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Physicochemical and antimicrobial properties of soaps formulated with essential oils of some plant species

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ABSTRACT

In recent decades, there has been a growing global interest in natural and sustainable alternatives to synthetic chemical products, particularly in the area of personal hygiene. Conventional soaps often contain synthetic chemicals such as triclosan and parabens, which have been linked to antimicrobial resistance and skin irritation. Essential oils with diverse antimicrobial properties offer a promising alternative for enhancing soap formulations. This study was conducted to evaluate the physicochemical properties and antimicrobial properties of soap formulated with essential oils extracted from plant species. Essential oils from *Hyptis suaveolens*, *Citrus aurantifolia*, *Curcuma longa*, *Citrus limon*, and *Thuja koraiensis* were obtained through the hydrodistillation method using a Clavenger apparatus. Soap was prepared using the hot process method and was fortified with essential oils using the standard method. The physicochemical properties of the essential oil (pH, viscosity, specific gravity, and color) were analyzed. The soaps were evaluated for detergency, foaming capacity, and antimicrobial activity against some selected bacterial and fungal isolates. The results showed that the essential oils showed acceptable pH, viscosity, specific gravity, and good lathering properties comparable to conventional soaps. The antimicrobial assays demonstrated that soaps containing essential oils displayed enhanced inhibitory effects compared to the plain soap, with formulated soaps showing the broadest antimicrobial spectrum. The essential oils also demonstrated strong concentration-dependent activity against both bacteria and fungi. These confirm the synergistic antimicrobial effect of the unformulated soap, formulated soap, and essential oils, highlighting their potential for producing safe, effective, and affordable hygiene products. The study concludes that the essential oils and the formulated soaps offer enhanced cleansing, dermatological safety, and antimicrobial effectiveness, making it a promising natural alternative to synthetic soaps.

Highlights

- Soaps formulated with essential oils from plant species improved physicochemical properties compared to plain medicated soaps.
- The incorporation of essential oils significantly enhances the antimicrobial properties of the soaps due to bioactive compounds.
- Plant essential oil-based soaps combine cleaning, skin-friendly, physicochemical parameters, and broad-spectrum antimicrobial action.
- These plant essential oil-based soaps are a viable natural alternative to synthetic antibacterial soaps with fewer side effects.

1. Introduction

Soap making is one of the oldest practices in human history, with archaeological evidence tracing its origins to ancient Babylon around 2800 BC (Davidson, 1965). Traditionally, soap is produced through the process of saponification (Okeke et al, 2020), which contributes to the hardness of the soap (Bello et al., 2019), in which fats or oils react with an alkali such as sodium hydroxide to yield soap (McDaniel, 2020). This chemical process creates a surfactant capable of emulsifying oils and

removing dirt from surfaces, making soap an indispensable commodity in daily life (Draeos, 2020). Although this basic process has remained unchanged for centuries, modern soap production has evolved significantly, with the incorporation of additives that enhance cleansing efficiency, skin compatibility, fragrance, and therapeutic properties (Ali et al., 2021). Modern techniques, such as hot-process and cold-process methods, prioritize natural ingredients, aligning with consumer demand for sustainable, health-conscious products free from harmful synthetics like parabens and sulfates (Siddiqui et al., 2022).

In recent decades, growing consumer awareness of health and environmental issues has influenced a shift toward natural and organic personal care products (Nguyen and Pham, 2022). This trend has fueled increasing interest in the application of essential oils in soap formulation. Essential oils are volatile, plant-derived compounds responsible for their aroma, therapeutic effects, and chemical reactivity (Tisserand et al., 2020). It contains secondary metabolites that provide organisms with adaptive advantages, like insect-repellent properties. (Moussa et al., 2021). The oils enhance sensory appeal and functionality (Siddiqui et al., 2022) and contribute fragrance and bioactivity (Baser et al., 2015). The chemical components of essential oils help nourish and moisturize the skin, reducing dryness and irritation commonly associated with chemical soaps (Alabi et al, 2019).

Extensive studies have demonstrated that essential oils exhibit diverse biological activities, including antifungal, anti-inflammatory, antioxidant, and moisturizing effects (Kumar et al, 2022). For instance, lavender oil is widely recognized for its calming and skin-soothing properties, while tea tree oil has shown effectiveness against a broad spectrum of microbes (Carson et al, 2006). Peppermint (*Mentha piperita*) was responsible for soothing effects (Chandrasekaran et al., 2023), and basil (*Ocimum basilicum*) is known for its uplifting scent (Mondal et al., 2024). Natural oils like eucalyptus and cinnamon have demonstrated antimicrobial properties and can be incorporated into soap formulations to enhance antibacterial effects (Hammer et al., 2019) and muscle relaxation (Ali et al., 2015; Kusuma et al., 2024). Orange (*Citrus sinensis*)

and lemon (*Citrus limon*) have bright, uplifting aromas and antiseptic properties (Dosoky et al, 2021).

The use of essential oils in soap production thus offers dual advantages and improves the quality and therapeutic value of the product while aligning with the global demand for safer, natural, and environmentally sustainable alternatives (Ali et al., 2021; Nguyen et al, 2022). Its antimicrobial properties are effective against both bacteria and fungi, supporting its application in natural and herbal soap formulations (Anwar et al., 2020). By using natural antimicrobial properties, this approach improves skin health and decreases infection risks. At the same time, it reduces the use of synthetic chemicals that are often tied to allergic reactions and antimicrobial resistance. (Bello et al, 2021). Essential oils not only give soaps a pleasant natural fragrance but also improve their therapeutic value, which has contributed to their growing use in natural skincare products (Wahyuningsih et al., 2021).

2. Materials and Methods

2.1 Sample collection

Curcuma longa was purchased at Akungba main market, while *Hyptis suaveolens*, *Citrus aurantifolia*, *Cymbopogon citrates*, and *Thuja koraiensis* were collected on the Adekunle Ajasin University premises, Akungba-Akoko, Ondo State, Nigeria, as shown in Figure 1.



Curcuma Longa Rhizome



Thuja koraiensis Plant



Hyptis suaveolens plant



Citrus aurantifolia leaves



Cymbopogon citrates

Figure 1: Pictures of the plants and rhizome used.

2.2 Sample Preparation

The samples (*Hyptis suaveolens*, *Citrus aurantifolia*, *Curcuma longa*, *Cymbopogon citrates*, and *Thuja koraiensis*) were cleaned to remove dust and washed under running water to remove dirt.

2.2.1 Extraction of essential oil using hydrodistillation

150 g of freshly ground *Hyptis suaveolens*, *Citrus aurantifolia*, *Curcuma longa*, *Cymbopogon citrates*, and *Thuja koraiensis* were boiled separately with distilled water for 5 hours until oil droplets separated. The distillate was collected, dried over anhydrous sodium sulfate to remove residual water, and stored in sealed amber vials at 4 °C. This method was done following the method given by Blazevic and Mastelic (Blazevic and Mastelic, 2009).

2.3 Physicochemical characteristics of the essential oil

2.3.1 Determination of specific gravity of oil (pycnometer method)

The specific gravity (SG) of the oil was determined using a pycnometer. The bottle was first cleaned, dried, and weighed with its stopper to obtain the weight of the empty bottle (W_1). It was then filled with distilled water at a controlled temperature of 25 °C, after which the stopper was carefully inserted to avoid air bubbles. The bottle was wiped dry and weighed again to obtain the weight with water (W_2). After emptying, cleaning, and drying the bottle, it was refilled with the oil sample at the same temperature, stoppered, and weighed to obtain the weight with oil (W_3). The specific gravity of the oil was calculated using Equation 1.

$$SG = \frac{w_3 - w_1}{w_2 - w_1} \quad (1)$$

where $w_3 - w_1$ is the weight of the oil and $w_2 - w_1$ is the weight of the water at the same temperature.

