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Effectiveness of Natural Plant Extracts and Ziziphus Honey against Multidrug-resistant Klebsiella pneumoniae

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Abstract

Background

The increasing prevalence of multidrug-resistant *Klebsiella pneumoniae* has created an urgent need for alternative antimicrobial agents. Natural products such as *Ziziphus* (Sidr) honey and medicinal plants such as *Moringa oleifera* and *Nigella sativa* extracts have attracted attention because of their reported antibacterial properties and potential role against resistant organisms.

Aim

To compare the antibacterial effects of *M. oleifera*, *N. sativa*, and *Ziziphus* honey against multidrug-resistant *K. pneumoniae* isolates obtained from pediatric wound and burn infections.

Methods

Nine (*N = 9*) clinical isolates of multidrug-resistant *K. pneumoniae* were tested using the agar well diffusion method. Three concentrations (100%, 75%, and 50%) of each natural product were evaluated, and inhibition zones (mm) were measured in triplicate. Extracts were prepared using standard maceration procedures, and *Ziziphus* honey was diluted (1:1) with sterile distilled water. Statistical analysis was performed using one-way ANOVA ($p < 0.05$).

Results

All tested agents demonstrated antibacterial activity with variable inhibition zones. *Ziziphus* honey showed the highest activity, with inhibition zones of 34, 18, and 12 mm at 100%, 75%, and 50%, respectively. *M. oleifera* exhibited lower activity (12, 10, and 8 mm), while *N. sativa* showed moderate activity (13, 12, and 10 mm). The positive control (Imipenem, 10 µg) produced an average inhibition zone of 21.7 mm.

Conclusion

Ziziphus honey demonstrated the strongest antibacterial activity against multidrug-resistant *K. pneumoniae*, followed by *M. oleifera* and *N. sativa*. These findings suggest that natural products, particularly honey, may serve as potential complementary antimicrobial agents, although their activity remains lower than conventional antibiotics.

Introduction

Klebsiella pneumoniae is a gram-negative bacterium and one of the important emergent opportunistic pathogens, particularly in healthcare settings, that can lead to death and is associated with high mortality and morbidity rates due to its ability to develop resistance to multiple antibiotics, including the β-lactam class such as penicillin and cephalosporins through mechanisms like extended-spectrum β-lactamase (ESBL) production and carbapenem resistance. It can cause severe infections such as pneumonia, sepsis, urinary tract infections, and liver abscesses(1). Nowadays, antibiotic resistance represents a major global burden in healthcare systems, prompting the search for alternative therapeutic approaches to reduce the impact of multidrug-resistant organisms(2). Many natural plants possess antioxidant and antibacterial properties, including *Moringa oleifera, Ziziphus spina-christi, and Nigella sativa*.

N. sativa, commonly known as black seed, is a traditional herbal plant widely used in Middle Eastern and Asian medicine. It has multiple therapeutic applications and has been used as a natural remedy for various conditions, particularly inflammatory diseases(3). Studies have demonstrated that *N. sativa* possesses antibacterial, antioxidant, and immunomodulatory properties (4). *M. oleifera*, known as the "miracle tree," is a herbal plant that grows in tropical regions and is valued for its nutritional and medicinal properties. Research has shown that it exhibits antifungal, antibacterial, antioxidant, and anti-inflammatory activities (5). Sidr (*Ziziphus*) honey has been used for centuries as a natural therapeutic agent, particularly in wound healing and burn management. It contains both peroxide and non-peroxide antibacterial factors, making it effective against a wide range of microorganisms (6).

The current study aimed to compare the antibacterial effects of *M. oleifera, N. sativa*, and *Ziziphus* honey against Multidrug-resistant *K. pneumoniae* isolates from varieties of pediatric wound and burn infections. We hypothesized that all three would demonstrate dose-dependent activity.

2. Materials and Methods

2.1 Study Design and Ethical Considerations

This comparative in vitro study was conducted using de-identified clinical bacterial isolates obtained from routine pediatric surgical care in local clinical institutions. Ethical approval was obtained from the Research Ethics Committee of King Faisal University, Saudi Arabia (IRB: Research Ethics Committee of King Faisal University, Approval No.: KFU-2026-ETHICS4308), in accordance with institutional regulations. Informed consent was obtained in accordance with institutional and national ethical guidelines

The study complied with the principles of the Declaration of Helsinki, as applicable, and aligns with standard microbiological and antimicrobial resistance research practices (7).

