Assessing the Antibacterial Activity of Alternative Medicinal Remedies on Antibiotic-Resistant Bacterial Pathogens

Word Count: 5,062

Abstract

Antibiotic resistance is a prominent challenge that healthcare and medicine are facing globally. The evolution of bacterial infections is proving many antibiotics to be ineffective. The antibiotic-resistant bacteria have led to even more problems, including hospitalization, increased costs, prolonged sickness, and even some fatal cases. With the overuse of antibiotics in medicine and the environment, this issue has only grown. This problem has led researchers to explore microbial treatments from natural substances that have chemical makeup with antibacterial properties. Using natural substances can slow down the development of resistant bacteria and also better pharmaceutical approaches. This paper will evaluate the effectiveness of honey, garlic extract, tea tree oil, apple cider vinegar, ampicillin, and tetracycline on two strains of bacteria: Staphylococcus aureus and Escherichia coli. Comparing the antibiotics to the natural remedies helps set up a potential future for natural substances in pharmaceuticals

Each agar plate with the bacterial strains was made using the disc diffusion technique. Each disc was soaked in its respective treatment and placed on the agar plates to be placed in incubator for 24-hour periods at 37 °C. The effectiveness was determined by the zone of inhibition diameter. The zone of inhibition shows how much the bacteria can resist the specific treatment. The tests were each conducted three times over three days.

The data shows that both of the antibiotics, ampicillin and tetracycline, produced the largest inhibition zones, but the natural substances still produced a significant zone of inhibition. The tea tree oil and garlic extract were more effective against the S. aureus, and overall, the tea tree oil is almost comparable to the antibiotics. Honey and apple cider vinegar produced a much smaller zone of inhibition, but still fought off some bacteria. The hypothesis that natural products could be effective against bacterial strains was supported by the results, even though they didnt perform better than the antibiotics. The mechanisms of action that led to the zone of inhibition were from disrupting the membrane, enzyme, and potentially oxidation. This paper attempts to help identify the role natural products can play in healthcare and medicine. Natural remedies may work just as well as medication in terms of sickness, infections, and treating other issues. These findings can lead to further discussion about the effect of natural agents with antibiotics.

In conclusion, the study provides evidence that certain natural products, especially tea tree oil and garlic extract, displayed significant antibacterial activity. If natural remedies were working together with antibiotics, as part of a comprehensive approach, they may help reduce the need for antibiotics. Using natural compounds can help with cost, machinery, etc., and can overall help safeguard health.

Introduction

Antimicrobial resistance (AMR) has become a significant issue in modern medicine across the globe. Human survival is dependent on medicine, but as more antibiotics are used, more bacteria become resistant. AMR grows further, and sometimes the ineffective treatments can lead to worse ailments. The simplest bacterial infections are hard to treat because of this huge, growing threat. The bacteria that used to respond to commercial antibiotics, like Z-PAK 750 mg Zithromax, can now resist multiple chains of drugs, transforming typically harmless illnesses into life-threatening challenges. The growing crisis of

AMR is very real and is one of the greatest technological threats that the world may face if it is left untreated.

The center of the thesis problem is natural selection. All life forms, including bacteria, respond to their environment by adapting and evolving. AS bacterial populations repeatedly face the same antibiotics, they can undergo mutations through gene transfer or even spontaneously. The resistance can spread rapidly between bacteria and can leave whole groups of antibiotics useless. The World Health Organization (WHO) has officially listed resistance to antibiotics as one of the ten most important threats to global health. Without quick and effective collaborative measures, the world will head towards a time where antibiotics can be useless, and infections will become more serious. It should not get to a point where even minor scratches and cuts are deadly, but at this rate, that's a plausible future.

Overprescribing antibiotics, using them for viral infections, using them as preventative measures, etc. are all ways that this resistance has been consistently building up. Patients in many countries can buy antibiotics over the counter without a prescription, resulting in needless consumption, and this allows resistant strains to flourish. Livestock agriculture also heavily relies on antibiotics, not just for treating diseases but also as a preventative measure and for growth stimulation. This may be another cause of antibiotic-resistant bacteria that could be transmitted to humans.

