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A review of wound dressings treated with Aloe vera and its application on natural fabrics

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ABSTRACT

Natural wound dressings extracted from Aloe vera leaves have gained greater recognition in the treatment of wounds due to their ability to accelerate wound healing and their nontoxic nature for humans and the environment. Treated wound dressing allows the removal of moisture and movement of gases to and from the wound area while the antimicrobial agent in it suppresses microbial growth. Extracted Aloe vera components can be applied directly into a fabric or they can be electrospun to nanoparticles that are incorporated into the fabric. Because biological antimicrobial agents like Aloe vera are not highly effective against high concentrations of microorganisms, chemical antimicrobial agents are still used even though they are harmful. Processing Aloe vera using methods like the thermal treatment method makes the Aloe vera lose some of its therapeutic benefits. Natural fabrics treated with Aloe vera can be used as an alternative to chemical agents used for wound treatment. Natural wound dressings treated with natural antimicrobial agents have the advantage of preventing microbial growth while at the same time promoting wound healing without activating the immune response as they are biocompatible.

摘要

从芦荟叶中提取的天然伤口敷料因其加速伤口愈合的能力及其对人类和环境的无毒性而在伤口治疗中获得了更大的认可。经处理的伤口敷料允许去除水分和气体进出伤口区域,同时其中的抗菌剂抑制微生物生长。提取的芦荟成分可以直接应用到织物中,也可以电纺成并入织物中的纳米颗粒。因为像芦荟这样的生物抗菌剂对高浓度的微生物不是很有效,所以即使化学抗菌剂是有害的,它们仍然被使用。使用热处理法等方法加工芦荟会使芦荟失去一些治疗效果。用芦荟处理过的天然织物可以用作伤口治疗用化学制剂的替代品。用天然抗菌剂处理的天然伤口敷料具有防止微生物生长的优点,同时促进伤口愈合而不激活免疫反应,因为它们是生物相容的。

KEYWORDS

Aloe vera; antimicrobial; bioactive compounds; natural fabrics; wound dressing

关键词

芦荟; 抗微生物的; 生物活性化合物; 天然织物; 伤口敷料

Introduction

Historically, untreated wound dressings have been used to protect wounds against microbial invasion and mechanical damage by acting as barriers. However, being a barrier is not always effective in preventing microbial invasion; hence the need to incorporate antimicrobial compounds into wound dressings. Once a wound area is invaded by microbes, a minor acute wound can quickly turn into a chronic one which can necessitate the need for major medical treatments. This will in turn delay the healing and pain (Chauhan and Kumar 2020; Guo et al. 2022; Ji et al. 2022; Kaur, Joshi, and Singh

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2022). Conventional wound dressings like cotton and silk have limited fluid absorption. In contrast, synthetic wound dressings such as synthetic hydrogels and superabsorbents do not suffer from this as they retain some fluids. Fluid retention by wound dressings is essential in keeping the wound area moist, as moisture promotes wound healing (Baghersad et al. 2018; Yao et al. 2022). Another disadvantage with conventional wound dressings is that it is not easy to incorporate antimicrobials for sustained release of the antimicrobials at the wound site. However, synthetic wound dressings are possible (Hu et al. 2019).

Antimicrobials can be classified into two types: biological and chemical. Biological antimicrobials are extracted from plants whereas chemical ones are synthesized using chemical elements such as silver, copper, zinc oxide, zinc, etc. Chemical antimicrobials can be toxic to humans and the environment; hence, biological antimicrobials are a good alternative as they are biocompatible and nontoxic. Amongst the candidates from natural antimicrobials is Aloe vera which contains active compounds that prevent microbial growth and promote wound healing (Balaji et al. 2015; Natarajan, Rajan, and Das 2020; Nizam et al. 2021). Some of Aloe vera's compounds responsible for antimicrobial activity are anthraquinones, dihydroxyanthraquinone, saponins, glycoproteins, gamma-linolenic acid, prostaglandins, and mucopolysaccharides (Singh, Gupta, and Gupta 2018). It was reported that when it comes to the virus, Aloe vera does not kill it but acts as a barrier that prevents the virus from attaching to the host cell. Aloe vera gel can be easily extracted from the leaves by squeezing the leaves and then coated onto the fabric. This technique is the simplest way to recover compounds and apply them to fabric to impart antimicrobial activity. The chemical method is also used to recover the compounds; however, it is not cheap compared to the physical method (Chauhan and Kumar 2020). Factors that can influence the use of antimicrobial wound dressing are hydrophilicity, cost, durability, stability, toxicity, and long lifetime (Mayet et al. 2014; Mignon et al. 2019; Naseri-Nosar and Ziora 2018). It is highly unlikely that real wound dressings can meet all these demands. The goal is to select factors that can meet the requirements for the wound.

The usefulness of Aloe vera as a product with a variety of applications is widely researched. Babu et al. (2018) reviewed Aloe/kapok/palmyra/corn fiber/vetiver natural fibers for biomedical applications. Balaji et al. (2015) reviewed biomaterials-based nano-applications of Aloe vera and its perspective. Maenthaisong et al. (2007) reviewed the efficacy of Aloe vera used for burn wound healing. Khanzada et al. (2020) investigated the fabrication of promising antimicrobial Aloe vera/PVA electrospun nanofibers for protective clothing. Our review in this paper is to provide the discussions on Aloe vera-treated wound dressings as agents that promote wound healing while simultaneously preventing microbial growth. The application and challenges of using Aloe vera as an antimicrobial in fibrous wound dressings are also highlighted.

Aloe vera plant

The Aloe vera plant is a succulent plant that belongs to the Liliaceae family. It is grown all over the world because of its numerous health and cosmetic benefits. Some people call it an emergency doctor or a natural beautician. There are wide varieties of Aloe vera species, ranging from 360–500. Of these species, the *Aloe barbadensis* Miller, *Aloe arborescens* Miller, *Aloe ferox* Miller, *Aloe vera* var. *chinensis*, and *Aloe Saponaria* are considered to have the most health benefits, with *Aloe barbadensis* Miller being the most important (Ali et al. 2014; Gong and Lu 2015). Other species, such as the *Aloe greatheadii* var. *davyana* (Figure 1) and *Aloe ferox* Miller are common in South Africa.

