Microbiology Research Journal International

Volume 34, Issue 12, Page 214-223, 2024; Article no.MRJI.127704
ISSN: 2456-7043, NLM ID: 101726596
(Past name: British Microbiology Research Journal, Past ISSN: 2231-0886, NLM ID: 101608140)

Evaluation of the Antibacterial Activity of *Solanum torvum* Fruit Extracts on Hospital Strains of Enterobacteria

KEKE Margery Claude-Charlène [a,b*], KONAN Kouadio Fernique [a], OKOU Obou Constantin [b], KRA Adou Koffi Mathieu [c] and GUESSENND Nathalie [a]

[a] *Unité des Antibiotiques, des Substances naturelles et de la Surveillance de Résistances des Micro-organismes aux anti-infectieux, Institut Pasteur Côte d'Ivoire 01 BP 490 ABIDJAN 01, Côte d'Ivoire.*
[b] *Groupe d'excellence de Recherche sur les Produits de la Pharmacopée Traditionnelle (GeRProPhat), Laboratoire d'Agrovalorisation, UFR Agroforesterie, Université Jean LOROUGNON GUEDE, Daloa, BP 150 Daloa, Côte d'Ivoire.*
[c] *UFR Biosciences, Laboratoire de Pharmacodynamie Biochimique, Université Félix HOUPHOUËT-BOIGNY (UFHB), Abidjan, Côte d'Ivoire.*

Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

Article Information

DOI: https://doi.org/10.9734/mrji/2024/v34i121522

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://www.sdiarticle5.com/review-history/127704

Original Research Article

Received: 16/10/2024
Accepted: 18/12/2024
Published: 21/12/2024

ABSTRACT

Enterobacteriaceae are among the most pervasive bacteria globally and are the most commonly identified in clinical consultations. It is unfortunate that these disease-causing germs are now increasingly resistant to the standard antibiotics that are generally used. In order to propose

---

**Corresponding author: E-mail: margeryclaude@gmail.com;*

Cite as: *Claude-Charlène, KEKE Margery, KONAN Kouadio Fernique, OKOU Obou Constantin, KRA Adou Koffi Mathieu, and GUESSENND Nathalie. 2024. "Evaluation of the Antibacterial Activity of Solanum Torvum Fruit Extracts on Hospital Strains of Enterobacteria". Microbiology Research Journal International 34 (12):214-23. https://doi.org/10.9734/mrji/2024/v34i121522.*

probable therapeutic alternatives, this study focused on evaluating the antibacterial activity of *Solanum torvum* fruits on a few strains of enterobacteria. To this end, 70% hydroethanolic and 100% ethanolic extracts were prepared from *Solanum torvum* fruits and tested, respectively and separately, on a reference strain of *Escherichia coli* (ATCC), on sensitive strains of *Salmonella sp.* and *Shigella sp.*, and on resistant strains of *Escherichia coli*, *Citrobacter koseri*, *Enterobacter cloacae*, *Klebsiella pneumoniae*, *Proteus mirabilis*, and *Citrobacter freundii*. All susceptible and resistant strains of Enterobacteriaceae were isolated from various biological products of patients. The results demonstrated that these extracts exhibited antibacterial activity with a bactericidal effect on these strains. These extracts could therefore be employed in the manufacture of phytomedicines for the treatment of enterobacterial infections.

Keywords: Enterobacteriaceae; resistance; bactericidal effect; Solanum torvum.

1. INTRODUCTION

The Enterobacteriaceae are a vast family of Gram-negative bacilli. The family comprises over 130 species, which are grouped into 40 genera. They colonize humans, animals, and the environment (Zrardi, 2020; Prével, 2021). They are typically commensal organisms of the digestive tracts of humans and animals, which is reflected in their nomenclature, "Enterobacteriaceae" (Morice, 2003; Joly and Reynaud, 2007; Bentabet, 2021). They are frequently the causative agents of both community-acquired and nosocomial infections in human pathology. Additionally, they are implicated in a multitude of infections, including urinary, pulmonary, intra-abdominal, bacteremia, and meningitis. The enterobacteria most commonly implicated in clinical pathology are *Escherichia*, *Salmonella*, *Shigella*, *Yersinia*, *Klebsiella*, *Enterobacter*, *Serratia*, *Morganella*, *Proteus*, *Providencia*, and *Citrobacter* (Verhaegen, 2002; Zrardi, 2020; Maddi and Menasra, 2022).

