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Assessment of antimicrobial efficacy in selected antibacterial cosmetics*

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ABSTRACT

Introduction: Many microorganisms present on human skin can cause various diseases. One preventive measure is the use of cosmetics with antibacterial properties. These include everyday body care products and specialized ones designed to limit bacterial growth. This study aims to assess the antimicrobial efficacy of various cosmetics against selected bacteria and yeasts naturally found on the skin.

Materials and methods: The study used clinical strains of: *Staphylococcus aureus, Staphylococcus epidermidis, Enterococcus faecium, Candida albicans*, and reference strains of: *Pseudomonas aeruginosa* ATCC 27853, *Escherichia coli* ATCC 25922, and *Acinetobacter baumannii* ATCC 19606. Five commercially available antibacterial cosmetics were tested. Effectiveness was assessed by the reduction in bacterial numbers, expressed as log colony-forming units (CFU)×cm^{-3}, and the size of the growth inhibition zone, expressed in mm.

Results: Our research found that the highest antibacterial efficacy was achieved by the face gel and antiperspirant. The gel caused an average reduction in bacterial numbers by 4.73 log CFU×cm^{-3}. The mattifying powder and creams were less effective. In the disc-diffusion method, the antiperspirant most frequently showed the largest inhibition zone, while the regenerating cream showed the smallest.

Conclusion: The use of antibacterial cosmetics limits the growth of microorganisms, which is crucial for maintaining body hygiene and alleviating symptoms of skin diseases.

Keywords: antibacterial cosmetics; skin pathogens; skin diseases; disc-diffusion method; quantitative method.

INTRODUCTION

Human skin performs several essential functions for the body, one of the most crucial being the protection of tissues and organs from infections caused by microorganisms. The effectiveness of this protection is largely determined by the composition of the skin's microbiota [1]. This microbiota is unique to each individual and primarily consists of 4 types: *Actinobacteria*, *Bacteroidetes*, *Firmicutes*, and *Proteobacteria* [2]. Additionally, the skin can harbor potentially harmful microorganisms such as: *Staphylococcus aureus*, *Staphylococcus epidermidis*, *Streptococcus pyogenes*, and *Pseudomonas aeruginosa*. Among fungi, the yeast *Candida albicans* is an opportunistic microorganism that can cause skin diseases under favorable conditions, such as decreased immunity, skin damage, or the presence of foreign bodies. It is also important to note that the overgrowth of normal skin microbiota can lead to infections, especially if these microorganisms migrate to non-native niches, like entering the urethra from the anal area or entering the bloodstream through skin damage [1, 3].

In recent years, increased consumer awareness and advances in manufacturing techniques have driven the rapid and diverse development of the cosmetics industry worldwide [4]. A noteworthy category of personal care products includes those with antibacterial properties. These products range widely, encompassing: body care, scalp care, facial care, makeup, oral hygiene, intimate hygiene, and products designed to reduce perspiration or eliminate odor [5]. However, there is limited data analyzing the actual antibacterial properties of these finished products. Some of the antibacterial substances used in cosmetics include: green tea extract (effective against: *S. aureus*, *S. epidermidis*, *S. pyogenes*, *P. aeruginosa*, *Klebsiella pneumoniae*, *Escherichia coli*, *Serratia marcescens*) [6], tea tree oil (effective against: *P. aeruginosa*, *S. aureus*, *Cutibacterium acnes*, *E. coli*, and *C. albicans*, *Candida glabrata*, and *Saccharomyces cerevisiae*) [7, 8], zinc oxide (effective against: *S. aureus*, *E. coli*, *Listeria monocytogenes*, *Salmonella enteritidis*, *S. cerevisiae*) [9, 10, 11], copper compounds [12], aluminum compounds [13], nanosilver (effective against: *E. coli*, *P. aeruginosa*, *S. aureus*, *Trichophyton mentagrophytes*, and *Candida* species) [14], and various preservatives [15]. Most literature information is available on the composition and use of antiperspirants [16, 17, 18] and oral hygiene products [19, 20].

This study aimed to evaluate the antimicrobial efficacy of various cosmetics with antimicrobial activity (creams,

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washing gel, antiperspirant, powder) against skinborne bacteria: *S. aureus*, *S. epidermidis*, *Enterococcus faecium*, *P. aeruginosa*, *E. coli*, *Acinetobacter baumannii*, and the yeast *C. albicans*.

MATERIALS AND METHODS

The following strains were used in the study (one of each species): *S. aureus* (clinical strain isolated from blood), *S. epidermidis* (clinical strain isolated from blood), *E. faecium* (clinical strain isolated from wound), *C. albicans* (clinical strain isolated from skin), *P. aeruginosa* ATCC 27853 (reference strain from the American Type Culture Collection), *E. coli* ATCC 25922, and *A. baumannii* ATCC 19606. All strains were sourced from the collection of the Department of Microbiology, Ludwik Rydygier Collegium Medicum in Bydgoszcz, Nicolaus Copernicus University in Toruń, Poland. The clinical strains used in the study exhibited antimicrobial drug susceptibility, with assays performed in accordance with EUCAST v. 11 recommendations [21]. The tested strains were treated with 5 widely available antibacterial cosmetics with different purposes to evaluate their effectiveness.