Aloe vera farming is a big business, and countries that are big growers are Latin American countries, the USA, China, and Thailand (Radha and Laxmipriya 2015; Rodriguez-Gonzalez et al. 2011). The most important part of the plant is the long-thick succulent leaves rich in biological compounds (Figure 1). Hence, it is regarded as a global plant. The leaf has three layers, the inner, middle, and outer layers, which contain about 99% water and 1% bioactive compounds. The inner layer comprises the transparent gel, which is rich in components. The middle layer comprises the yellow-bitter sap, which has anthraquinones and glycosides. The outer layer is for protection and



Figure 1. Aloe greatheadii var. davyana. .

enables it to survive in various extreme conditions (hot and dry areas with low rainfall). It can also survive in areas with low freezing temperatures (Ali et al. 2014; Baruah, Bordoloi, and Baruah 2016; Gong and Lu 2015; Nejatizadeh-Barandozi 2013; Radha and Laxmipriya 2015).

Aloe vera compounds

Aloe vera consists of a variety of bioactive compounds. The chemical constituents of Aloe vera and associated properties for various applications are shown in Figure 2 (Balaji et al. 2015).

There are about 20 minerals, 75 nutrients, 18–20 amino acids, 12 vitamins, and 75–200 active compounds, aloesin, anthraquinones (aloin and aloe-emodin), aloe-mannan, acemannan (gel polysaccharides), mannose-6-phosphate, barbaloin, aloe ride, verectin, gibberellin like substance, aloe resin I, 5-methyl chromone, flavonoids, glycoprotein fraction, anthraglyco- sides, reducing sugars, cardiotoxic glycosides, saponins, naphthoquinones, sterols and triterpenoids (Ali et al. 2014; Chauhan and Kumar 2020; Mondal, Saha, and Rahman 2021). Most constituents are glycoprotein, barbaloin, emodin, mannose-6-phosphate, polysaccharides, acemannan, and aloesin (Ali et al. 2014; Mondal, Saha, and Rahman 2021). Differences in the content of compounds can be due to differences in climate, seasons, and geographic locations (Rodriguez-Gonzalez et al. 2011). The presence of these compounds makes the Aloe vera plant a good candidate as an antimicrobial, anti-inflammatory, or

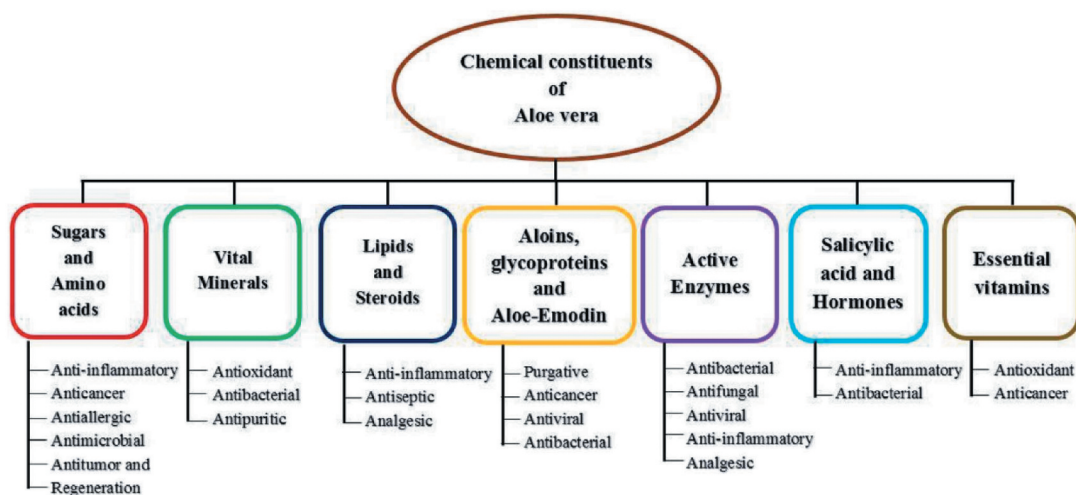


Figure 2. Chemical constituents of Aloe vera and its biological properties (Balaji et al. 2015).

antioxidant agent. The synergistic effects of compounds make them have a wide variety of health benefits in one plant (Baghersad et al. 2018; Singh, Gupta, and Gupta 2018).

As stated previously, the broad health benefits and combinations of compounds make Aloe vera an important plant (Baruah, Bordoloi, and Baruah 2016). Seven amino acids a human body cannot synthesize are present in Aloe vera. Amino acids promote wound healing by repairing damaged cells such as wounds. The glycoprotein, mannose-6-phosphate, and acemannan compounds also promote wound healing. Sanchez-Machado et al. (2017) reported that they promote wound healing by promoting cell proliferation, vascular endothelial growth factor, and type I collagen. Glycoproteins also have antiallergic properties and suppress histamine that can cause allergic reactions in some people. Mannose 6-phosphate also suppresses inflammation. Other anti-inflammatory compounds in Aloe vera are β -sitosterol, lupeol, emodin, Aloeresin, veracylglycan, cinnamoyl, and glucopyranosyl. Compounds such as polysaccharides, anthraquinones, and barbaloin are responsible for antimicrobial activity. Gong and Lu (2015) reported that Aloe vera enzymes also suppress inflammation, and they also break down fats and glucose (Ali et al. 2014; Baruah, Bordoloi, and Baruah 2016; Chauhan and Kumar 2020; Gong and Lu 2015; Mondal, Saha, and Rahman 2021; Nia, Taghipour, and Siahmansour 2021; Sanchez-Machado et al. 2017). Polysaccharides can act as antioxidants and remove free radicals in the body. Anthraquinones have also found application as laxatives (Gong and Lu 2015). Vitamins are also present in Aloe vera and can also act as antioxidants. Vitamins promote wound healing by ensuring the proper functioning of metabolism (Gong and Lu 2015). Concerns about the compound Aloin, reported to be carcinogenic when it is oxidized, were found not to have evidence support (Gong and Lu 2015). Aloe vera has many health benefits and is being explored as a natural wound healing agent incorporated into wound dressings to prevent microbial growth and promote the wound healing process is complicated and requires multiple compounds.

