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Comparative Analysis of Antioxidant Capacities and Antimicrobial Activities in Selected Berry Fruits

Shruti A. Satashia[1*] and Nileshkumar Pandya[2]

[1]Department of Microbiology, Atmanand Saraswati Science College, Surat, Gujarat, India
[2]Department of Microbiology, Arts, Science & Commerce College, Kholwad, Surat, India

**Corresponding author*

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A B S T R A C T

Foodborne illnesses and oxidative stress represent major global health challenges, prompting interest in natural alternatives to synthetic chemicals. This study evaluates and compares the antioxidant capacities and antimicrobial activities of various berry fruits, including blueberries, gooseberries, raspberries, blackberries, mulberries, Indian blackberries, and star gooseberries. The antioxidant activity was assessed using the DPPH radical scavenging assay, with extracts prepared at concentrations ranging from 100 to 500 µg/mL. Antimicrobial activity was tested against *Bacillus cereus*, *Staphylococcus aureus*, *Salmonella typhimurium*, pathogenic and normal flora *Escherichia coli*, and *Lactobacillus spp*. using the agar well diffusion method. Extracts from both fresh and dried berries were compared with positive controls (streptomycin and azithromycin) and negative controls (sterile distilled water and 20% DMSO). Fresh berry extracts displayed varying antioxidant activities, with blueberries showing the highest activity (75.78 µg/mL). Dried berry extracts generally exhibited enhanced antimicrobial effects, with dried raspberries and blackberries showing the most substantial inhibition zones. Notably, gooseberries demonstrated significant antimicrobial activity, particularly against *Salmonella typhimurium* (21 mm inhibition zone). These findings highlight the potent antioxidant and antimicrobial properties of both fresh and dried berry extracts, suggesting their potential as natural alternatives for food safety and therapeutic applications. Further research is needed to isolate specific bioactive compounds and explore their efficacy in diverse applications.

Introduction

In developing countries, food poisoning is a major contributor to both illness and mortality (Doughari *et al.,* 2007; Pirbalouti *et al.,* 2009). Research by Solomakos *et al.,* (2008) and Pandey & Singh (2011) indicates that a significant number of food poisoning incidents are caused by bacterial contamination, particularly by Gram-negative bacteria such as *Salmonella typhi*, *Escherichia coli*, and *Pseudomonas aeruginosa*. Additionally, Gram-positive bacteria like *Staphylococcus aureus* and *Bacillus cereus* are also known to cause foodborne illnesses and

spoilage. Historically, chemical preservatives have been used to inhibit food spoilage and control the bacteria responsible for these conditions (Shan *et al.,* 2007).

However, although chemical preservatives have been successful in managing and preventing foodborne illnesses, their extensive use has resulted in the accumulation of chemical residues in the food chain, the development of microbial resistance, and various health risks (Bialonska *et al.,* 2010). This has led to a growing interest in developing safer, natural, and effective alternatives for food preservation. In this regard, plant extracts are being explored as potential natural antibacterial agents for food preservation (Nasar-Abbas & Halkman, 2004). These extracts are considered to be natural sources of antibacterial compounds, are biodegradable, and are safe for consumption (Duffy & Power, 2001).

In recent years, the search for natural alternatives to synthetic materials has intensified (Saleh & Otaibi, 2013). It is estimated that about 20% of the world's plant species have undergone some form of pharmacological or biological evaluation, and a substantial number of newly developed antibiotics have been derived from natural or semi-synthetic sources (Al-Daihan *et al.,* 2012). Many studies have demonstrated the antibacterial properties of plant extracts against microorganisms that cause food poisoning (Verma *et al.,* 2012). For example, Gupta *et al.,* (2010) assessed the antibacterial effects of five ethanolic and aqueous plant extracts against *S. aureus*, *Pseudomonas aeruginosa*, and *Bacillus subtilis*. Their research found that the ethanolic extracts of four plants—*Achyranthes aspera*, *Cynodon dactylon*, *Lantana camara*, and *Tagetes patula*—were effective against all tested microorganisms, with minimum inhibitory concentrations (MICs) ranging from 25 to 125 mg/ml.

