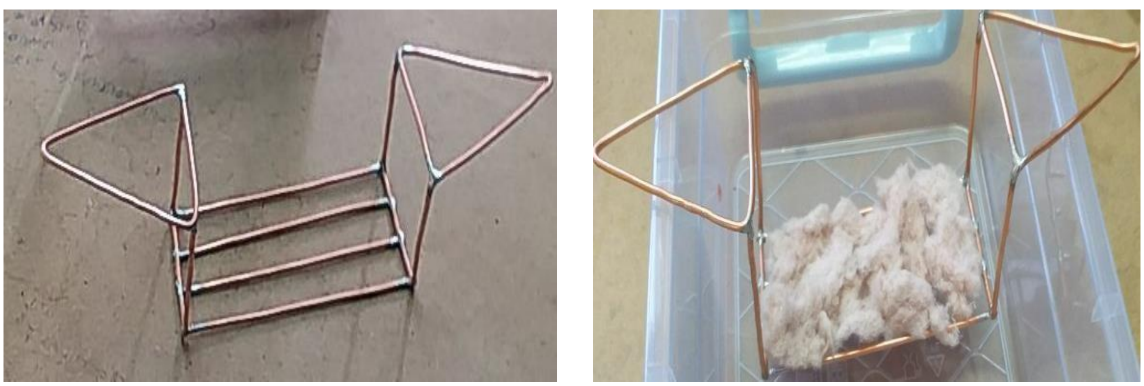


Figure 23:The sample holder and Enset pulp.

After that, the pulp was soaked inside 750 ml water approximately 1.2 cm above the surface of the water. The time taken for the complete sub immersion was recorded and the pulp was removed from water; plus it was allowed to drain for 10 seconds. Afterwards, the wet pulp was placed immediately on a balance and the weight was recorded (see also Fig. 24 and 25). Finally, the weight of the water absorbed was calculated by using Equation 1 below. The procedure was performed twice and the mean value was computed. This procedure was made under standard room temperature (Temperature=32^{o}c and humidity =25) and the way prescribed in the literature [27].

Figure 24:The pulp soaking in water.

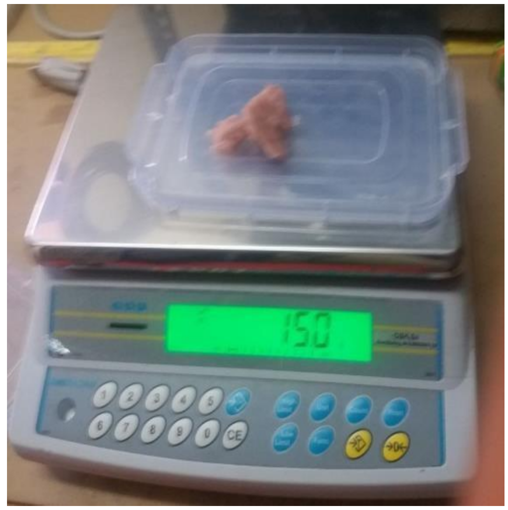


Figure 25:Mass of wet pulp.

Table 2:Absorbency test.

Category	**Sample1**	**Sample2**
Initial mass of pulp (g)	1	1
Time taken for complete sub immersion (sec)	9	10
Wight of wet pulp (g)	15	16
Wight of the water absorbed (g)	14	15
Mean time taken for complete sub immersion (sec)	9.5	
Mean value of the water absorbed (g)	14.5	

$M_{wa}=M_2-M_1$……………………………………………………………………………(1) where

M_{wa} = mass of water absorbed,

M_2 = mass of the sample after immersion, and M_1 = the dry mass of the pulp sample.

Table 2 summarizes the outcomes of the measurements performed for the two samples. Accordingly, the mean time taken for complete sub immersion was found to be 9.5 seconds while the mean value of the water absorbed was computed to be 14.5 grams.

5.2 Phase Two: Development of the Sanitary Pad

In this section the size and the dimension of the developed sanitary pad is described. The final design was produced with size of a standard sanitary pad currently available on the market. The physical parameters of the sample sanitary pads are presented in Table 3.

Table 3:Physical parameters of sample sanitary pads.

Size	Length (cm)	Width (cm)	Thickness (cm)
Regular	20	6.5	1.5

The pad consisted of three main layers: top sheet, absorbent core and bottom layer as depicted in Fig. 26.