The global problem is exacerbated by a gap in the regulation of aids and the supply of medical treatments. Most low- and middle-income nations lack a monitoring infrastructure to track patterns of resistance. This problem is exacerbated in higher-income nations by a culture of easy fixes and a prescription culture where people anticipate receiving prescription drugs. Antibiotics, which were previously heralded as miraculous medications, are fast losing their potency as a result of all these activities.

There are extremely risky consequences, which include needing major surgeries, chemotherapy, organ transplants, and many people may end up with weakened immune systems. Infections that are caused by certain drug-resistant pathogens like Methicillin-resistant Staphylococcus aureus (MRSA), Carbapenem-resistant Enterobacteriaceae, and multidrug-resistant Pseudomonas aeruginosa are generalized to have the worst outcomes. Along with that, there has been an increase in antibiotic-resistant gonorrhea and tuberculosis.

The overuse of antibiotics was worsened during the COVID-19 pandemic when people were trying to cure themselves with any sort of medication. While no antibacterial COVID-19 virus exists, there was a use of antibiotics in infected patients during the early days of the pandemic. The WHO review found that significantly less than 10% of the COVID-19-infected patients had co-bacterial infections, nevertheless, more than 70% of them were prescribed antibiotics. Unnecessary and excessive use of antibiotics of this magnitude is most likely to have worsened the problem of bacterial resistance.

Due to the economic and health-based negative effects of antibiotics, researchers have turned to natural remedies from classic and folk medicine. Honey, apple cider vinegar, garlic, and tea tree oil have been proven to work against some infections and wounds. These treatments started reconsidering, based on scientific evidence, the employment of claims that have shaped the modern healing system.

Starting with honey, it was used for medicine back in Ancient Egypt and possesses osmotic effects. Its low pH and hydrogen peroxide are also more of its antibiotic traits. Garlic is known to have many antimicrobial properties and contains allicin. Allicin is known to be released when crushing or chopping garlic. Apple cider vinegar also has some medical significance. Its main purpose is to clear gut bacteria, but its presence of acetic acid can modify the cell membrane, leading to disruption of bacterial activity. Tea tree oil is from the Melaleuca alternifolia plant, which has volatile compounds within the oil that can attack cell membranes. The oil has shown a lot of potential in fighting against bacteria, fungi, and even some viruses

This paper tries to answer the research question: What is the comparative effectiveness of honey, garlic, apple cider vinegar, and tea tree oil against E. coli and S. aureus compared to standard antibiotics like ampicillin and tetracycline?

The results of this study affect clinical practice, public health strategy, and global measures pertaining to the AMR crisis. If some natural cures are found to have consistent and reproducible bactericidal effects, they may be used as complementary therapies, topical agents, or even as primary treatment for mild infections. The inclusion of such remedies within healthcare systems can reduce the use of antibiotics. At a time when intellectual effort is required to maintain the operational advantages of 20th-century medicine, harnessing the antimicrobial properties of natural compounds is neither sensible nor critical.

Literature Review

Potential of Natural Remedies Serving as Antimicrobial Agents

Since antiquity, natural remedies have been the base of traditional medicine and are gaining prominence in contemporary science for their effectiveness against the growing global concern of antibiotic resistance. The herbal and natural flora already has great antimicrobial potential, but its means of functioning differs from that of traditional antibiotics. Natural antibiotics are far less likely to have a resistance developed towards them because, unlike single-target pharmaceutical antibiotics, natural antibiotics are multi-targeted and can act on numerous sites within a bacterial cell.

Consider honey: even in ancient Egyptian times, it was regarded as an effective treatment for wounds and infections. Today's medicine is equally affirming, corroborating its antimicrobial properties due to high osmolarity and low pH, as well as hydrogen peroxide and non-peroxide compounds like methylglyoxal. According to Lotfollahian et al. (2020), the honey's osmotic pressure, low pH, hydrogen peroxide's presence, and even methylglyoxal combine to create an environment unfavorable for bacterial development, inhibiting both Gram positive and Gram-negative strains. In addition, honey is credited with encouraging regeneration and tissue repair, bolstering its usefulness as an antimicrobial agent.