In recent years, there has been a notable increase in the resistance of enterobacteria to antibiotics. This phenomenon may be attributed to the overuse and/or inappropriate application of antibiotics. This constitutes a genuine public health concern. Indeed, these bacteria are capable of producing enzymes that can render beta-lactam antibiotics inactive through the production of extended-spectrum β-lactamases (ESBL) (Kouadio et al., 2020; Maloth et al., 2021). The production of extended-spectrum β-lactamases (ESBL) is frequently associated with resistance to specific antibiotic classes, including aminoglycosides and fluoroquinolones (Iabadene *et al.*, 2010; Gadou, 2019). As stated by Patterson (2001), Masterton *et al.*, (2003), and Bentabet (2021), infections caused by ESBL-producing Enterobacteriaceae (ESBL-PE) are typically associated with high morbidity and mortality rates. Indeed, antimicrobial resistance is estimated to be responsible for approximately 700,000 deaths globally (Maddi & Menasra, 2022). In light of the emergence of antibiotic resistance among Enterobacteriaceae, there is an urgent need to identify novel molecules with alternative mechanisms of action (Okou, 2012). Among the various avenues of investigation, traditional pharmacopoeia represents a promising source of potential candidates (Okou, 2012). The objective of this study is to assess the antibacterial efficacy of *Solanum torvum* fruits against a range of hospital-acquired strains of enterobacteria.

2. MATERIALS AND METHODS

2.1 Plant Material

The dried fruit powder of *Solanum torvum* served as our plant material. The fruits were collected in the city of Vavoua (Haut-Sassandra region, Côte d'Ivoire) on May 2, 2023.

2.2 Biological Material

Several human-derived bacterial strains, sourced from the Biobank and previously implicated in bacterial infections, constituted the biological material. These strains were isolated from various diagnostic samples and profiled within the Unité des Antibiotiques, des Substances naturelles et de la Surveillance de Résistances des Micro-organismes aux anti-infectieux (ASSURMI). They were subsequently preserved in the Biobank of the Pasteur Institute of Côte d'Ivoire. Table 1 summarizes the phenotypic profiles of the different bacterial strains used.

Preparation of the various plant extracts: The fruits of *Solanum torvum* were sorted, washed, and air-dried at ambient temperature for three weeks in a well-ventilated, shaded area. Once dried, the fruits were ground into powder using a Retsch-SK100 mill to prepare the various extracts.

Table 1. Phenotypic profile of bacterial strains

Bacterial strains	Identification number	Biological products	Profile
Escherichia coli	ATCC 25922	-	SAVAGE
Escherichia coli	1017KOR/23	Stool	ESBL/FQR
Citrobacter koseri	3350C/22	Urine	ESBL /FQR
Citrobacter freundii	1002C/22	Urine	ESBL /FQR
E*nterobacter cloacae*	383C/22	Urine	FQR/HPCASE
Klebsiella pneumoniae	908C/23	Urine	ESBL /FQR
Salmonella sp	710C/23	Stool	SAVAGE
Shigella sp	579C/23	Stool	SAVAGE
Proteus mirabilis	603C/23	Urine	HPCASE

HPCASE: probable plasmid cephalosporinase; ESBL: extended-spectrum β-lactamases; FQR: fluoroquinolone-resistant

The 100% ethanolic extract was prepared following the method described by Zihiri et al., (2005). Specifically, 100 g of fruit powder was macerated in 1 liter of distilled water using a blender for 5 minutes. The resulting homogenate was filtered and then evaporated to dryness in a BLENDER-type oven at 50 °C over three days to obtain the aqueous extract.

Subsequently, the aqueous extract was macerated with 300 mL of pure ethanol using a blender for 5 minutes and left to decant. This process yielded a supernatant and a pellet, which were separated and dried individually in a BLENDER-type oven at 50 °C for three days. The evaporated residue from the pellet constituted the 100% ethanolic extract (Eth 100%).

The 70% hydroethanolic extract was prepared following the method described by Zihiri et al., (2003) and Okou et al., (2019). Specifically, 100 g of fruit powder was macerated in 1 liter of 70% ethanol (ethanol-distilled water: 70/30, v/v) using a blender for 5 minutes. The resulting homogenate was filtered and evaporated to dryness in a BLENDER-type oven at 50 °C over three days to obtain the 70% hydroethanolic extract (HydroEth 70%).

Calculation of extraction yield : Yield is the amount of extract obtained from a plant material (Dinzedi, 2015 and Okou et al., 2019). It is expressed as a percentage of dry matter (plant powder) and was calculated using the following formula:

$$R (\%) = M_1 \times 100/M_0$$

R: Extract yield expressed as percentage (%),

M_1: Weight of the extract (en g),
M_0: Weight of plant powder (en g).