2.3.2 Determination of viscosity of oil (Ostwald viscometer method)

The viscometer was thoroughly cleaned and dried before use. A known volume of the oil sample was introduced into the viscometer. The sample was then placed in a water bath maintained at a constant temperature, usually 25 °C, to ensure uniformity. Using gentle suction, the oil was drawn above the upper mark of the viscometer and then allowed to flow freely under gravity. The time taken for the oil to flow between the two marks on the capillary tube was recorded using a stopwatch. The viscosity of the oil was determined by comparing its flow time with that of distilled water under the same conditions using Equation 2.

$$\eta = \frac{\eta(\text{water}) \times t(\text{water}) \times d(\text{oil})}{t(\text{oil}) \times d(\text{water})} \quad (2)$$

where η is the viscosity, t is the flow time, and d is the density of the liquid.

2.3.3 Determination of pH

The pH of the sample was determined using a digital pH meter. The instrument was first standardized with buffer solutions of known pH values (pH 4.0, 7.0, and 9.0) to ensure accuracy. After calibration, 10 mL of the oil was dissolved in distilled water and thoroughly mixed to form a uniform solution. The electrode of the pH meter was then immersed in the solution, and the pH value was recorded in triplicate, reading the mean and the standard deviation (Bhavani et al., 2023; Ameh et al., 2013).

2.3.4 Determination of the color of oil

The color of the oil sample was determined visually by pouring a portion of the oil into a clean, transparent glass container. The sample was then observed under natural light against a white background to detect its appearance and color intensity. The observed color was compared with standard color charts or reference descriptions, and the result was recorded accordingly.

2.4 Preparation of soap

2.4.1 Preparation of 20% sodium hydroxide solution

A 20% sodium hydroxide (NaOH) solution was prepared by dissolving 8 g of NaOH in 500 mL of distilled water. The solution was stirred until complete dissolution of the NaOH was achieved.

For the soap preparation, according to Prieto Vidal et al. (2018), 25 mL of coconut oil was measured and combined with 30 mL of the prepared 20% NaOH solution in an evaporating dish. The mixture was placed on a magnetic stirrer, heated, and continuously stirred to ensure homogeneity until a white, thick solution was formed. After partial cooling, 50 g of sodium chloride (NaCl) was added to facilitate soap precipitation.

2.4.1(a) Preparation of the formulation soap

To formulate the soap, three soap samples were prepared as follows:

Sample A: Unformulated soap

Sample B: Formulated soap + 0.5 mL essential oil

Sample C: Formulated soap + 1.0 mL essential oil

Sample D: Essential oil

2.4.2 Determination of detergency of soap samples

In order to determine the detergency of the soap samples, three different samples were used, labeled as sample A, sample B, and sample C. A piece of cloth was soiled with a mixture of red oil and charcoal to serve as the stained material for testing. For each soap sample, 0.3 g of soap was weighed and dissolved in 30 mL of water in a beaker to prepare the soap solution. The soiled cloth was then immersed in the prepared solution and agitated for about 5 to 10 minutes to allow washing to take place. After washing, the cloth was thoroughly rinsed with clean water and dried. The dried cloth was subsequently weighed to assess the removal of the stain, which provided an indication of the detergency level of each soap sample. Based on the observed stain removal and weight difference, the effectiveness of each soap sample was determined as either highly effective or moderately effective.

2.4.3 Determination of foaming capacity of soap samples

To determine the foaming capacity of the soap samples (sample A, sample B, and sample C), 0.1 g of each soap sample was weighed into a test tube, and 5 mL of distilled water was added. The mixture was shaken thoroughly until foam was produced. A stopwatch was then used to measure the time taken for the foam to completely disappear in each sample. The recorded time was used to evaluate and compare the foaming capacity of the soap samples; the experiment was carried out in triplicate (Hassan et al., 2015; Ameh et al., 2013).

2.4.4 Antimicrobial assay of soap and oil on the test isolate

Organisms isolated were collected from the Federal Medical Centre, Owo, Ondo State. The bacterial cultures were maintained on nutrient broth, while the fungal cultures were maintained on Sabouraud liquid medium. An inoculum size containing 1.5×10^8 cfu/ml for bacterial and 1.5×10^8 sfu/ml for fungal was used to seed already solidified Petri plates of Mueller-Hinton agar. The antimicrobial activities of the unformulated soap, formulated soap, and the essential oil were determined using the modified agar well diffusion method. Ten organisms were used in all (three Gram-positive, five Gram-negative, and two fungi). A sterile 6mm cork borer was used to make a well on already solidified agar. The wells were filled with the oil, ensuring that there was no spill on the agar surface surrounding the well. The plates were allowed to stand for about 2 hours to allow absorption of the oil into the medium, after which they were incubated at 37 °C for bacteria and 25 °C for fungi for 24 hours for bacteria and 7 days for fungi.

2.4.5 Minimum inhibitory concentration (MIC)

The macro-broth dilution technique, as modified, was used for MIC.

Table 1: Physicochemical properties of different essential oils.

Sample code	Ph	Specific gravity	Color	Viscosity
<i>Thuja koraiensis</i>	3.5+ 0.40	0.930 + 0.01	Cream	No viscosity
<i>Citrus aurantifolia</i>	5.6 + 0.20	0.878 + 0.00	Light yellow	Watery viscosity
<i>Curcuma longa</i>	6.2 + 0.26	0.945 + 0.01	Bright yellow	Low viscosity
<i>Hyptis suaveolens</i>	6.8 + 0.10	0.897 + 0.00	Pale yellow	Liquid viscosity
<i>Cymbopogon citrates</i>	5.7 + 0.20	0.909 + 0.00	Bright yellow	Low viscosity

Table 2: Detergency of the soap and formulated soaps.

Samples	<i>Thuja koraiensis</i>	<i>Citru aurantifolia</i>	<i>Curcuma longa</i>	<i>Hyptis suaveolens</i>	<i>Cymbopogon citrates</i>
A	Highly effective	Moderately effective	Highly effective	Moderately effective	Highly effective
B	Moderately effective	Highly effective	Moderately effective	Highly effective	Highly effective
C	Moderately effective	Moderately effective	Highly effective	Highly effective	Highly effective

KEY: Sample A – Unformulated soap; Sample B – Formulated soap + 0.5 mL of essential oil; Sample C – Formulated soap + 1.0 mL of essential oil

Table 3: Results on the determination of the foaming property of the soap and formulated soaps.

Samples	<i>Thuja koraiensis</i>	<i>Citrus aurantifolia</i>	<i>Curcuma longa</i>	<i>Hyptis suaveolens</i>	<i>Cymbopogon citrates</i>
A	1hr 45min	55 min 7secs	1hr 30sec	19min 3sec	1hr 32min
B	55min 33secs	1hr24 min	55min 4sec	1hr 10min	1hr 45min
C	56 mins 32secs	50min 18secs	1hr 15sec	1hr 19min	1hr 10min

KEY: Sample A – Unformulated soap; Sample B – Formulated soap + 0.5 mL of essential oil; Sample C – Formulated soap + 1.0 mL of essential oil

Those recorded as MIC were the lowest concentration of the tested oil that showed either bactericidal or bacteriostatic effect on the growth of the tested isolate. Serial dilutions of the oil were carried out to give a concentration of 0.5 ml/ml, 0.25 ml/ml, 0.125 ml/ml, 0.625 ml/ml, and 0.3125 ml/ml. 2 mL of each diluted concentration was added to 18ml of pre-sterilized molten Mueller-Hinton and Sabouraud agar, mixed properly, and allowed to set. After which, the standardized inocula were seeded on the plates. The bacterial plates were incubated at 37 °C for 24 h, while the fungi were incubated at 25 °C for 7 days. The results were observed and recorded. All the experiments were done in triplicate.