Garlic is another natural remedy that can bne used as an antimicrobial agent. It contains allicin contains sulfur and is released when garlic is chopped or cut. Dong et al. (2019) argued that allicin has a

broad spectrum of activity because it can disrupt bacterial RNA synthesis, block critical enzyme pathways, and damage membranes. Also, garlic has been shown to act on both aerobic and anaerobic bacteria, including some multidrug-resistant strains.The history of using it in treating gastro-intestinal and respiratory infections is borne out by research indicating effectiveness against such infections as Helicobacter pylori and Streptococcus pneumoniae.

Apple cider vinegar (ACV) consists mainly of acetic acid, which is known to disrupt bacterial cell membranes which causing leakages in cytoplasm and enzymes. ACV was found to inhibit E. coli and S. aureus under certain concentrations, but it depended on the bacterial strain, length of exposure, and the concentration of ACV used (Sengupta et al., 2018). Although applying it to chronic wounds was listed as a preferred treatment due to lower efficacy compared to other natural substances, its low cost, easy access, long shelf life, and relative non-toxicity warrant further study in those applications.

The plant Melaleuca alternifolia provides us with tea oil which contains bioactive compounds such as terpinen-4-ol and alpha-terpineol. Carson et al. (2006) suggest that the primary action of tea tree oil is by interfering with the membrane structure of the bacteria and damaging their respiration system. This has been observed in both Gram-positive and Gram-negative bacteria. Its range of applicability is further enhanced through its antiviral and fungicidal properties. However, concerns regarding possible dermal sensitivity and toxic effects of using the oil in large amounts have limited the extent of its use, particularly the need of further pharmacological researches.

Comparison of Natural Remedies and Conventional Antibiotics

It is important to evaluate natural treatments alongside conventional antibiotics to assess their potential therapeutic approaches. Traditional antibiotics, such as ampicillin and tetracycline, have their own strategies; ampicillin inhibits synthesis of the bacterial cell wall while tetracycline binds to ribosomes and inhibits protein synthesis. These pathways, while advantageous, carry a high susceptibility to being resistant to many methods, like enzymatic degradation (beta-lactamase), efflux pumps, or other gene mutation pathways.

In contrast, natural remedies combine multiple mechanisms of action in a more passive manner, causing increased difficulty for bacterial resistance. Honey's osmotically active and oxidative functions, as well as its antagonistic actions towards several enzymes, endow it with remarkable antimicrobial properties which bacteria are unable to overcome over time. Further, the multi-site action of thiol group modification in garlic prevents many active metabolic and enzymatic pathways, thereby neutralizing biological activity.

Multiple attempts at comparative research have tried to study the effectiveness of natural remedies in comparison to synthetic antibiotics. Mallat et al. (2019) observed that both garlic and tea tree oil formed inhibition zones greater than those caused by ampicillin in some S. aureus strains. However, effectiveness was highly dependent on the bacterial strain, concentration of the compound, and preparation technique. As Saud Almughais et al. (2019) highlighted, variation in preparation and application greatly alters the clinical reliability of natural products.

The combined action of natural products and synthetic drugs is an aspect that is increasingly gaining attention. Some studies provide evidence that application of naturopathic products with antibiotics improves their antibacterial activity, or what is known as a synergistic effect. For instance, Chaaban et al. (2020) reported that the addition of allicin to beta-lactam antibiotics increased the susceptibility of bacterial membranes, which allowed enhanced uptake of the antibiotics into bacteria. This and other forms of synergism may reduce the amount of each drug needed, thereby reducing side effects and slowing the rate of resistance development.

Knowledge Gap

Many studies evaluate singular remedies ot considering other factors, or comparing them to anything. Regardless of some encouraging results, gaps in the research remain. While this may provide some baseline data, it does not give full issnight on what natural remedies can fully do. It may lead one way of encouraging that they are the perfect solution, or it may fully reject the idea of natural remedies; it is far from the clinical scenario where multidrug-resistant pathogens are the norm. In addition, many studies fail to pit natural remedies against conventional antibiotics under controlled conditions and only compare remedies to each other or nothing at all, which makes their findings irrelevant to a broader population.