In molecular biology, oxidative stress is often linked to an excess of free radicals, which can drive harmful oxidative reactions within organisms. Plant compounds with antioxidant properties—such as flavonoids, anthocyanins, phenolics, unsaturated fatty acids, vitamins, enzymes, and cofactors—are of increasing interest for their potential in both preventive and therapeutic applications in phytotherapy.

Over the past thirty years, the role of oxidative stress in diseases such as diabetes, hypertension, preeclampsia, atherosclerosis, acute renal failure, Alzheimer's disease, and Parkinson's disease has become a significant focus in medical research (Rodrigo, 2009). Antioxidants are vital in biological systems as they neutralize free radicals, thus mitigating their harmful effects. They help maintain the balance between oxidants and antioxidants, reducing the levels of harmful prooxidant species and protecting the body from damage. According to Leopoldini *et al.,* (2011), antioxidants act through three primary mechanisms: (1) transferring hydrogen atoms (which disrupts the free radical's structure); (2) donating a single electron (which neutralizes the radical); and (3) chelating transition metals (forming stable metal-antioxidant complexes).

Fruits and vegetables are rich in antioxidants, especially polyphenols, which have been shown to slow tumor growth and mitigate the progression of neurological and cardiovascular diseases, among other health benefits (Scalbert *et al.,* 2005; Visioli & Davalos, 2011). Polyphenols also have the ability to influence the activity of various enzymes and cellular receptors (Leary *et al.,* 2004; Sadik *et al.,* 2003). Berry fruits, often celebrated for their high bioactive and non-nutritive content, include red raspberries (*Rubus idaeus*), blueberries (*Vaccinium corymbosum*), blackberries (*Rubus spp.*), and strawberries (*Fragaria spp.*). These berries are recognized for their significant polyphenol content (Pascual-Teresa *et al.,* 2010). Despite extensive research on the nutritional benefits of these fruits, there is a lack of comprehensive studies that combine nutritional assessments with evaluations of antibacterial activity.

This study aims to address this gap by systematically evaluating and comparing the antioxidant capacities and antimicrobial properties of various berry fruits, including blackberries (*Rubus spp.*), raspberries (*Rubus idaeus*), blueberries (*Vaccinium corymbosum*), mulberries (*Morus spp.*), Indian blackberries (*Syzygium cumini*), gooseberries (*Ribes uva-crispa*), and star gooseberries (*Phyllanthus acidus*).

Materials and Methods

Chemicals and Reagents

All the chemicals and reagents utilized for the extraction and analysis of bioactive compounds were of analytical grade. Ethanol (at concentrations of 85% and 80%) was purchased from Finar Chemicals in Ahmedabad, India. The 2,2'-Diphenyl-1-picrylhydrazyl (DPPH) and methanol, used in the antioxidant activity assays, were sourced from Research Lab Fine Chem, Mumbai, India.

Other materials, including agar agar, dimethyl sulfoxide (DMSO at 20%), Mueller-Hinton broth (MHB), and antibiotics like streptomycin (50 µg/100 mL) and azithromycin (50 µg/100 mL), were supplied by HiMedia Laboratories Pvt. Ltd., Mumbai, India.

Sample Preparation

Blueberries, raspberries, mulberries, and blackberries were sourced from local markets in Surat, Gujarat, India. Additionally, mulberries, Indian blackberries, star gooseberries, and gooseberries were obtained directly from local farms. The taxonomic identification of all collected species was verified by the Department of Biosciences at Veer Narmad South Gujarat University. The berries were thoroughly rinsed under running tap water and sorted based on their ripeness. After weighing, the fruits were stored at -20°C until they were ready for extraction. Voucher specimens were deposited in the herbarium of the Department of Biosciences at Veer Narmad South Gujarat University.

