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# Antimicrobial effect of Vitamin C on different strains of E. coli

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**ABSTRACT**

In recent years, there has been a growing interest in exploring the potential antimicrobial effects of Vitamin C, known for its antioxidant properties. However, an extensive investigation into the impact of Vitamin C on different strains of Escherichia coli (E. coli) has been lacking. In this study, four distinct strains, including Enterotoxigenic, Enteroinvasive, Enteropathogenic, and Enteroaggregative E. coli were treated with three concentrations of Vitamin C (5, 10, and 20 mg/ml) to assess its antimicrobial properties. Following treatment, absorbance measurements were taken to evaluate the proliferation and viability of the E. coli strains. The results revealed a dose-dependent inhibitory effect across all E. coli strains. A dose-dependent inhibitory effect was exhibited by all E. coli strains with absorbance significantly decreasing from 0.310±0.082 (positive control with 0mg/ml Vitamin C) to a range of 0.102±0.017 to 0.107±0.015 ($p<0.001$) when treated with 20 mg/ml of Vitamin C. Despite the slight changes in absorbance, Vitamin C at a concentration of 5 mg/ml showed the most significant inhibitory effect from 0.310±0.082 to a range of 0.125±0.025 to 0.140±0.012 ($p<0.001$), indicating the potential of Vitamin C to inhibit the growth of different E. coli strains even at smaller concentrations. However, our results suggest the importance of strain-specific responses when assessing the antimicrobial efficacy of vitamin C. In conclusion, this study provides positive indications of the ability of Vitamin C to disrupt and reduce E. coli proliferation and viability. Nevertheless, further investigations are required to determine the optimal concentration in human-relevant setup and comprehensively elucidate the underlying mechanism of action.

## Introduction

Vitamin C is a nutrient known for its immune-boosting and cold-fighting properties and has been the subject of recent research exploring its potential as an antimicrobial agent.[1] *Escherichia coli* (*E. coli*) is a bacterial species that colonises the intestinal tracts of both humans and animals.[2] Although several strains of *E. coli* reside in the intestines, certain types can result in severe gastrointestinal infections, urinary tract infections, and potentially fatal ailments.[3] The emergence of antibiotic-resistant strains of *E. coli* has intensified the necessity for alternative strategies to address these infections,[4] prompting a surge of interest in investigating the potential of Vitamin C as an antimicrobial agent.[5]

Ascorbic acid, commonly referred to as Vitamin C, is a potent antioxidant essential for the proper functioning of the immune system.[6] Recent research has revealed the capacity of Vitamin

C to demonstrate antimicrobial characteristics, specifically against *E. coli*.[7] Thus, this raised interest and elicited optimism for the vitamin's prospective remedial implementations.[8] Vitamin C was found to impede the proliferation of different strains of *E. coli*.[9] According to a study by Hassuna et al.,[10] the viability of E. coli was reduced when exposed to high concentrations of Vitamin C, indicating its high potential as an antimicrobial agent. Additionally, Vitamin C can disturb the membrane integrity of bacteria[11] and obstruct their metabolic processes[12], ultimately blocking their proliferation and viability.[13] The efficacy of antibiotics against antibiotic-resistant *E. coli* strains can be potentially enhanced by Vitamin C.[14] The observed synergistic effect can potentially address the escalating issue of antibiotic resistance, offering a novel approach to conquer these tenacious bacteria.[15]

Although the potential antimicrobial impact of Vitamin C on *E. coli* is encouraging, additional investigations are required to comprehensively understand its mechanisms of action, optimal dosages, and possible adverse reactions. This study aims to explore the antimicrobial properties of Vitamin C on four strains of *E. coli*, presenting a promising avenue for further investigation and potential implications for human health.

## 1. Methods

### 2.1 Used *E. coli* strains

1. *Enterotoxigenic E. coli* (ETEC) adheres to the intestinal lining through hair-like projections known as fimbriae and generates harmful substances. ETEC is known to induce diarrhoea, frequently observed in neonates, and is a common aetiology of travellers' diarrhoea.[16]
2. *Enteroinvasive E. coli* (EIEC) infiltrates and eradicates the epithelial cells of the colon, resulting in diarrhoea that resembles dysentery. Pyrexia is an additional prevalent symptom.[17]
3. *Enteropathogenic E. coli* (EPEC) adheres to intestinal cells through intimin, a specific attachment protein. The symptomatology of EPEC infection is characterised by watery stool, which may occasionally exhibit hematochezia. EPEC is known to affect infants in low-economic nations.[18]
4. *Enteroaggregative E. coli* (EAEC) exhibits a unique pattern of adherence to the intestinal epithelium, forming aggregates, and is capable of synthesising enteroaggregative toxin. The EAEC strain is a common cause of persistent diarrhoea in paediatric patients.[19]

