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Legume Peptides as Novel Antibacterial Sources for Human Pathogenic Bacteria

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A B S T R A C T

Many studies have focused on the use of natural alternatives in the treatment of multidrug-resistant pathogenic bacteria, so the interest focused on Nodule cysteine-rich (NCR) peptides from legumes, exploiting their effect on the differentiation of Rhizobium bacteria within root nodules and inhibiting their growth by affecting the permeability of the bacterial cell membrane. Therefore, concentrations of 50-1.6µg/ml of four NCR peptides extracted from four legumes were used to study their antimicrobial activity on the growth of five genus of multidrug-resistant human pathogenic bacteria. The study was carried out using a disc diffusion method to examine the impact of these peptides on these pathogenic bacteria. It became evident that Gram-positive was more affected by these peptides than Gram-negative bacteria. Using the microplate method, Pseudomonas aeruginosa and Escherichia coli, Staphylococcus aureus showed clear sensitivity to peptides 1 and 2, while Acinetobacter baumannii and Proteus mirabilis were completely resistant to all types of peptides tested. Results in the infected mice revealed that 6.25µg/ml was superior to 50 µg/ml of Medicago sativa peptide in completely healing wounds in laboratory mice 17 days after infection with both Pseudomonas aeruginosa and Staphylococcus aureus. This is the first local study that used NCR peptides from legumes as selected alternatives for antibiotic use.

Introduction

According to Rosenberger et al., [1] and Morales et al., [2], patients are seriously at danger from antimicrobial resistance (AMR). This is indicated byincreasing morbidity and mortality and causing a large financial loss. Antibiotic resistance is spreading quickly in clinically isolated samples such as Pseudomonas aeruginosa, Staphylococcus aureus, and members of the Enterobacteriaceae family like Klebsiella pneumoniae, E. coli, and Proteus sp. [3]. Acinetobacter baumannii, Pseudomonas aeruginosa, Klebsiella pneumoniae, Escherichia coli, and Enterobacter spp. are the most important drug-resistant bacteria, according to the World Health Organization (WHO). Other bacteria that are resistant to conventional antibiotics and treatment include Enterococcus spp., Staphylococcus aureus, Salmonella spp., and Neisseria gonorrhoeae [4]. It was found that A. baumannii infections are growing more quickly than others, its carbapenem-resistant variants are becoming more prevalent. a major focus for new antibiotic discovery [5;6], and threatening to render antimicrobial antibiotics useless.

Therefore, new antimicrobials with new modes of action and non-toxicity to human cells are exigent, so antimicrobial peptides AMPs are promising entrants as new types of potent antimicrobials [7], because of their wide range of antibacterial activity and various modes of action, and low susceptibility of bacteria to develop resistance [8]. Although the majority of AMPs are sourced from animals, plants have developed a multitude of AMPs, including defensive chemicals that are high in cysteine [9]. Their amphipathic properties, positive charge, four conserved disulfide bridges, the capacity to permeate cells and engage with microbial membranes in order to prevent enzymatic activity [10;11]. The ability to encode nodule cysteine-rich (NCR) peptides, which are essential for symbiosis, has been developed in legumes, which contain 56 genera and about 4000 species [12]. NCR peptides differentiate Rhizobium bacteria in root nodules into Bacteroides, which are large, polyploid, non-replicating, non-dividing bacteria that fix atmospheric nitrogen to ammonia [13]. In this respect, the most investigated non-saline antibiotic, the cationic NCR247, known to be effective against the symbiotic bacterium Sinorhizobium meliloti Rm2011 found in alfalfa root nodules, was found to have a very good efficacy against multidrug resistant pathogens. In most cases, it outperforms the antibiotic levofloxacin in vitro [14].

In this study, we investigated the antibacterial activity of four legume NCR peptides because previous research has only evaluated a small number of NCRs for antimicrobial activity against human pathogenic microorganisms. There is an urgent need to explore innovative alternatives to antibiotics that work differently by preventing infection and reducing the emergence of resistance, for future use as biocontrol agents against these bacteria.