Challenges

The separation of the individual Aloe vera biological compounds is complex as different compounds react differently (Ali et al. 2014) to chemicals or heat. Furthermore, in the presence of air, the components oxidize and degrade. This is one of the reasons why they have a shorter lifetime, unlike synthetics which have a longer lifetime. The chemical or physical method can be used to recover the compounds (Alvarado-Morales et al. 2019; Hu et al. 2019). The chemical method uses chemicals to extract the compounds, and when the used chemicals are disposed of, they pollute the environment. Toxicity to humans can also be an issue. The physical method is the simplest, and most cost-effective. Leaves are squeezed and filtered to recover fluids which make up about 70–80% of the whole leaf weight. Because air oxidizes Aloe vera's compounds, they are processed immediately to minimize oxidation once the leaves are harvested. A change in the color of the Aloe vera solution is an indicator of degradation. Techniques such as irradiation, thermal, and dehydration can be used to preserve them. The use of heat is a challenge as different compounds have different heat tolerances. Temperatures above 60°C are reported to degrade those compounds that are not tolerant to these temperatures. Nicolau-Lapena et al. (2021) reported the degradation of acemannan. Rodriguez-Gonzalez et al. reported that polysaccharide compounds recovered at about 70°C were more stable than those recovered at 50–60°C and 80–90°C. Heat is also used to extend the shorter shelf life of natural antimicrobials, and this further degrades the compounds. The use of Aloe vera-treated wound dressing is still a challenge for wounds that need to be treated for extended periods as the components have a shorter lifetime as stated previously, and such wound dressings will require frequent replacement resulting in increased cost for the patient. Patients also experience pain when the dressings are removed or applied. This is one of the reasons why synthetic antimicrobials like nano-metals and nano-carbons still dominate the market even though they pose risks to the environment and health. Nicolau-Lapena et al. (2021) suggested storing Aloe vera gel at low temperatures. At lower temperatures, the natural antimicrobials can be stored for up to 5 days, and at room temperatures, it is only for up to 2 days (Ali et al. 2014; Alvarado-Morales et al. 2019; Chauhan and Kumar 2020; Hu et al. 2019;

Rodriguez-Gonzalez et al. 2011; Sanchez-Machado et al. 2017). Alternatives that have been suggested are ultrasound and thermosonication methods. Ultrasound uses sound waves, whereas thermosonication uses sound waves and low heat. Ultrasound is already being used in the food industry to process food (Alvarado-Morales et al. 2019).

The effectiveness of antimicrobials against microorganisms is highly dependent on their concentration. With natural antimicrobials, concentrations can differ from one plant to the other. On the other hand, synthetic antimicrobial concentrations are constant; and predetermined before production. Despite their shortcomings, natural antimicrobials pose no risk to humans and the environment, unlike synthetic antimicrobials that are environmentally unfriendly and can be toxic to humans. A natural antimicrobial is biocompatible and does not induce an immune response (Maenthaisong et al. 2007; Mohseni et al. 2019). The antimicrobial quaternary ammonium salt suppresses microbial growth when applied to wounds; however, it causes hemolysis of red blood cells (Gharibi et al. 2019). Nano-Silver and nano-metal oxides can cause damage to the liver, spleen, and kidney. Nano-carbons can pierce cells and induce inflammatory cytokines, hence, the need for natural antimicrobial agents as they do not interfere with the body's mechanisms (Hu et al. 2019).

Even when the antimicrobials are incorporated into the wound dressing, there are still challenges, as they can be removed by laundering when the dressing is laundered or abrasion when it is worn. Low durability and weak bonding make it easier to remove the antimicrobials (Chauhan and Kumar 2020).

Application

The simplest application of antimicrobial agents to a wound dressing involves the immersion of the fabric dressing in a solution containing the agent. Another simple way is to spread them on the surface of the fabric dressing that will be in direct contact with the wound (Pereira, Mendes, and Bartolo 2013). The incorporation of antimicrobial agents into fabric is not permanent, as the antimicrobial activity decreases with increased cleaning cycles (Natarajan, Rajan, and Das 2020). Silk fabric treated with Aloe vera still had its antimicrobial activity after 5 cleaning cycles (Mondal, Saha, and Rahman 2021; Subramani et al. 2018). Subramani et al. (2018) reported that cotton fabric treated with Aloe vera nanoparticles has antimicrobial activity even after 10 cleaning cycles.

Korra (2022) reported the cotton fabric treated with an Aloe vera finish had no fungus growth for up to 10 washes ((Table 1). The laundering durability was due to the strong covalent bond with the cotton fabric by Aloe vera active components that are cross-linked by citric acid. The carboxylic groups of the citric acid are linked with the hydroxyl part of the cellulose through a covalent bond (Ketema and Worku 2020). There were no significant changes in the tensile properties at 5 and 10 washes. After 15 and 20 washes, there was a growth of fungus in the fabrics, which can be attributed to the breakage of intermolecular hydrogen bonds within the cellulose molecules. A decrease in tensile properties was reported.

Antimicrobial nanoparticles are also incorporated into the wound dressings, and they are released to the wound area when the dressing is applied. Two methods of generating and incorporating them are physical and chemical (Chauhan and Kumar 2020; Khanzada et al. 2020). The physical method uses heat, making nanoparticles more stable as the temperature of the particles is kept constant. High heat increases the consumption of electricity. Chemical methods use chemicals (Khan et al. 2022;

Table 1. Antifungal property of washed fabric treated with 10 g/L Aloe vera finish (Korra 2022).