3. Results

The results in Table 1 showed some physical characteristics of the essential oils, such as common name, color of extracted oil, specific gravity, pH, and viscosity. In Table 2, the results of the foaming property of the soaps were shown. Table 3 shows the detergency of the soaps. Table 4 shows the antimicrobial results of *Thuja koraiensis* essential oil, formulated soaps, and soap against some test organisms. Table 5 shows the antimicrobial results of *Citrus aurantifolia* essential oil, formulated soaps, and soap on some test organisms. Also, Table 6 shows the antimicrobial results of *Curcuma longa* essential oil, formulated soaps, and soap made from the oil against some test organisms. The results in Tables 7 and 8 show the antimicrobial results of *Hyptis suaveolens* and *Cymbopogon citrates* essential oils, formulated soaps, and soaps against some test organisms. Furthermore, the results in Tables 9, 10, and 11 show the MIC results of *Thuja koraiensis*, *Citrus aurantifolia*, and *Curcuma longa* essential oils, formulated soaps, and soaps made from the oils against some test organisms. The MIC results of *Hyptis suaveolens* and *Cymbopogon citratus* essential oils, formulated soaps, and soaps made from the oils against some test organisms are shown in Tables 12 and 13.

Table 4: The antimicrobial result of soap, formulated soaps, and the essential oil of *Thuja koraiensis* against some tested organisms.

Isolated code plate	A	B	C	D	PC
<i>Staphylococcus aureus</i>	12.5 + 0.50	16.6 + 0.20	21 + 2.00	10 + 1.00	0 + 0.00
<i>Streptococcus pyogenic</i>	0 + 0.00	20 + 0.00	16 + 0.50	20 + 1.00	30 + 0.00
<i>Pseudomonas aeruginosa</i>	22 + 0.10	20 + 1.00	21 + 2.00	17 + 1.00	0 + 0.00
<i>Cornibacterium xerosis</i>	11.5 + 0.50	15 + 0.00	22 + 2.00	0 + 0.00	0 + 0.00
<i>Enterobacter raerogenes</i>	13 + 0.00	15.5 + 0.50	26 + 0.50	0 + 0.00	20 + 0.00
<i>Micrococcus varians</i>	0 + 0.00	16 + 1.00	28 + 1.00	25 + 2.00	28 + 0.00
<i>Staphylococcus epidermides</i>	12 + 2.00	16 + 2.00	25 + 1.00	0 + 0.00	25 + 0.50
<i>Candida albican</i>	15 + 1.00	16 + 1.00	22.5 + 0.50	17 + 1.00	30 + 2.00
<i>Candida gilabrata</i>	19 + 1.00	20 + 0.00	27.5 + 0.50	0 + 0.00	30 + 0.50
<i>Candida tropicalis</i>	15 + 0.00	20 + 0.00	30 + 0.00	25 + 0.00	30 + 2.00

KEY: Sensitive ≥ 15 , Intermediate 14 to 11, and Resistance ≤ 10 ; A – Soap; B – Formulated soap with 0.5mL of essential oil; C – Formulated soap with 1.0mL of essential oil; D – Essential oil; PC – Amoxicillin Antibiotic (Positive control)

Table 5: The antimicrobial result of soap, formulated soaps, and essential oil of *Citrus aurantifolia* against some tested organisms.

Isolated code plate	A	B	C	D	PC
<i>Staphylococcus aureus</i>	20 + 1.00	15 + 0.00	24 + 1.00	15 + 0.00	25 + 2.00
<i>Streptococcus pyogenic</i>	25 + 0.00	24 + 2.00	27.5 + 0.50	0 + 0.00	30 + 1.00
<i>Pseudomonas aeruginosa</i>	22.5 + 0.50	25 + 1.00	26 + 0.00	15 + 1.00	0 + 0.00
<i>Cornibacterium xerosis</i>	30 + 2.00	20 + 0.00	35 + 0.00	25 + 2.00	0 + 0.00
<i>Enterobacter raerogenes</i>	20 + 0.00	27.5 + 0.50	25 + 1.00	15 + 1.00	20 + 2.00
<i>Micrococcus varians</i>	20 + 2.00	22.5 + 0.50	26.5 + 0.50	15 + 0.50	25 + 1.00
<i>Staphylococcus epidermides</i>	28 + 0.00	20 + 1.00	27.5 + 0.50	0 + 0.00	30 + 1.00
<i>Candida albican</i>	20 + 2.00	22.5 + 0.50	23.5 + 0.50	25 + 0.50	0 + 0.00
<i>Candida gilabrata</i>	30 + 0.00	27.5 + 0.50	20 + 0.00	15 + 0.50	30 + 0.00
<i>Candida tropicalis</i>	22.5 + 0.50	25 + 1.00	23.5 + 0.00	20 + 0.00	30 + 0.00

KEY: Sensitive ≥ 15 , Intermediate 14 to 11, and Resistance ≤ 10

Table 6: The antimicrobial results of soap, formulated soaps, and essential oil of *Curcuma longa* against some tested organisms.

Isolated code plate	A	B	C	D	PC
<i>Staphylococcus aureus</i>	9 + 0.50	14 + 0.50	18 + 0.00	0 + 0.00	0 + 0.00
<i>Streptococcus pyogenic</i>	13.5 + 0.50	12.5 + 0.5	25 + 0.00	9 + 2.00	28 + 0.00
<i>Pseudomonas aeruginosa</i>	0 + 0.00	25 + 1.00	20 + 0.00	0 + 0.00	0 + 0.00
<i>Cornibacterium xerosis</i>	12 + 1.00	20 + 1.00	9.5 + 0.00	10 + 1.00	25 + 0.00
<i>Enterobacter raerogenes</i>	14 + 0.00	13.5 + 0.5	17.5 + 2.00	12 + 2.00	0 + 0.00
<i>Micrococcus varians</i>	12.5 + 0.00	18 + 2.00	20 + 0.00	13 + 2.00	27 + 0.00
<i>Staphylococcus epidermides</i>	11 + 2.00	20 + 1.00	0 + 0.00	12 + 2.00	28 + 0.00
<i>Candida albican</i>	15.5 + 2.00	22.5 + 0.50	17 + 0.00	13 + 1.00	27 + 0.00
<i>Candida gilabrata</i>	0 + 0.00	40 + 0.00	17.5 + 1.00	11 + 1.00	0 + 0.00
<i>Candida tropicalis</i>	9 + 0.50	19.5 + 2.00	15 + 2.00	9 + 0.00	26 + 0.00

KEY: Sensitive ≥ 15 , Intermediate 14 to 11, and Resistance ≤ 10

Table 7: The antimicrobial result of soap, formulated soaps, and essential oil of *Hyptis suaveolens* against some tested organisms.