### 2.2 *E. coli* strains culture and treatment

Incubation of freshly prepared *E. coli* broths suspended in peptone water was carried out for a duration of 2 hours. L-Ascorbic Acid was introduced into three separate batches of Trypticase Soy Broth (TSB; Himedia, India) to achieve final concentrations of 5, 10, and 20 mg/ml, following a previously published protocol by Isela et al (Reference?). The experimental procedure involved the inoculation of 250 µL of the bacterial broth (*E. coli*) into test tubes containing 1000 µL of the prepared solution. Subsequently, tubes were incubated overnight at 37°C under aerobic conditions. The experimental setup involved three treatment groups, which included bacterial broths in TSB without Vitamin C (positive control), uninoculated TSB devoid of Vitamin C (negative control),

and uninoculated TSB enriched Vitamin C. Absorbance measurements of the inoculated broths and controls were conducted using a microplate reader (BIO-RAD Model 680) at a wavelength of 450 nm via spectrophotometric analysis.

### 2.3 Statistical analysis

Independent samples t-test using SPSS software (SPSS 20.0) was used to perform the statistical analysis. A P value < 0.005 was considered as statistically significant.

## 2. Results

The mean absorbance of the *Enterotoxigenic E. coli* samples varied with different concentrations of vitamin C. Absorbance decreased from 0.140±0.012 to 0.107±0.015 ($p<0.001$) with increasing Vitamin C concentration compared to the high absorbance (0.310±0.082) in positive controls (Table 1 and Figure 1).

**Table 1. Comparison of the absorbance values of *Enterotoxigenic E. coli* post-treatment with Vitamin C.**

| Treatment group | Mean±SEM | *P* value |
|---|---|---|
| Vitamin C control | 0.089±0.010 | NA |
| Negative control | 0.0899±0.013 | NA |
| Positive control (0mg/ml) | 0.310±0.082 | References |
| Vitamin C (5 mg/ml) | 0.140±0.012 | <0.001* |
| Vitamin C (10 mg/ml) | 0.111±0.013 | <0.001* |
| Vitamin C (20 mg/ml) | 0.107±0.015 | <0.001* |

Results are expressed as Mean ± SEM (n=3). *Values at p <0.05 are significantly different.

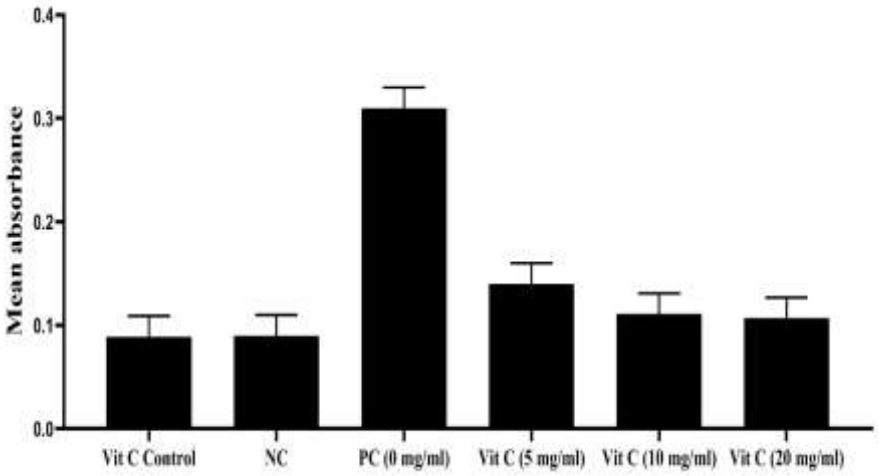


**Figure 1. Comparison of the absorbance values of *Enterotoxigenic E. coli* post-treatment with Vitamin C.**

A similar correlation was observed between the concentration of Vitamin C and the mean absorbance values of *Enteroinvasive E. coli*. Statistical analysis revealed a significant decrease in absorbance from 0.130±0.02 to 0.104±0.01 ($p<0.001$) with increasing Vitamin C concentration in comparison to the positive controls (Table 2 and Figure 2).