Material and Methodes

Nodule cysteine-rich (NCR)peptides:

In an under-published paper [15], cysteine-rich nodule peptides were extracted from four legumes 1- Phaseolus vulgaris,2- Trifolium repens,3- Medicago sativa, and 4- Vicia faba.

Collection and diagnosis of human pathogenic bacterial isolates:

Human pathogenic bacteria samples were collected from the Mosul Burns Hospital and tentatively diagnosed as P. aeruginosa, A.baumannii , E. coli, S. aureus and Proteus mirabilis. Its diagnosis was confirmed by VITEK®2 COMPACT (bioMerieny Company).

Evaluation of NCR peptides for antimicrobial activity:

Two methods (Disk diffusion method and Microplate reader method) were used to evaluate the efficiency of the inhibitory effect of the four cysteine-rich peptides and to compare their effect with that of the most resistant antibiotics of this bacterium selected from the VITEK results. Six half concentrations (50, 25, 12.5, 6.25, 3.125 and 1.6 µg/mL) of these peptides and antibiotics were used.

Disk diffusion method :

NCR peptides were tested for antimicrobial activity against five types of human pathogenic and multidrug-resistant bacteria according to VITEC results. All bacterial samples in this study were activated by culture on Luria-Bertani (LB) agar medium Petri dishes and incubation (37 ºC for 24 hours). Growing colonies were transferred to a test tube filled with five milliliters of liquid LB medium, and after a few hours of incubation, the turbidity was adjusted to match the 0.5 McFarland standard. The results corrsponded to 1.5 × 108 CFU/ml [16]. Using a sterile cotton swab, the LB medium's surface was equally covered with 100 µL of the bacterial solution.. For comparison, 6-mm-diameter discs of filter paper (Whatman No. 1) saturated with half-strength

concentrations of the four cysteine-rich peptides and four antibiotics ; Ciprofloxacin (CIP), Meropenem (MER), Amikacin (AMK), and Erythromycin (ERY) were used with three replicates for each. Plates were incubated for 24-48 hours at 37 ºC. The diameter of the inhibition zone surrounding the disc was then measured in mm.

Microplate reader method:

In a 96-well microplate, 200 µl (10 µl bacterial suspension, 40 µl nutrient medium, and 150 µl half dilutions of each peptide species) and negative control samples (no peptide treatment) were added to each well. The same treatment with peptides replaced by antibiotics was used as a positive control. With three replicates per treatment, Every plate was incubated at 37 degrees Celsius for 24-48 hours. A microplate reader set to 630 nm wavelength was used to read the result.

Estimate the in vivo inhibitory effect of peptides:

Following the method of Stepińska et al., [17] an NCR peptide extracted from the root nodules of M. sativa was selected in this test because it has better antimicrobial activity in vitro than other peptides studied. Gram-negative (P. aeruginosa) and gram-positive (S. aureus) bacteria, were chosen because of their natural ability to cause skin infections. Therefore, this peptide was used at two concentrations ;50 and 6.25 µg/ml to determine its in vivo effect in the treatment of skin wounds in rats infected with these two types of bacteria.

Twenty-seven male albino rats, weighing 45 to 50 g and aged 1-2 months, obtained from the animal house of the Veterinary Medicine College/Mosul University, were used in the experiment. The rats were placed in plastic cages measuring 10 x 10 x 30 cm with metal mesh covers. The bottom of the cages was covered with clean sawdust, which was changed every 3 days, and the rats used were distributed into 9 groups (1 -A negative control group included three healthy uninjured rats. 2- A positive control group of three experimentally injured rats infected with P.aeruginosa and left untreated. 3-A Three experimentally injured rats infected with P. aeruginosa and given ciprofloxacin as a treatment comprised the control group. 4-A Three rats were given an NCR extract at a 50 µg/ml dosage to treat experimental wounds infected with P. aeruginosa. 5-A Three rats were experimentally injured, infected with P. aeruginosa, and given the NCR extract at a 6.25 µg/ml dosage. 6-A positive control group of three experimentally injured rats infected with S. aureus and left untreated. 7-A Three experimentally wounded rats infected with S. aureus and given erythromycin as a treatment comprised the control group. 8-A Three rats were given NCR extract at a 50 µg/ml dosage to treat experimental wounds infected with S. aureus. 9-A Three rats were experimentally injured, infected with S. aureus, and given the NCR extract at a 6.25 µg/ml dosage. Healing all wounds was monitored at 3, 6, 10, 14, and 17 days [18]. Bacteria in the wound area treated and untreated with peptide or antibiotic were determined by swabbing, culturing on nutrient agar, and incubating at 37 ºC for 24 hours [17].