2.3 Evaluation of the *In vitro* Antibacterial Activity of Different Solanum torvum Extracts

Preparation of concentration series: One gram (1 g) of each extract was weighed and dissolved in 10 mL of distilled water to obtain a concentration of 100 mg/mL (initial concentration or tube 1). The other concentrations were prepared from this initial concentration using the double dilution method in liquid medium. For this purpose, six sterile tubes numbered T1 to T6 were used. Then, 5 mL of sterile distilled water were distributed into the remaining five tubes (tubes 2 to 6). Next, a volume of 5 mL of the initial concentration (T1) was taken and added to tube 2, followed by homogenization. This procedure was repeated up to tube 6. The excess was discarded from tube 6. Thus, the concentration range varied from the initial tube to tube 6, decreasing from 100 mg/mL to 3.125 mg/mL.

2.4 Agar Diffusion Sensitivity Tests

The bacterial inoculum was prepared using one or two bacterial colonies of a given strain. The samples were homogenized in 85% NaCl solution to obtain a 0.5 McFarland standard. Subsequently, the inoculum was swabbed onto a Muller-Hinton (MH) agar plate, and wells were dug into the agar using a Pasteur pipette. A pre-prepared extract range was placed in a given well, and the plate was incubated for 18 to 24 hours at 37°C. After this incubation period, the presence or absence of a zone of inhibition was observed, and readings were taken by measuring the diameter of the zone of inhibition.

2.5 Susceptibility Testing by the Dilution Method

Preparation of inoculated broth: Inoculated broth was prepared using two colonies of the bacterial strain to be tested that were 18 to 24 hours old. These colonies were picked and mixed with a platinum loop in 10 mL of MH broth, then incubated for 3 to 5 hours at 37°C to obtain a preculture. Next, 0.1 mL of the preculture broth was removed and homogenized in another 10 mL of MH broth. This last broth constituted the inoculated broth of the bacterial strain to be tested, with an opalescence of 10^6 CFU/mL.

2.6 Determination of Minimum Inhibitory Concentration (MIC)

The minimum inhibitory concentration (MIC) was determined using the following methodology. A volume of 1.8 mL of inoculated broth of the bacterial strain to be tested, initially prepared, was transferred to seven tubes to form the experimental series. Each of the six tubes in the experimental series contained 0.2 mL of a given extract at varying concentrations. The seventh tube served as a growth control, receiving 0.2 mL of sterile distilled water in lieu of the plant extract. Subsequently, the entire preparation was incubated at 37°C for 18 to 24 hours. Following this incubation period, the preparation was visually inspected for turbidity in daylight. According to Marmonier (1990) and Okou (2012), the minimum inhibitory concentration is defined as the lowest concentration of a compound or substance capable of inhibiting bacterial growth. It is determined by the concentration of the first tube in which the culture is not cloudy.

Bacterial enumeration: Bacterial enumeration was performed using the culture from the control growth tube, which had been previously incubated at 37°C for 18 to 24 hours. To do this, the culture was serially diluted by factors of 10 up to a dilution of 10^{-4}. The pure inoculum from the control growth tube and its four successive dilutions were streaked in 5 cm lines on a MH agar plate using a calibrated platinum loop (2 µL) to form plate A. The plate was then incubated for 18 to 24 hours at 37°C.

2.7 Determination of the Minimum Bactericidal Concentration (MBC)

Each bacterial culture from the experimental series was separately streaked onto a 5 cm line using a calibrated platinum loop (2 µL) on an MH agar plate to create plate B. This plate was incubated at 37°C for 18 to 24 hours. After incubation, the comparison of the number of colonies on the various streaks of plate B with that of the 10^{-4} dilution from plate A allowed the determination of the MBC. According to Sirot (1990) and Okou (2012), the MBC can be determined by identifying the concentration at which no more than 0.01% of the bacteria survive. However, according to Marmonier (1990), a tested substance is considered bactericidal when the MBC/MIC ratio ≤ 4, and bacteriostatic when it is strictly less than 4 (MBC/MIC > 4).

3. RESULTS

Yield of different extracts: The yield of the Eth 100% extract was 13.94%, while the yield of the HydroEth 70% extract was 5.64%. Thus, the yield of the Eth 100% extract was just over 2 times higher (13.94/5.64) than that of the HydroEth 70% extract.