**Table 2. Comparison of the absorbance values of *Enteroinvasive E. coli* post-treatment with Vitamin C.**

| Treatment group | Mean±SEM | *P* value |
|---|---|---|
| Vitamin C control | 0.089±0.010 | NA |
| Negative control | 0.0899±0.013 | NA |
| Positive control (0mg/ml) | 0.310±0.082 | References |
| Vitamin C (5 mg/ml) | 0.130±0.02 | <0.001* |
| Vitamin C (10 mg/ml) | 0.107±0.01 | <0.001* |
| Vitamin C (20 mg/ml) | 0.104±0.01 | <0.001* |

Results are expressed as Mean ± SEM (n=3). *Values at p <0.05 are significantly different.

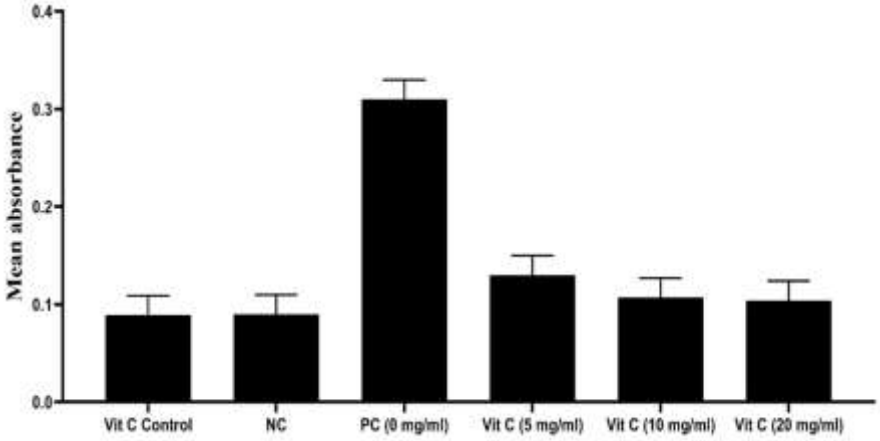


**Figure 2. Comparison of the absorbance values of *Enteroinvasive E. coli* post-treatment with Vitamin C.**

The results indicate a negative correlation between the concentration of Vitamin C and the mean absorbance values for *Enteropathogenic E. coli*. Statistical analysis revealed a significant decrease in absorbance from 0.125±0.025 to 0.106±0.018 (p<0.001) with increasing Vitamin C concentration in comparison to the positive controls (Table 3 and Figure 3).

**Table 3. Comparison of the absorbance values of *Enteropathogenic E. coli* post-treatment with Vitamin C.**

| Treatment group | Mean±SEM | P value |
|---|---|---|
| Vitamin C control | 0.089±0.010 | NA |
| Negative control | 0.0899±0.013 | NA |
| Positive control (0mg/ml) | 0.310±0.082 | References |
| Vitamin C (5 mg/ml) | 0.125±0.025 | <0.001* |
| Vitamin C (10 mg/ml) | 0.109±0.013 | <0.001* |
| Vitamin C (20 mg/ml) | 0.106±0.018 | <0.001* |

Results are expressed as Mean ± SEM (n=3). *Values at p <0.05 are significantly different.

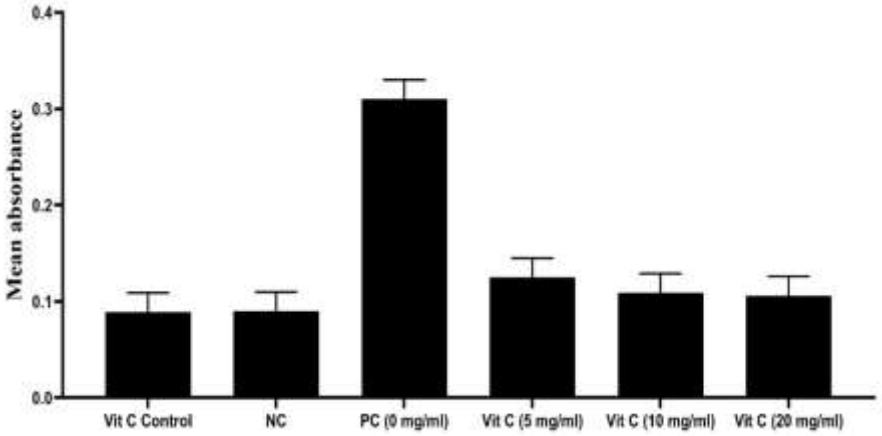


**Figure 3. Comparison of the absorbance values of *Enteropathogenic E. coli* post-treatment with Vitamin C.**

The results indicate a negative correlation between the concentration of Vitamin C and the mean absorbance values for *Enteroaggregative E. coli*. Statistical analysis revealed a significant decrease in absorbance from 0.127±0.024 to 0.102±0.017 ($p<0.001$) with increasing Vitamin C concentration in comparison to the positive controls (Table 4 and Figure 4).