No. of washes	Visual inspection	Warp strength (N)	Loss (%)	Weft strength (N)	Loss (%)
0	No growth	314.85	0.05	224.83	0.08
5	No growth	314.82	0.06	224.83	0.08
10	No growth	314.81	0.06	224.72	0.12
15	Microscopic	311.35	1.16	216.56	3.75
20	Macroscopic	266.19	15.50	176.86	21.40

Khanzada et al. 2020) and concerns are being raised about their impact on the environment. Biological methods can be an alternative by using bacteria and fungi from plants to synthesize Au, Cd, ZnO, Pb, Pd, Fe, and Ag nanoparticles. Even though the biological method is environmentally friendly, its efficiency is dependent on the growth conditions of microbes, genetics of microbes, and biocatalysts (Khan et al. 2022). Electronic sensors can also be incorporated into wound dressings to monitor the healing process (Ambekar and Kandasubramanian 2019).

Wound dressings

An ideal wound dressing prevents microbial invasion from the outside environment while simultaneously promoting wound healing by providing a moist environment, absorption of excess fluids, and allowing free movement of gases to regenerate the skin (Yao et al. 2022). In burn wounds, microbial invasion can occur within 48 hours (Liu et al. 2019). Requirements for the materials are strength, biocompatibility, biodegradability, antimicrobial, nontoxic, and promotion of cell adhesion and proliferation. Wound dressings must also meet the same requirements, in addition to permeability to gases and absorption of exudates. Excessive exudates cause maceration creating an environment favorable for microbial growth (Khan et al. 2022; Prakash et al. 2021).

Wound dressings can be made using synthetic polymers or natural biopolymers. Polymers can be blended to produce dressings with desired properties. Blending takes advantage of individual polymer properties. Natural biopolymers have received huge attention as they are environmentally friendly and do not induce an immunological response. Natural biopolymers are more susceptible to microbial attacks than synthetic ones (Korra 2022; Naseri-Nosar and Ziora 2018; Prakash et al. 2021; Singh, Gupta, and Gupta 2018). Synthetic polymers like polyvinyl and polycaprolactone have received attention as they are biodegradable, biocompatible, and nontoxic. In addition, they have better chemical and physical properties than natural biopolymers (Ji et al. 2022). Other factors taken into consideration when it comes to the choice of the polymer are cost, simplicity, and versatility.

Abdel-Mohsen et al. (2020) fabricated Collagen (CO)/chitosan-glucan complex (CSGC) hollow fibers encapsulated Aloe vera scaffold for wound dressing applications, particularly for infected chronic wounds and ulcers. Using Aloe vera powders, they reported that the hydrolytic stability of the wound dressing sheet was improved when compared with native collagen dressing sheets.

Prakash et al. (2021) reported a wound dressing material coated with natural extracts of curcumin, aloe vera, and chitosan solution enhanced with rhEGF (REGEN-D). One of their studies was on the rat wound closure rate starting from 2, 7, 12, 17, and 21 days (Figure 3). The wound size was 2.5 cm in length and 2 cm in width. A coating containing 20% Aloe vera was applied on 100% bamboo fabrics. Other components of the coating were curcumin, chitosan, and rhEGF. Samples CAC II and CAC III had better wound closure rates due to better drug loading.

The electrospinning technique is widely used to produce nanofiber membranes used to make wound dressings. A high current is applied to the polymer solution to create a voltage difference which creates the formation of nanofibers. It consumes a lot of electricity (Khan et al. 2022; Patnaik et al.

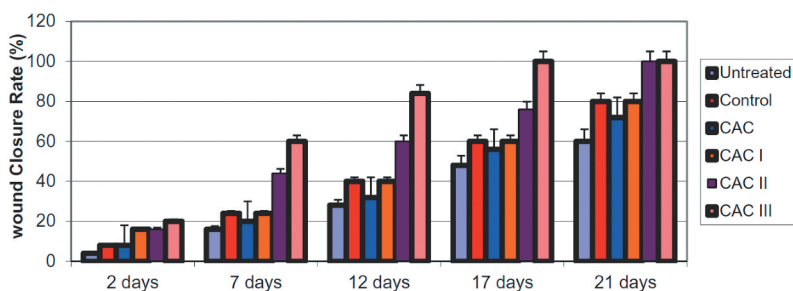


Figure 3. Wound closure rate-% (Prakash et al. 2021).

2007; Patnaik, Jacobs, and Anandjiwala 2010). The synthetic polymer solution can be more easily electrospun than the natural polymer solution. In general, natural polymers tend to have lower mechanical and structural stability than synthetic ones (Chen et al. 2022). Most electrospun wound dressings are prepared from natural biopolymers such as silk fibroin, alginate, collagen, chitosan, gelatin, hyaluronic acid, and starch because of their better biocompatibility and biodegradability (Adamu et al. 2021; Hu et al. 2019). Polycaprolactone (PCL) and polyvinyl alcohol (PVA) dominate in synthetics (Mohseni et al. 2019). A combination of the hydrophobic PCL and hydrophilic PVA fibers produces a structure that possesses good mechanical properties (Mohseni et al. 2019). The use of Aloe vera nano cellulose fibers with polyvinyl alcohol (PVA) improves the thermal stability and mechanical strength of PVA due to the increased interaction of nanofibers and PVA (Babu et al. 2018). Increasing the concentration of Aloe vera when preparing electrospun PVA/Aloe vera nanofibers is reported to increase the fineness of the PVA fibers (Khanzada et al. 2020), and the reason for this was not given.

Aloe vera extract solution on its own cannot be electrospun to make nanofibers and it must be blended with fiber polymers (spinning agents) to produce nanofibers. For example, Aloe vera and polycaprolactone are electrospun to produce nanofibers that can be used as a wound dressing. The nanofibers mat is permeable, antiseptic, and has good moisture retention. Good permeability allows increased movement of oxygen and moisture which are essential for wound healing. For the electrospun hydroxypropyl methylcellulose membrane, it is reported that when the concentration of Aloe vera was from 2% to 4% and then to 6%, it was accompanied by increases in fabric permeability. Another biocompatible polymer that can be used to produce an antimicrobial membrane for medical applications is chitosan polymer which is electrospun with Aloe vera (Grothe et al. 2017; Miguel et al. 2018; Mondal, Saha, and Rahman 2021). Chitosan on its own has antimicrobial activity (Nia, Taghipour, and Siahmansour 2021) and the incorporation of antimicrobials further enhances its antimicrobial activity.