3.1 Agar Diffusion Sensitivity Tests

The results are presented in Table 2. At a concentration of 100 mg/mL, the results demonstrate the activity of both the HydroEth 70% and the Eth 100% extracts on the bacterial strains under investigation. The inhibition zones of the HydroEth 70% extract exhibited diameters ranging from 10 to 14 mm, while those of the Eth 100% extract ranged from 6 to 15 mm. In accordance with the findings of Ponce *et al.,* (2003) and Atsain (2017), a bacterium is classified as resistant to a plant extract when the inhibition zone diameter is less than or equal to 8 mm, sensitive between 9 and 14 mm, very sensitive between 15 and 19 mm, and extremely sensitive when the diameter is equal to or greater than 20 mm.

3.2 Susceptibility Testing using the Dilution Method

Determination of MIC and BMC: The results of the determination of the Minimum Inhibitory Concentrations (MIC) and Minimum Bactericidal Concentrations (MBC) are presented in Table 3. Regarding the MICs, it should be noted that they generally range from 3.125 to 50 mg/mL and from 6.25 to 50 mg/mL for the Eth 100% and HydrEth 70% extracts, respectively, regardless of the bacterial strain used. As for the MBCs, they generally range from 6.25 to 50 mg/mL and from 12.5 to 50 mg/mL for the Eth 100% and

Table 2. Determination of Inhibition Zones for Extracts

	Bacterial strains	Eth 100%			HydroEth 70%			Antibiotic	
		Concentration (mg/mL)						AMC	COX
		100	50	Tm	100	50	Tm		
Inhibition zone (mm)	***Escherichia coli* ATCC**	15	12	06	14	13	06	18	26
	Escherichia coli 1017KOR/23	12	10	06	10	08	06	14	22
	Enterobacter cloacae 383C/22	10	10	06	11	10	06	20	19
	Proteus mirabilis 603C/23	15	12	06	13	10	06	21	27
	Salmonella sp 710C/23	09	06	06	10	07	06	28	29
	Shigella sp 579C/23	06	06	06	10	06	06	11	06
	Klebsiella pneumoniae 908C/23	10	09	06	11	09	06	10	28
	Citrobacter freundii 1002C/22	11	09	06	12	08	06	21	30
	Citrobacter koseri 3350C/22	10	09	06	10	06	06	20	23

Tm: *Control;* ***AMC:*** *Amoxicillin + clavulanic acid;* ***COX:*** *cefotaxime*

Table 3. Summary of antibacterial parameters for the various extracts tested

	Eth 100%				HydroEth 70%			
	MIC (mg/mL)	**MBC (mg/mL)**	**MBC/MIC**	**POWER**	**MIC (mg/mL)**	**MBC (mg/mL)**	**MBC/MIC**	**POWER**
Escherichia coli ATCC 25922	3,125	6,25	2	Bactericide	12,5	25	2	Bactericide
Escherichia coli 1017C/23	25	50	2	Bactericide	25	25	1	Bactericide
Enterobacter cloacae 383C/23	50	50	1	Bactericide	50	50	1	Bactericide
Proteus mirabilis 603C/23	6,25	12,5	2	Bactericide	6,25	12,5	2	Bactericide
Salmonella sp 710C/23	50	50	1	Bactericide	12,5	25	2	Bactericide
Shigella sp 579C/23	-	-	-	Bactericide	12,5	25	2	Bactericide
Klebsiella pneumoniae 908C/23	25	50	2	Bactericide	12,5	25	2	Bactericide
Citrobacter freundii 1002C/23	25	25	1	Bactericide	25	25	1	Bactericide
Citrobacter koseri 3350C/23	50	50	1	Bactericide	25	25	1	Bactericide

HydroEth 70% extracts, respectively, regardless of the bacterial strain. However, concerning the Eth 100% extract, the MIC is lower (3.125 mg/mL) for the reference strain (*Escherichia coli* ATCC 25922) and higher (50 mg/mL) for the strains of *Enterobacter cloacae*, *Salmonella sp.*, *Shigella sp.*, and *Citrobacter koseri*. For the resistant *Escherichia coli* strains, *Klebsiella pneumoniae*, and *Citrobacter freundii*, it is 25 mg/mL. The MIC for the HPCASE phenotype strain of *Proteus mirabilis* was 6.25 mg/mL. Regarding the MBC, it is smaller (6.25 mg/mL) for *Escherichia coli* ATCC 25922 and larger (50 mg/mL) for the strains of *Escherichia coli*, *Enterobacter cloacae*, *Salmonella sp.*, *Shigella sp.*, *Klebsiella pneumoniae*, and *Citrobacter koseri*. For the strains of *Proteus mirabilis* and *Citrobacter freundii*, the MBC was 12.5 and 25 mg/mL, respectively.