2.2 Bacterial Isolates and Identification

A total of nine (*N = 9*) clinical isolates of *K. pneumoniae* were collected from pediatric patients presenting with wound and burn infections and processed in a hospital microbiology laboratory. All samples were fully anonymized prior to analysis.

Initial identification was performed using standard microbiological methods, including colony morphology assessment, oxidase testing, and conventional biochemical reactions, as described in established laboratory manuals(8) .

2.3 Antimicrobial Susceptibility Testing (AST)

Confirmatory identification and antimicrobial susceptibility testing (AST) were performed using the automated VITEK® 2 system (bioMérieux, France), following the manufacturer's instructions (bioMérieux, 2022). Bacterial suspensions were prepared to match a 0.5 McFarland turbidity standard prior to inoculation into VITEK cards.

Minimum inhibitory concentration (MIC) values were generated automatically, and results were interpreted as susceptible (S), intermediate (I), or resistant (R) according to Clinical and Laboratory Standards Institute (CLSI) guidelines (CLSI, 2023).

Multidrug resistance (MDR) was defined as resistance to at least three classes of antimicrobial agents, consistent with previously established definitions in antimicrobial resistance studies (9).

2.4 Preparation of *N. sativa* Seed Extracts, *M. oleifera* leaves extract and GC–MS Analysis

N. sativa seeds and authentic Sidr honey produced from Ziziphus spp. were collected during the spring (April- May 2024) from the Agricultural-Veterinary Training and Research Station at King Faisal University, after approval from the station administration. The Agricultural-Veterinary Training and Research Station, King Faisal University, deposited voucher specimens of each species (Research Ethics Committee of King Faisal University, voucher number: KFU 3456). Formal identification of the *N. sativa* seed and *M. oleifera* leaf extracts used was done by Prof. Fadia El Sherif, Department of Biological Sciences, College of Sciences, King Faisal University, Al Ahsa, Saudi Arabia.

.*N. sativa* seeds were washed, air-dried, and ground into a fine powder. The powdered seeds (160 g) were macerated in ethanol (1000 mL) at 37°C for 48 h. The resulting extract was filtered and concentrated by evaporation using a rotary evaporator at 45°C. *M. oleifera* leaves were collected from a local farm and washed with distilled water for 5 minutes. The leaves were subsequently air-dried at room temperature on a clean surface for 48 hours. Once completely dried, they were ground into a fine powder using an electric blender. The extract was prepared by dissolving 35 g of moringa powder in 262 mL of ethanol to achieve a concentration of 0.13 g/mL. The mixture was continuously stirred using a magnetic stirrer for 48 hours to ensure proper extraction. Following this, the solution was centrifuged at 40,000 rpm for 4 minutes to remove particulate matter. The supernatant was then filtered using filter paper and subjected to evaporation using a rotary evaporator to remove the majority of the ethanol. The remaining

concentrated extract was collected and stored in a separate container. The concentrated extract was then filtered through a 0.2 µm syringe filter, and 2 µL of the filtrate was injected into the GC–MS system for analysis. The GC–MS operating conditions, separation procedures, and identification of the separated compounds were carried out according to the method described by(10).

2.5 Antibacterial Activity Assays

2.5.1 Agar Well Diffusion Assay

Ethanolic extracts of *N. sativa* seeds and *M. oleifera* leaves were prepared using standard maceration and solvent evaporation techniques. The antibacterial activity of the extracts was initially screened using the agar well diffusion method against multidrug-resistant *K. pneumoniae* isolates, following established protocols (11)).

Sidr (*Ziziphus*) honey was diluted in a 1:1 (v/v) ratio with sterile distilled water and homogenized thoroughly. The solution was sterilized using a 0.22 µm membrane filter. Working concentrations (100%, 75%, and 50%) were freshly prepared prior to use.