Characteristics of selected cosmetics with antibacterial activity:

1. mattifying cream with green tea (product name: "Zielona herbata matujący krem na dzień", manufacturer: Bielenda Kosmetyki Naturalne Sp. z. o.o. Sp. k.): the main antibacterial ingredients are green tea extract and, in lower concentrations, tea tree oil. The cream also contains preservatives: phenoxyethanol, methylparaben, ethylparaben, and disodium EDTA, which support their action;
2. antibacterial regenerating cream (product name: "Avene Cicalfate antybakteryjny krem regenerujący", manufacturer: Pierre Fabre Dermo-Cosmetique Polska Sp. z. o.o.): this formulation combines copper sulfate, zinc sulfate, and zinc oxide to prevent bacterial growth and secondary infections. The cream does not contain fragrances or preservatives;
3. antibacterial face wash gel (product name: "Dermedic Normacne preventi antybakteryjny żel do mycia", manufacturer: Biogened S.A.): the product contains green tea extract and zinc, both with antibacterial properties. To protect the gel from microbial proliferation, the manufacturer used 2 preservatives – formaldehyde-releasing DMDM hydantoin and iodopropyl butylcarbamate;
4. antiperspirant in a stick (product name: "Rexona Active Protection+ invisible antiperspirant", manufacturer: Unilever Polska Sp. z. o.o.): the anti-sweat effect is achieved through the use of aluminum zirconium tetrachlorohydrex GLY. The formulation includes moisture-absorbing substances (silica, sodium starch octenylsuccinate, maltodextrin), emollients (sunflower oil, castor oil, dimethicone), stabilizers, fragrances, and preservatives (sodium benzoate, benzyl alcohol);
5. mattifying antibacterial powder (product name: "Selfie Project matujący puder antybakteryjny", manufacturer: Maurisse Sp. z. o.o.): contains antibacterial zinc oxide to reduce the formation of inflammatory lesions. The powder also includes bamboo extract for its sebum-inhibiting effects, numerous pigments, and preservatives (phenoxyethanol, ethylhexylglycerin).

Evaluation of antimicrobial efficacy of tested cosmetics

The quantitative method

The tested bacterial strains: *S. aureus*, *S. epidermidis*, *P. aeruginosa*, *A. baumannii*, *E. coli*, and *E. faecium* were plated on tryptose-soy agar (TSA; Becton Dickinson), while the *C. albicans* strain was plated on Sabouraud agar (Becton Dickinson). The bacterial strains were incubated for 24 h at 37°C, and *C. albicans* was incubated for 24 h at 37°C and 48 h at 25°C. The grown colonies were then recultured onto appropriate media and incubated under the same conditions. For each strain, a suspension was prepared from the obtained colonies in sterile saline (Polpharma) with an optical density of 0.5 McFarland (measured with a DEN-1B densitometer, Biosan).

Before assessing the antimicrobial effectiveness of the tested cosmetics, the toxicity of the neutralizer used (10% Tween 80.1% lecithin, 0.5% histidine L, 2.5% $Na_2S_2O_3$) towards the tested strains was checked. This involved comparing the effect of storing the suspension with the addition of sterile saline or a neutralizer for 2 min. The number of recovered microorganisms was determined as described below.

For each of the cosmetics tested, samples of 250 µg were prepared and transferred to sterile tubes. Then, 27 µL of the previously prepared microbial suspensions were added to the cosmetic samples. Three replicates were performed for each strain. The added suspension was thoroughly mixed with the cosmetic sample. Immediately after adding the suspension (to determine the initial number of microorganisms in the contaminated cosmetic; 3 repetitions) and after 30 min of contact between microorganisms and cosmetics (to determine the final number of microorganisms in the contaminated cosmetic; 3 repetitions), 1000 µL of sterile neutralizer was thoroughly mixed by vortexing for 1 min. The whole mixture was left for 2 min. Then, a series of tenfold dilutions (from 10^{-1} to 10^{-4}) in sterile phosphate-buffered saline (PBS; BTL) were performed. From the dilutions, 100 µL was surface plated onto TSA medium (for cosmetics contaminated with bacteria) or Sabouraud agar (for cosmetics contaminated with *C. albicans*) and incubated at 37°C for 24 h (bacteria) or for 24 h at 37°C and 48 h at 25°C (*C. albicans*). After incubation, the grown colonies were counted and expressed as log colony-forming units (CFU)×cm^{-3} of the cosmetic. The initial level of microbial contamination of the tested cosmetics was also checked. Additionally, a negative control was prepared by transferring an appropriate volume of the suspension of a given strain without contact with the cosmetic to the neutralizer, vortexing, and leaving it in the neutralizer for 2 min.