Isolated code plate	A	B	C	D	PC
<i>Staphylococcus aureus</i>	0 + 0.00	13 + 2.00	15 + 1.00	11 + 0.00	20 + 0.00
<i>Streptococcus pyogenic</i>	20 + 1.00	15 + 1.00	20 + 0.00	0 + 0.00	30 + 0.00
<i>Pseudomonas aeruginosa</i>	15 + 1.00	10 + 0.50	12 + 1.00	0 + 0.00	0 + 0.00
<i>Cornibacterium xerosis</i>	24 + 0.00	17.5 + 0.50	13.5 + 0.5	13 + 0.00	0 + 0.00
<i>Enterobacter raerogenes</i>	15 + 2.00	15 + 1.00	11.5 + 0.5	0 + 0.00	23 + 2.00
<i>Micrococcus varians</i>	13 + 2.00	0 + 0.00	15 + 0.50	0 + 0.00	23 + 1.00
<i>Staphylococcus epidermides</i>	12 + 1.00	22.5 + 2.00	15 + 0.50	4 + 0.00	33 + 1.00
<i>Candida albican</i>	19 + 0.50	15 + 1.00	8 + 0.50	15 + 1.00	0 + 0.00
<i>Candida gilabrata</i>	17 + 0.50	20 + 1.00	15 + 1.00	0 + 0.00	29 + 2.00
<i>Candida tropicalis</i>	6 + 0.50	10 + 1.00	22.5 + 2.00	15 + 2.00	0 + 0.00

KEY: Sensitive ≥ 15 , Intermediate 14 to 11, and Resistance ≤ 10

Table 8: The antimicrobial result of soap, formulated soaps, and essential oil of *Cymbopogon citratus* against some tested organisms.

Isolated code plate	A	B	C	D	PC
<i>Staphylococcus aureus</i>	15 + 0.50	25 + 0.00	24 + 0.50	34 + 1.00	15 + 0.50
<i>Streptococcus pyogenic</i>	18 + 0.50	17 + 0.50	20.5 + 0.50	0 + 0.00	24 + 2.00
<i>Pseudomonas aeruginosa</i>	14 + 1.00	19 + 1.00	30 + 0.00	0 + 0.00	0 + 0.00
<i>Cornibacterium xerosis</i>	19 + 2.00	21 + 2.00	22.5 + 0.50	15 + 1.00	24 + 1.00
<i>Enterobacter raerogenes</i>	23 + 1.00	12 + 0.00	22 + 0.50	25 + 0.50	35 + 0.00
<i>Micrococcus varians</i>	15 + 0.50	25 + 1.00	14 + 1.00	0 + 0.00	21 + 0.50
<i>Staphylococcus epidermides</i>	15 + 0.00	20 + 2.00	18.5 + 0.50	26 + 2.00	35 + 0.50
<i>Candida albican</i>	25 + 0.50	29 + 0.00	16.5 + 1.00	30 + 0.50	35 + 0.50
<i>Candida gilabrata</i>	19 + 1.00	19 + 0.00	19 + 1.00	30 + 0.50	32 + 0.00
<i>Candida tropicalis</i>	9.5 + 0.50	0 + 0.00	7.5 + 1.00	0 + 0.00	0 + 0.00

KEY: Sensitive ≥ 15 , Intermediate 14 to 11, and Resistance ≤ 10

Table 9: The MIC result of soap, formulated soaps, and *Thuja koraiensis* essential oil against some tested organisms.

Isolated code plate	Concentrations (mg/ml)	A	B	C	D
<i>Staphylococcus aureus</i>	50	-	+	+	+
	25	-	-	-	+
	12.5	-	-	-	-
	6.25	-	-	-	-
	3.125	-	-	-	-
<i>Streptococcus pyogenic</i>	50	+	+	+	+
	25	-	-	-	+
	12.5	-	-	-	-
	6.25	-	-	-	-
	3.125	-	-	-	-
<i>Pseudomonas aeruginosa</i>	50	+	+	+	+
	25	-	-	+	-
	12.5	-	-	-	-
	6.25	-	-	-	-
	3.125	-	-	-	-
<i>Cornibacterium xerosis</i>	50	+	+	+	+
	25	-	-	-	-
	12.5	-	-	-	-
	6.25	-	-	-	-
	3.125	-	-	-	-
<i>Enterobacter raerogenes</i>	50	+	+	+	-
	25	-	-	-	-
	12.5	-	-	-	-
	6.25	-	-	-	-
	3.125	-	-	-	-
<i>Micrococcus varians</i>	50	+	+	+	+
	25	-	-	-	-
	12.5	-	-	-	-
	6.25	-	-	-	-
	3.125	-	-	-	-
<i>Staphylococcus epidermides</i>	50	-	-	-	+
	25	-	-	-	-
	12.5	-	-	-	-
	6.25	-	-	-	-
	3.125	-	-	-	-
<i>Candida albican</i>	50	-	-	-	-
	25	-	-	-	-
	12.5	-	-	-	-
	6.25	-	-	-	-
	3.125	-	-	-	-
<i>Candida gilabrata</i>	50	+	+	+	+
	25	+	-	-	+
	12.5	-	-	-	-
	6.25	-	-	-	-
	3.125	-	-	-	-
<i>Candida tropicalis</i>	50	+	+	+	+
	25	-	+	+	+
	12.5	-	-	-	-
	6.25	-	-	-	-
	3.125	-	-	-	-

KEY: (+) – Sensitive; (-) – Resistance

Table 10: The MIC result of soap, formulated soaps, and *Citrus aurantifolia* essential oil against some tested organisms.

Isolated code plate	Concentrations (mg/ml)	A	B	C	D
<i>Staphylococcus aureus</i>	50	+	+	+	+
	25	-	-	-	+
	12.5	-	-	-	-
	6.25	-	-	-	-
	3.125	-	-	-	-
<i>Streptococcus pyogenic</i>	50	+	+	+	+
	25	+	+	+	+
	12.5	-	-	-	-
	6.25	-	-	-	-
	3.125	-	-	-	-
<i>Pseudomonas aeruginosa</i>	50	+	+	+	+
	25	+	+	+	-
	12.5	-	-	-	-
	6.25	-	-	-	-
	3.125	-	-	-	-
<i>Cornibacterium xerosis</i>	50	+	+	+	+
	25	+	-	+	+
	12.5	-	-	+	-
	6.25	-	-	-	-
	3.125	-	-	-	-
<i>Enterobacter raerogenes</i>	50	+	+	+	+
	25	-	-	-	+
	12.5	-	-	-	+
	6.25	-	-	-	-
	3.125	-	-	-	-
<i>Micrococcus varians</i>	50	-	+	+	+
	25	-	-	+	+
	12.5	-	-	+	-
	6.25	-	-	-	-
	3.125	-	-	-	-
<i>Staphylococcus epidermides</i>	50	-	-	-	+
	25	-	-	-	-
	12.5	-	-	-	-
	6.25	-	-	-	-
	3.125	-	-	-	-
<i>Candida albican</i>	50	-	-	-	-
	25	-	-	-	-
	12.5	-	-	-	-
	6.25	-	-	-	-
	3.125	-	-	-	-
<i>Candida gilabrata</i>	50	+	+	+	+
	25	+	+	-	+
	12.5	-	+	-	-
	6.25	-	-	-	-
	3.125	-	-	-	-
<i>Candida tropicalis</i>	50	+	+	+	+
	25	+	+	+	+
	12.5	-	-	-	-
	6.25	-	-	-	-
	3.125	-	-	-	-

KEY: (+) – Sensitive; (-) – Resistance

Table 11: The MIC result of soap, formulated soaps, and *Curcuma longa* essential oil against some tested organisms.