Figure 26:The composition of the proposed sanitary pad.

5.2.1 Top Sheet

This layer was intended to transfer the blood or the fluid to the absorbent core. Cotton fabric was used to meet the needed behavior of the layer. Compared to the polymeric sheet that is used to prepare top sheet of commercial sanitary pads, a cotton fabric is more eco-friendly and feasible to our country.

Figure 27:Cotton fabric (Nethla).

5.2.2 Absorbent Core

It is the main part of the pad which is important to absorb the blood or the fluid coming to the surface. Hence, Enset pulp was used to make this layer. The mold of this part was prepared using sample pulp padding object which is made up of wood. Exactly 5g of Enset pulp was evenly distributed in the padding object and the mold was prepared as shown in Fig. 28 and 29 below.

Figure 28:Sample pulp padding material.

Figure 29:Molded absorbent core.

5.2.3 Bottom Layer

This was intended to prevent if any leakage has to happen from the absorbent core. PLA with a specific brand name of ‘Naturework’ was used in this regard. Finally, by putting the absorbent core between the two layers, the cotton fabric and the bioplastic were stocked together by ironing using conventional cloth ironing device. The bottom bioplastic layer is depicted in Fig. 30.

Figure 30:Bottom layer bioplastic.

5.3 Phase Three: Functional Properties

In this section, three major types of testing were carried out on the final sanitary pad. The features are important in order to justify the quality, affordability and safety of the final product**.**

5.3.1 Absorbency

The absorbency of the pad was measured using a routine test. First the sanitary napkin was laid on the flat surface. Then 30ml (30ml of water plus 3 droplet of food color) of colored water was dripped at the rate of 15ml of colored water per minute at the center of the sanitary pad at the height of 1-2mm as shown in Fig. 31.

Figure 31:Image taken during the absorbency test.

5.3.2 Ability to Stand Pressure After Absorption

This test was done next to the absorbency test after the pad absorbed all amount of the colored water. After the sanitary pad absorbed all amount of fluid, a standard weight of one kg was kept for one minute on the middle of the pad as shown in Fig. 32. Then the side and the back of the sanitary pad were observed if any leakage and stain have appeared.

Figure 32:Pad subjected to pressure through 1kg of weight.

5.3.3 Disposability

Following the sanitary napkins standard IS:5405-1980, the disposability measurement was done by removing the top sheet and bottom layer of the sanitary pad immersing the absorbent core into a 15 liter water and stirring the mixture (see also Fig. 33). The time taken by the absorbent core to disintegrate should not take longer than 5 minutes in order to meet the standard**.**

Figure 33:Image taken during the disposability test.

5.3.4 pH Value

The pH value measurement was the same as the procedure that was followed in the first phase of the methodology.

5.3.5 Fluid Retention Test

The measurement of fluid retention was determined using a standard ASTM D 461. The sample of the pad has to be immersed in a fluid at room temperature for 5 minutes to make it completely wet. The fluid/logged sanitary pad was weighted, dried and reweighted. Fluid retention was calculated as percentage of the dry mass (see also Fig. 34, 35 and 36).

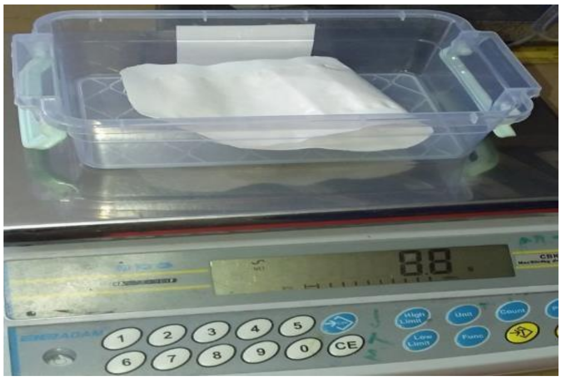


Figure 34:Dry mass of a sanitary pad.