Disc-diffusion method

For this part of the study, suspensions of the tested microbial strains, prepared as described above, were used. A sterile swab was immersed in each suspension and a turf culture was

performed in 3 antiparallel planes on the surface of Muller–Hinton agar (Becton Dickinson). Each strain was tested in triplicate. Sterile paper discs (6 mm) were immediately soaked with the tested cosmetics and then applied to the prepared cultures. The plates were incubated for 24 h at 35°C. After the incubation period, the diameter of the growth inhibition zones around the cosmetic-soaked discs was measured and expressed in mm.

Statistical analysis

In the quantitative method, the mean of 3 replicates was calculated for both the initial and final microbial counts. The mean difference between the number of microorganisms immediately after contamination of the cosmetic and their number after 30 min of contact was then calculated and presented as a logarithmic decrease in the number of bacteria, expressed as log CFU×cm^{-3}. The magnitude of the decrease indicated the antimicrobial efficacy of the tested cosmetic. Normal distribution of the data was assessed using the Shapiro–Wilk test, and the homogeneity of variances was checked with Levene's test. The effectiveness of the tested cosmetics was evaluated using the Tukey test at a significance level of $\alpha = 0.05$. Calculations were performed using Statistica (TIBCO Software Inc., Palo Alto, CA, USA) and R Statistical Software (v 4.3.2; R Core Team 2023) [22]. The significance of differences was also assessed for the neutralizer toxicity test in the same manner.

For the quantitative method, the mean for all tested strains was calculated for each cosmetic to compare the total efficacy of the tested antimicrobial cosmetics. Assumptions about the normality of distribution were tested with the Shapiro–Wilk test, and those about equality of variance were tested with the Levene test. If the assumptions about normality of distribution were not met, the nonparametric Dunn test with Bonferroni correction was used for analysis.

Using the disc-diffusion method, the mean was calculated for 3 replicates for each strain. Statistically significant differences in the efficacy of the tested cosmetics, depending on the type of cosmetic and the tested strain, were tested using the Tukey test with a significance level of $\alpha = 0.05$. Calculations were performed using Statistica (TIBCO Software Inc., Palo Alto, CA, USA) software.

RESULTS

Evaluation of the efficacy of selected cosmetics with antimicrobial activity – a quantitative method

The tests conducted to assess the toxicity of the neutralizer did not show any significant differences between the number of bacteria recovered from a suspension prepared in sterile saline and those from a sample mixed with the neutralizer and stored for 2 min (Tab. 1). The observed differences were within the error limits of the method, demonstrating the absence of toxicity of the neutralizer towards the tested strains of microorganisms.

For the *S. epidermidis* strain, the lowest decrease in microbial count was found for the regenerating cream (1.94 log CFU×cm^{-3}), while the highest was for the antibacterial gel (7.05 log CFU×cm^{-3}). Statistically significant differences in the magnitude of the decrease in the number of *S. epidermidis* were found between the antibacterial gel and all the cosmetics tested, with the exception of the antiperspirant (Tab. 2).

The lowest decrease in *E. faecium* was recorded for the mattifying cream (3.59 log CFU×cm^{-3}), and the highest for the antiperspirant (8.20 log CFU×cm^{-3}). The decrease observed for the antiperspirant was statistically significantly greater than those for the other cosmetics tested (Tab. 2).

For the *E. coli* strain, the lowest decrease in number was found with the antiperspirant (2.18 log CFU×cm^{-3}), and the highest with the antibacterial gel (3.59 log CFU×cm^{-3}). The antibacterial gel showed the highest effectiveness against *E. coli*, with the decrease being statistically significantly different only from the value found for the antiperspirant (Tab. 2).

The lowest decrease in the number of *P. aeruginosa* was shown for the regenerating cream (1.39 log CFU×cm^{-3}), and the highest for the antibacterial gel (5.18 log CFU×cm^{-3}). The antimicrobial efficacy of the antibacterial gel against *P. aeruginosa* was statistically significantly higher compared to the other cosmetics tested (Tab. 2).

In contrast, the lowest recorded decline in *A. baumannii* was 2.01 log CFU×cm^{-3} (regenerating cream), while the highest was 5.58 log CFU×cm^{-3} (antibacterial gel). The antimicrobial efficacy of the antibacterial gel against the tested *A. baumannii*