Results and Discussion

VITEK®2 COMPACT results:

Table 1 displays the VITEK test findings in terms of antibiotic sensitivity and bacterial probability of diagnosis. Given their resistance to three or more types of antimicrobial medicines, these findings suggest that the bacterial species under investigation are multidrug-resistant [19]. Public health is at risk from antibiotic-resistant Gram-positive (S. aureus) and Gram-negative (E. coli and P. aeruginosa) bacteria [20]. One of the biggest threats to world health in the twenty-first century is antimicrobial resistance [21]. Antibiotics target particular parts of the bacterial cell, including the membrane and cell wall, as well as the production of DNA and proteins. The primary mechanisms of antimicrobial resistance include decreasing drug absorption, altering drug targets, deactivating medications, and increasing the flux of active pharmaceuticals [22]. Resistance genes can help dangerous microorganisms and modify their enzymes and create biofilms, resulting in a "silent pandemic" [23; 24].

Table 1. VITEK®2 compact results on antibiotic resistance by pathogenic bacteria.

Pathogenic Bacteria (%)				
P. aeruginosa (99)*	*A. baumannii* (99)	*E. coli* (95)	*S. aureus* (95)	*P. mirabilis* (95)
Ceftazidime (CAZ)	Cefotaxime (CTX)	Cefazolin (CFZ)	Gentamicin (GEN)	Ceftazidime (CAZ)
Cefepime (FEP)	Ceftazidime (CAZ)	Cefuroxime (CXM)	Tobramycin	Cefepime (FEP)
Imipenem	Imipenem	Ceftazidime	Erythromyci	Imipenem

(IPM)	(IPM)	(CAZ)	n (ERY)	(IPM)
Meropenem (MER)	Meropenem (MER)	Ceftriaxone (CRO)	Clindamycin (DA)	Meropenem (MER)
Amikacin (AMK)	Amikacin (AMK)	Ertapenem (ETP)	Tetracyclin (TET)	Ciprofloxacin (CIP)
Ciprofloxacin (CIP)	Gentamicin (GEN)	Ciprofloxacin (CIP)	Rifampicin (RD)	Tigecycline (TG)

* Probability of diagnosis

NCR peptides' antibacterial efficacy against harmful bacteria in vitro:

Disc diffusion method:

Table 2 shows that the effect of antibiotics known to be resistant by pathogenic bacteria varied according to the results of VITEC when using the same concentrations of the four peptides, as P. aeruginosa was only resistant to the antibiotic Ciprofloxacin (CIP) at the first concentration (1.6 µg/ml), while S. aureus was absolutely resistant to all concentrations of the antibiotic Erythromycin (ERY). Differences in growth rate between cells that are tolerant to varying antibiotic concentrations can result in antibiotic resistance at non-lethal concentrations. This is why bacteria can develop tolerance at concentrations hundreds of times lower than those that kill sensitive cells [25].