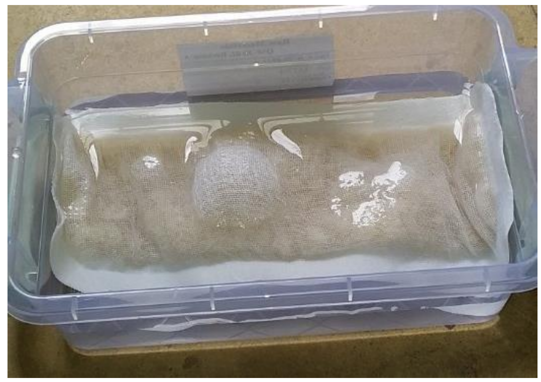


Figure 35:Soaked sanitary pad.

Figure 36:Mass of wet sanitary pad.

5.3.6 Liquid Strike Test

This test was done by allowing the test solution to fall on the sanitary pad and recording the time taken for the solution to transport from the upper layer of the pad to the absorbent core. This is measured by observing the drop closely so that the dull wet spot was seen on the wet area of the pad as shown in Fig. 37.

Figure 37:Image taken during liquid striking through test.

5.3.7 Wicking Experiment

The test was done according to the standard BS3424 METHOD 21 (1973). This experiment is important to test the ability of the pad to take up fluid. Thus, one end of the pad was immersed vertically to 10mm in the test solution and fluid absorption along the pad was measured in mm after 30 minutes. Wicking is the desired characteristics of the sanitary pad as it allows fluid to spread along the entire absorbent structure. The wicking experiment in action has been depicted in Fig. 38.

Figure 38:Image during wicking experiment.

5.3.8 Sterilization

The finished sanitary napkin was placed within a UV sterilizer for 15 seconds to achieve its utmost hygienic state.

5.3.9 Cost Estimation

The rough cost estimation was done and summarized in Table 4 below.

Table 4:Cost Analysis.

No.	Materials	Cost per a single pad (ETB)
1	Enset fiber	0.01
2	Cotton fabric	0.1
3	Bioplastic	0.3
4	NaOH	0.2
5	Labour cost	0.142
6	Other (pulp padding material, electricity, transportation…etc.)	0.1
	Total	0.852

Chapter Six

6. Results and Discussion

6.1 Phase One

6.1.1 Antimicrobial Test

The produced pulp was tested against a very common type of bacteria that grow on textile materials: Staphyloccus Aures (gram positive) and Escherichia coli (gram negative). By using test conditions that were indicated in the methodology section, the responses of the pulp were examined and the three main questions that were asked in the methodology part were answered.

A. Whether the Enset pulp has antibacterial property or not?

Enset pulp had shown zero zone of inhibition or no antimicrobial property for both Staphyloccus Aures and Escherichia coli bacteria. If there is a need to make Enset pulp to have antimicrobial property, that might require to go to other pulp treatment steps. Nevertheless, antimicrobial property is not a mandatory criterion for MHM products; that is why most of the commercial sanitary pads do not assume this property. Figure 39 presents incubated Mac & MSA plates to carry out the antibacterial test.

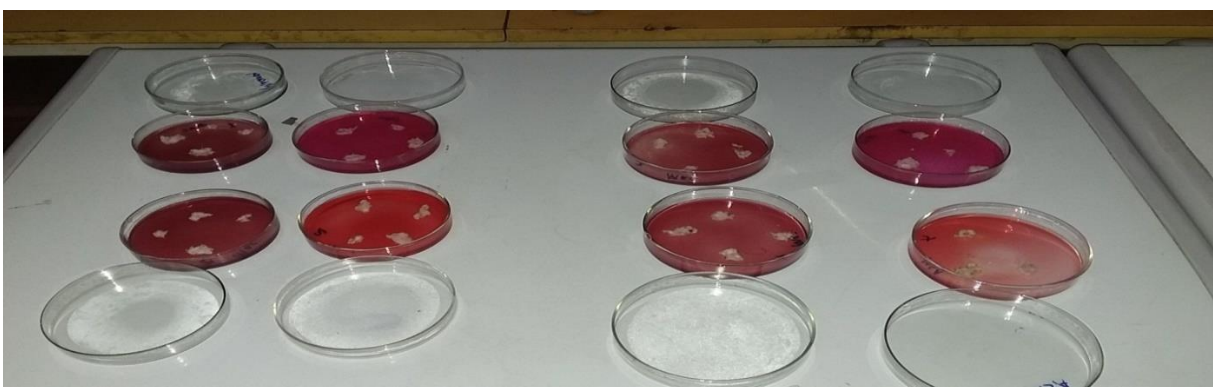


Figure 39:Incubated Mac & MSA plates.