Mueller–Hinton agar plates were inoculated with bacterial suspensions standardized to 0.5 McFarland turbidity. Wells (6 mm diameter) were aseptically prepared, and 50 µL of each test solution was added. Imipenem discs (10 µg) were used as positive controls, while sterile diluent served as a negative control.

Plates were incubated at 37°C for 18–24 hours, and inhibition zones were measured in millimeters using a calibrated digital caliper. All experiments were performed in triplicate, and mean values were recorded.

2.5.2 Minimum Inhibitory Concentration (MIC) Determination

The minimum inhibitory concentration (MIC) of the tested extracts and honey was determined using the broth microdilution method in accordance with CLSI guidelines (CLSI, 2023).

Serial two-fold dilutions of each extract were prepared in sterile Mueller–Hinton broth to obtain a range of concentrations. Each well was inoculated with standardized bacterial suspension equivalent to 0.5 McFarland and incubated at 37°C for 18–24 hours.

The MIC was defined as the lowest concentration of the tested substance that showed no visible bacterial growth. All assays were performed in triplicate to ensure reproducibility.

2.5.3 Data Integration and Interpretation

The antibacterial efficacy of the tested agents was evaluated by correlating inhibition zone diameters obtained from agar diffusion assays with MIC values obtained from broth microdilution. This combined approach provides both qualitative and quantitative assessment of antimicrobial activity and enhances the reliability of the findings (11).

2.6 Statistic analysis

One-way ANOVA tested differences among treatments, with Tukey's post hoc comparisons where appropriate. A two-tailed p-value < 0.05 was considered statistically significant. Graphs and summaries were prepared for descriptive clarity.

3. Results

3.1 Antimicrobial Susceptibility Patterns of Multidrug-Resistant *K. pneumoniae* Isolates (N = 9)

The antimicrobial susceptibility profile of multidrug-resistant Klebsiella pneumoniae isolates (N = 9), as determined using the VITEK® 2 system, is presented in Table 1.

Table 1
Antimicrobial susceptibility profile of multidrug-resistant *Klebsiella pneumoniae* isolates (N = 9) determined using the VITEK® 2 system.

Antimicrobial Agent	MIC (µg/mL)	Interpretation
Amoxicillin/Clavulanic Acid	16	I
Piperacillin/Tazobactam	≤ 4	S
Cefazolin	≥ 64	R
Cefuroxime	≥ 64	R
Cefuroxime Axetil	≥ 64	R
Ceftazidime	8	I
Ceftriaxone	≥ 64	R
Cefepime	≥ 32	R
Ertapenem	≤ 0.12	S
Imipenem	≤ 0.25	S
Meropenem	≤ 0.25	S
Amikacin	2	S
Gentamicin	≥ 16	R
Ciprofloxacin	≥ 4	R
Fosfomycin	128	R
Nitrofurantoin	≤ 16	S
Trimethoprim/Sulfamethoxazole	≥ 320	R

MIC: Minimum Inhibitory Concentration; S: Susceptible, I: Intermediate, R: Resistant; Results obtained using the VITEK® 2 automated system; Interpretation based on Clinical and Laboratory Standards Institute (CLSI) guidelines (latest edition); Data represent multidrug-resistant clinical isolates (N = 9)

The isolates showed susceptibility to piperacillin/tazobactam (MIC ≤ 4 µg/mL), ertapenem (MIC ≤ 0.12 µg/mL), imipenem (MIC ≤ 0.25 µg/mL), meropenem (MIC ≤ 0.25 µg/mL), amikacin (MIC = 2 µg/mL), and nitrofurantoin (MIC ≤ 16 µg/mL).

Intermediate susceptibility was observed for amoxicillin/clavulanic acid (MIC = 16 µg/mL) and ceftazidime (MIC = 8 µg/mL).

Resistance was detected against multiple antibiotics, including cefazolin (MIC ≥ 64 µg/mL), cefuroxime (MIC ≥ 64 µg/mL), cefuroxime axetil (MIC ≥ 64 µg/mL), ceftriaxone (MIC ≥ 64 µg/mL), cefepime (MIC ≥ 32

μg/mL), gentamicin (MIC ≥ 16 μg/mL), ciprofloxacin (MIC ≥ 4 μg/mL), fosfomycin (MIC = 128 μg/mL), and trimethoprim/sulfamethoxazole (MIC ≥ 320 μg/mL).