Another concern is the uncontrolled extraction and preparation processes of an application of natural remedies which does not fall within a specified set of guidelines. This is different from pharmaceutical-grade antibiotics, which have well-defined boundaries regarding sources of natural substances, their environment, and processing techniques. For instance, the concentration of allicin in garlic depends on how the garlic was grown, how the allicin was extracted, and how old the garlic is.

There is limited longitudinal research regarding the clinical pharmacology associated with natural remedies. There is more concern about the bioavailability, potential systemic toxicity, and possible contraindications with other therapies. In addition, most natural remedies are more bacteriostatic than bactericidal, which raises doubts about their efficacy in resolving severe and acute infections.

This examination seeks to bridge the gaps by conducting a controlled comparative analysis of four commonly referenced natural therapies: honey, garlic, apple cider vinegar, and tea tree oil, measuring their effects against the antibiotics ampicillin and tetracycline. Using standardized disc diffusion techniques, this research will assess the antibacterial action of E. coli (Gram-negative) and S. aureus (Gram-positive) bacteria, thus establishing important benchmarks regarding the degree of efficacy of these natural therapies. This work will add to the growing body of literature concerning the use of alternative and adjunct therapies in place of standard antibiotic treatment.

Methods

Laboratory Setup

Every step of the experiment was performed in a classroom laboratory with clean conditions. All surfaces were disinfected along with any equipment and materials. Contamination was avoided with the use of personal protective wear, and everything was sterilized with 70% ethanol solution.

The nutrient agar was kept in Petri dishes in the refrigerator 4°C to maintain its quality and prevent heat affecting it. Later, it reached room temperature around 25°C to ensure that no condensation was present, which would affect how the bacteria would grow later and be a major experimental error. Cultures of Escherichia coli (E. coli) and Staphylococcus aureus (S. aureus) were obtained from a biological supply company and kept at the same temperature until the experiment was ready to be performed and until they were ready for inoculation. The natural remedies were either freshly prepared (garlic extract) or purchased from health care suppliers. Prepared garlic extract was made by crushing peeled garlic cloves in a mortar and pestle and filtering the juice through sterile gauze. Tea tree oil and apple cider vinegar were used as-is. Honey was used raw, without dilution.

Bacterial suspensions were collected with sterile cotton swabs, and all liquids were handled with micropipettes fitted with sterile tips. All waste, used swabs and petri dishes in particular, were placed in biohazard waste containers and properly disposed of later. During the entire process, a qualified science teacher was monitoring the experiment.

Materials

- The materials used in the experiment included:
- Petri dishes pre-filled with nutrient agar
- Cultures of Escherichia coli (gram-negative) and Staphylococcus aureus (gram-positive)
- Honey (raw and unpasteurized)
- Garlic extract (freshly prepared)
- Apple cider vinegar (organic and unfiltered)
- Tea tree oil (100% pure essential oil)
- Standard antibiotic discs (ampicillin and tetracycline)
- Sterile cotton swabs
- Micropipettes with sterile tips
- Filter paper discs (6 mm diameter)
- Preparation of Natural Remedies

Procedure

- Preparation of Bacterial Lawns (Day 0):
    - The treatment agar plates were taken out of the fridge and placed in the incubator, which allowed them to warm up to room temperature. Each plate is labelled appropriately with the performed treatment.