**Table 4. Comparison of the absorbance values of *Enteroaggregative E. coli* post-treatment with Vitamin C.**

| Treatment group | Mean±SEM | P value |
|---|---|---|
| Vitamin C control | 0.089±0.010 | NA |
| Negative control | 0.0899±0.013 | NA |
| Positive control (0mg/ml) | 0.310±0.082 | References |
| Vitamin C (5 mg/ml) | 0.127±0.024 | <0.001* |
| Vitamin C (10 mg/ml) | 0.104±0.013 | <0.001* |
| Vitamin C (20 mg/ml) | 0.102±0.017 | <0.001* |

Results are expressed as Mean ± SEM (n=3). *Values at $p < 0.05$ are significantly different.

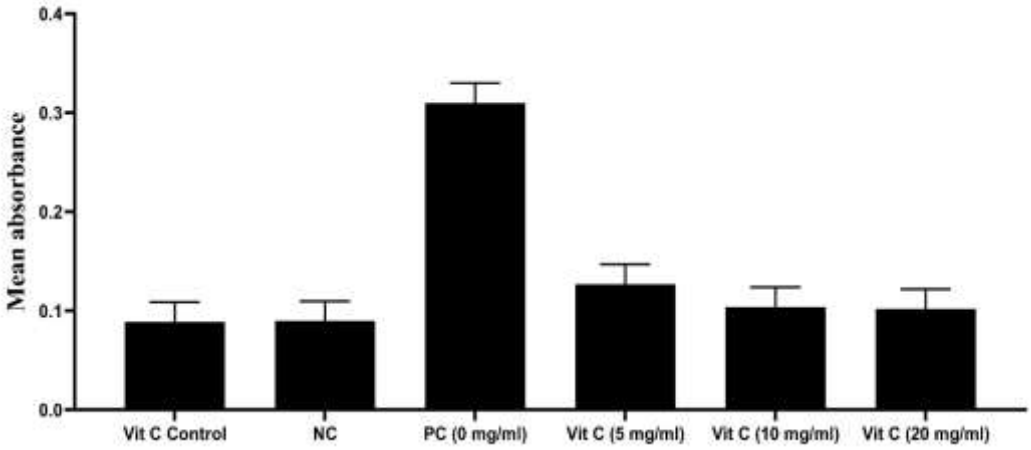


**Figure 4. Comparison of the absorbance values of *Enteroaggregative E. coli* treated with Vitamin C.**

A comparative analysis was conducted to evaluate the variation in the absorbance of Vitamin C at concentrations of 5, 10, and 20 mg/ml with the corresponding measurements of Vitamin C at 0, 5, and 10 mg/ml concentrations. Although the concentration of 20 mg/ml of Vitamin C exhibited the greatest inhibition of *E. coli*, no statistically significant difference was observed in the absorbance values of *E. coli* for Vitamin C concentrations at 10 and 20 mg/ml (P = 0.315). Hence, the results showed that the inhibitory effect of Vitamin C does not extend beyond the concentration of 10 mg/ml but statistically significant differences in absorbance levels (P <0.001) of *E. coli* were observed between the ranges of 0 to 5 mg/ml and 5 to 10 mg/ml of Vitamin C treatments (Table 5 and Figure 5).

**Table 5. The relative absorbance difference among *E. Coli* strains with increasing Vitamin C concentrations.**

| ***Enterotoxigenic E. coli*** | | |
|---|---|---|
| **Vitamin C (mg/ml)** | **Mean±SEM** | **P value** |
| **Positive control 0** | 0.310±0.082 | NA |
| **5** | 0.140±0.012 | NA |
| **5** | 0.140±0.012 | References |
| **10** | 0.111±0.026 | <0.001* |
| **10** | 0.111±0.014 | <0.001* |
| **20** | 0.107±0.019 | <0.001* |
| ***Enteroinvasive E. coli*** | | |
| **Vitamin C (mg/ml)** | **Mean±SEM** | **P value** |
| **Positive control 0** | 0.310±0.082 | NA |
| **5** | 0.130±0.02 | NA |
| **5** | 0.130±0.02 | References |
| **10** | 0.107±0.01 | <0.001* |
| **10** | 0.107±0.01 | <0.001* |
| **20** | 0.104±0.01 | <0.001* |
| ***Enteropathogenic E. coli*** | | |