B. Whether Enset pulp facilitates bacterial growth or not?

The other major point was the natural characteristics of the pulp for aggravating bacterial growth. This is the basic question in order to use the pulp in sanitary pad development. The experimental approach of the current thesis study revealed that Enset does not initiate any bacterial growth. Therefore, it is good news that the pulp can be used for the production of sanitary pads.

C. Sterilization of Enset pulp prior to sanitary pad production is obligatory or not?

Sterilization of the pulp had not shown any effect on all of the test conditions of our experiments. Therefore, sterilization of the pulp after pulping is not mandatory. But, we have to be sure that the entire processes of pre-pulping and pro-pulping procedures are done in hygienic ways. Therefore, only final sterilization would be enough for the proposed sanitary pad.

6.1.2 pH Value

As per the standard ISO: 5405, the sanitary napkins should to have a pH value between 6.9 and 8.5 to ensure they fulfill their purpose without causing any irritation and discomfort. The pH value of the Enset pulp was found to be 7.04, which is well acceptable for standard sanitary pad development.

6.1.3 Absorbency

One gram of Enset pulp can absorb fluid an average of 14.5 times its original weight in 9.5 seconds, which was considered a positive sign for the intended use. Since, absorption is the major responsibility of the absorbent core, this ability of our Enset pulp was preferable for sanitary pad production.

Generally, phase one of the sanitary pad design confirmed that Enset pulp could be used as an alternative raw material for sanitary pad production. This is indeed very good news for countries like Ethiopia that are rich of Enset plantation. Transferring the sanitary industry to this raw material should have great economic, social and environmental impacts. Nowadays, materials that have antimicrobial effects started to be preferred though almost all of the commercial sanitary pads that are available in local as well as international markets have not antimicrobial characteristics. Enset pulp also did not have this property. But it is possible to add this characteristic to the pulp by treating it using different type plants which have antimicrobial property such as eucalyptus, ginger, garlic and the like. However, this topic is beyond the scope of the current study and requires further investigation and analysis.

6.2 Phase Two

The physical parameters of the proposed sanitary pad were the same as those for regular size sanitary pads available in the market. As discussed in Chapter 3, cotton and Enset are widely available materials in countries like Ethiopia. The other material, PLA, is currently not manufactured in Ethiopia. However, countries like Ethiopia are considered to be ideal places for PLA manufacturing because of availability of the needed raw materials. Nowadays, a number of interesting researches are being carried out in universities to make PLA production locally which can be upgraded to manufacturing [20].

The color, thickness as well as comfort of the proposed sanitary pad are comparable to the sanitary pads already available in the market. The proposed sanitary pad is soft and thin which is a favorable feature for the end users. The most important materials used in the sanitary pad design are abundant locally. This could greatly alleviate the long standing problem with women and underprivileged girls dwelling in low resource settings with regards to MHM.

It is also worth nothing that the materials used to produce the proposed sanitary pad product were environmental friendly as those were biodegradable materials. Hence, if we are able to manufacture such sanitary pads locally, we may solve the environmental pollution caused by disposal of the commercial ones.

Figure 40:Final produced sanitary pad.

6.3 Phase Three

6.3.1 Absorbency

The absorbency is one of the major needed characteristics of a sanitary pad. This property was mainly the duty of the absorbent core. The sanitary pad that has a high quality of absorbency makes girls and women to feel comfortable and secure. The absorbency capacity of the proposed sanitary pad was tested using the procedure indicated in the methodology section in the previous chapter. Table 5 summarizes the values that were recorded following the test.

Table 5:Time taken to absorb the colored fluid.