Regarding the HydrEth 70% extract, the lowest inhibitory value was observed with the resistant strain of *Proteus mirabilis* (6.25 mg/mL), followed by *Escherichia coli* ATCC 25922, *Klebsiella pneumoniae*, *Salmonella sp.*, and *Shigella sp.* (12.5 mg/mL), then by the resistant *Escherichia coli*, *Citrobacter koseri*, and *Citrobacter freundii* strains (25 mg/mL), and finally, the highest value was observed with the *Enterobacter cloacae* strain (50 mg/mL). Regarding the minimum bactericidal concentration, the lowest value was obtained with the *Proteus mirabilis* strain (12.5 mg/mL), and the highest with the *Enterobacter cloacae* strain (50 mg/mL). For the *Citrobacter freundii*, *Salmonella sp.*, *Shigella sp.*, *Citrobacter koseri*, *Klebsiella pneumoniae*, and resistant *Escherichia coli strains*, the MBC was 25 mg/mL.

4. DISCUSSION

Yields of the different extracts: The results of the yield calculation revealed that the Eth 100% extract exhibited a slightly higher yield (13.94/5.64) than the HydroEth 70% extract. This observation can be explained by the fact that, according to the literature (Cowan, 1999; Okou, 2012), the extraction of bioactive molecules is a function of the solvent and the method used. In consideration of the extraction of bioactive molecules, water can be employed to yield anthocyanins, tannins, saponins, terpenes, and other compounds. Conversely, ethanol can be utilized to isolate tannins, polyphenols, polyacetylenes, flavonoids, sterols, and other molecules. With regard to the method, it should be noted that the ethanolic extract (100%) was obtained from the aqueous extract. Consequently, this extract will contain compounds that are soluble in both water and pure ethanol, as well as substances that can only be extracted with one of the solvents. This may account for the higher concentration of bioactive molecules in this extract, which in turn may promote higher yields. In contrast to the 70% hydroethanol extraction, which isolated compounds with a solubility intermediate between ethanol and water.

4.1 Agar Diffusion Sensitivity Tests

The results of sensitivity tests on agar media at a concentration of 100 mg/mL of Eth 100% extract yielded respective inhibition zones of 15 mm (*Escherichia coli* ATCC 25922 and *Proteus mirabilis*), 1 The inhibition zones were 2 mm (resistant *Escherichia coli*), 11 mm (*Citrobacter freundi*), 10 mm (*Enterobacter cloacae*, *Klebsiella pneumoniae*, and *Citrobacter koseri*), 9 mm (*Salmonella sp.*), and 6 mm (*Shigella sp.*). These results corroborate the hypothesis that the sensitivity of the aforementioned strains (*Escherichia coli* ATCC 25922 and *Proteus mirabilis*, as well as resistant *Escherichia coli*, *Citrobacter freundii*, *Enterobacter cloacae*, *Klebsiella pneumoniae*, *Citrobacter koseri*, and *Salmonella sp.*) to the Eth 100% extract is variable. The extract demonstrates greater activity against *Escherichia coli* ATCC 25922 and *Proteus mirabilis* than against *Citrobacter freundii*, *Enterobacter cloacae*, *Klebsiella pneumoniae*, *Citrobacter koseri*, and *Salmonella sp*. The *Shigella sp* strain exhibits resistance to this extract.

The inhibition diameters obtained for the 100 mg/mL concentration of HydroEth in agar medium are 14 mm for *Escherichia coli* ATCC 25922, 13 mm for *Proteus mirabilis*, and so forth. The inhibition diameters obtained for the 100 mg/mL concentration in agar medium were 14 mm (*Escherichia coli* ATCC 25922), 13 mm (*Proteus mirabilis*), 12 mm (*Citrobacter freundii*), 11 mm (*Enterobacter cloacae* and *Klebsiella pneumoniae*), and 10 mm (resistant *Escherichia coli*, *Salmonella sp.*, *Shigella sp.*, and *Citrobacter koseri*). The results demonstrate that the bacterial strains utilized exhibit sensitivity to this extract. Based on these observations, it can be posited that the extracts under examination are active on all the strains tested, with the exception of *Shigella sp*. Indeed, according to Biyiti (2004), an extract is considered active when it induces a zone of inhibition greater than or equal to 10 mm.