| Vitamin C (mg/ml) | Mean±SEM | P value |
|---|---|---|
| **Positive control 0** | 0.310±0.082 | NA |
| **5** | 0.125±0.025 | NA |
| **5** | 0.125±0.025 | References |
| **10** | 0.109±0.013 | <0.001* |
| **10** | 0.109±0.013 | <0.001* |
| **20** | 0.106±0.018 | <0.001* |
| ***Enteroaggregative E. coli*** | | |
| **Vitamin C (mg/ml)** | **Mean±SEM** | **P value** |
| **Positive control 0** | 0.310±0.082 | NA |
| **5** | 0.127±0.024 | NA |
| **5** | 0.127±0.024 | References |
| **10** | 0.104±0.013 | <0.001* |
| **10** | 0.104±0.013 | <0.001* |
| **20** | 0.102±0.017 | <0.001* |

Results are expressed as Mean ± SEM (n=3). *Values at p <0.05 are significantly different.

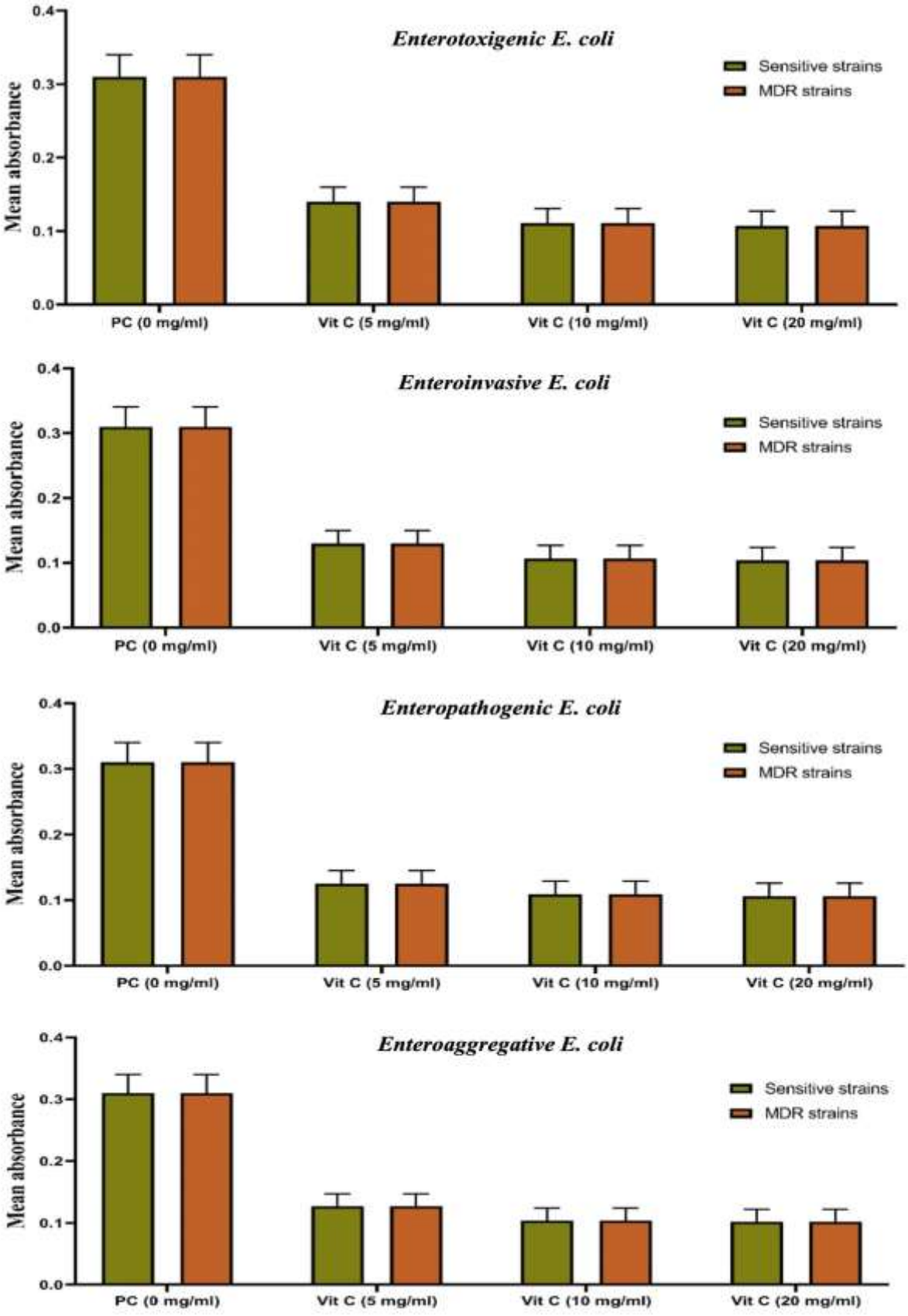


**Figure 5. The relative difference in absorbance of the strains of *E. coli* with increasing Vitamin C concentrations.**

## 3. Discussion

The prevalence of enteric infections resulting from diverse pathogenic strains of *Escherichia coli* (*E. coli*), including *Enterotoxigenic*, *Enteroinvasive*, *Enteropathogenic*, and *Enteroaggregative E. coli*, presents a substantial worldwide health concern.[20] Researchers have been investigating prospective interventions to address these infections, such as the utilisation of Vitamin C.[21] There exist discrete strains of *E. coli* responsible for different types of gastrointestinal ailments. The production of toxins by ETEC results in diarrhea,[22] whereas EIEC can invade and inflict damage upon the intestinal cells. EPEC and EAEC are two types of E. coli that exhibit distinct modes of interaction with the intestinal cells.[23] EPEC is known to attach to the intestinal cells and create "attaching and effacing" lesions, while EAEC is known to form biofilms within the intestinal tract. Each strain possesses a distinct pathogenic mechanism.[24]

Vitamin C (Ascorbic acid) is a crucial dietary component recognised for its antioxidative characteristics and contribution to the immune system's functionality.[25, 26] Vitamin C has been found to exhibit antimicrobial properties, which include the ability to obstruct the proliferation and virulence of *E. coli* strains.[27, 28] The potential of vitamin C is rooted in its ability to disrupt bacterial cell membranes,[29] impede bacterial adhesion,[30] and impede toxin production,[31] thereby leading to a reduction in the pathogenicity of *E. coli*.