Isolated code plate	Concentrations (mg/ml)	A	B	C	D
<i>Staphylococcus aureus</i>	50	-	+	-	-
	25	-	-	-	-
	12.5	-	-	-	-
	6.25	-	-	-	-
	3.125	-	-	-	-
<i>Streptococcus pyogenic</i>	50	+	+	+	+
	25	-	-	-	-
	12.5	-	-	-	-
	6.25	-	-	-	-
	3.125	-	-	-	-
<i>Pseudomonas aeruginosa</i>	50	+	+	+	+
	25	-	-	+	-
	12.5	-	-	-	-
	6.25	-	-	-	-
	3.125	-	-	-	-
<i>Cornibacterium xerosis</i>	50	+	+	+	+
	25	-	-	-	-
	12.5	-	-	-	-
	6.25	-	-	-	-
	3.125	-	-	-	-
<i>Enterobacter raerogenes</i>	50	+	+	+	-
	25	-	-	-	-
	12.5	-	-	-	-
	6.25	-	-	-	-
	3.125	-	-	-	-
<i>Micrococcus varians</i>	50	-	+	+	+
	25	-	-	-	-
	12.5	-	-	-	-
	6.25	-	-	-	-
	3.125	-	-	-	-
<i>Staphylococcus epidermides</i>	50	-	-	-	+
	25	-	-	-	-
	12.5	-	-	-	-
	6.25	-	-	-	-
	3.125	-	-	-	-
<i>Candida albican</i>	50	-	-	-	+
	25	-	-	-	+
	12.5	-	-	-	-
	6.25	-	-	-	-
	3.125	-	-	-	-
<i>Candida gilabrata</i>	50	+	+	+	+
	25	+	-	-	+
	12.5	-	-	-	-
	6.25	-	-	-	-
	3.125	-	-	-	-
<i>Candida tropicalis</i>	50	+	+	+	+
	25	-	+	+	+
	12.5	-	-	-	-
	6.25	-	-	-	-
	3.125	-	-	-	-

KEY: (+) – Sensitive; (-) – Resistance

Table 12: The MIC result of soap, formulated soaps, and *Hyptis suaveolens* essential oil against some tested organisms.

Isolated code plate	Concentrations (mg/ml)	A	B	C	D
<i>Staphylococcus aureus</i>	50	-	+	+	+
	25	-	-	-	+
	12.5	-	-	-	-
	6.25	-	-	-	-
	3.125	-	-	-	-
<i>Streptococcus pyogenic</i>	50	+	+	+	+
	25	-	-	-	+
	12.5	-	-	-	-
	6.25	-	-	-	-
	3.125	-	-	-	-
<i>Pseudomonas aeruginosa</i>	50	+	+	+	+
	25	-	-	+	-
	12.5	-	-	-	-
	6.25	-	-	-	-
	3.125	-	-	-	-
<i>Cornibacterium xerosis</i>	50	+	+	+	+
	25	-	-	-	-
	12.5	-	-	-	-
	6.25	-	-	-	-
	3.125	-	-	-	-
<i>Enterobacter raerogenes</i>	50	+	+	+	-
	25	-	-	-	-
	12.5	-	-	-	-
	6.25	-	-	-	-
	3.125	-	-	-	-
<i>Micrococcus varians</i>	50	-	+	+	+
	25	-	-	-	-
	12.5	-	-	-	-
	6.25	-	-	-	-
	3.125	-	-	-	-
<i>Staphylococcus epidermides</i>	50	-	-	-	+
	25	-	-	-	-
	12.5	-	-	-	-
	6.25	-	-	-	-
	3.125	-	-	-	-
<i>Candida albican</i>	50	-	-	-	+
	25	-	-	-	+
	12.5	-	-	-	-
	6.25	-	-	-	-
	3.125	-	-	-	-
<i>Candida gilabrata</i>	50	+	+	+	+
	25	+	-	-	+
	12.5	-	-	-	-
	6.25	-	-	-	-
	3.125	-	-	-	-
<i>Candida tropicalis</i>	50	+	+	+	+
	25	-	+	+	+
	12.5	-	-	-	-
	6.25	-	-	-	-
	3.125	-	-	-	-

KEY: (+) – Sensitive; (-) – Resistance

Table 13: The MIC result of soap, formulated soaps, and *Cymbopogon citratus* essential oil against some tested organisms.

Isolated code plate	Concentrations (mg/ml)	A	B	C	D
<i>Staphylococcus aureus</i>	50	+	+	+	+
	25	-	-	-	+
	12.5	-	-	-	-
	6.25	-	-	-	-
	3.125	-	-	-	-
<i>Streptococcus pyogenic</i>	50	+	+	-	-
	25	-	-	-	-
	12.5	-	-	-	-
	6.25	-	-	-	-
	3.125	-	-	-	-
<i>Pseudomonas aeruginosa</i>	50	+	+	+	+
	25	-	-	+	-
	12.5	-	-	-	-
	6.25	-	-	-	-
	3.125	-	-	-	-
<i>Cornibacterium xerosis</i>	50	+	+	+	+
	25	-	-	-	+
	12.5	-	-	-	+
	6.25	-	-	-	-
	3.125	-	-	-	-
<i>Enterobacter raerogenes</i>	50	+	+	+	+
	25	-	-	-	+
	12.5	-	-	-	-
	6.25	-	-	-	-
	3.125	-	-	-	-
<i>Micrococcus varians</i>	50	-	+	+	+
	25	-	-	-	+
	12.5	-	-	-	-
	6.25	-	-	-	-
	3.125	-	-	-	-
<i>Staphylococcus epidermides</i>	50	-	-	-	+
	25	-	-	-	+
	12.5	-	-	-	-
	6.25	-	-	-	-
	3.125	-	-	-	-
<i>Candida albican</i>	50	-	-	-	+
	25	-	-	-	+
	12.5	-	-	-	-
	6.25	-	-	-	-
	3.125	-	-	-	-
<i>Candida gilabrata</i>	50	+	+	+	+
	25	+	-	-	+
	12.5	-	-	-	-
	6.25	-	-	-	-
	3.125	-	-	-	-
<i>Candida tropicalis</i>	50	+	+	+	+
	25	-	+	+	+
	12.5	-	-	-	-
	6.25	-	-	-	-
	3.125	-	-	-	-

KEY: (+) – Sensitive; (-) – Resistance

4. Discussions

4.1 Physicochemical properties of different essential oils

In Table 1, *Thuja koraiensis* essential oil showed a pH value of 3.5, indicating that it is acidic in nature. This acidity may affect the direct application of the oil on the skin; low pH is corrosive to skin and contributes to the hardness of hands and skin after washing, causing irritation and destruction, which can be reduced by the addition of excess fat or oil during processes (Mahesar et al., 2019). However, in soap production, where alkaline substances like sodium hydroxide are used, it can contribute to achieving a balanced final pH, resulting in mild and skin-friendly soap. The alkalinity of soap works as a barrier against bacteria and viruses by neutralizing the skin's protective acid mantle (Zuhair et al., 2018). The pH of the *Citrus aurantifolia* and *Cymbopogon citrates* essential oils revealed 5.6 and 5.7, respectively. It is placed in the mildly acidic range; the value is beneficial in soap formulation as it enhances skin compatibility, considering that the natural skin surface has a slightly acidic pH (4.5–6.0), which serves as a protective barrier against microbial invasion. Thus, the acidic nature of the oil aligns with cosmetic and pharmaceutical applications. In natural soap formulations, especially with citrus-based oils like lime, there is often a slight reduction in pH, contributing to milder soap (Nwachukwu et al., 2022). The pH value of the *Curcuma longa* and *Hyptis suaveolens* essential oils were recorded as 6.2 and 6.8 respectively, the value are slightly acidic and fall within acceptable limits for toilet soap, as most standard soaps have pH between 9 and 11 and within acceptable range (7-10) that is permitted by a regulating authority especially in Nigeria and standard organization of Nigeria (Zuhair et al., 2018; oyekunle et al., 2021; Oyedele, 2002). Soaps with pH values closer to neutral were better suited for cosmetic purposes since they are less likely to irritate the skin (Abubakar et al., 2020). All the pH values observed were relatively low compared to the recommended pH range (8.5-10.0) for cosmetic soaps (Oyeleke, 2009).