On the other hand, the effect of the peptides isolated from the root nodules varied according to their type and concentration on the growth of the pathogenic bacteria studied: E. coli was sensitive to four concentrations (6.5, 12.5, 25 and 50) µg /ml and S. aureus was sensitive to five concentrations (2.125, 6.5, 12.5, 25 and 50) µg /ml of the first peptide, while both P. aeruginosa and S. aureus were sensitive to four concentrations (6.5, 12.5, 25 and 50) µg /ml of the second peptide. Yet, A. baumannii and P. mirabilis were completely resistant to all concentrations of the four peptides used. These results might rely on these cationic antimicrobial peptides (AMP) capacity to attach to and interact with negatively charged bacterial cell membranes, changing their electrochemical characteristics and ultimately causing harm, while destroying cell and membrane morphology and finally causing cell death [26]. Gram-negative bacteria are protected against antimicrobial peptides that break down microbial cell membranes by their intricate cell envelope. However, when the outer membrane contact was investigated using the antibacterial peptide melittin, a model of di[3-deoxy-d-manno-octulosonyl]-lipid A (KLA) in the outer and 1-palmitoyl-2-oleoyl-*sn*-glycero-3-phosphoethanolamine (POPE) in the inner membrane, the results demonstrated that the flexible N-terminus of melittin contacts the phosphate groups of KLA. Also, the positively charged helical C-terminus of melittin quickly docks with the hydrophilic headgroup region of KLA, supporting melittin penetration into the hydrophilic-hydrophobic interface within the lipid region of the bacterial cell wall [27].

The intricately structured cell envelope of gram-negative bacteria acts as a barrier against antimicrobial peptides that break down their cell membranes. However, the outer membrane interaction between POPE and KLA in the outer leaflet was investigated using the antibacterial peptide melittin. The findings showed that the hydrophilic headgroup region of KLA rapidly interacts with the Melittin's positively charged helical C-terminus. Furthermore, melittin enters the lipid area of the bacterial cell wall's hydrophilic-hydrophobic border more easily because the phosphate groups of KLA are in touch with the flexible N-terminus (25).

In the same line , a study indicated that antibacterial peptides are a valuable therapeutic option to heal illnesses brought on by the multi-resistant E. coli bacterium because of their significant effect on membranes and low potential to induce resistance, [28]. By altering cell membrane permeability, a novel peptide (MR-22) was recently found to be effective against multi-resistant E. coli bacteria, suggesting that it could be used as a medication to treat drug-resistant E. coli [29]. However, these antimicrobial peptides' main mode of action against P. aeruginosa strains involved rupturing the membrane's structure by interacting with lipopolysaccharide (LPS), increasing reactive oxygen species (ROS), or targeting cellular components, which resulted in cell lysis and death [30]. Due to its mechanism of action, which involves destroying the membrane's integrity while increasing its permeability and altering the membrane's electromotive force, the antimicrobial peptide (MPX) can also kill S. aureus and decrease the formation of biofilms. These results have encouraged the use of MPX as an effective antagonist against these human-pathogenic bacteria [31].

Table 2. The disc diffusion technique of NCR peptides' antibacterial activity against pathogenic bacteria.

Bacteria	Extract (NCR)	Concentrations (µg/ml)						
		50	**25**	**12.5**	**6.25**	**3.125**	**1.6**	**0.0**
P.	1	R	R	R	R	R	R	+
Aeruginosa	2	S	S	S	S	R	R	

	3	R	R	R	R	R	R	
	4	R	R	R	R	R	R	
	CIP	S	S	S	S	I	R	
	1	R	R	R	R	R	R	
	2	R	R	R	R	R	R	
A. baumannii	3	R	R	R	R	R	R	+
	4	R	R	R	R	R	R	
	MER	I	S	S	S	S	R	
	1	S	S	S	S	I	R	
	2	I	I	I	I	R	R	
E.coli	3	R	R	R	R	R	R	+
	4	I	I	I	I	I	R	
	AMX	I	I	I	I	I	I	
	1	S	S	S	S	S	I	
	2	S	S	S	S	I	R	
S. aureus	3	I	I	I	I	R	R	+
	4	I	I	I	I	I	I	
	ERY	R	R	R	R	R	R	
	1	R	R	R	R	R	R	
	2	R	R	R	R	R	R	
P. mirabilis	3	R	R	R	R	R	R	+
	4	R	R	R	R	R	R	
	CIP	S	S	S	S	S	I	

R= without inhibition zone, S ≥ 2, I< 2, + = growth

CIP = Ciprofloxacin, MER= Meropenem, AMX= Amoxicillin, ERY= Erythromycin.