Sanitary pads	**Time taken for the 1st 15ml absorption (Seconds)**	**Time taken for the 2nd 15ml absorption (Seconds)**
1	9	21
2	11	24
3	10	25
Average	10	23.3

The average time taken for the 1st 15ml absorption was found to be 10 seconds while for the 2nd 15ml was fund to be 23.3 seconds (see also Fig. 41). That shows the pad can absorbe the 30ml of color fluid with out leakage that justify Enset pulp met the required absorbancy level based on the standard. The rate of absorbancy was also absolutly attractive and comparable to the conventional sanitary pads. The average time that was taken to absorb the total amount of fluid at 32^{o}c was around 33.3 seconds, which was very fast and absolutly acceptable. Most women **e**xperienced a blood flow between 10-80ml and the average amount of blood that a woman's body expel during her menstruation is found to be 35ml. So, on average, a woman needs to use two of the proposed sanitary pad per day. However, since it is recommended to change a pad 4-6 hours after each use for safety matters, we need at least 3 pads for a day [30].

Figure 41:Images taken after 15ml and 30ml of colored fluid absorbed, respectively.

6.3.2 Ability to Stand Pressure After Absorption

This test was important to consider different types of pressures that could be induced during use. Girls perform walking, running, sitting, standing and other exercises in their daily life. Hence, a sanitary pad should have the ability to withstand changes that might arise as a result of such kinds of daily activities. As discussed earlier, the sample sanitary pads were tested by putting 1 kg weight on the middle of the pad for five minutes after absorption test. No leakage at the back as well as at the side of the pad was observed. Following the test and peeling the core part of pad, no fluid was observed as shown in Figure 42. This clearly shows an excellent absorbency capacity of the Enset pulp.

Figure 42:Absorbent capacity of the absorbent core of the proposed sanitary pad.

6.3.3 Disposability

The other majorly needed but usually ignored criterion for sanitary pads is disposability. This property got a major attention in the current research since it is one of the main troubles that our world is facing today. The standard procedure for testing disposability of a sanitary pad was done by removing the upper and the bottom layers of the pad. The reason behind was that it is believed that most of the time the upper and the bottom layer of a sanitary pad are synthetic polymers, which take a long time to degrade during disposal. Therefore, the standard disposability test of a sanitary pad only concentrates on the absorbent core part. Following the standard procedure explained on the methodology section in the previous chapter, the Enset pulp, which is the absorbent core, was disintegrated in water just in 20 seconds, which shows its disposability (see also Fig. 43).

Additionally, the other materials used in the proposed sanitary pad design including the cotton and bioplastics are biodegradable and ecofriendly. The literature indicates that cotton materials take 1-5 months to degrade in land-fill [31] while bioplastics need 3-6 months to compost [32]. Therefore, compared to the conventional sanitary pads available in the markets, the proposed sanitary pads in this thesis are more eco-friendly for the environment during disposal.

Figure 43:Image of a fully disintegrated absorbent core.

6.3.4 pH Value

As per the IS 5405 standard, pH value of a given sanitary pad has to be between 6.0 and 8.5. The pH value of the proposed sanitary pad was measured at 7.04. Thus, one can conclude that Enset pulp is safe for sanitary pad production.

6.3.5 Fluid Retention Test

This is about the capacity of the product to hold a fluid. Following the procedure presented in the previous chapter, the sample pad absorbed 96.2gm (= 105gm – 8.8gm) of water and it retained 10.87gm of water as also indicated in Fig. 44.