The specific gravity of the following essential oils was *Hyptis suaveolens* (0.897), *Citrus aurantifolia* (0.878), *Curcuma longa* (0.945), *Cymbopogon citrates* (0.909), and *Thuja koraiensis* (0.930). The values fall within the typical range of most essential oils (0.85-0.98). This indicates that the oil is less dense than water, confirming its purity and consistency. The relatively low density is an important feature, as it ensures ease of mixing and solubility when incorporated into soap and other cosmetic formulations. Additionally, low density may influence the soap's lathering properties, since lighter soaps generally contain a higher proportion of unsaponified or loosely structured fatty acid salts that promote foam formation and are also indicative of good storage stability, which contributes to an extended shelf life during soap manufacturing (Martin et al., 2021)

The *Curcuma longa* and *Cymbopogon citratus* essential oils exhibited a bright yellow color, which is characteristic of many plant-derived oils rich in bioactive compounds such as phenolic and flavonoid compounds that exhibit antibacterial, antifungal, and antioxidant activities. These properties make them suitable for fortification in soaps and other personal care products (Parande et al., 2010; Nikita Pardhi et al, 2025). The color intensity can also be linked to the presence of pigments and natural antioxidants, which are desirable as they may contribute to the stability and activity of the oil in formulated products. The cream coloration of the *Thuja koraiensis* is aesthetically pleasing and suggests minimal use of artificial dyes. It reflects the natural tones of the base oils and may appeal to consumers seeking organic or minimally

processed products. *Citrus aurantifolia* was observed to have a light-yellow coloration. A light, uniform shade suggests adequate mixing and complete saponification, while darker or uneven tones may indicate residual oil or partial reaction. Thus, the consistent light-yellow colour supports the physicochemical integrity of the formulation. The colour of *Hyptis suaveolens* essential oil is Pale Blue.

In terms of viscosity, the *Curcuma longa* essential oil was described as low viscous, which is advantageous for formulation. Moderately viscous oil ensures good spreadability on the skin while still maintaining a suitable texture when blended with other ingredients in soap production. Hence, the low viscosity of the oil makes it ideal for cosmetic and cleansing products. *Thuja koraiensis* has no viscosity, while *Cymbopogon citrates* showed low viscosity; these may reduce the stability of the oil. *Citrus aurantifolia* showed a watery viscosity, which indicates that the formulation is softer and more fluid compared to typical commercial bar soaps. Viscosity in oil is influenced by the ratio of water to oil, the degree of saponification, and the presence of additives such as sodium chloride, which normally acts as a hardening agent. In this case, the watery consistency suggests either a relatively high-water content or reduced hardening efficiency, possibly due to the moderating effect of *Citrus aurantifolia*. *Hyptis suaveolens* showed liquid viscosity, which suggests that oils with liquid viscosity generally produce softer soaps with good moisturizing ability, but may require salt addition to achieve the desired hardness.

4.2 Results on detergency and foaming property of the soap

Tables 2 and 3 revealed the foaming properties and detergency test of the soap and formulated soaps with *Thuja koraiensis* essential oil at differences concentration in their effectiveness in removing stains from the soiled cloths. Sample A was observed to be highly effective, with a foam retention time of 1 hour 45 minutes, indicating that it had strong cleaning ability, stable foam, and efficiently removed the red oil and charcoal stains. This suggests that the ingredient used for Sample A contributed to its superior cleaning performance. Samples B and C were found to be moderately effective, which implies that their cleaning capacity was lower compared to Sample A. Sample C showed a foam retention time of 56 minutes 32 seconds, slightly longer than Sample B but still significantly lower than Sample A. Sample B produced foam that lasted 55 minutes 33 seconds, which is considerably shorter than Samples A and C. This implies that Sample C also has moderate foaming ability, though it performs marginally better than Sample B in terms of foam stability. The moderate detergency may be due to differences in the concentration of active ingredients or the type of oils used in their formulation, which may affect their ability to emulsify and remove grease and particulate matter from the cloth. This highlights that the formulation of Sample A is more effective in sustaining foam, which could positively influence user satisfaction and washing efficiency.

The detergency of Sample B in *Citrus aurantifolia* essential oil was highly effective; these findings support the report of Adewuyi and Adeleke (2019), stating that the inclusion of lipid oils in soap formulation enhances lathering ability and improves the emulsification of dirt and oils. Samples A and C were moderately effective, with foaming stability times observed as 55 minutes 7 seconds and 50 minutes 18 seconds, respectively. Sample A is only moderately effective; it may still be acceptable for light household use but might not perform as efficiently in heavy-duty cleaning situations. This suggests that they are capable of producing sufficient foam; their cleansing efficiency may have been

limited by factors such as slightly lower surfactant activity, weaker emulsification capacity, or less stable micelle formation compared to Sample B. The superior performance of Sample B can be linked to its stronger foaming stability (1 hr 24 min), which likely enhanced the emulsification and suspension of dirt particles during washing. Lasting foam ensures that surfactant molecules remain active on the surface for an extended period, increasing the soap's cleaning capacity. Additionally, the balance of fatty acid composition from coconut oil, combined with complete saponification, may have contributed to this higher detergency.

Foaming stability and detergency of *Curcuma longa* essential oil showed that Samples A and C recorded the highest foaming stability, Sample A maintaining its foam duration for 1 hour and 30 seconds. It was also rated as highly effective in detergency. This suggests that the formulation of Sample A possessed a balanced composition of fatty acids and surfactant activity, leading to strong foaming ability and efficient cleaning action. High foaming stability is desirable because it reflects the soap's capacity to emulsify oily and greasy particles effectively, which contributes to its cleaning efficiency. According to Akuaden et al. (2019), it was determined that the soap foam-producing ability was stable when compared to other soaps (Akuaden et al., 2019). Sample B, on the other hand, had the lowest foam stability, lasting only 55 minutes and 4 seconds. Its detergency was classified as moderately effective. This reduced performance compared to Samples A and C could be attributed to differences in the formulation, possibly a lower concentration of active cleaning components, or a less favorable fatty acid profile. The relatively short foam duration and moderate detergency imply that Sample B may not perform as effectively in heavy or oily cleaning tasks, although it may still be suitable for light washing purposes. Sample C maintained foam for 1 hour and 15 seconds and was also rated highly effective in detergency. While its foam duration was slightly lower than that of Sample A, its detergency was still excellent, indicating that effective cleaning action does not solely depend on foam longevity but also on the quality of the surfactant properties present in the soap.

Sample A (unformulated soap) removed stains moderately effectively, while Samples B and C (soap fortified with essential oil) exhibited high detergency. The improved performance in fortified soaps could be attributed to the surfactant action of terpenoid compounds present in *Hyptis suaveolens* essential oil, which can enhance the penetration of soap molecules into fabrics.

All three samples (A, B, and C) were rated as highly effective, exhibiting strong detergency and forming properties. Sample A (1 hr 32 min) and Sample C (1 hr 10 min) still exhibited substantial foam longevity, though lower than Sample B. Sample A was formed via the saponification process, which involves the reaction of fats or oils with an alkali to produce soap and glycerol. The coconut oil used has remained a staple due to its high lauric acid content, which contributes to desirable soap properties such as cleansing power, lathering ability, and antimicrobial activity (Mena et al, 2020; Mbouche et al., 2022). However, foam longevity should be considered together with detergency and mildness. The *Cymbopogon citrates* essential oil in the formulation contained limonene, which enhances lathering properties (Shah et al., 2023). Coconut oil contains high unsaturated fatty acids, providing sufficient surfactant activity when properly saponified with sodium hydroxide, enabling efficient emulsification and suspension of dirt particles. The addition of *Cymbopogon citrates* essential oil, rich in compounds such as citral, may have further enhanced detergency through its antimicrobial and degreasing properties. The detergency results also align well with the strong foaming properties recorded (foam stability

ranging from 1 hr 10 min to 1 hr 45 min). Long-lasting foam provides more active surface area for dirt removal and improves cleansing efficiency. The excellent detergency across all samples indicates that the two formulations achieved a favorable balance of surfactant activity, foam stability, and oil composition. From a practical standpoint, the finding is that all three samples were highly effective.