Microplate reader method:

Table (3) shows that at all concentrations used, Gram-positive bacteria (such S. aureus) were more susceptible to the first peptide's effects than Gram-negative bacteria in the present study, as indicated by the increased percentage of growth inhibition compared to the control sample (untreated with peptide extract, 0.0 mg/ml). The inhibitory effect varied according to the bacterial species and the concentration of second peptide. It was found that the proportion increases as the concentration of growth inhibition increases as compared to the control sample (0.0 mg/ml), but P. merabilis had the highest growth inhibition (77, 82 and 87%) at the last three concentrations (12.5, 25 and 50 mg/ml). The third peptide was only effective in inhibiting the growth of A. baumannii at all concentrations compared to the control sample, and was even better than the effect of the antibiotic MER. On the other hand, it was found that the fourth peptide's action increases in direct proportion to the concentration rise, so that the effect of the concentration (1.6 mg/ml) on bacterial growth was lower than at higher concentrations, and the lowest percentage was recorded according to the following sequence: A. baumannii (26%), P. aeruginosa (15%), P. merabilis (14%), S. aureus (4%) and finally E. coli (2%).

According to Exner et al., [32] and Gupta and Datta [33], the absence of this crucial layer makes Gram-positive bacteria more resistant to antibiotics than Gram-negative bacteria. The resistance of Gram-negative bacteria may be caused by modifications in the outer membrane, such as changes in hydrophobicity or mutations in porins. Gram-negative bacteria are inherently more dangerous than Gram-positive bacteria because of their hard, protective outer coating, which increases their resistance to antibiotics and makes them more difficult to eradicate [34]. The bacterial states (susceptibility, resistance, tolerance, persistence, and biofilms), inoculum size, and antimicrobial concentrations are some of the parameters that contribute to the other three peptides' inhibitory impact as antimicrobials [35].

On the other hand, the superiority of these four peptides over antibiotics against pathogenic bacterial growth can be attributed to several advantages they possess, including their ability to bypass the usual resistance mechanisms observed against conventional antibiotics [36], their direct and rapid killing of bacteria [37], their inhibitory effect on bacterial growth regardless of resistance phenotype, as they are not affected by known resistance mechanisms [38;39]. It has been demonstrated that natural or artificial antimicrobial peptides prevent bacteria from colonizing surfaces, destroy bacteria in biofilms, and alter the structure of biofilms [40]. For example, the lethal inhibitory effect of AMPs may occur by disrupting the cytoplasmic membrane through membrane polarization of bacterial cells in biofilms, as evidenced by their rapid penetration of biofilms and their direct effect on the cytoplasmic membrane permeability of P. aeruginosa PAO1 [41;42].

Table 3. Antimicrobial activity of NCR peptides against pathogenic bacteria by microplate method at 630 nm absorbance.

Bacteria	**NCR**	**Concentration µg/ml**						
		50	**25**	**12.5**	**6.25**	**3.125**	**1.6**	**0.0**
P.	1	0.041(79)"	0.076(61)	0.082(58)	0.085(56)	0.096(51)	0.099(49)	0.194