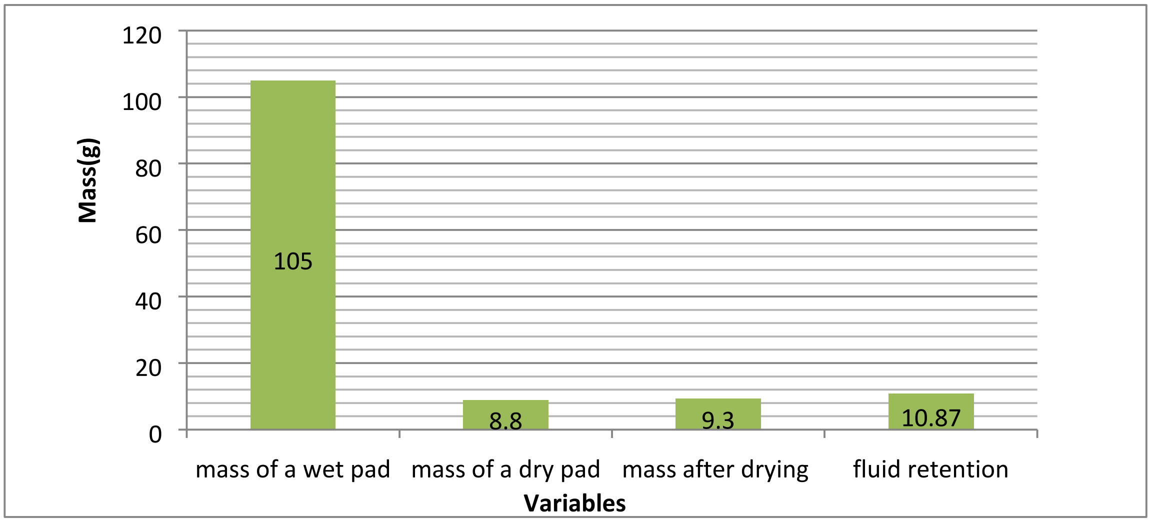


Figure 44:Fluid retention.

6.3.6 Liquid Strike Test

This property is important for the user to feel comfortable while using the pad. This characteristic is majorly the duty of the upper layer of the pad. Liquid strike test measures how fast the upper layer transfers the blood or the fluid to the absorbent core. So, the upper layer of the proposed sanitary pad, which was cotton fabric, was measured under this test. It was observed that the cotton fabric transferred the first drop of fluid within couple of seconds. But when the volume of the fluid was increased, the time taken to transfer also increased to about 5-6 seconds. However, it is still acceptable and convenient for use.

One could increase liquid striking ability of the proposed pad by adding a thin layer of additional cotton fabric between the top sheet and absorbent core as a liquid distributing layer. This layer is considered as part of the top sheet and it is used to drawing away a fluid from the top sheet and holds it for the absorbent core to absorb. By including this thin cotton fabric in the top sheet, one could increase the liquid striking ability of the pad even more.

6.3.7 Wicking Experiment

This experiment measured the ability of materials to uptake liquid. This was particularly important quality of the top sheet, so that menstrual blood might be immediately absorbed from the wearer. This test was also important to give the user comfort by distributing any discharge to every part of the absorbent core. The cotton material that was used in the pad design exhibited an attractive wicking property. During the test, the liquid travelled through about 13 cm of the cotton in 30 minutes (i.e. rate of 4.3 mm per minute). See also Fig. 45.

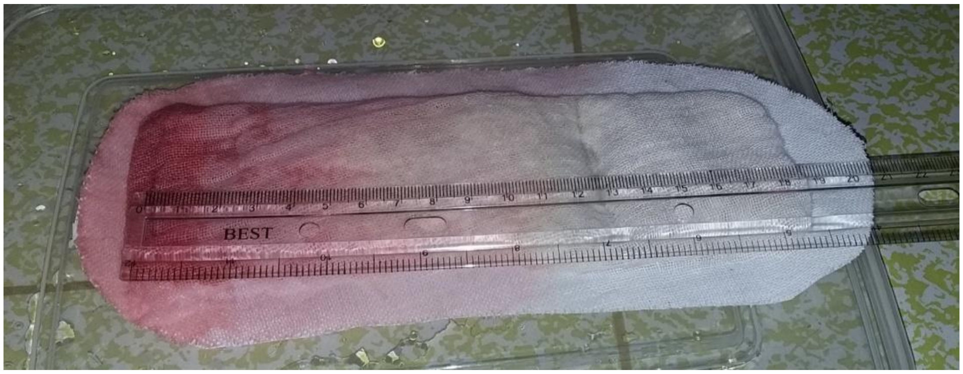


Figure 45:Image shown wicking capacity of the sample sanitary pad.

6.3.8 Cost Estimation

The cost is a major constraint for the users especially it is basic criteria for most girls in low income societies. Sanitary pad is not a luxurious material but rather a basic need for every girl. Therefore, the cost has to be minimal in order to make the product affordable.

The cost of a single pad was calculated by considering every expenditure that was invested to make the final sanitary pad as shown in the methodology section in the previous chapter. The estimated cost of the proposed sanitary pad is 0.85 Ethiopian birr. Assuming a pack contains a total of 13 pieces, the total production cost per pack would be around 11.05 birr. Assuming the selling price is 14-15 birr, available sanitary pads in the market would be 2 to 5 times more expensive than the proposed pad in this thesis. This could be considered a substantial saving of cost for women and underprivileged girls who want to use the new sanitary pad.