4.3 The antimicrobial result of soap, formulated soaps, and the essential oil of *Thuja koraiensis* against some test organisms

Table 4 revealed the antimicrobial evaluation of *Thuja koraiensis* essential oils and their corresponding soap and formulated soaps showed varying levels of effectiveness against a panel of bacterial and fungal isolates. Sample A exhibited the least antimicrobial activity overall. *Streptococcus pyogenes* and *Micrococcus varians* showed no inhibition, while *Staphylococcus aureus* (12.5 mm) and *Corynebacterium xerosis* (11.5 mm) were only moderately inhibited. The value was the same with Dettol against *Staphylococcus aureus* (12.5 mm) (Obi, 2014). This reduced activity may be due to lower concentrations of active compounds or inefficient extraction methods. Sample B showed notable antimicrobial effects against *Streptococcus pyogenes* (20 mm), *Candida tropicalis* (20 mm), and *Candida glabrata* (20 mm). Sample C consistently demonstrated the highest antimicrobial activity across most test organisms. It exhibited strong inhibition zones against *Micrococcus varians* (28 mm), *Candida tropicalis* (30 mm), *Enterobacter aerogenes* (26.5 mm), and *Staphylococcus epidermidis* (25 mm). This broad-spectrum efficacy suggests that *Thuja koraiensis* essential oil in Sample C may provide synergistic antimicrobial properties likely due to terpenes disrupting microbial membranes and inhibiting growth. Sample D displayed selective antimicrobial activity, showing strong inhibition against *Micrococcus varians* (25 mm) and *Candida tropicalis* (25 mm) but was ineffective against *Enterobacter aerogenes*, *Staphylococcus epidermidis*, and *Corynebacterium xerosis*, where no inhibition was recorded. This indicates that the oil composition in Sample D may lack certain active compounds or their concentrations are suboptimal. The positive control (PC) validated the testing process, demonstrating high sensitivity (≥ 30 mm) against *Streptococcus pyogenes*, *Candida albicans*, *Candida glabrata*, and *Candida tropicalis*, confirming the reliability and accuracy of the comparative antimicrobial assessment. Sample C represents the most promising formulation with broad and potent antimicrobial efficacy. Sample B is moderately effective and may serve as a viable alternative. Sample D, which is the essential oil, shows selective antimicrobial activity and may benefit from further formulation optimization. Sample A requires enhancement to improve its antimicrobial profile.

4.4 The antimicrobial result of soap, formulated soaps, and *Citrus aurantifolia* essential oil against some test organisms

In Table 5, *Staphylococcus aureus* and *Streptococcus pyogenes* were strongly inhibited, reflecting the ability of the soaps to suppress pathogens frequently implicated in skin infections. According to Nwachukwu et al. (2021), who reported that *Citrus aurantifolia* essential oil exhibited broad-spectrum antimicrobial activity due to its high limonene and citral contents. The activity of Sample C, which consistently produced larger inhibition zones (e.g., 24 mm for *S. aureus* and 27.5 mm for *S. pyogenes*), suggests a superior formulation, possibly due to higher concentrations of bioactive compounds or enhanced

penetration of microbial cell walls and microbial populations beyond just cleansing (Chukwu *et al.*, 2018). Gram-negative bacteria such as *Pseudomonas aeruginosa* and *Enterobacter aerogenes* also showed significant inhibition (15–27.5 mm). This agrees with the findings of Obi (2014), where Crusader soap was found to possess antibacterial activity of 25 mm against *Pseudomonas aeruginosa*. In his study on antibacterial activities, this is remarkable considering their resistance tendencies. For fungi, *Candida albicans*, *C. glabrata*, and *C. tropicalis* all showed moderate to high sensitivity with inhibition zones ranging from 20–30 mm. Overall, the results demonstrated that essential oils and their soap formulations possess broad-spectrum antimicrobial properties, comparable in some cases to standard antibiotics.

4.5 The antimicrobial result of soap, formulated soaps, and *Curcuma longa* essential oil against some test organisms

Table 6 revealed that Sample A showed weak antimicrobial activity. Most of the results fell within the intermediate or resistance range (e.g., *S. aureus* 9 mm - resistance, *S. pyogenes* 13.5 - intermediate). Only moderate inhibition was seen against *C. albicans* (15.5 mm - sensitive). This suggests that Sample A has limited antimicrobial effectiveness, with its main potential against certain fungi. Sample B displayed the strongest and broadest activity among all samples. Most test organisms were sensitive, which indicates that Sample B has excellent broad gram-negative bacteria and fungi. Its strong inhibition against *C. glabrata* highlights a possible role in antifungal applications. Sample C demonstrated strong activity against some organisms (*S. pyogenes*, 25 mm - sensitive, *M. varians*, 20 mm - sensitive, *C. tropicalis* 15 mm - sensitive). However, it was completely ineffective against *S. epidermidis* (0 mm - resistance). This suggests that Sample C may be effective against specific pathogens but lacks broad-spectrum coverage. Sample D, which is the essential oil, showed the weakest antimicrobial activity compared to the soaps. This implies that the essential oil loses some antimicrobial potency in its raw form and performs better when incorporated into soaps. The positive Control (Amoxicillin) showed consistency, strong inhibition across most test organisms (25–28 mm). However, it was completely ineffective against some organisms (*S. aureus* 0 mm, *P. aeruginosa* 0 mm, *E. aerogenes* 0 mm, *C. glabrata* 0 mm). Interestingly, Sample B outperformed Amoxicillin against certain fungi (*C. glabrata* 40 mm vs. 0 mm).

4.6 The antimicrobial result of soap, formulated soaps, and *Hyptis suaveolens* essential oil against some test organisms

Table 7 shows that the fortified soaps exhibited greater inhibitory effects against test organisms. Sample A showed no activity against *Staphylococcus aureus*, *Escherichia coli*, and *Candida albicans*. In contrast, Samples B and C produced clear zones of inhibition against all test organisms. The zones were wider in Sample C, indicating that antimicrobial activity increased with higher concentrations of essential oil. This result agrees with the report of Oyediji and Afolayan (2006), who found that *Hyptis suaveolens* essential oil possesses broad-spectrum antimicrobial activity due to compounds like 1,8-cineole and sabinene. The improved performance of fortified soaps compared to soap highlights the synergistic effect of combining coconut oil (based soap) with essential oil. Sample D (essential oil) produced the highest zones of inhibition across all test organisms. Incorporating it into soap formulations is more practical for consumer use. The soap provides a

cleansing base, while the essential oil contributes antimicrobial action and fragrance. Therefore, fortified soaps (Samples B and C) represent an effective combination of cleansing and antimicrobial properties.