4.2 Sensitivity Tests using the Dilution Method

Determination of MIC and BMC: For MIC determination, the absence of turbidity was observed for the Eth 100% extract from:

- 3.125 mg/mL for *Escherichia coli* ATCC 25922,
- 6.25 mg/mL for *Proteus mirabilis*,
- 25 mg/mL for resistant *Escherichia coli*, *Klebsiella pneumoniae* and *Citrobacter freundii*,
- 50 mg/mL for *Enterobacter cloacae*, *Citrobacter koseri* and *Samonella sp*. With the same extract, turbidity was observed for *Shigella sp*.

In the case of HydroEth 70% extract, however, it was found that from:

- 6.25 mg/mL for *Proteus mirabilis*,
- 12.5 mg/mL for *Escherichia coli* ATCC 25922, *Klebsiella pneumoniae*, *Shigella sp* and *Salmonella sp*,
- 25 mg/mL for resistant *Escherichia coli*, *Klebsiella pneumoniae*, and *Citrobacter freundii*,
- 50 mg/mL for *Enterobacter cloacae*.

It can be said that the different concentrations observed represent the minimum inhibitory concentrations (MICs) of the different strains studied (Marmonier (1990) and Okou (2012)).

The dilution of the inoculated broth resulted in colonies isolated at a dilution of 10-4, which means that the work was carried out under standard culture conditions. A comparison of the number of colonies on the 10-4 dilution strip in Dish A and the strip in Dish B yielded the following values for the Eth 100% extract:

- 6.25 mg/mL for *Escherichia coli* ATCC 25922,
- 12.5 mg/mL for *Proteus mirabilis*,
- 25 mg/mL for *Citrobacter freundii*,
- 50 mg/mL for *Enterobacter cloacae*, *Citrobacter koseri*, *Samonella sp*, resistant *Escherichia coli* and *Klebsiella pneumoniae*.

Similar for HydroEth 70% extract:

- 12.5 mg/mL for *Proteus mirabilis*,
- 25 mg/mL for *Escherichia coli* ATCC 25922, resistant *Escherichia coli*, *Klebsiella pneumoniae*, and *Citrobacter freundii*, *Citrobacter koseri*, *Samonella sp*. and *Shigella sp*,
- 50 mg/mL for *Enterobacter cloacae*.

According to Sirot (1990) and Okou (2012), these values represent the different BMCs of the studied extracts for each strain used.

Based on the BMCs, when comparing the two extracts requested and each strain used, it is observed that:

- The 100% ethanol extract (6.25 mg/mL) has a lower BMC than the 70% hydroethanol extract (25 mg/mL) for *Escherichia coli* strain ATCC 25922,
- The 100% and 70% ethanol extracts have identical BMC values for the strains *Enterobacter cloacae* (50 mg/mL), *Proteus mirabilis* (12.5 mg/mL) and *Citrobacter freundii* (25 mg/mL),
- Eth 100% extract had identical, higher BMC values (50 mg/mL) for resistant *Escherichia coli*, *Salmonella sp*, *Klebsiella pneumoniae* and *Citrobacter koseri* strains compared to 25 mg/mL for the same strains with HydroEth 70% extract. According to Okou *et al*., (2019), the lower the CMB value, the higher the activity of the extract. Therefore, it can be concluded that:
- Eth 100% extract has better activity on the reference strain *Escherichia coli* ATCC 25922 than HydroEth 70% extract,
- both Eth 100% and HydroEth 70% extracts have the same activity on *Enterobacter cloacae*, *Proteus mirabilis* and *Citrobacter freundii* strains.
- Eth 100% extract has weaker activity than HydroEth 70% extract on resistant *Escherichia coli*, *Klebsiella pneumoniae*, *Citrobacter koseri* and *Salmonella sp*,
- Eth 100% extract has no activity on *Shigella sp*, unlike HydroEth 70% extract.

The results of the bacterial microdilution checkerboard method (BMC/MIC) ratios of the two Solanum torvum extracts tested on these bacterial strains generally yielded values that were consistently below 4 (≤ 4). This finding suggests that all extracts tested on the bacterial strains used have bactericidal activity. Indeed, as Marnonier (1990) asserts, when the CMB/CMI ratio is less than or equal to four (CMB/CMI ≤ 4),

the solicited substance has a bactericidal effect on the strain tested. Conversely, if the ratio is precisely greater than four (CMB/CMI > 4), the substance exerts a bacteriostatic effect on the strain. However, this bactericidal effect is concentration-dependent, as it is influenced by the substance's dosage. Notably, this phenomenon does not apply to the *Shigella sp* strain in the presence of an Eth 100% extract.