Hydrogels and superabsorbent wound dressings

Traditional hydrophilic wound dressings such as gauze, bandages, and cotton pads are still widely used as they are cheaper to produce. They are usually made from hydrophilic cotton or flax fibers to absorb wound fluids. Using these fibers can cause secondary trauma as the fibers tend to adhere to the surface of the wound when fluids evaporate, and the wound area becomes dry (Guo et al. 2022; Ji et al. 2022). Sticky and dry wound dressings are not easy to remove, and the patient will experience pain. To address this hurdle, hydrogel, and superabsorbent dressings were developed. They are soft, and elastic, have high hydrophilicity, good biocompatibility, and good mechanical performance. They can maintain their structures in different environments (water, temperature, and pH). They can swell and still maintain their structures. Some of the smart hydrogels can be stimulated by factors such as temperature, pH, light, electricity, ions, and enzymes to swell or shrink. Due to the complex process of manufacturing them and the materials needed, the cost is too high compared to conventional dressings. These wound dressings retain some of the fluids that keep the wound area moist. The wound dressing does not stick to the wound, making it easier to remove (Baghersad et al. 2018). Superabsorbent dressings were developed to further improve the absorption capacity of hydrogels. They can absorb up to 1000 times their weight even when under pressure compared to 10 times the hydrogels. Superabsorbents can absorb large volumes of fluids due to their high ionic concentrations compared to the surrounding fluid. Their absorption capacity is influenced by the ionic concentration of the fluids (Mignon et al. 2019). Superabsorbent sodium alginate, a derivative of alginate, is an example of a superabsorbent. Its ionic structure is porous and enables it to be super absorbent. Antimicrobials can be bonded with hydroxyl groups of sodium alginate to make an antimicrobial dressing. Sodium alginate can be sulfonated or quaternized. The sulfonated groups have charges and form bonds with the bacterial metal ions, thereby preventing bacterial growth. The quaternised groups also have charges and form bonds with bacterial charges on the surface of bacteria to alter membrane

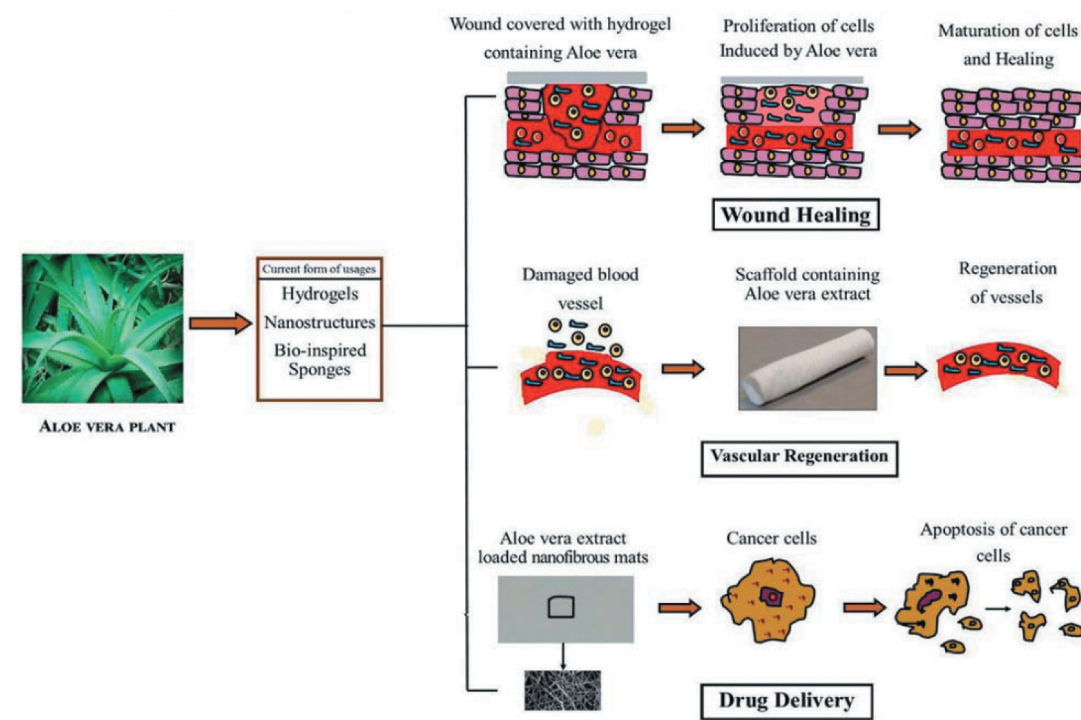


Figure 4. Some examples of Aloe vera in clinical applications (Balaji et al. 2015).

permeability (Guo et al. 2022). Not all hydrogel and superabsorbent membranes are the same, some can be toxic to wound tissues and the environment. An ideal hydrogel or superabsorbent membrane must be nontoxic, soft, and flexible. A softness and flexibility membrane improves comfort (Xie et al. 2022). Antimicrobials can be incorporated into hydrogels and superabsorbent dressings to allow for the slow release of the compounds into the wound area. The antimicrobials protect the wound and accelerate the healing process as seen in Figure 4 (Yao et al. 2022).

Depending on the condition of the wound, a dry wound dressing can be a better choice, especially when a wound is excreting excessive fluids, and you do not want to use dressings that retain fluids. Xie et al. (2022) reported that hydrogels have poor blood absorption and will take longer to stop bleeding. Blood contains platelets that promote the formation of blood clots to stop the bleeding. The incorporation of calcium ions and graphene oxide can address this limitation. Even though fluid promotes wound healing, excessive accumulation causes maceration and slows down the healing process (Pereira, Mendes, and Bartolo 2013). A moist environment also promotes microbial growth. By having high moisture absorption, treated super absorbents are better suited for wounds with excessive while at the same releasing antimicrobials (Pereira, Mendes, and Bartolo 2013).