    - Individual sterile saline suspensions containing E coli and S Aureus cultured with uniform bacterial growth for lawn inoculation as per the McFarland standard were prepared.
    - Cotton swabs were dipped into each bacterial suspension and used to spread the bacteria evenly onto the entire surface of a petri dish by the lawn method. Each bacterium has its corresponding clean set of plates.
- Application of Remedies and Antibiotics (Day 0):
    - Discs of filter paper with a 6mm radius were also placed onto the surface of each of the agar plates.
    - A soakage disc for each of the natural remedies (honey, garlic extract, apple cider vinegar, tea tea tree oil) was prepared by applying 20 uL Methanol to the bottom of the plastic container with permeable discs until they were completely saturated but did not exceed the height of the bottom surface souls to avoid overflow.
    - Positive controls prepared were discs containing commercial antibiotics, ampicillin, a nd tetracycline.
    - To prevent condensation dripping onto the agar, the plates were incubated upside down at 37 degrees Celsius.
- Day 1 (After 24 hours of incubation):
    - All plates have bacterial growth, with all forming a uniform lawn. The largest zones were recorded around tetracycline, ampicillin, garlic, and tea tree oil also showed evident clear zones.
    - Apple cider vinegar and honey had smaller inhibition zones, but these were still visible. All zones recorded were made in millimeters. Then, plates were returned to the incubator for extended observation.
- Day 2 (48-hour mark):
    - Zones of inhibition became more distinct and measurable. Some natural remedies, especially garlic and tea tree oil, showed slight expansion in their zones.
    - No additional growth was observed in the clear zones, indicating sustained antimicrobial activity.
    - Observations were recorded again, and average diameters were calculated across three trials for each substance.
- Day 3 (72-hour mark):
    - Further observation confirmed the consistency of inhibition zones, with minimal changes from Day 2.
    - No regrowth was observed within the zones, indicating that the antimicrobial effects had not diminished.
    - All plates were photographed and labeled for visual reference and future data analysis.
    - Plates were subsequently disposed of using proper biohazard protocols, and the lab environment was sterilized.

Observational Notes:

- The tea tree oil discs consistently showed a distinct aroma and occasional slight discoloration around the disc area, which did not interfere with bacterial growth but was noted for accuracy.
- Garlic extract discs were sometimes soaked slightly more into the agar, which may have enhanced diffusion.
- Some honey samples slightly crystallized during application but reabsorbed into the disc once warmed to room temperature.
- Apple cider vinegar occasionally caused mild discoloration of the agar, which did not affect measurement accuracy.

Data Collection

Every procedure was conducted in three repeats. The obtained values for the differing strains of bacteria and substances were averaged so that each value represented the mean for inhibition zones of all diameters against each strain of bacteria. This was done to ensure that there was little random variation and mechanical error in the reproducibility of results within a single experiment or treatment.

Results

The measured average inhibition zones (in millimeters) for each treatment against E. coli and S. aureus are summarized below:

Treatment	***E. coli* Mean Zone (mm)**	***S. aureus* Mean Zone (mm)**
Honey	12 mm	14 mm
Garlic Extract	15 mm	17 mm
Apple Cider Vinegar	10 mm	13 mm

Tea Tree Oil	17 mm	19 mm
Ampicillin	22 mm	24 mm
Tetracycline	23 mm	25 mm

Conventional antibiotics had the highest inhibitory zones for both strains of bacteria, but with some differences – ampilicillin came second with natural remedies while tetracyclin came first. The strongest effect was achieved by tea tree followed by garlic extract while apple cider vinegar and honey had moderate inhibition. All trials produced the same results which verified their uniformity. Looking over the plates demonstrated the clear cut zones of inhibition for those antibiotics and natural remedies that worked best like S. aureus, which to all intents and purposes seemed far more responsive than E. coli to most of the treatments used.

Discussion

The results of this study strengthen the claim that although bacterial infections can be treated effectively by antibiotics such as ampicillin and tetracycline, some forms of natural medicine can be used as an alternative or alongside the antibiotics. Some natural remedies may possess significant antibacterial activity, even though it is not as comparable to antibiotics themselves. These results and others about natural remedies can be taken into consideration when looking at modern treatment. The research results specifically charted the exceeding impact that tea tree oil and garlic extract had, both of which produced considerable zones of inhibition relative to Staphylococcus aureus, in comparison to antibiotics, and even though they generally matched rather than exceeded the performance of synthetic antibiotics, they came remarkably close. These results are vital because it appears that naturally occurring substances can have the potential in growing to an antibiotic, and are scientifically substantiated antibacterial substances.