3.2 GC-MS Analysis of N. sativa Seed Extracts and M. oleifera leaves ethanolic extract

GCMS analysis of the ethanolic extract of *N. sativa* Seed Extracts (Table 1 and Fig. 1) revealed a wide range of chemical constituents including fatty acids, fatty acid esters, lactones, long-chain alcohols, and hydrocarbons (Table 1 and Fig. 1). The results indicated that fatty acid derivatives were the dominant of compounds detected in the extract. The most abundant compound identified was linoleic acid ethyl ester (28.75%), followed by (Z)-18-octadec-9-enolide (11.15%), hexadecanoic acid ethyl ester (8.97%), hexadecanoic acid (8.08%), and 9,12-octadecadienoic acid (Z,Z)-, 2-hydroxy-1-(hydroxymethyl)ethyl ester (8.34%). Other compounds detected in moderate concentrations included ethyl 9-octadecenoate (4.63%), ethyl oleate (3.81%), hexadecanoic acid 2-hydroxy-1-(hydroxymethyl)ethyl ester (3.91%), cis-11,14-eicosadienoic acid methyl ester (3.06%), and butyl 9,12-octadecadienoate (2.06%). In addition, several minor compounds were detected such as o-cymene, tetradecanoic acid, oleic acid, octadecanoic acid, and 17-octadecynoic acid, which are also known to possess biological activities.

The GC–MS analysis of *M. oleifera* leaves ethanolic extract (Table 2 and Fig. 2) revealed a complex mixture of phytochemical constituents, with several compounds detected at relatively high percentages. The dominant compounds belonged mainly to fatty acids, esters, terpenoids, and long-chain alcohols. The most abundant compounds identified were 2H-pyran derivative (10.00%), palmitic acid (TMS derivative) (9.43%), oxiraneoctanoic acid methyl ester (7.57%), 12-methyl-octadecadien-1-ol (7.57%), phytol (6.71%), α-linolenic acid (TMS derivative) (5.61%), 8,11,14-eicosatrienoic acid (5.52%), and oleic acid (4.79%). These compounds are known for their significant biological activities, including antimicrobial, antioxidant, and anti-inflammatory effects, suggesting their importance in the overall bioactivity of the extract.

Table 2
Major bioactive compounds identified in *Nigella sativa* seed ethanolic extract by GC–MS analysis.

RT (min)	Compound Name	Area (%)	Molecular Formula	MW (g/mol)
31.16	Linoleic acid ethyl ester	28.75	C20H36O2	308
31.74	(Z)-18-Octadec-9-enolide	11.15	C18H32O2	280
27.91	Hexadecanoic acid, ethyl ester	8.97	C18H36O2	284
28.44	Hexadecanoic acid	8.08	C16H32O2	256
39.25	Linoleic acid derivative	8.34	C21H38O4	354
31.44	Ethyl 9-octadecenoate	4.63	C20H38O2	310
31.36	Ethyl oleate	3.81	C20H38O2	310
34.25	Eicosadienoic acid ester	3.06	C21H38O2	322

Table 3
Major compounds identified in *Moringa oleifera* leaves ethanolic extract by GC–MS analysis.

RT (min)	Compound Name	Area (%)	Molecular Formula	MW (g/mol)
36.71	2H-Pyran derivative	10.00	C22H40O2	336
28.93	Palmitic acid derivative	9.43	C19H40O2Si	328
40.87	Oxiraneoctanoic acid ester	7.57	C19H36O3	312
41.09	Octadecadienol derivative	7.57	C19H36O	280
29.94	Phytol	6.71	C20H40O	296
30.39	Eicosatrienoic acid	5.52	C20H34O2	306
31.81	α-Linolenic acid derivative	5.61	C21H38O2Si	350
27.25	Oleic acid	4.79	C18H34O2	282

3.3 Effect of Sidr Honey, *M. oleifera*, and *N. sativa* against *K. pneumoniae*

Agar well diffusion assays were performed to evaluate the antibacterial activity of the tested natural products against *Klebsiella pneumoniae* isolates. The inhibition zone data demonstrated variable antimicrobial activity depending on the tested solution and concentration (Table 4).