Cotton dressing

Cotton, the most common natural fiber, can be treated with antimicrobial to impart antimicrobial activity. Cotton wound dressing treated with Aloe vera incorporated into the oxidized pectin – gelatin gel showed good antimicrobial activity against *E. coli* and *S. aureus*, and the wound showed improved cell regeneration. Aloe vera is reported to decrease bacterial growth when its concentration is increased by 20%. However, further increases above 20% did not have a beneficial effect (Singh, Gupta, and Gupta 2018). Ali et al. (2014) reported that after repeated washing of a cotton fabric treated

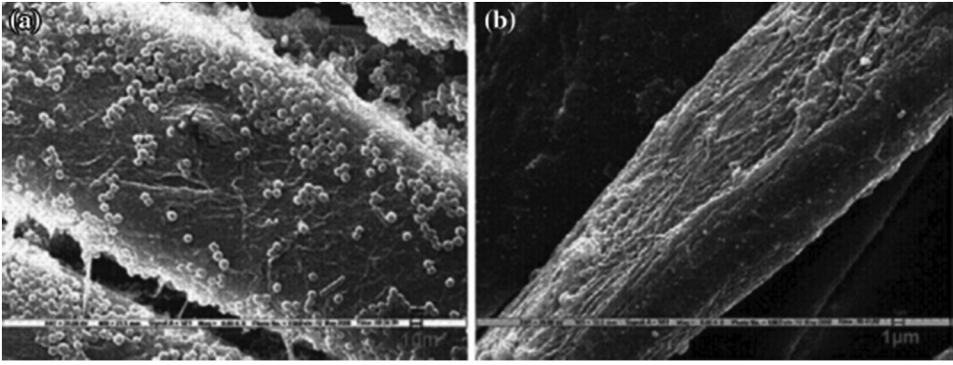


Figure 5. SEM images, (a) cotton fabric without Aloe vera showing *S. aureus* bacterial colony on the fiber surface (b) cotton fabric treated with Aloe vera showing prevention of *S. aureus* bacterial colony on the fiber surface (Mondal et al. 2021).

with Aloe vera, its antimicrobial activity against *E. coli* and *S. aureus* did not completely diminish. However, it decreases with an increased number of cleaning cycles.

Cotton fabric was treated with Aloe vera and compared with non-treated cotton fabric for *S. aureus* bacterial growth (Figure 5). In non-treated cotton fabric, as seen in Figure 5a, there was a large colony of bacteria on the surfaces of the fibers. A cotton fabric that was treated with Aloe vera was able to prevent the growth of *S. aureus*, as shown in Figure 5b. These figures show that treating a fabric with Aloe vera protects the wound against microbes (Mondal, Saha, and Rahman 2021).

Cotton fabric treated with silver nanoparticles had mixed results against microorganisms. Against *E. coli* and *S. aureus*, it was effective at low, medium, and high concentrations. However, against the fungus *Candida albicans*, it was effective only at high concentrations (Hebeish et al. 2014). Prakash et al. (2021) reported that a bamboo fabric coated with Aloe vera, curcumin extracts, and a chitosan solution, possessed antimicrobial activity against *E. coli* and *S. aureus*. The coating was reported to not affect the fabric's tensile strength, tearing strength, abrasion resistance, areal density, and thickness properties. A cotton fabric treated with a solution of Aloe vera extract, almond oil, and Triton X-100 showed antimicrobial activity against *E. coli* and *S. aureus* bacteria, and *Candida albicans* fungus. Aluminum chloride was used as a crossing link in a solution. A cotton fabric treated with a solution of Aloe vera, and neem extracts were effective against *E. coli* bacteria and *Aspergillus niger* fungus but less so against *S. aureus* bacteria (Ghayempour, Montazer, and Rad 2016). The effectiveness of Aloe vera against bacteria and fungi is also reported by Korra (2022). 2020) prepared a hydrophobic antimicrobial cotton fabric by coating it with a mixture of HDTMS and aloe vera extract. This fabric showed good antimicrobial activity and hydrophobicity. It must be noted that even though this fabric maintained its hydrophobicity after washing, it was tested using the ultrasonication bath (Chauhan and Kumar 2020).

Silk dressing

Natural silk fibers are antimicrobial due to the sericin protein. However, subjecting silk to processing treatment dissolves the sericin and exposes the fibers to microbial attack. To compensate for this loss, formaldehyde can be applied. Unfortunately, it is harmful to the environment, and as such, an environmentally friendly polycarboxylic acid has been suggested as an alternative (Nadiger and Shukla 2015). Silk fibers have good properties (antimicrobial activity, strength, elasticity, lightweight, drapability, and moisture absorption). These make them good candidates to produce an ideal antimicrobial wound dressing. Nano-silk fibrous membranes can be successfully spun into the wound dressing. Nano silk solution can also be successfully electrospun with Aloe vera or manuka honey to impart antimicrobial activity. Khan et al. (2022) developed a silk fibroin nanofiber incorporated with

silver nanoparticles. Vitamin E can also be incorporated into nano dressings using silk fibroin/PVA/Aloe Vera. Chemicals such as nano silver, zinc oxide, and titanium oxide are also incorporated into silk fibroin to impart antimicrobial activity (Adamu et al. 2021; Patil, Reagan, and Bohara 2020). Heavy metals are toxic hence the need for nontoxic biological compounds from natural plants to be incorporated into wound dressings (Subramani et al. 2018).

Treated fabric antimicrobial activity

Aloe vera is one of the few plants that have compounds that can act against bacteria, viruses, and fungi (Sanchez-Machado et al. 2017). This makes wound dressings treated with Aloe vera good choices in treating wounds. Antimicrobials prevent microbial growth by altering microorganisms' membranes and protein processes (Naseri-Nosar and Ziora 2018). Aloe vera is effective against microbes, however, if the wound is highly infected, the active compounds are reduced, resulting in the need for synthetic antimicrobials like silver or antibiotics (Singh, Gupta, and Gupta 2018).