4.7 The antimicrobial result of soap, formulated soaps, and *Cymbopogon citratus* essential oil against some test organisms

In Table 8, Sample D exhibited the highest zone of inhibition against *Staphylococcus aureus* (34 mm), indicating strong sensitivity, while Samples A, B, and C showed effective inhibition (≥ 15 mm), suggesting that all four samples possess antibacterial properties against the organisms. For *Streptococcus pyogenes*, Sample B showed the highest activity (27 mm), followed by A and C, while Sample D showed no activity, indicating resistance. In the case of *Pseudomonas aeruginosa*, Sample C was most effective (30 mm), while D showed no inhibition, suggesting that Sample C contains components particularly active against Gram-negative bacteria. *Corynebacterium xerosis* was sensitive to all samples, with C showing the highest inhibition (22.5 mm), reinforcing its broad-spectrum potential. For *Enterobacter aerogenes*, sample D showed strong activity (25 mm), while B was the least effective (12 mm), falling into the intermediate category. *Micrococcus varians* responded best to Sample B (25 mm), while D showed no activity, indicating selective antimicrobial action. *Staphylococcus epidermidis* was sensitive to all samples, with D showing the highest inhibition (26 mm), suggesting its effectiveness against skin-associated pathogens. Among the fungal organisms, *Candida albicans* and *Candida glabrata* were highly sensitive to Sample D (30 mm), while *Candida tropicalis* showed resistance to all samples, with Sample A showing the only measurable but still resistant activity (9.5 mm). The positive control (PC) consistently showed high inhibition zones across most organisms, validating the test procedure. Overall, the results suggest that essential oils used in Samples A, B, C, and D possess varying degrees of antimicrobial activity, with Sample D showing strong antifungal and Gram-positive bacteria activity, Sample C being effective against Gram-negative bacteria, and Sample B demonstrating broad-spectrum antibacterial potential. These findings highlight the potential of essential oils in soap formulations as natural antimicrobial agents, though further optimization and testing are recommended to enhance efficacy and ensure safety.

4.8 The MIC result of soap, formulated soaps, and *Thuja koraiensis* essential oil against some test organisms

Table 9 shows that the samples exhibited activity at higher concentrations, with inhibition generally observed at 50 mg/ml and 25 mg/ml, while no appreciable effect was recorded at lower concentrations (12.5-3.125 mg/ml). Among the tested samples, D showed inhibitory activity at comparatively lower concentrations (25 mg/ml) against *Staphylococcus aureus*, *Streptococcus pyogenes*, *Candida glabrata*, and *Candida tropicalis*. This suggests that Sample D possesses stronger antimicrobial potential compared to the other tested samples. In contrast, Sample A demonstrated the weakest activity, with inhibition observed only at 50 mg/ml, and it was completely inactive against *Micrococcus varians*, *Staphylococcus epidermidis*, and *Candida albicans*. Samples B and C produced moderate effects, inhibiting most of the organisms but requiring higher concentrations to achieve activity. With respect to individual test organisms, Gram-positive bacteria such as *Staphylococcus aureus* and *Streptococcus pyogenes* were particularly sensitive, especially to sample D, which inhibited at 25 mg/ml. *Pseudomonas*

aeruginosa, a Gram-negative bacterium known for its high intrinsic resistance, was inhibited at 25 mg/ml by sample C but showed reduced susceptibility to the other samples. Similarly, *Enterobacter aerogenes* was resistant to Sample D but susceptible to oils A, B, and C at 50 mg/ml. *Staphylococcus epidermidis* was inhibited only by Sample D at 50 mg/ml.

4.9 The MIC result of soap, formulated soaps, and *Citrus aurantifolia* essential oil against some test organisms

In Table 10, the results showed that *Micrococcus varians* and *Corynebacterium xerosis* were sensitive in Sample C, inhibited at a concentration of 12.5 mg/ml. *Pseudomonas aeruginosa* and *Candida glabrata* were highly sensitive, with Samples A and B showing inhibition even at 12.5 mg/ml, confirming their strong activity. In sample D, *Enterobacter aerogenes* was inhibited at 12.5 mg/ml but showed inhibitory activity at lower concentrations (25 mg/ml) against all the organisms except *Streptococcus pyogenes* at 50mg/ml. *Staphylococcus epidermidis* was inhibited only by sample D at 25 mg/ml. *Candida albicans* demonstrated the weakest activity (Kusuma *et al.*, 2024).

4.10 The MIC result of soap, formulated soaps, and *Curcuma longa* essential oil against some test organisms

Table 11 shows that all the samples showed inhibition at 25 mg/ml and 50 mg/ml; Sample D maintained activity at 25 mg/ml, indicating a stronger potency against *Streptococcus pyogenes*, *Candida albicans*, *Candida glabrata*, and *Candida tropicalis*. This reinforces the antifungal potential of Sample D, consistent with its performance in the antimicrobial zone inhibition test. Similarly, *Staphylococcus aureus* and *Staphylococcus epidermidis* were inhibited only by Samples B and D, respectively, at 50 mg/ml (Kusuma *et al.*, 2024). *Candida albicans* was inhibited only by Sample D at 25 mg/ml, with the MIC value reaching down to 25 mg/ml in several cases. Samples A, B, and C were generally effective only at the highest concentration tested (50 mg/ml), indicating lower potency or a narrower spectrum.

4.11 The MIC result of soap, formulated soaps, and *Hyptis suaveolens* essential oil against some test organisms

Table 12 showed *Candida albicans* demonstrated the weakest activity in all the samples. Sample D maintained activity at 25 mg/ml, indicating a stronger potency against *Staphylococcus aureus*, *Streptococcus pyogenes*, *Candida glabrata*, and *Candida tropicalis*. *Candida tropicalis* showed inhibitory activity at comparatively lower concentrations (25 mg/ml) in all the samples except Sample A.

4.12 The MIC result of soap, formulated soaps, and *Cymbopogon citratus* essential oil against some test organisms

Table 13 showed *Staphylococcus aureus*, *Enterobacter aerogenes*, *Micrococcus varians*, *Candida glabrata*, and *Candida tropicalis* maintained activity at 25 mg/ml, indicating a stronger potency. Citral, the primary component of *Cymbopogon citratus*, drives antimicrobial activity by disrupting microbial cell membranes, as seen in the 25–30 mm inhibition zones against *Staphylococcus aureus* and *Pseudomonas aeruginosa* (Aiemsraad *et al.*, 2021). This suggests that the essential oil retained the bioactive components but also facilitated improved delivery

and interaction with bacterial cells. Similarly, *Candida tropicalis* showed inhibitory activity at comparatively lower concentrations (25 mg/ml) in all the samples except Sample A. *Corynebacterium xerosis* showed sensitivity to all the samples at 50 mg/ml except Sample D, with a concentration of 12.5 mg/ml. *Streptococcus pyogenes* showed inhibitory activity at comparatively lower concentrations (50 mg/ml) in Samples A and B.

4. Conclusion

This study concludes that soaps formulated with essential oils possess both satisfactory physicochemical characteristics and significant antimicrobial activity against common skin pathogens. The incorporation of essential oils such as *Hyptis suaveolens*, *Citrus aurantifolia*, *Curcuma longa*, *Cymbopogon citratus*, and *Thuja koraiensis* improved the soaps' antibacterial and antifungal performance and added natural fragrance and therapeutic properties, aligning with growing consumer preferences for herbal-based personal care products. The research, therefore, validates the potential of essential oil-based soaps as safe, natural, and effective alternatives to conventional synthetic antimicrobial soaps, thereby contributing to public health improvement and addressing the growing problem of antimicrobial resistance.

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Author Contributions

KKS performed the extraction of plant essential oil and handled submission and correspondence with the journal. AO conceptualized the research idea, designed the experiment, developed the methodology, carried out antibacterial assays, prepared figures and tables, and interpreted the findings in relation to existing literature. KAO wrote the initial draft of the manuscript and revised it critically for intellectual content.

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Competing Interest

The author affirms that there are no identifiable conflicts of interest, either financial or personal, that could be perceived as influencing the work presented in this paper.

Data Availability Statement

All data generated or analyzed during this study are included in this published article.

Ethics Approval

This study did not involve human participants or animals and therefore did not require ethics approval.

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