Table 4
Antibacterial activity of tested natural products expressed as inhibition zone diameter (mm) against the tested bacterial isolate (N = 9).

Test Solution	Concentration (%)	Inhibition Zone (mm)
Sidr honey	100	34
	75	18
	50	12
Imipenem (10 µg)	—	21.5
Moringa oleifera	100	12
	75	10
	50	8
Imipenem (10 µg)	—	21.5
Nigella sativa	100	13
	75	12
	50	10
Imipenem (10 µg)	—	21.5

Sidr honey exhibited the highest antibacterial activity among all tested agents, with the largest inhibition zone observed at 100% concentration (34 mm), followed by 75% (18 mm) and 50% (12 mm), indicating a concentration-dependent effect.

Moringa oleifera ethanolic extract showed comparatively lower activity, with inhibition zones of 12 mm at 100%, 10 mm at 75%, and 8 mm at 50%.

Similarly, *Nigella sativa* ethanolic extract demonstrated moderate antibacterial activity, with inhibition zones of 13 mm, 12 mm, and 10 mm at concentrations of 100%, 75%, and 50%, respectively.

The positive control, Imipenem (10 µg), produced an average inhibition zone of 21.7 mm.

3.4 Minimum Inhibitory Concentration (MIC) of Tested Natural Products

The minimum inhibitory concentration (MIC) values of the tested natural products against multidrug-resistant *Klebsiella pneumoniae* isolates (N = 9) are presented in Table 5.

Table 5
Minimum inhibitory concentration (MIC) of tested natural products against multidrug-resistant *Klebsiella pneumoniae* isolates (N = 9)

Test Solution	MIC Range (µg/mL)	MIC_{50} (µg/mL)	MIC_{90} (µg/mL)
Sidr honey	250–1000	500	1000
Moringa oleifera	1000–4000	2000	4000
Nigella sativa	500–2000	1000	2000
Imipenem	≤ 0.25	0.12	0.25

Sidr honey exhibited the strongest antibacterial activity among the tested natural products, with MIC values ranging from 250 to 1000 µg/mL. The MIC_{50} and MIC_{90} values were 500 µg/mL and 1000 µg/mL, respectively.

Nigella sativa demonstrated moderate antibacterial activity, with MIC values ranging from 500 to 2000 µg/mL, and MIC_{50} and MIC_{90} values of 1000 µg/mL and 2000 µg/mL, respectively.

Moringa oleifera showed comparatively lower antibacterial activity, with MIC values ranging from 1000 to 4000 µg/mL, and MIC_{50} and MIC_{90} values of 2000 µg/mL and 4000 µg/mL, respectively.

The reference antibiotic, imipenem, exhibited the highest antibacterial potency, with MIC values ≤ 0.25 µg/mL, and MIC_{50} and MIC_{90} values of 0.12 µg/mL and 0.25 µg/mL, respectively.

4. Discussion

The present study demonstrated that *Sidr* (Ziziphus) honey, *M. oleifera*, and *N. sativa* exhibited measurable in vitro antibacterial activity against multidrug-resistant (MDR) *K. pneumoniae*, with significant variation in efficacy among the tested agents. Among these, *Sidr* honey showed the highest inhibitory activity, followed by *M. oleifera* and *N. sativa*, respectively. This pattern is consistent with previous studies reporting the antibacterial potential of natural products against clinically relevant Gram-negative pathogens (12, 13).

The relevance of these findings is underscored by the increasing global burden of MDR K. pneumoniae, which is driven by multiple resistance mechanisms, including extended-spectrum β-lactamase (ESBL) production, carbapenemase enzymes, efflux pumps, reduced membrane permeability, and biofilm formation (1, 14). These mechanisms significantly compromise the effectiveness of conventional antibiotics, thereby necessitating the exploration of alternative antimicrobial strategies. The observed antibacterial activity of the tested natural products suggests that their mechanisms of action may partially circumvent these resistance pathways.