One of the techniques that can be used to assess the effectiveness of Aloe vera-treated wound dressing against microorganisms is the inhibition zone (Kirby-Bauer) test (Mohseni et al. 2019). If the treated dressing is antimicrobial, it will prevent the growth of microbes around the edges of the fabric specimen exposed to agar gel that has bacteria as seen in Figure 6. Treated cotton fabrics B (chitosan coated) and C (Aloe vera-chitosan nanoparticles coated) have clear inhibition zones around the fabrics. Clear zones show that the antimicrobials migrated from the fabric to the surrounding area and prevented the growth of the bacteria. In an untreated fabric A, there was no inhibition zone as the fabric has no antimicrobials to prevent bacterial growth (Subramani et al. 2018). The effectiveness of Aloe vera as an antimicrobial is supported by Amanuel and Teferi (2017), who reported that a cotton fabric specimen treated with Aloe vera gel exhibited good inhibition against the *E. coli* bacteria due to the slow release of the Aloe vera compounds. Mondal et al. reported that the inhibition zone can increase by increasing the compound's concentration. Increasing the concentration of Aloe vera compounds from 20 to 40%; increases the inhibition zone from 17–19 mm to 23–29 mm. Mistry, Mundkur, and Tulshyan (2020) reported that treated cotton, bamboo, and soybean fabrics with Aloe vera had inhibition zones ranging from 25 to 27 mm against *E. coli* and *S. aureus*.

Mondal, Saha, and Rahman (2021) reported the antibacterial activity of bleached cotton fabrics treated with chitosan and Aloe vera against *S. aureus* (Table 2). The number of bacterial colonies decreased for the chitosan and Aloe vera compared to an untreated fabric. As the concentration of

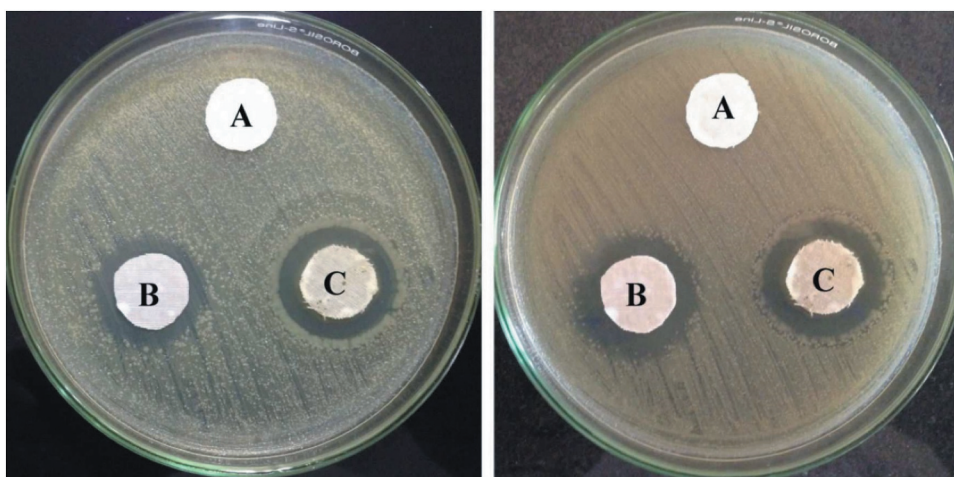


Figure 6. Agar plate antimicrobial activities of untreated cotton fabrics (A) and treated cotton fabrics (B and C) against *E. coli* (left) and *S. aureus* (right) bacteria (Subramani et al. 2018).

Table 2. The antibacterial activity of bleached cotton fabrics treated by chitosan and Aloe vera against *S. aureus* (Mondal and Saha, 2019).

Observation	Number of colonies	Bacterial reduction (%)	Bacterial reduction (%) after five washes	Bacterial reduction (%) after ten washes	Inhibition zone in mm
Untreated	824	00	00	00	00
2 g/l chitosan	360	56	40	30	1.4
4 g/l chitosan	280	66	50	42	1.7
6 g/l chitosan	202	76	65	53	2.1
2 g/l Aloe vera	492	40	32	25	1.0
4 g/l Aloe vera	410	50	40	32	1.2
6 g/l Aloe vera	350	58	50	38	1.5
Combined	160	81	70	58	2.3

chitosan and Aloe vera was increased, there was a decrease in bacterial colonies. The inhibition zone increased with increasing concentrations of Aloe vera and chitosan. The combined influence of chitosan and Aloe vera has the highest effect in reducing the number of bacterial colonies and improving bacterial reduction (%). It can be attributed to the synergetic effects of both antimicrobial agents by creating new functional groups which improved biocidal activity as compared to single antimicrobial agents. The durability of the antibacterial activity after repeated washing decreased with the increased number of cycles which can be attributed to the weak hydrogen bond and van der Waal's forces with cellulose. Some of the active ingredients in Aloe vera having antibacterial properties are polysaccharide acemannan, anthraquinones, and tannins. They can inactivate enzymes, denature proteins and disrupt the membrane, limit the growth of microbes, by disabling cell functioning or reproduction.

Antimicrobial activity against bacteria has also been reported for a silk fabric treated with Aloe vera. The treated fabric retained its antimicrobial activity even after repeated washing. Retention of antimicrobials is essential if the treated fabric is going to be used a couple of times and thereby necessitates the need to wash it. Exposing a fabric to liquids is reported to cause a minor loss in fabric strength and abrasion resistance when a liquid antimicrobial is used (Nadiger and Shukla 2015).