TABLE 1. Toxicity assessment of the neutralizer on tested microorganisms

Strains	The initial number of bacteria/yeast (log CFU×cm^{-3})	The number of bacteria/yeast after storage* of suspension in saline (log CFU×cm^{-3})	The number of bacteria/yeast after neutralization (log CFU×cm^{-3})
Staphylococcus aureus	8.02 (±0.36)	7.83 (±0.27)^{a}	7.75 (±0.42)^{a}
Staphylococcus epidermidis	7.48 (±0.23)	7.21 (±0.41)^{a}	7.32 (±0.64)^{a}
Enterococcus faecium	8.20 (±0.24)	7.95 (±0.19)^{a}	8.01 (±0.52)^{a}
Escherichia coli ATCC 25922	7.54 (±0.56)	7.00 (±0.48)^{a}	6.90 (±0.33)^{a}
Pseudomonas aeruginosa ATCC 27853	7.18 (±0.28)	6.92 (±0.39)^{a}	6.67 (±0.72)^{a}
Acinetobacter baumannii ATCC 19606	7.65 (±0.16)	6.99 (±0.49)^{a}	7.07 (±0.68)^{a}
Candida albicans	5.30 (±0.19)	5.00 (±0.27)^{a}	5.02 (±0.54)^{a}

CFU – colony-forming unit; ATCC – American Type Culture Collection
^{a} values marked with different letters are statistically significantly different ($p \leq 0.05$) – comparison of values in table rows
* time of storage was equal to time of neutralizer action (t = 2 min)
Values expressed as mean (± standard deviation).

TABLE 2. Number of bacteria/yeast before and after the use of cosmetics

Cosmetic	The initial number of bacteria/yeast (log CFU×cm^{-3}) – mean from 3 replicates	The number of bacteria/ yeast after using the cosmetic (log CFU×cm^{-3}) – mean from 3 replicates	Decrease in the number of bacteria/yeast (log CFU×cm^{-3}) – mean from 3 replicates	The number of bacteria/ yeast in negative control (log CFU×cm^{-3}) – mean from 3 replicates
Staphylococcus aureus				
Mattifying cream	8.02 (±0.36)	5.40 (±0.14)	2.61 (±0.16)[a]	7.91 (±0.51)
Regenerating cream	8.02 (±0.36)	4.18 (±0.10)	3.84 (±0.24)[b]	
Antibacterial gel	8.02 (±0.36)	3.24 (±0.34)	4.78 (±0.30)[b]	
Antiperspirant	8.02 (±0.36)	0.0 (±0.00)	8.02 (±0.00)[c]	
Antibacterial powder	8.02 (±0.36)	3.57 (±0.38)	4.45 (±0.41)[a, b]	
Staphylococcus epidermidis				
Mattifying cream	7.48 (±0.23)	5.45 (±0.03)	2.02 (±0.09)[a]	7.11 (±0.71)
Regenerating cream	7.48 (±0.23)	5.53 (±0.24)	1.94 (±0.17)[a]	
Antibacterial gel	7.48 (±0.23)	0.42 (±0.60)	7.05 (±0.76)[b]	
Antiperspirant	7.48 (±0.23)	0.74 (±1.04)	6.74 (±0.99)[b]	
Antibacterial powder	7.48 (±0.23)	5.41 (±0.22)	2.07 (±0.34)[a]	
Enterococcus faecium				
Mattifying cream	8.20 (±0.24)	4.61 (±0.07)	3.59 (±0.11)[a]	8.02 (±0.43)
Regenerating cream	8.20 (±0.24)	3.69 (±0.19)	4.51 (±0.23)[a, b]	
Antibacterial gel	8.20 (±0.24)	3.14 (±0.13)	5.07 (±0.19)[b]	
Antiperspirant	8.20 (±0.24)	0.0 (±0.00)	8.20 (±0.00)[c]	
Antibacterial powder	8.20 (±0.24)	3.05 (±0.13)	5.15 (±0.05)[b]	
***Escherichia coli* ATCC 25922**				
Mattifying cream	7.54 (±0.56)	5.12 (±0.47)	2.42 (±0.40)[a, b]	7.36 (±0.38)
Regenerating cream	7.54 (±0.56)	4.90 (±0.00)	2.64 (±0.11)[a, b]	
Antibacterial gel	7.54 (±0.56)	3.95 (±0.92)	3.59 (±0.58)[b]	
Antiperspirant	7.54 (±0.56)	5.37 (±0.19)	2.18 (±0.23)[a]	
Antibacterial powder	7.54 (±0.56)	4.91 (±0.28)	2.63 (±0.18)[a, b]	
***Pseudomonas aeruginosa* ATCC 27853**				
Mattifying cream	7.18 (±0.28)	3.72 (±0.60)	3.45 (±0.12)[a, c]	6.99 (±0.63)
Regenerating cream	7.18 (±0.28)	5.79 (±0.25)	1.39 (±0.18)[d]	
Antibacterial gel	7.18 (±0.28)	2.00 (±1.63)	5.18 (±1.48)[b]	
Antiperspirant	7.18 (±0.28)	4.59 (±0.47)	2.59 (±0.29)[c, e]	
Antibacterial powder	7.18 (±0.28)	5.30 (±0.42)	1.88 (±0.37)[d, e]	
***Acinetobacter baumannii* ATCC 19606**				
Mattifying cream	7.65 (±0.16)	5.41 (±0.04)	2.25 (±0.10)[a]	7.24 (±0.74)
Regenerating cream	7.65 (±0.16)	5.64 (±0.09)	2.01 (±0.15)[a]	
Antibacterial gel	7.65 (±0.16)	2.07 (±0.41)	5.58 (±0.37)[b]	
Antiperspirant	7.65 (±0.16)	5.41 (±0.10)	2.24 (0.26)[a]	
Antibacterial powder	7.65 (±0.16)	5.44 (±0.03)	2.21 (±0.09)[a]	