The superior antibacterial activity of *Sidr* honey can be attributed to its multifactorial mode of action. Honey exerts antimicrobial effects through a combination of high osmotic pressure, low pH, hydrogen

peroxide generation, and the presence of bioactive compounds such as phenolics and flavonoids(13, 15). These combined physicochemical and biochemical stresses make it more difficult for bacteria to develop resistance, particularly in comparison to single-target antibiotics. Previous studies have demonstrated that honey derived from *Ziziphus spina-christi* exhibits significant antibacterial activity against Gram-negative bacteria, including *K. pneumoniae*, supporting the findings of the present study (12, 16).

The moderate antibacterial activity observed for *Moringa oleifera* is also supported by the literature. *M. oleifera* contains various bioactive compounds, including flavonoids, phenolic acids, alkaloids, and isothiocyanates, which have been associated with antimicrobial activity (5). However, the efficacy of *M. oleifera* extracts is influenced by several factors, including extraction method, solvent polarity, plant part, and concentration. Notably, Gram-negative bacteria are generally less susceptible to plant extracts due to the protective nature of their outer membrane (17), which may explain the relatively lower inhibition observed in the present study.

Similarly, *N. sativa* demonstrated moderate antibacterial activity, which aligns with previous reports highlighting the role of thymoquinone as a key bioactive compound. Thymoquinone has been shown to disrupt bacterial membranes, increase permeability, inhibit biofilm formation, and interfere with bacterial virulence factors(18, 19). However, the relatively lower inhibition zones observed may be influenced by the limited diffusion of hydrophobic compounds in agar-based assays, as well as variations in extract composition and concentration.

The GC–MS analysis further supports the biological activity observed in this study. The presence of fatty acids, fatty acid esters, terpenoids, and related compounds in *both N. sativa* and *M. oleifera* extracts provides a plausible explanation for their antibacterial effects. These compounds are known to disrupt membrane integrity, alter permeability, interfere with enzymatic processes, and inhibit biofilm formation (20). Such multi-target mechanisms are particularly relevant in combating MDR pathogens, where single-target antibiotics often fail.

An important methodological consideration in this study is the use of imipenem antibiotics as a reference control. Imipenem was used as a clinically relevant antibiotic for Gram-negative bacteria, including *Klebsiella pneumoniae* (14). However, comparisons between imipenem and natural products should be interpreted cautiously, as differences in physicochemical properties particularly diffusion capacity in agar media may influence inhibition zone diameters. Unlike purified antibiotics, natural extracts represent complex mixtures of bioactive compounds, which may not diffuse uniformly, potentially affecting the observed antibacterial activity.

The concentration-dependent activity observed for *Sidr* honey highlights the importance of dosage optimization in natural product research. However, in diffusion-based assays, inhibition zone diameter is influenced not only by antimicrobial potency but also by factors such as viscosity, solubility, and diffusion rate in agar media(11). This may explain the non-linear relationship between concentration and inhibition observed in some cases.

Despite the promising findings, several limitations should be acknowledged. The study relied primarily on agar diffusion assays, which do not provide precise quantitative measures such as minimum inhibitory concentration (MIC) or minimum bactericidal concentration (MBC). Additionally, the study did not evaluate anti-biofilm activity, cytotoxicity, or in vivo efficacy, which are critical for clinical translation. Furthermore, the active compounds responsible for the observed antibacterial effects were not isolated or quantified.

Future studies should therefore focus on comprehensive phytochemical characterization, determination of MIC and MBC values, investigation of synergistic effects with conventional antibiotics, and evaluation of safety and efficacy in in vivo models. Such approaches will be essential to validate the therapeutic potential of these natural products.

Declarations

Ethics Approval and Consent to Participate

Ethical approval was obtained from the Research Ethics Committee of King Faisal University, Saudi Arabia (Approval No.: KFU-2026-ETHICS4308), in accordance with institutional regulations. A waiver of informed consent was granted due to the use of anonymized samples with no direct patient involvement.The study complied with the principles of the Declaration of Helsinki, as applicable, and aligns with standard microbiological and antimicrobial resistance research practices

Consent for Publication

Not applicable.