These findings are not consistent with those reported by Okou *et al.*, (2019). Indeed, the aforementioned study demonstrated that Eth 100% extract and HydroEth 70% exhibited bacteriostatic activity against the resistant Escherichia coli strain, as well as against *Klebsiella pneumoniae* and *Citrobacter koseri* strains. Additionally, the Eth 100% extract demonstrated bactericidal activity against the *Klebsiella pneumoniae* and *Citrobacter koseri* strains, whereas the HydroEth 70% extract exhibited bactericidal activity against the resistant *Escherichia coli* strain. The discrepancy in findings may be attributed to various factors, including the extraction methodology, the geographical origin of the plant material, soil quality, the time of plant harvesting, the duration of the extraction process, and other variables. Additionally, Okou *et al.*, (2018) demonstrated that an Eth 100% extract of *Solanum torvum* leaves exhibits bactericidal activity against *Klebsiella pneumoniae*, *Escherichia coli*, and *Salmonella sp* strains. This finding corroborates the notion that despite the organ utilized being disparate, the results align with those observed in this study. This would substantiate *Solanum torvum's* comprehensive antibacterial efficacy.

5. CONCLUSION

The present study demonstrated the antibacterial activity of two ethanolic extracts (ETh 100% and HydroEth 70%) derived from the fruits of *Solanum torvum* against a range of enterobacterial strains. The results demonstrated that the Eth 100% extract exhibited superior efficacy in the extraction of bioactive compounds. Furthermore, sensitivity tests on agar media demonstrated that both extracts exhibited antibacterial activity against the strains under investigation, with the exception of the *Shigella sp* strain, which demonstrated resistance to the Eth 100% extract. With regard to the GPC/MIC ratio, the various extracts demonstrated bactericidal activity against all strains tested. This bactericidal action is dose-dependent, as it is linked to increasing concentrations of the extract under study, with the exception of the *Shigella sp* strain and the Eth 100% extract. It may therefore be concluded that Solanum torvum fruit could be employed in the development of a phytomedicine for the treatment of enterobacterial infections.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

RÉFÉRENCES

Atsain, M. R. (2017). *Phytochemical, microbiological and antioxidant investigations of organ extracts of Schrankia leptocarpa D.C (Mimosaceae)*. Doctoral thesis in Chemistry of Natural Substances/Microbiology, Nangui Abrogoua University, Abidjan, Ivory Coast.

Bentabet, J. (2021). *Epidemiological profile of enterobacteria producing extended-spectrum β-lactamases at Ibn Tofail Hospital*. Doctoral thesis, Cadi Ayyad University, Marrakech.

Cowan, M. M. (1999). Plants products as antimicrobial agents. *Clinical Microbiology Reviews, 12*(4), 564-582.

Dinzedi, M. R. (2015). *Antibacterial activities of Terminalia catappa and Thonningia sanguinea extracts on multidrug-resistant Escherichia coli, Klebsiella pneumoniae and Staphylococcus aureus of human origin*. Doctoral thesis in Pharmacology of Natural Substances, Félix Houphouët-Boigny University, Abidjan, Ivory Coast.

Dromer, F., & Dupont, B. (1996). The increasing problem of fungal infections in immunocompromised hosts. *Journal of Mycology Medical, 6*(Suppl 1), 1-6.

Gadou, V. (2019). *Molecular epidemiology of enterobacteria producing extended-*

spectrum β-lactamases resistant to aminoglycosides and fluoroquinolones in the district of Abidjan, Ivory Coast. Doctoral thesis in Functional and Molecular Biology, Félix Houphouët-Boigny University, Abidjan, Ivory Coast.

Iabadene, H., Messai, Y., Alouache, S., Arlet, G., & Bakour, R. (2010). Mechanisms of resistance to β-lactams and quinolones of *Enterobacter* in hospitals in Algiers. *Tunisian Journal of Infectiology, 4*, 24.

Joly, B., & Reynaud, A. (2007). *Enterobacteriaceae: Systematics and diagnostic methods*. Edition Te.