TABLE 2. Number of bacteria/yeast before and after the use of cosmetics

Cosmetic	The initial number of bacteria/yeast (log CFU×cm^{-3}) – mean from 3 replicates	The number of bacteria/ yeast after using the cosmetic (log CFU×cm^{-3}) – mean from 3 replicates	Decrease in the number of bacteria/yeast (log CFU×cm^{-3}) – mean from 3 replicates	The number of bacteria/ yeast in negative control (log CFU×cm^{-3}) – mean from 3 replicates
		Candida albicans		
Mattifying cream	5.30 (±0.19)	3.72 (±0.34)	1.59 (±0.27)^{a}	5.08 (±0.74)
Regenerating cream	5.30 (±0.19)	3.80 (±0.45)	1.51 (±0.40)^{a}	
Antibacterial gel	5.30 (±0.19)	3.45 (±0.21)	1.85 (±0.19)^{a}	
Antiperspirant	5.30 (±0.19)	3.74 (±0.37)	1.56 (±0.45)^{a}	
Antibacterial powder	5.30 (±0.19)	3.59 (±0.16)	1.71 (±0.31)^{a}	

CFU – colony forming unit; ATCC – American Type Culture Collection
$^{a, b, c, d, e}$ values marked with different letters are statistically significantly different ($p \leq 0.05$)
Values expressed as mean (± standard deviation).

strain was statistically significantly higher compared to the other tested cosmetic products (Tab. 2).

The lowest decrease in the number of *C. albicans* was found for the regenerating cream (1.51 log CFU×cm^{-3}), and the highest for the antibacterial gel (1.85 log CFU×cm^{-3}). The tested cosmetics achieved similar antimicrobial efficacy values, which were not statistically significantly different from each other (Tab. 2).

Comparison of the efficacy of the tested preparations

The most effective antibacterial cosmetic against most of the tested strains was the antibacterial gel, while the least effective was the regenerating cream. The highest decrease in the number of microorganisms – 8.20 log CFU×cm^{-3} – was observed for the antiperspirant against the *E. faecium* strain. In contrast, the regenerating cream, which had the lowest effectiveness among the tested cosmetics, showed the smallest reduction rate (1.39 log CFU×cm^{-3}) for the *P. aeruginosa* strain (Tab. 3).

The antimicrobial efficacy of the tested cosmetics was expressed as the mean efficacy of each formulation against all tested strains. The maximum antimicrobial efficacy was determined for the antibacterial gel, and the minimum for the mattifying cream; however, no statistically significant differences were found (Fig. 1). Limitations of the present approach include the small and heterogeneous groups (different strains), indicating a need for further studies. The Shapiro–Wilk test did not show normality of distribution for antibacterial powder ($p = 0.0487$) and antiperspirant ($p = 0.0360$).

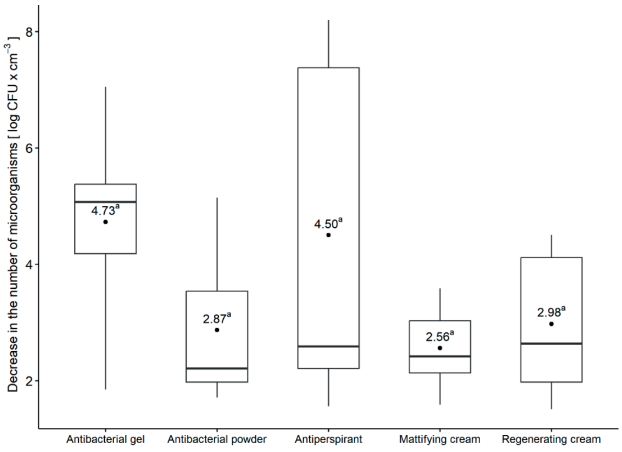

FIGURE 1. Mean reduction in microorganism count following application of cosmetic products (based on 7 strains in triplicate). Boxplot details: center line – median, dot – mean, box limits – 25th and 75th centiles, whiskers – minimum and maximum. Letter (a) indicated statistically significant differences

TABLE 3. Comparison of the results of the least and most effective preparations against the tested strains