The complete understanding of the precise mechanism through which Vitamin C obstructs the growth of *E. coli* strains is yet to be explored. Nevertheless, scholarly investigations propose various potential avenues, such as the ability of Vitamin C to compromise the structural stability of the bacterial cell membrane.[31] The administration of Vitamin C was found to elicit oxidative stress in bacterial cells, impairing various structural constituents of the cell, such as the cell membrane and other intracellular structures.[32] The liberation of intracellular components may lead to deleterious consequences on the functional and survival aspects of the bacterial cells. Disruption of crucial cellular processes may impede the ability of the bacterium to uphold its typical physiological functions. The compromised structural stability and loss of cellular integrity can inhibit the growth of *E. coli*.[33]

The concentration of Vitamin C that is most effective against *E. coli* strains may exhibit variability changes with the type of strain and the intended use.[34] Several studies have been conducted to evaluate the efficacy of different concentrations. Studies have demonstrated that concentrations within the 1-10 mM range can impede the growth and virulence of E. coli. Notably, concentrations exceeding 20 mM may elicit cytotoxicity in host healthy cells, whereas concentrations below this threshold may not yield substantial inhibitory effects.[35]

Our results may not be generalisable to the entire population of *E. coli* strains owing to the restricted sample size, which included only four types of *E. coli* strains. The diminutive size of the sample may limit the applicability of the findings. The limited genetic representation of the four *E. coli* strains selected for the study may result in inadequate diversity within the species. Thus, the generalizability of the results to other strains of *E. coli* may be constrained by this factor. To ensure a precise evaluation of the impact of Vitamin C, it is crucial to incorporate suitable control cohorts. Discerning whether the observed effects are exclusively attributable to Vitamin C or other variables becomes difficult without appropriate controls.

The absorbance intensity of *E. coli* strains was utilised as a quantitative metric to assess the impact of vitamin C. Using objective and precise measurements can potentially improve the reliability and reproducibility of the study. In addition, the measurement of absorption intensity

exhibits a high degree of sensitivity, enabling the detection of even minor variations in the samples. The heightened sensitivity exhibited by *E. coli* strains enables the detection of minute variations in their response to varying concentrations of Vitamin C. Interestingly, our results showed that Vitamin C could significantly impact ($p<0.001$) the viability of the four *E. coli* strains, indicating its potential use as an antimicrobial agent.