Kouadio, K., Kouakou, M.-D. A., Adingra, M. K., Kouadio, M., Disseka, W. K., Gbotognon, O. J., & Kouadio, E. J. P. (2020). Proximate composition and phytochemical properties of fresh and boiled *Solanum torvum* consumed in East of Côte d'Ivoire. *Asian Food Science Journal, 18*(2), 31-40. https://doi.org/10.9734/afsj/2020/v18i230214

Maddi, S. N., & Menasra, L. (2022). Enterobacteriaceae infections and their antibiotic resistance at the EPH of El Khroub, Constantine. *Master of Microbiology and Hospital Hygiene*, University of the Mentouri Brothers Constantine, Algeria.

Maloth, G., Singh, R., Marka, R., & Nanna, R. S. (2021). Effect of plant growth regulators on somatic embryogenesis and plantlet development of turkey berry (*Solanum torvum* SW). *European Journal of Medicinal Plants, 32*(7), 1-8. https://doi.org/10.9734/ejmp/2021/v32i730400

Marmonier, A. A. (1990). Introduction to antibiotic study techniques. In *Medical Bacteriology, Usual Techniques* (pp. 227-236). Doin.

Masterton, R., Drusano, G., Paterson, D. L., & Park, G. (2003). Appropriate antimicrobial treatment in nosocomial infections—the clinical challenges. *Journal of Hospital Infection, 55*(Suppl 1), 1-12.

Morice, V. (2003). Chapter 7: Enterobacteria and other non-fastidious Gram-negative bacilli. Available from: http://www.chups.jussieu.fr/polys/bacterio/bacterio/POLY.Chp.7.html

Okou, O. C. (2012). *Efficacy and spectrum of activity of extracts of Mitracarpus scaber Zucc. ex Schult & Schult.f. (Rubiaceae) and fusidic acid on Gram-positive cocci bacteria*. Doctoral thesis in Biochemistry-Pharmacology, Félix Houphouët-Boigny University, Abidjan, Ivory Coast.

Okou, O. C., Yapo, S. E.-S., Kouassi, K. C., Komenan, N. R., Monthaut, S. V., Kra, A. K. M., & Djaman, A. J. (2019). Evaluation of the antibacterial activity of *Solanum torvum* Swartz (Solanaceae) fruit extracts on the in vitro growth of seven strains of enterobacteria of different profiles (resistant or sensitive). *International Journal of Biological and Chemical Science, 13*(3), 1510-1526.

Okou, O. C., Yapo, S. E.-S., Kporou, K. E., Baibo, G. L., Monthaut, S., & Djaman, A. J. (2018). Evaluation of the antibacterial activity of *Solanum torvum* Swartz (Solanaceae) leaf extracts on the in vitro growth of three strains of enterobacteria. *Journal of Applied Biosciences, 122*, 12287-12295.

Patterson, J. E. (2001). Antibiotic utilization: Is there an effect on antimicrobial resistance? *Chest, 119*(2 Suppl), 426S-430S.

Prével, R. (2021). *Mechanisms of dissemination of Enterobacteriaceae producing extended-spectrum beta-lactamase in intensive care medicine*. Doctoral thesis in Microbiology-Immunology, University of Bordeaux, Bordeaux, France.

Sirot, J. (1990). Evaluation of the antibacterial activity of antibiotics in vitro. In *Medical Bacteriology* (2nd ed., pp. 297-315). Flammarion.

Verhaegen, J. (2002). Bacteriology course: Enterobacteriaceae. Available on www.kuleuven.be/vesaliusonline/UNIKEN%20KONGO.doc.

Zirihi, G. N., Grenier, P., Guédé-Guina, F., Bodo, B., & Mambu, L. (2005). Isolation, characterization, and antiplasmodial activity of steroidal alkaloids from *Funtumia elastica* (Preuss) Stapf. *Bioorganic and Medicinal Chemistry Letters, 15*, 2637-2640.

Zirihi, G. N., Kra, A. K. M., & Guédé-Guina, F. (2003). Evaluation of the antifungal activity of *Microglossa pyrifolia* (Lamarck) O. Kuntze (Asteraceae) "pymi" on the in vitro growth of *Candida albicans*. *Journal of African Medicines and Pharmacopoeias, 17*, 11-18.

Zrardi, M. E. (2020). *Enterobacteria: Epidemiology and antibiotic resistance*. Master of Molecular Biology of Microorganisms, University of the Mentouri Brothers Constantine, Algeria.

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of the publisher and/or the editor(s). This publisher and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.

© Copyright (2024): Author(s). The licensee is the journal publisher. This is an Open Access article distributed under the terms of the Creative Commons Attribution License (http://creativecommons.org/licenses/by/4.0), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Peer-review history:
The peer review history for this paper can be accessed here:
https://www.sdiarticle5.com/review-history/127704