Species	The least effective cosmetic	Lowest bacteria/yeast reduction value (log CFU×cm^{-3}) – mean from 3 replicates	The most effective cosmetic	Highest bacteria/yeast reduction value (log CFU×cm^{-3}) – mean from 3 replicates
Staphylococcus aureus	mattifying cream	2.61 (±0.16)	antiperspirant	8.02 (±0.00)
Staphylococcus epidermidis	regenerating cream	1.94 (±0.17)	antibacterial gel	7.05 (±0.76)
Enterococcus faecium	mattifying cream	3.59 (±0.11)	antiperspirant	8.20 (±0.00)
Escherichia coli ATCC 25922	antiperspirant	2.18 (±0.23)	antibacterial gel	3.59 (±0.58)
Pseudomonas aeruginosa ATCC 27853	regenerating cream	1.39 (±0.18)	antibacterial gel	5.18 (±1.48)
Acinetobacter baumannii ATCC 19606	regenerating cream	2.01 (±0.15)	antibacterial gel	5.58 (±0.37)
Candida albicans	regenerating cream	1.51 (±0.40)	antibacterial gel	1.85 (±0.19)

CFU – colony forming unit; ATCC – American Type Culture Collection
Values expressed as mean (± standard deviation).

Evaluation of the efficacy of selected antimicrobial cosmetics – disc-diffusion method

For the *A. baumannii* strain, the zone of growth inhibition observed for the gel was the smallest but statistically significantly greater than the zone determined for the regenerating cream (Tab. 4).

The highest inhibitory activity against *E. faecium* was attributed to the antiperspirant. The zone of growth inhibition observed for the antiperspirant was statistically significantly larger than the zone assigned to the mattifying cream.

The most effective antimicrobial activity against the *E. coli* strain was found for the antibacterial powder and regenerating

TABLE 4. The size of the zone of inhibition of bacterial/yeast growth after using cosmetics

Species	Cosmetic	Size of the growth inhibition zone (mm) – mean from 3 replicates
Staphylococcus epidermidis	mattifying cream	13.33 (±6.66)$^{a, b, c, d, e}$
	regenerating cream	12.67 (±6.81)$^{a, b, c, d}$
	antibacterial gel	20.33 (±1.53)$^{g, h, i}$
	antiperspirant	20.33 (±2.52)$^{g, h, i}$
	antibacterial powder	14.67 (±2.08)$^{f, g, h, i}$
Staphylococcus aureus	mattifying cream	20.33 (±0.58)$^{g, h, i}$
	regenerating cream	16.67 (±7.77)$^{c, d, e, f, g, h}$
	antibacterial gel	17.33 (±5.51)$^{d, e, f, g, h, i}$
	antiperspirant	22.67 (±6.03)^{i}
	antibacterial powder	19.67 (±2.08)$^{f, g, h, i}$
Enterococcus faecium	mattifying cream	16.67 (±1.53)$^{c, d, e, f, g, h}$
	regenerating cream	17.33 (±3.06)$^{d, e, f, g, h, i}$
	antibacterial gel	18.33 (±3.21)$^{e, f, g, h, i}$
	antiperspirant	22.67 (±2.52)^{i}
	antibacterial powder	19.67 (±2.52)$^{f, g, h, i}$
Escherichia coli	mattifying cream	18.33 (±1.53)$^{e, f, g, h, i}$
	regenerating cream	20.33 (±2.52)$^{g, h, i}$
	antibacterial gel	16.67 (±4.04)$^{c, d, e, f, g, h}$
	antiperspirant	16.67 (±2.52)$^{c, d, e, f, g, h}$
	antibacterial powder	20.33 (±4.16)$^{g, h, i}$
Pseudomonas aeruginosa	mattifying cream	15.33 (±4.04)$^{c, d, e, f, g}$
	regenerating cream	8.67 (±3.06)^{a}
	antibacterial gel	19.67 (±4.51)$^{f, g, h, i}$
	antiperspirant	19.67 (±3.21)$^{f, g, h, i}$
	antibacterial powder	13.33 (±2.31)$^{a, b, c, d, e}$
Acinetobacter baumannii	mattifying cream	17.33 (±2.52)$^{d, e, f, g, h, i}$
	regenerating cream	12.67 (±1.53)$^{a, b, c, d}$
	antibacterial gel	19.67 (±2.08)$^{f, g, h, i}$
	antiperspirant	16.67 (±2.52)$^{c, d, e, f, g, h}$
	antibacterial powder	14.67 (±2.52)$^{b, c, d, e, f}$
Candida albicans	mattifying cream	11.33 (±2.08)$^{a, b, c}$
	regenerating cream	9.33 (±1.53)$^{a, b}$
	antibacterial gel	13.33 (±1.15)$^{a, b, c, d, e}$
	antiperspirant	11.33 (±2.08)$^{a, b, c}$
	antibacterial powder	19.67 (±7.57)$^{f, g, h, i}$

$^{a, b, c, d, e, f, g, h, i}$ different letters denote statistically significant differences ($p \leq 0.05$)
Values expressed as mean (± standard deviation).

cream, while the weakest was observed with the antibacterial gel and antiperspirant. The values of the largest and smallest sizes of the growth inhibition zones were not statistically significantly different from other results in the same sample (Tab. 4).