## 4. Conclusion

Vitamin C exhibits potential as a prophylactic and therapeutic strategy against infections caused by various *Escherichia coli* strains. The inhibitory effects of Vitamin C on the growth and virulence of E. coli are attributed to its ability to disrupt bacterial cell membranes, interfere with adhesion, and inhibit toxin production. Additional investigation is required to determine the optimal concentration and comprehensively elucidate the underlying mechanisms. However, the potential of Vitamin C as a supplementary intervention in managing *E. coli* infections is worth further exploration.

**References:**

1. Axe J. Ancient Remedies for Modern Life: from the bestselling author of Keto Diet. Hachette UK; 2021 Feb 4.
2. Lawal OU, Parreira VR, Goodridge L. The biology and the evolutionary dynamics of diarrheagenic Escherichia coli pathotypes. InEscherichia coli 2022 Feb 3. IntechOpen.
3. Mann R, Mediati DG, Duggin IG, Harry EJ, Bottomley AL. Metabolic adaptations of uropathogenic E. coli in the urinary tract. Frontiers in cellular and infection microbiology. 2017 Jun 8;7:241.
4. Wood SJ, Kuzel TM, Shafikhani SH. Pseudomonas aeruginosa: Infections, Animal Modeling, and Therapeutics. Cells. 2023 Jan 3;12(1):199.
5. Ghosh T, Srivastava SK, Gaurav A, Kumar A, Kumar P, Yadav AS, Pathania R, Navani NK. A combination of linalool, vitamin C, and copper synergistically triggers reactive oxygen species and DNA damage and inhibits Salmonella enterica subsp. enterica Serovar Typhi and Vibrio fluvialis. Applied and Environmental Microbiology. 2019 Feb 15;85(4):e02487-18.
6. Firouzi S, Pahlavani N, Navashenaq JG, Clayton ZS, Beigmohammadi MT, Malekahmadi M. The effect of Vitamin C and Zn supplementation on the immune system and clinical outcomes in COVID-19 patients. Clinical nutrition open science. 2022 Jun 25.
7. Abdussalam-Mohammed W, Abraheem MS, Mezoughi AB, Ettarhouni ZO, Dakhil OO. Novel Compatible Silver Nanoparticles Functionalised by Vitamin C and its Derivatives: Characterisation and their antibacterial Activity against Escherichia coli and Staphylococcus aureus.
8. Corbo MR, Bevilacqua A, Petruzzi L, Casanova FP, Sinigaglia M. Functional beverages: the emerging side of functional foods: commercial trends, research, and health implications. Comprehensive reviews in food science and food safety. 2014 Nov;13(6):1192-206.

9. Max BL, Angolile CM, Raymond VG, Mashauri HL. The dawn of repurposing vitamins as potential novel antimicrobial agents: A call for global emergency response amidst AMR crisis. Health Science Reports. 2023 May;6(5):e1276.
10. Hassuna NA, Rabie EM, Mahd WK, Refaie MM, Yousef RK, Abdelraheem WM. Antibacterial effect of vitamin C against uropathogenic E. coli in vitro and in vivo. BMC microbiology. 2023 Dec;23(1):1-2.
11. Addorisio SR, Shteynberg R, Dasilva M, Mixon J, Mucciarone K, Vu L, Arsenault K, Briand V, Parker S, Smith S, Vise C. Oxidative Stress Response in Bacteria: A Review. Fine Focus. 2022 Jul 18;8(1):36-46.
12. Poli V, Madduru R, Aparna Y, Kandukuri V, Motireddy SR. Amelioration of cadmium-induced oxidative damage in wistar rats by Vitamin C, zinc and N-acetylcysteine. Medical Sciences. 2022 Jan 26;10(1):7.
13. Atila D, Karataş A, Keskin D, Tezcaner A. Pullulan hydrogel-immobilised bacterial cellulose membranes with dual-release of vitamin C and E for wound dressing applications. International Journal of Biological Macromolecules. 2022 Oct 1;218:760-74.
14. Doughari JH, Human IS, Benadé AJ, Ndakidemi PA. Phytochemicals as chemotherapeutic agents and antioxidants: Possible solution to the control of antibiotic resistant verocytotoxin producing bacteria.
15. Hamed S, Emara M. Antibacterial and Antivirulence Activities of Acetate, Zinc Oxide Nanoparticles, and Vitamin C Against E. coli O157: H7 and P. aeruginosa. Current Microbiology. 2023 Feb;80(2):57.
16. Chrienová Ž. Carbohydrate recognition of the novel colonisation factor CS30 of enterotoxigenic E. coli.
17. Panarelli NC. Infectious Diseases of the Gastrointestinal Tract. Gastrointestinal and Liver Pathology. 2024 Jan 1:243-98.
18. Escherichia coli, Diarrheagenic. CDC Yellow Book 2024. Available at: https:wwwnc.cdc.gov/travel/yellowbook/2024/infections-diseases/escherichia-coli-diarrheagenic. Accessed on 1st June 2024.
19. Govindarajan DK, Viswalingam N, Meganathan Y, Kandaswamy K. Adherence patterns of Escherichia coli in the intestine and its role in pathogenesis. Medicine in Microecology. 2020 Sep 1;5:100025.
20. Huang TD, Bauraing C, Bogaerts P, Berhin C, Glupczynski Y. Diagnostics of antibiotic resistance.
21. González de Llano D, Moreno-Arribas MV, Bartolomé B. Cranberry polyphenols and prevention against urinary tract infections: relevant considerations. Molecules. 2020 Aug 1;25(15):3523.
22. Dubreuil JD, Isaacson RE, Schifferli DM. Animal enterotoxigenic Escherichia coli. EcoSal Plus. 2016 Sep 8;7(1).
23. Aminian F, Moshirsadri A, Bahrami S, Bahrami S. E. coli bacteria causing diarrhea, threatening travelers in the world, a narrative review. International Journal of Travel Medicine and Global Health. 2023 Mar 1;11(1).
24. Rodriguez-Valverde D, Giron JA, Hu Y, Nataro JP, Ruiz-Perez F, Santiago AE. Highly-conserved regulatory activity of the ANR family in the virulence of diarrheagenic