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Author Contribution

Conceptualization: O.M.Z., A.A.G., A.H.K.Methodology: O.M.Z., H.M.A., A.H.K.Formal analysis: O.M.Z., A.H.K, A.A.G..Investigation: O.M.Z., H.M.A., A.H.K., A.A.A., M.Y.I.D., A.S.A., M.F.A., F.E.S., H.A.A., H.M.Z., S.A.A., H.M.A., H.H.A., N.K.A., I.K.A., R.M.M., A.A.A., N.M.A., E.A., R.M.A., M.A.A.Data curation: O.M.Z., H.M.A., A.H.K., A.A.A., M.Y.I.D., A.S.A., M.F.A., F.E.S., H.A.A., A.A.A., N.M.A., E.A., R.M.A.Resources: A.A.A., M.Y.I.D., H.M.A., H.H.A., N.K.A., I.K.A.Validation: H.M.Z., S.A.A., R.M.M.Writing – original draft: O.M.Z., A.H.K, A.A.G..Writing – review & editing: All authors.Supervision: M.A.A.Project administration: M.A.A.

Availability of Data and Materials

The datasets generated and/or analyzed during the current study are available from the corresponding author upon reasonable request.

Competing Interests

The authors declare that they have no competing interests.

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Figures

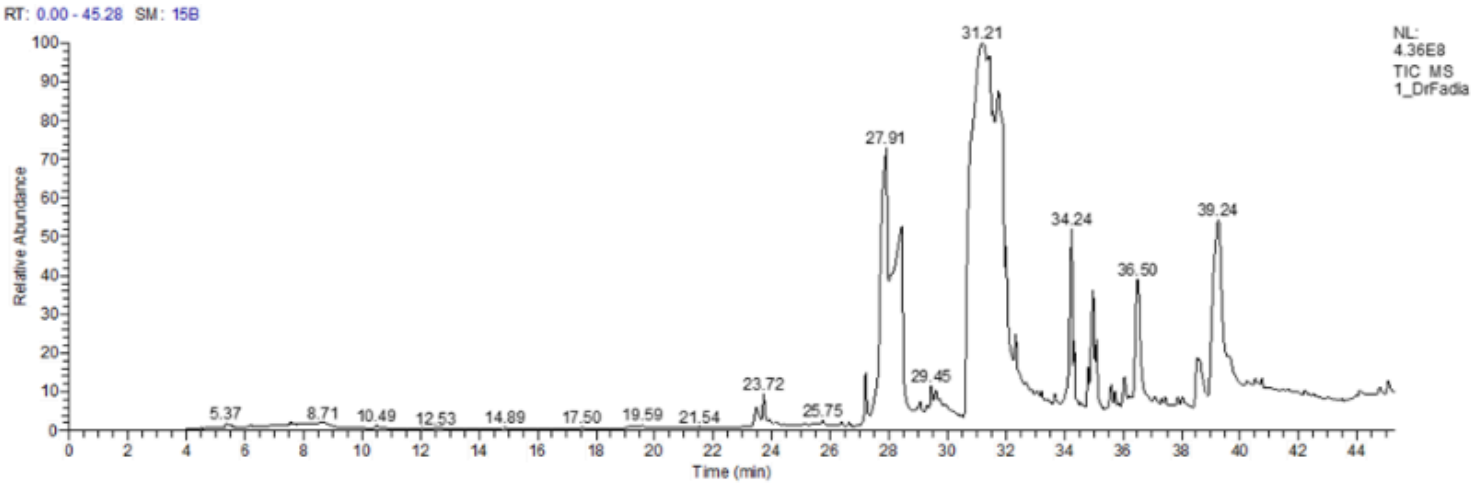


Figure 1

Total ion chromatogram (TIC) of the ethanolic extract of Nigella sativa seeds obtained by GC–MS analysis, showing detected compounds across the retention time range (0–45 min).