The zone of growth inhibition established for *P. aeruginosa* with the antibacterial gel and antiperspirant was statistically significantly larger than the zones assigned to the regenerating cream and powder. The smallest diameter of the zone of growth inhibition of *P. aeruginosa* was determined for the regenerating cream. This zone was statistically significantly smaller compared to the zones found for other cosmetics, excluding the antibacterial powder (Tab. 4).

The best limiting effect on the proliferation of *S. aureus* was found for the antiperspirant, which was statistically significantly higher than that determined for the regenerating cream (Tab. 4).

Against the *S. epidermidis* strain, the largest diameters of the zone of growth inhibition were determined for the antibacterial gel and antiperspirant. These zones were statistically significantly larger than those observed for other preparations. However, the zone observed for the regenerating cream was statistically significantly smaller than the zones assigned to the gel and antiperspirant (Tab. 4).

The highest antifungal activity against *C. albicans* was found for the antibacterial powder. The diameter of the zone of growth inhibition observed for the powder was statistically significantly larger compared to the diameters of the zones found for the other cosmetics. The smallest zone of inhibition of *C. albicans* growth was established for the regenerating cream (Tab. 4).

The differences in the size of the zones of inhibition determined for the antiperspirant against *S. aureus* and *E. faecium* were statistically significant compared to the zones for *A. baumannii*, *E. coli*, and *C. albicans* strains (Tab. 4).

For the antiperspirant used against the *P. aeruginosa* and *S. epidermidis* strains, the largest zones of growth inhibition observed were statistically significantly larger than the largest zone assigned to the *C. albicans* strain. The smallest zones of growth inhibition found for the regenerating cream used against *P. aeruginosa* and *C. albicans* strains were statistically significantly smaller compared to the smallest zones established for *E. faecium*, *E. coli*, and *S. aureus* strains. The result of the smallest zone of growth inhibition determined for the regenerating cream used against the *S. aureus* strain was statistically significantly greater than the values of the smallest zones observed for *P. aeruginosa* and *C. albicans* (Tab. 4).

The results obtained in the disc-diffusion method are consistent with those from the quantitative method regarding the least antimicrobial efficacy, which was shown for the regenerating cream in both methods. However, the data for the product with the highest efficacy differed between the methods. In the quantitative method, the antibacterial gel demonstrated the best microbial-reducing effect, while in the disc-diffusion method, the antiperspirant exhibited the highest efficacy.

DISCUSSION

Cosmetics are widely used products around the world. When it comes to antimicrobial cosmetics, the selection of the optimal product depends not only on providing proper cleansing, protection, and skin care but also on its bactericidal, fungicidal, and virucidal effectiveness. Laboratory tests are essential to confirm these properties.

In this study, 6 bacterial strains of different species and 1 strain of yeast were treated with 5 antibacterial cosmetics. The cosmetics differed in formulation and purpose, resulting in significant differences in their antibacterial properties. All tested cosmetics demonstrated antimicrobial activity, though the degree of inhibition varied among the tested strains. Mwambete and Simon also observed varying antimicrobial activity in 10 tested cosmetics, with 5 showing no antifungal activity against *C. albicans* [23]. However, all significantly reduced the growth of *S. aureus* and *E. coli*. The lower antimicrobial efficacy of some cosmetics may result from interactions between formulation ingredients and preservatives or the presence of substances that promote pathogen growth. Comparing our study with that of Mwambete and Simon, it is evident that using antibacterial cosmetic preparations is more beneficial in preventing skin infections than relying on cosmetics where preservatives are the only antimicrobial ingredients [23].

In our study, the antibacterial gel and antiperspirant exhibited the highest effectiveness against the tested microorganisms. The antibacterial gel showed the greatest reduction in *C. albicans* numbers, although its antifungal activity was statistically significantly lower than its antibacterial activity. The mattifying powder, mattifying cream and regenerating cream were less effective. The superior antibacterial activity of the washing gel is likely due to its higher concentration of preservatives compared to non-rinsing products. Chen et al. found that an external application gel with 3.0% and 6.0% zinc sulfate inhibited the growth of *E. coli* and *S. aureus* [24]. The catechins in the green tea extract in the antibacterial gel contribute to its antibacterial properties. Calixto et al. demonstrated that a gel with 10.0% glycol extract of green tea significantly reduced the proliferation of *S. aureus*, *P. aeruginosa*, and *E. coli* [25]. Sharma et al. confirmed the effectiveness of *Camellia sinensis* extract against *S. epidermidis*. In their study, an antibacterial gel containing the extract prevented the growth of all tested microorganisms, with *P. aeruginosa*, *S. epidermidis*, and *A. baumannii* being the most sensitive [26]. Our findings and the described studies suggest that the presence of green tea extract and zinc in the face wash gel enhances its antibacterial action, which is crucial in preventing bacterial skin infections.