aeruginosa	2	0.034(83)	0.041(79)	0.074(62)	0.080(59)	0.089(54)	0.095(51)	
	3	0.033(83)	0.059(70)	0.083(57)	0.099(49)	0.107(45)	0.119 (39)	
	4	0.028(86)	0.069(64)	0.087(55)	0.106(45)	0.146(25)	0.165(15)	
	CIP	0.085 (56)	0.097 (50)	0.101 (48)	0.140 (28)	0.152 (22)	0.160 (18)	
A. baumannii	1	0.035(82)	0.070(64)	0.089(55)	0.098(50)	0.100(49)	0.134(32)	0. 196
	2	0.040(80)	0.042(79)	0.045(77)	0.048(76)	0.067(66)	0.096(51)	
	3	0.018(91)	0.032(84)	0.073(63)	0.080(59)	0.098(50)	0.106(46)	
	4	0.041(79)	0.089(55)	0.092(53)	0.096(51)	0.121(38)	0.146(26)	
	MER	0.064 (67)	0.073 (63)	0.075 (62)	0.079 (60)	0.091 (54)	0.143 (27)	
E.coli	1	0.030(84)	0.044(77)	0.059(69)	0.049(51)	0.100(48)	0.105(45)	0.192
	2	0.034(82)	0.043(78)	0.045(77)	0.050(74)	0.059(69)	0.080(58)	
	3	0.026(86)	0.049(51)	0.064(67)	0.090(53)	0.107(44)	0.123(36)	
	4	0.033(83)	0.092(52)	0.112(42)	0.132(31)	0.155(19)	0.188(2)	
	AMX	0.134 (30)	0.170 (12)	0.169 (12)	0.168 (13)	0.168 (13)	0.182 (6)	
S. aureus	1	0.020(91)	0.033(85)	0.051(77)	0.074(66)	0.079(64)	0.083(62)	0.217
	2	0.048(78)	0.049(77)	0.057(74)	0.063(71)	0.066(70)	0.079(64)	
	3	0.028(87)	0.078(64)	0.091(58)	0.125(42)	0.167(23)	0.198(9)	
	4	0.032(85)	0.074(66)	0.092(58)	0.116(47)	0.195(10)	0.208(4)	
	ERY	0.159 (27)	0.169 (22)	0.185 (15)	0.195 (10)	0.197 (9)	0.203 (7)	
P. mirabilis	1	0.037(83)	0.072(66)	0.087(59)	0.090(57)	0.099(53)	0.107(49)	0.211
	2	0.028(87)	0.038(82)	0.049(77)	0.062(71)	0.076(64)	0.093(56)	
	3	0.024(89)	0.049(77)	0.065(69)	0.073(65)	0.102(52)	0.110(48)	
	4	0.031(85)	0.092(56)	0.108(49)	0.147(30)	0.169(20)	0.181(14)	
	CIP	0.116 (45)	0.116 (45)	0.117 (45)	0.132 (37)	0.155 (27)	0.177 (16)	

CIP = Ciprofloxacin, MER= Meropenem, AMX= Amoxicillin, ERY= Erythromycin, " = % inhibition

In vivo antimicrobial activity of NCR peptides against pathogenic bacteria:

Figures 1and 2 show that the progression of recovery from S. aureus and P. aeruginosa infection varied according to the type of treatment compared to the control (untreated) sample. In general, peptide treatment was better than antibiotic treatment (ERY or CIP), and the second concentration (6.25 µg/ml) of peptide was better than the first concentration (50 µg/ml) in achieving full recovery after 17 days of infection, with no differences in wound healing based on bacterial species. This is because the activity of the peptides may extend beyond their inhibitory effect on microbial growth to clear and potent interactions with the host immune system, interfering with inflammatory pathways and wound repair [43; 44; 45]. In a laboratory animal study, several AMPs were shown to inhibit bacterial endotoxins by boosting innate immunity to initiate their antimicrobial activity and protect mice from methicillin-resistant Staphylococcus aureus (MRSA) infections [46].