bacteria through interaction with master and global regulators. Scientific Reports. 2023 Apr 29;13(1):7024.
25. Jafari D, Esmaeilzadeh A, Mohammadi-Kordkhayli M, Rezaei N. Vitamin C and the immune system. Nutrition and immunity. 2019:81-102.
26. Yin X, Chen K, Cheng H, Chen X, Feng S, Song Y, Liang L. Chemical stability of ascorbic acid integrated into commercial products: A review on bioactivity and delivery technology. Antioxidants. 2022 Jan 13;11(1):153.
27. Zhou F, Wang D, Hu J, Zhang Y, Tan BK, Lin S. Control Measurements of Escherichia coli Biofilm: A Review. Foods. 2022 Aug 16;11(16):2469.
28. Max BL, Angolile CM, Raymond VG, Mashauri HL. The dawn of repurposing vitamins as potential novel antimicrobial agents: A call for global emergency response amidst AMR crisis. Health Science Reports. 2023 May;6(5):e1276.
29. Akpoka AO, Erifeta G, Akinyeye AJ, Solanke EO, Izevbuwa OE. Comparative Antimicrobial Effects of Ethanolic and Aqueous Extracts of the Stem and Root of Moringa oleifera on some Clinical Isolates (Klebsiella pneumoniae, Pseudomonas aeruginosa, Escherichia coli and Candida. Int J Healthc Sci. 2019;7(1):141-7.
30. Mumtaz S, Ali S, Tahir HM, Kazmi SA, Mughal TA, Younas M. Evaluation of antibacterial activity of vitamin C against human bacterial pathogens. Brazilian Journal of Biology. 2021 Aug 27;83.
31. Mousavi S, Bereswill S, Heimesaat MM. Immunomodulatory and antimicrobial effects of vitamin C. European Journal of Microbiology and Immunology. 2019 Sep;9(3):73-9.
32. Shivaprasad DP, Taneja NK, Lakra A, Sachdev D. In vitro and in situ abrogation of biofilm formation in E. coli by vitamin C through ROS generation, disruption of quorum sensing and exopolysaccharide production. Food Chemistry. 2021 Mar 30;341:128171.
33. McMillan HM, Kuehn MJ. The extracellular vesicle generation paradox: a bacterial point of view. The EMBO Journal. 2021 Nov 2;40(21):e108174.
34. Đukić I, Kaličanin N, Senćanski M, Pajović SB, Milićević J, Prljić J, Paessler S, Prodanović R, Glišić S. Inhibition of SARS-CoV-2 Mpro with Vitamin C, L-Arginine and a Vitamin C/L-Arginine Combination. Frontiers in Bioscience Landmark. 2023;28(1):8.