The high effectiveness of the tested antiperspirant is likely due to its formulation, which includes numerous anti-hydrotic substances. These ingredients reduce environmental moisture, depriving microorganisms of water and preventing their proliferation. Aluminum salts are commonly added to antiperspirants for their antibacterial properties. Hölzle and Neubert assessed the antibacterial effect of aluminum chloride hexahydrate, finding

its efficacy against skin bacteria satisfactory [27]. Bnyan et al. analyzed potassium alum, showing that a 20.0% concentration reduced the growth of: *S. aureus*, *S. epidermidis*, *E. coli*, and *K. pneumoniae* [28]. Al-Talib et al. found that the lowest concentration of alum to completely inhibit *S. epidermidis* growth was 7.5 mg/mL [29]. El-Desoukey et al. demonstrated that all tested natural and synthetic substances in antiperspirants exhibited antimicrobial activity at varying levels. The highest inhibitory effect on *S. epidermidis* proliferation among natural substances was from cold aqueous extract of alum, followed by cold aqueous extract of sodium bicarbonate, and then lemon [30]. However, Ermenlieva et al. found that a cosmetic antiperspirant containing alcohol showed no antibacterial activity against *S. epidermidis* but was effective against *S. pneumoniae* and *C. albicans*. Based on these studies and our own research, we conclude that cosmetic products containing sweat-inhibiting ingredients exhibit good antibacterial activity [31].

A reduction in the growth of all examined strains was observed for the mattifying powder used in this study. In the disc-diffusion method, the powder showed higher antimicrobial efficacy than both the antiperspirant and the antimicrobial gel against *E. coli* and *C. albicans* strains. The potent inhibitory effect against these microorganisms may be attributed to the zinc oxide content in the powder formulation. Pasquet et al. analyzed the pathogen inhibition properties of zinc oxide, showing that, depending on the concentration, zinc oxide causes inhibition of bacteria, including *E. coli* and yeast of the *C. albicans* species [32]. Additionally, the lack of water content and the presence of moisture-absorbing substances in the cosmetic formulation could hinder the ability of bacteria to multiply.

The 2 face creams tested reduced the growth of microorganisms to a lesser extent than the other cosmetics. The mattifying cream contained antibacterial substances such as green tea extract and tea tree oil, as well as preservatives. Herman et al. analyzed the antimicrobial activity of tea tree oil and methylparaben in cosmetic emulsions. They demonstrated that both ingredients reduce the excessive bacterial growth of: *S. aureus*, *E. coli*, *P. aeruginosa*, and *C. albicans*, with an emulsion containing 2.5% tea tree oil showing stronger antimicrobial activity than an emulsion with 0.4% paraben [33]. The lower antimicrobial activity of the cosmetic in our study may be due to the lower concentration of tea tree oil or the presence of compounds that act nutritionally on bacteria.

The least antimicrobial efficacy in this study was shown by the regenerating cream, which contains antibacterial compounds such as: sucralfate (aluminum salt of sucrose sulfate), zinc oxide, zinc sulfate, and copper sulfate. Yen et al. conducted a study on the same cream and its effect on cutaneous bacterial strains, demonstrating its effectiveness in inhibiting the growth of strains including: *E. coli* ATCC 25922, *S. aureus* ATCC 29213, *Enterococcus faecalis* ATCC 29212, and *P. aeruginosa* ATCC 27853 [34]. However, in our study, *P. aeruginosa* ATCC 27853 was more resistant to the cosmetic agent than the other microorganisms, likely due to the different testing methods used in the 2 experiments.

In our study, we demonstrated the high antimicrobial efficacy of selected antibacterial products available on the cosmetic market. The compositions of these preparations are based on natural and synthetic substances with proven pathogen-reducing effects. It can be concluded that cosmetics with the highest possible concentration of ingredients that inhibit bacterial growth (such as the antibacterial gel) or those with minimal water content in the formulation (such as the antiperspirant) exhibit better antimicrobial activity. The use of such cosmetics can be helpful in preventing bacterial and fungal infections and alleviating symptoms of skin diseases associated with microbial activity.

CONCLUSIONS

Cosmetics with antibacterial properties vary in composition and application and are in high demand among consumers. In our study, these products were shown to reduce the number of skin bacteria: *S. aureus, S. epidermidis, P. aeruginosa, E. coli, E. faecium, A. baumannii,* and the yeast *C. albicans*. Compounds in cosmetics declared by the manufacturer as antibacterial may also have antifungal properties, although, as this study has shown, the reduction in the number of *C. albicans* cells is lower than that of most tested bacteria.

The antimicrobial gel and antiperspirant demonstrated the strongest antimicrobial properties against most of the tested strains, making them suitable for both daily body care and supporting the treatment of certain skin diseases. The antimicrobial powder also had good efficacy, justifying its use instead of traditional makeup powder for acne-prone skin, for example. The regenerating cream and mattifying cream inhibited bacterial proliferation at similar levels, making them interchangeable in skincare routines.

Given the variable composition of antimicrobial cosmetics, further research is desirable to evaluate the effectiveness of other active substances, including those of natural origin.

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