Statistical analysis

Abdel-Mohsen et al. (2020) reported the wound contraction property of chitosan-glucan hollow fiber reinforced collagen embedded with Aloe vera (Figure 7) evaluated for 8 days from the day of the wound. In Figure 7, the sample codes are collagen (CO), chitosan-glucan (CSGC) hollow fibers, and Aloe vera (AV). CO/CSGC (1/2) means CO is 0.5 g and CSGC is 1 g in the wound dressing formulation and CO/CSGC/AV (1/2/2) means CO is 0.5 g, CSGC is 1 g and AV is 1 g in the wound dressing formulation. The control sample is a gauge fabric. Maximum wound contraction was observed on the 8th day for the CO/CSGC/AV (1/2/2) at about 84%, followed by CO/CSGC (1/2) at about 64%. These values are statistically significant at a 99% level of significance, compared to the control and CO samples. It can be attributed to the combined effect of CSGC (antibacterial, healing, hemostatic) and AV (antibacterial, healing, hemostatic) properties. Abdel-Mohsen et al. (2020) reported the wound contraction property of chitosan-glucan hollow fiber reinforced collagen embedded with Aloe vera (Figure 7) evaluated for 8 days from the day of the wound. In Figure 7, the sample codes are collagen (CO), chitosan-glucan (CSGC) hollow fibers, and Aloe vera (AV). CO/CSGC (1/2) means CO is 0.5 g and CSGC is 1 g in the wound dressing formulation and CO/CSGC/AV (1/2/2) means CO is 0.5 g, CSGC is 1 g and AV is 1 g in the wound dressing formulation. The control sample is a gauge fabric. Maximum wound contraction was observed on the 8th day for the CO/CSGC/AV (1/2/2), around 84%, followed by CO/CSGC (1/2) around 64%. These values are statistically significant at a 99% level of significance as compared to the control and CO samples. It can be attributed to the combined effect of CSGC (antibacterial, healing, hemostatic) and AV (antibacterial, healing, hemostatic) properties.

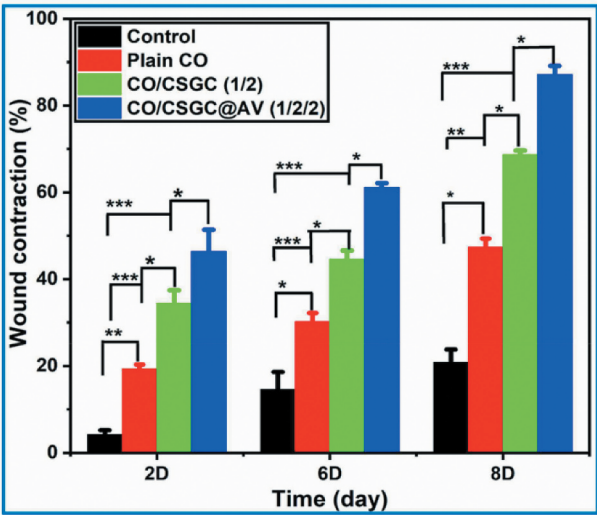


Figure 7. Representative wound contraction percentage using different wound dressings. Data mean $\pm$ SD ($n = 4$). Error bars indicated standard deviation (* $p < .5$, ** $p < .01$, *** $p < .001$, (Abdel-Mohsen et al. 2020).

Table 3. Chi-square (χ^2) hypothesis test observation (Mondal and Saha, 2019).

Observation	Calculated value	Tabulated value	Degree of freedom	Level of significance
Thermal conductivity of treated and untreated fabric	4.4721	12.59	6	5%
Air permeability of treated and untreated fabric	3.3488	12.59		
Water vapor of permeability of treated and untreated fabric	2.4034	12.59		

Mondal and Saha (2019) reported the antimicrobial property of the chitosan- and Aloe vera-modified cotton fabric. They have also done statistical analysis on the treated (chitosan- and Aloe vera) fabrics and untreated fabrics for thermal comfort properties to see if other important properties are affected by the antimicrobial treatment (Table 3). The Chi-square test shows that the calculated value is lower than the tabulated value at a 5% level of significance. Therefore, there is no significant difference in the thermal comfort properties of the antimicrobial-treated and non-antimicrobial-treated fabrics.

In another paper, Korra (2022) used the three-level factorial design of the experiment and analysis of variance (ANOVA) to quantify the yield of extraction of Aloe vera powders from leaves. The factors were extraction temperature, extraction time, and the concentration of the methanol solvent. The F-value of the model was 391.42 at a 95% level of significance indicating the above 3 factors have a significant influence on the yield extraction of Aloe vera.

Other uses of Aloe vera

Other applications of Aloe vera are in the beauty, agricultural, and filtration industries. For the beauty industry, Aloe vera contains compounds that promote cell proliferation. These compounds are used in beauty products to slow aging (Gong and Lu 2015). In the agricultural sector, it can be used to protect fruits against microbes that cause fruit decay. Treating fruits with Aloe vera gel and chitosan can prolong the fruit shelf life by reducing moisture loss (Nia, Taghipour, and Siahmansour 2021). In the filtration industry, it can be used as a finishing agent on fibrous masks to impart antimicrobial properties to further enhance the mask's protection against microbes. Captured microbes are then deactivated by the Aloe vera antimicrobial compounds. It also reduces the risk of transmitting or

contracting infectious pathogens. In the clothing industry, Aloe vera has found some applications. The ultraviolet protection factor (UPF) of a fabric treated with Aloe vera is 8× higher than that of an untreated one; due to the presence of polyphenols in Aloe vera; that block and absorb the UV rays (Mondal and Saha 2019). It shows that wound dressings treated with Aloe vera have protection against UV rays.

Conclusion

The use of natural wound dressings treated with Aloe vera suppresses microbial growth while at the same time promoting wound healing. Discussions have shown that Aloe vera is a good alternative that imparts antimicrobial activity to wound dressings. In contrast, traditional chemical antimicrobials are a risk to the environment and people. They are toxic, non-biocompatible, and non-biodegradable. Some of the shortcomings of using Aloe vera as antimicrobials are their susceptibility to heat and air. In addition, their concentrations vary from plant to plant. Despite these challenges, it was demonstrated that wound dressings treated with Aloe vera suppress the growth of microbes.

Highlights

- Natural wound dressings extracted from Aloe vera
- Extracted Aloe vera components can be applied directly into fabrics
- Aloe vera active components electrospun with nanoparticles and incorporated into the fabric.
- Natural wound dressings have the advantage of preventing microbial growth while at the same time promoting wound healing.

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