Mechanisms of Action and Comparative Analysis

The main reason for the high efficacy of tea tree oil is its intricate complex phytochemical structure which contains high concentration of terpinen-4-ol as well as monoterpenes such as γ-terpinene, α-terpinene, α-pinene. These natural extracts are known to damage the membranes of bacteria by

reinforcing the membranes and aiding the outflow of intracellular fluids like ions, ATP, and especially nucleotides. The destruction of the cell membrane potential and or integrity ceaselessly leads to the death of bacterial cells. One of the most important attributes of tea tree oil is that its multi-targeted mechanism of action minimizes the chances of bacteria developing resistance like they do towards antibiotics that work on a single target. This oil, due to the myriad of internal components that are influenced within the bacterial cell, is a clear representative of polypharmacology—in research terminology, an approach in pharmaceuticals which aims to optimize the treatment targeting infection to a pace faster than the rate of microbial resistance development.

Also, the extract of garlic exhibited strong antibacterial activity which may be attributed to allicin, the active ingredient of garlic, which is synthesized when garlic is crushed and undergoes some biochemical changes. Allicin interacts with thiol enzymes in bacteria and prevents important steps in metabolism of bacteria such as processes involving RNA, DNA, and energy transduction. Furthermore, allicin may inflict damage by oxidative stress from reactive oxygen species (ROS), therefore, the bacterial systems experience these harsh oxidative conditions which damages the cell. The same as tea tree oil, garlic's multifactorial biochemical mechanisms lowers the probability of resistance development and demonstrates the utility of such compounds not only as sole agents but also in conjunction with standard antibiotics as resistance modifying agents.

Conversely, the water-soluble forms of honey and apple cider vinegar (ACV) have relatively moderate yet meaningful antibacterial effectiveness. The action of honey is due to multiple overlapping reasons such as high sugar concentration hyperosmotic stress, low pH environment, and hydrogen peroxide generation via glucose oxidase. Additionally, some honey types, such as Manuka, are believed to contain methylglyoxal that directly damages bacterial protein and DNA. Synthetic antibiotics, or stronger natural substances, far outstrip honey's antibacterial prowess in precision and potency. ACV's main constituent, acetic acid, undermines bacterial membranes, denatures proteins, and meddles with a cell's internal pH gradient, exerting antibacterial effects. The tested hypotheses may be weaker than others, but the controlled results were dependable every time they were repeated.

This hypothesis makes clear that ACV and honey, though not potent enough for advanced infection treatment, act as auxiliary defenders in preventive healthcare situations in conjunction with synthetic antibiotics that have the unwanted possibility of resistance or numerous side effects.

Temporal Dynamics and Experimental Observations

The understanding of the temporal progression BTE's dynamics in the window of three days capture the analysis and the recording of data's temporal dynamics. On Day 1, there was early stage blurriness surrounding the antibiotic discs which can be described as preliminary steps of bacterial inhibition transforming sharp margins by Day 2. It is astonishing how rapidly they responded to the synthetic antibiotics because of the amount of effectiveness and precision. On the other hand, the slower response among natural ones was to some extent striking, particularly for tea tree oil and garlic. They did reach their peak by Day 3, but significantly increased by Day 2 which is a stage suggestive of the assumed lag attributable to the restrictions of reality.

S. aureus is more susceptible than E. Coli for all nature inspired treatments (which is gram negative), which is microbiologically correct. E. coli's outer membrane makes it more resistant to many (even natural) antimicrobials, shielding the cell like armor. Thus, all healing techniques implemented in this research were effective on both bacteria, but had a greater effect on S. aureus demonstrating these remedies were easier to heal for gram-positive infections – likely those involving skin or other associated mucosal tissues.