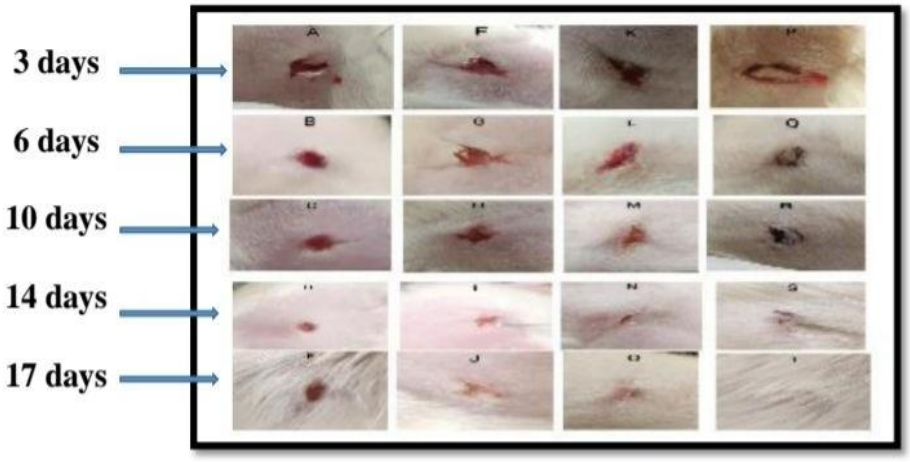

Figure 1. Effect of treating skin wounds infected with *S. aureus* with a peptide extracted from the root nodules of the alfalfa plant for 3, 6, 10, 14 and17 days.

A-E, Control sample (untreated wounds from mice infected with bacteria). F-J, Mice with bacterial infections and antibiotic treatment (ERY). K-O mice were given a 50 µg/ml peptide concentration. P-T following bacterial infection, the sample from mice treated with a 6.25 µg/ml peptide concentration..

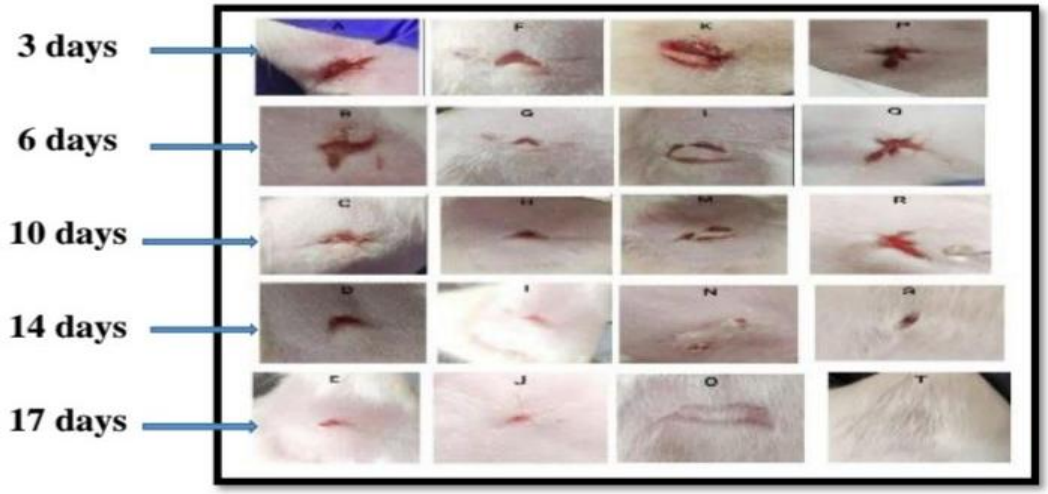

Figure 2. Effect of treating skin wounds infected with *P. aeruginosa* with a peptide extracted from the root nodules of the alfalfa plant for 3, 6, 10, 14 and17 days.

A-E, Control sample (untreated wounds from mice infected with bacteria). F–J is Bacterially infected mice receiving antibiotic treatment (CIP). Following bacterial infection, K-O mice were given a 50 µg/ml peptide dosage. P-T, Following bacterial infection, the mice were administered a peptide dose of 6.25 µg/ml.

The study determines the effect of treatment in terms of bacterial counts in wounds infected with both types of bacteria and treated separately with antibiotics and the third peptide with the concentration astimated at 6. 25 µg/ml. It was realized that the impact of the peptide is stronger than the effect of the antibiotic used against both bacteria studied, and the effect is almost equal for both types of bacteria, positive (S. aureus) and negative (P. aeruginosa) for Cram's stain, as shown in Figure 3. Numerous studies have verified that AMPs have a wide range of activity against both Gram-positive and Gram-negative bacteria [47; 48]. They have a low ability to stimulate drug resistance, offering the possibility of use as a specific type of antibiotic [49; 50].