Chapter Seven

7. Conclusion

The research focused on an alternative material that can be used for sanitary pad production. The proposed sanitary pad was made up of cotton fabric, Enset pulp and bioplastic. These raw materials were convenient and locally available in countries like Ethiopia. The quality of the proposed sanitary pads was tested in terms of their absorbency, pH, wicking property, fluid retention, liquid stricken property, antibacterial property, cost-effectiveness and disposability. The sample pads showed a positive and attractive response for all functional tests. Therefore, the research justified the reliability and convenience of the final product as MHM material.

The research could contribute a great deal to women and girls living in low resource settings regarding MHM products. The affordability and high hygienic value of the proposed sanitary pad means a lot to those underprivileged users. Two of the materials used in the pad design, namely cotton fabric and Enset pulp, are very widely available in countries like Ethiopia. Countries like Ethiopia have again vast potential to manufacture the third material used in the pad design which is bioplastic. These facts make the Enset based sanitary pads the most feasible among all other types of pads currently available in the market.

The ecofriendly nature of the proposed sanitary pad should also be capitalized. The issue is particularly more important in places and regions with no modern disposal facilities but traditional mechanisms including landfill and burning. So this research could be taken as a transition to switch to more sustainable and safer raw materials in sanitary pad manufacturing.

The other contribution of this research is cost minimization. This is a major reason that makes our girls not to use sanitary pads. In this regard, this research can be a milestone to transfer to a more affordable raw material that has a potential to minimize the price of the end MHM product and in doing so, it is assumed we can decrease the burden on our women and girls.

7.1 Recommendation and Future work

More research would be recommended to test and validate the efficacy of the Enset based sanitary pad design to justify why it has at least the right to exist in parallel with other designs currently existing in the market. Manufactures could be encouraged by the many superiorities of the Enset based design: wide raw material availability, comfort, affordability and ecofriendliness are the main ones. The pad product still needs to be tested on users to guarantee its final acceptability before it has to go for commercialization.

Designing part of the pad and comparison of the produced pad with other commercial sanitary pads is considered as the major future work.

References

[1] Rajanbir Kaur et al. “Menstrual Hygiene, Management, and Waste Disposal: Practices and Challenges Faced by Girls/Women of Developing Countries.” Journal of Environmental and Public Health, volume 2018, pp1-9, February 2018.

[2] Tharanga Yakupitiyage. “Menstrual Hygiene Gaps Continue to Keep Girls from School.” Internet: http://www.ipsnews.net, May 27, 2016 [Apr.12,2020].

[3] Marielle Snel. “Study on Menstrual Management in Ugandan Schools.” 1st Menstrual Hygiene Management Conference, 2014, pp. 21-30.

[4] Yemi Lufadeju. “FAST FACTS: Nine things you didn't know about menstruation.” Internet: http://www.unicef.org, May 25, 2018 [Apr.15, 2020].

[5] Snigdha Sinha. “Eco-friendly sanitary pads made of banana fibre – Saathi pads‟s solution to menstrual waste.” Internet: http://www.youurstory.com, August 10, 2015 [Apr.10, 2020].

[6] Shannon Rosenberg et al. PSI. Expanding Access to Menstrual Hygiene Products for Adolescent Girls and Young Women in Ethiopia. Washington, D.C.: PSI; 2018.

[7] Alexandra Geertz et al. “Menstrual Health in Ethiopia | Country Landscape Analysis”, May 2016.

[8] “Menstrual Cycle Basics.” Internet:http://www.yourperiod.ca/normal-periods/menstrualcycle-basics/ [Apr.10, 2020]

[9] Jennifer Knudtson and Jessica E.Mc Laughlin. “Female Reproductive Endocrinolog.” Internet: http://www.merckmanuals.com, March 2019, [Apr.11, 2020].

[10] Budhathoki et al. (2018, Feb.). “Menestrual hygiene management among women and adolescent girls in the aftermath of the earthquake in Nepal.” BMC Women‟s Health. [On-line]. 18(33), pp.1-3. Available: http://www.doi.org/10.1186/s12905-018-0527-y [Apr.11, 2020].

[11] Zinash Tsegaye et al. “Towards a Local Solution for Menstrual Hygiene Management in School.” Case studies Ethiopia, 2011.