Implications for Healthcare and Antibiotic Stewardship

The results further explain an already existing problem of responsible antibiotic use considering that low grade natural substances will ease the dependence on classical antibiotics when used to treat milder cases, lesser infections, or used in conjunction with other antibiotics. As an illustration, tea tree oil has applications as a topical antimicrobial agent in ointments, wound dressings, and in other MRSA nasal decolonization procedures. In addition, garlic extracts can used in the formulation of mouthwash and skin disinfectants as well as dietary supplements and other disinfecting agents for the body.

Moreover, a wider array of natural components is less likely to give rise to resistance than antibiotics which work on a single or predominant mechanism. Thus, natural extracts would serve as more ideal candidates to neutralize resistance or allow antibiotics to work more optimally at sub-therapeutic levels. Some studies suggest that natural substances may actively engage in bypassing efflux pumps or down modulating resistant genes to pre-existing resistance. While these statements require further validation, they explore a pathway toward integrative solutions for antimicrobial control.

Limitations and Directions for Future Research

There are a couple limitations present in this study, especially since previous papers haave identified many promising outcomes. The first limitation is that these results were obtained solely using the disc diffusion method, which is not how the human body works. There are plenty of different factors present in the human body that affect how natural remedies react to the bacteria. Pharmacokinetics and pharmacodynamics (absorption, distribution, metabolism, and excretion), for example, are vital in determining the clinical applicability of a compound. Allicin, for instance, doesn’t work the same in the bloodstream because of the minimal bioavailability. Tea tree oil is also toxic when ingested and may cause major allergic reactions if used as a medication.

Failing to utilize a standardized approach for the preparation of natural products is another challenge. The place where the plant is sourced from, the manner in which it is harvested, how it is stored, and even how it is extracted can heavily impact its bioactive compounds. In garlic, allicin proportion increases with the amount of crushing done on the garlic. The active monoterpenes present in tea tree oil differ in concentration from one batch to the next. Such alteration makes reproducibility impossible, complicating the control and marketing of naturalantimicrobial agents for medicinal use. This variation hinders the development of medicines. There is a demand for sharper focus on the control of standardization and quality in future studies.

Considering the scope of this concerning experiment was limited to two strains of bacteria, it would be beneficial for the advanced stages of the project to integrate multi-drug resistant strains, anaerobic fungi, and other microorganisms. The examination of natural and synthetic agents to determine if lower dosages of antibiotics yield better clinical outcomes is another avenue to explore in further studies.

Lastly, self-treatment with natural substances provides an avenue of potential therapy and comforting therapy, such methods should be approached with extreme caution because they can lead to overuse of unverified therapies. Especially when nature's cures is advertised on the internet. They will be accompanied by clinical trials, toxicology examinations, and comprehensive regulatory scrutiny before they are proven safe, effective, and standardized.

Conclusion

In conclusion, the careful results of this study corroborate the general claims about the natural antibacterial properties found in honey, garlic, apple cider vinegar, and tea tree oil to some degree affecting Escherichia coli and Staphylococcus aureus. The most potent natural agents discovered in the study, tea tree oil and garlic, had noteworthy zones of inhibition which meant that they could be used in combination with standard antibiotics.

The addition of natural products as supplements increases the range of available antimicrobial agents. First, the chances of development of resistance by bacteria is also lowered because of the many mechanisms at play. Second, they can mitigate the development of quantitative use of synthetic antibiotics, supporting global efforts against antibiotic resistance. Third, the substances are readily available and inexpensive, especially in developing economic regions. Every rule has an exception; in this case, the caveat is the rigid clinical evaluation of these materials.

The unexplored ideas of other methods of biocides biotechnology warrant further exploration. The aim of this research was to fill the gap created by evaluating the natural products and antibiotics through simplified microbiological techniques. Subsequent investigations should broaden to include in vivo work along with pharmacokinetics, toxicity studies, and potential synergistic use. Clinical scrutiny and investigation of the referred natural products require universally prepared policies with defined and clear dosage guidelines, as Miss Devon advocates.

Combining unnatural with traditional medicine could alleviate the burden of antibiotic resistance, even though synthetic antibiotics continue to serve as the most potent. If carried out as planned, this integration would significantly sustain the preservation of the efficacy of antibiotics as well as the general health and well-being of many future generations.

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