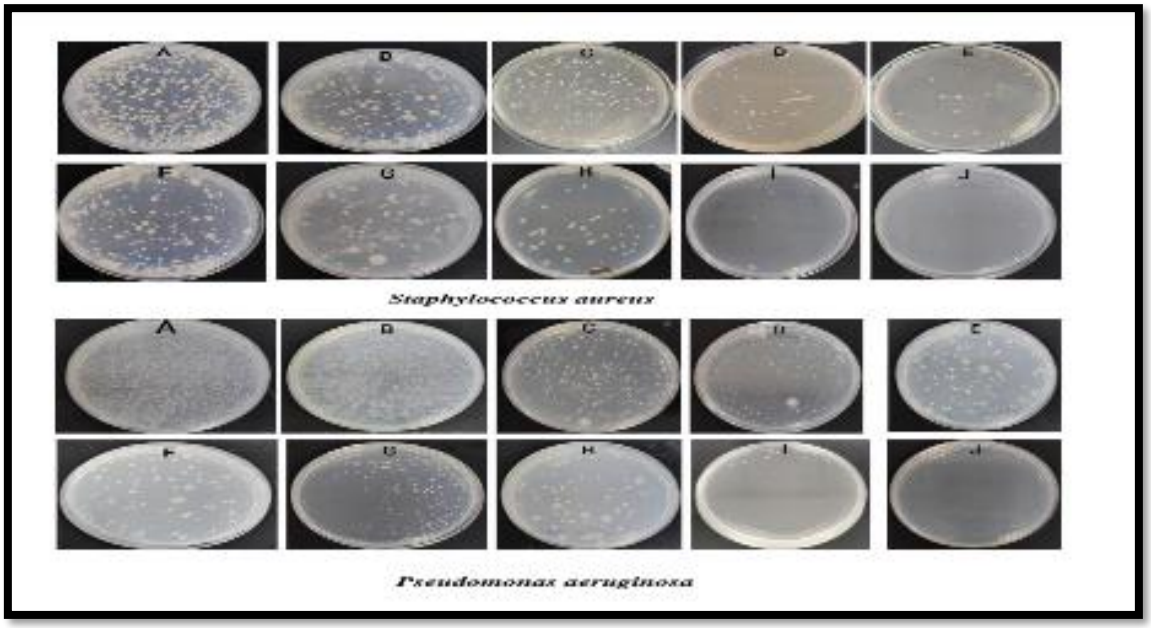

Figure 3. Growth of bacterial colonies after swabbing infected wounds for five time periods (3, 6, 10, 14, and 17 days).

A-E: after antibiotic (ERY or CIP) treatment, F-J: after treatment with a third peptide at a concentration of 6.25 µg/mL

Conclusion

For many years, concern has been raised regarding antibiotic resistance in harmful bacteria brought on by extended use. As a result, diseases brought on by a variety of germs are spreading quickly and having an impact on people's health. This resistance has a huge economic impact; losses are predicted to be enormous, and the hospital and agricultural systems will be severely strained financially. Antibiotic can be replaced with antimicrobial peptides (AMPs), to which many bacterial genera are resistant, and have the benefit of having broad-spectrum antibacterial properties and potent against bacteria, making them promising antimicrobial agents. In order to eradicate drug-resistant bacteria, we anticipate that more AMP research will improve the process of overcoming drug resistance safer and more efficient. This study may lead to new treatments for soft tissues and skin infections initiated by Staphylococcus aureus. It is to add that the results suggest that these treatments can improve bacterial eradication, minimize side effects and, in some cases, slow the development of drug resistance. In addition to killing bacteria, they also promote wound healing. Increased research efforts are expected to lead to the development of effective alternatives to antibiotics that are resistant to some highly pathogenicity.

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Competing Interests

I want to acknowledge that this project is entirely the property of the researchers and no one else.

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