[12] THE LAST TABOO, Research on managing menstruation in the Pacific, August 2016. Internet: http://www.pacificwomen.org

[13] Barman et al. “Natural and Sustainable Raw Materials for Sanitary Napkin.” Journal of Textile Science & Engineering Natural, Vol.7, pp. 1-3, July 2017.

[14] Jennifer Kotler. “A short history of modern menstrual products.” Internet:http://www.helloclue.com/article/culture/a-short-history-of-modern-menstrual-product , November 20, 2018 [Apr.20, 2020].

[15]Boris Hodakel.”Cotton fabric” Internet: http://www.sewport.com/fabricsdirectory/cottonfabric.may 07,2020 January 01, 2020 [Apr.20, 2020].

[16] Zeleke et al. “Cotton production and marketing trend in Ethiopia: A review.” Cogent Food & Agriculture, vol.5, pp.1-7, Nov.2019.

[17] “Properties and cotton products”. Internet: http://www.cottonaustralia.com.au/uses-ofcotton , 2020 [Feb.5, 2020].

[18] Hanna Berhanu.”CHARACTERIZATION, VALORIZATION AND OPTIMIZATION OF ENSET */ENSETE VENTRICOSUM/* FIBERS FOR PAPER PULP PRODUCTION.” PhD thesis, .Addis Ababa University, Ethiopia, 2018.

[19] Mangesh D. Teli and Jelalu M. Terega. “Chemical, Physical and Thermal Characterization of Ensete ventricosum Plant Fibre.” International Research Journal of Engineering and Technology (IRJET), vol. 04, pp.67-75, Dec.2017.

[20] Yonas Abate. “SYNTHESIS AND PRODUCTION OF LACTIC ACID (LA) FROM FALSE BANANA/BULA USING LACTOBACILLUSPLANTARIUM“““ M.A. thesis Addis Ababa University, Ethiopia, 2016

[21] Prof. Endashaw Bekele. “The Center of Origin and Domestication of Ensete ventricosum and its phylogenetic relationship to Some Musa Species.” International workshop on Enset, Oct. 2016, Addis Ababa, Ethiopia.

[22] Dr. Michael Thielen.”BIOPLASTICS-WHAT DOES IT MEAN, EXACTLY?” in BIOPLASTICS, Ed. Germany: Fachagentur Nachwachsende Rohstoffe e. V. (FNR) Agency for Renewable Resources, 2014, pp. 4-6.

[23] Gadhave et al. “Starch Based Bio-Plastics: The Future of Sustainable Packaging”. Open Journal of Polymer Chemistry, vol. 8, pp. 21-33. May, 2018.

[24] Shristi Basnet. “Production of Polylactic acid in laboratory scale, and characterizing the thermal properties” Degree Thesis, Arcada University, Finland, 2016:

[25] “Polylactic Acid Fibers” Internet: http://www.polymerdatabase.com/fiber/PLA.html, 2015 [Dec. 22, 2019].

[26] Majid Jamshidian et al. (2010, Aug.). “Poly-lactic Acid; Production, Application, Nano composites and Release studies.” Comprehensive reviews in food science and food safety. [online]. 9 (5), Available: http://www.doi.org/10.111/j.1541-4337.2010.00126.x [May 20, 2020]. [27] Mishra Sarika. “Desighn and Development of Sanitary Napkin with Herbal and Antimicrobial Potentials.” PhD thesis, Maharana Pratap University of Agriculture and Technology, India, 2017.

[28] “Sanitary napkin testing as per IS5405.” Internet: http://www.sigmatest.org, May 01, 2020 [June 04, 2020].

[29] Anuradha Barman et al. “An Overview on Sanitary Napkins.” Internet: http://www.Technicaltextile.net , [June 03, 2020].

[30] .Stephanie Kraus. “menestration: how much we bleed”,Internet: http://ecofemme.org, Feb. 2018 [June 02, 2020].

[31] Rhonda P.Hill. “EDGE Fast Fact| Non-Biodegradable Cloth Take 20 to200 Years to Biodegrade.” Internet: http://www.edgepo.com, 2017 [June 02, 2020].

[32] Amanda Keetly. “What about bioplastic, biodegradable plastic & compostable plastic.” Internet: http://www.lessplastic.org.uk, March 2019 [June 02, 2020].