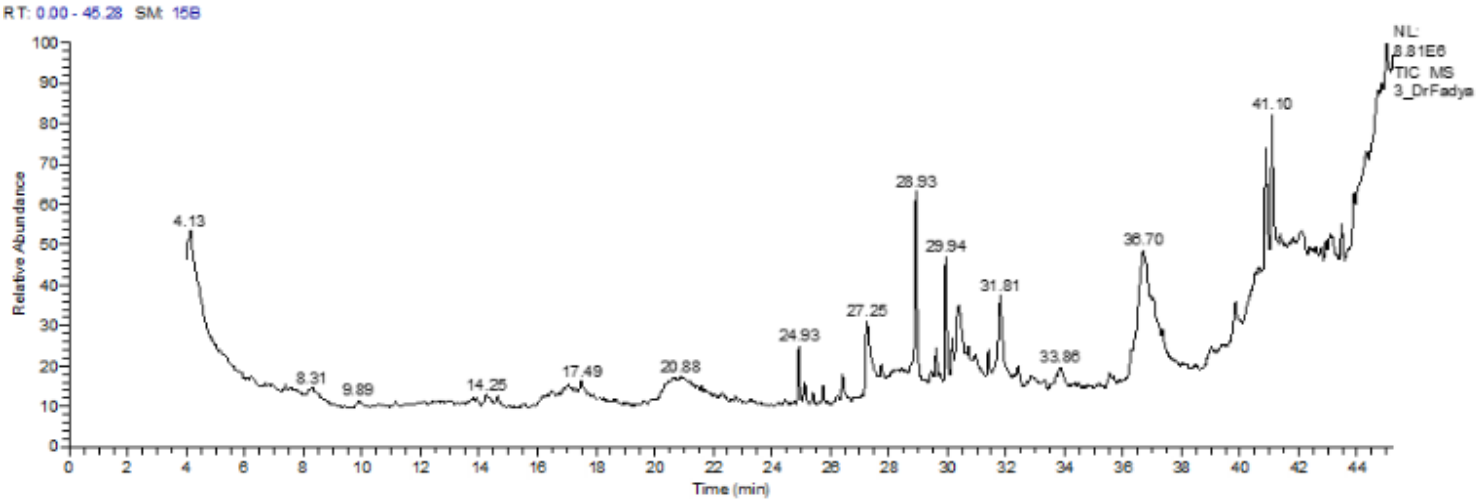


Figure 2

Total ion chromatogram (TIC) of the ethanolic extract of *Moringa oleifera* leaves obtained by GC–MS analysis, showing detected compounds across the retention time range (0–45 min).

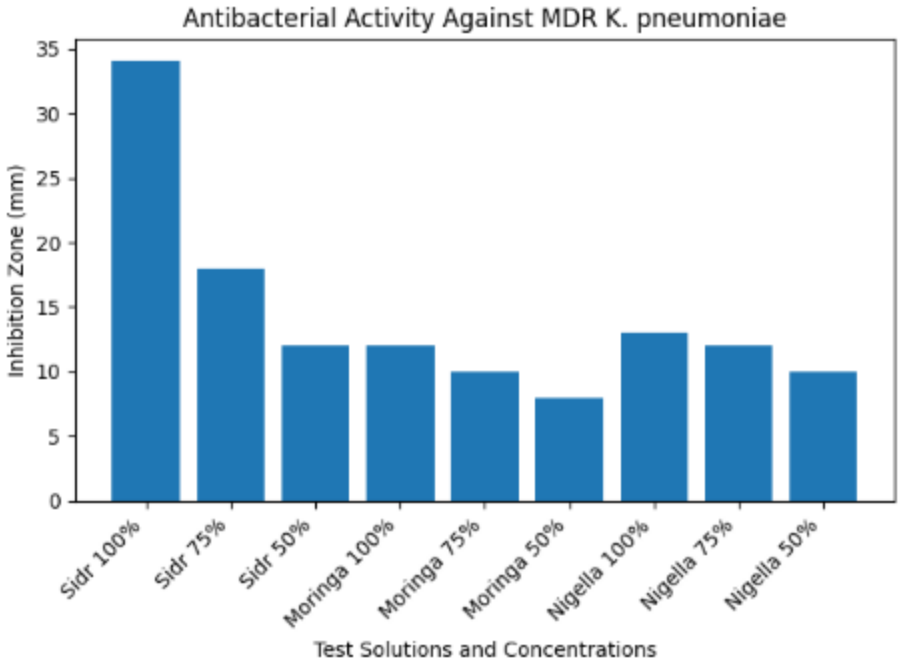


Figure 3

Inhibition zone diameters (mm) of Sidr honey, *Moringa oleifera*, and *Nigella sativa* at different concentrations against multidrug-resistant *Klebsiella pneumoniae* isolates (N = 9).