Extraction of Bioactive Compounds

Extraction from Dried Berries

To prepare dried extracts, the berries were first washed to remove any surface contaminants, sun-dried, and then ground into a fine paste. Twenty grams of this paste were mixed with 200 mL of 85% ethanol (comprising 170 mL of pure ethanol and 30 mL of distilled water) and incubated at 37°C for 24 hours with continuous agitation. The ethanol extract obtained was filtered using Whatman No. 1 filter paper and then concentrated using a rotary evaporator to yield the dried extract. This crude ethanol extract was then used for further analysis (Sadasivam & Manickam, 2008).

Extraction from Fresh Berries

For fresh berries, one gram of the sample was ground using a mortar and pestle in the presence of ten times its volume of 80% ethanol. The resulting homogenate was centrifuged at 10,000 rpm for 20 minutes. The residue was subjected to a second extraction using five times its volume of 80% ethanol. The supernatants from both extractions were combined, dried, and the resulting extract was used for subsequent analyses (Sadasivam & Manickam, 2008).

Determination of Antioxidant Activity

The antioxidant properties of the selected berries were assessed utilizing the method outlined by Brand-Williams *et al.,* (1995), which employs the stable radical scavenging assay involving 2,2'-diphenyl-1-picrylhydrazyl (DPPH). Berry extracts were prepared at various concentrations (100 µg/ml, 200 µg/ml, 300 µg/ml, 400 µg/ml, and 500 µg/ml) and added to cuvettes. To each cuvette, 2 mL of a 6×10^-5 M methanolic DPPH solution was introduced. Absorbance readings were taken immediately, and the reduction in absorbance at 517 nm was recorded using a spectrophotometer after one hour for each sample. Methanol served as the blank to calibrate the spectrophotometer. The absorbance of the DPPH radical without any antioxidant (as a control) was also measured. All tests were conducted in triplicate. The percentage of DPPH radical inhibition by the berry extracts was determined using the following formula:

$$\%\text{Inhibition} = \left(\frac{A_C(0) - A_A(t)}{A_C(0)} \right) \times 100$$

Where $A_C(0)$ is the absorbance of the control at t=0 minutes, and $A_A(t)$ is the absorbance of the antioxidant sample at t=1 hour.

Determination of Antimicrobial Activity of Bioactive Compounds Against Various Microorganisms

Test Microorganisms

The following microorganisms were sourced from the National Collection of Industrial Microorganisms (NCIM), Pune: *Bacillus cereus* NCIM 2156, *Staphylococcus aureus* NCIM 2079, *Salmonella typhimurium* NCIM 2501, *Escherichia coli* NCIM 2067 (pathogenic), and *Escherichia coli* NCIM 2032 (normal flora). Additionally, *Lactobacillus* spp. (lactic acid bacillus – Sporlac powder) was acquired from a local pharmacy. Both Gram-positive and Gram-negative bacteria were pre-cultured in Mueller-Hinton broth (MHB) overnight at 37°C in a rotary shaker. The bacterial cultures were then standardized to a concentration of 10^8 cells/mL, consistent with the 0.5 McFarland standard (Bhalodia & Shukla, 2011). The

media used were obtained from HiMedia Laboratories Pvt. Ltd., Mumbai, India. The identification of all strains was confirmed through standard biochemical tests and staining methods (Adisakwattana *et al.,* 2009).

Screening for Antimicrobial Activity

The antimicrobial efficacy of the berry extracts was tested using the agar well diffusion method as outlined by Okeke *et al.,* (2001). Pure cultures of the test microorganisms were incubated for 24 hours at 37°C on the appropriate growth media. A 100 µL aliquot of each microorganism's inoculum was spread uniformly over Mueller-Hinton Agar plates. Wells of 6 mm in diameter were aseptically created in the agar using a sterile borer (Nkere & Iroegbu, 2005). Each well was then filled with 100 µL (1 gm/ml) of the corresponding berry extract, and the plates were left at room temperature for 10 minutes to allow the extracts to diffuse into the agar (Rajasekaran *et al.,* 2008; Aneja & Joshi, 2009). The plates were then incubated at 37°C for 24 hours. Streptomycin at 50 µg/mL mL for *Bacillus cereus, Staphylococcus aureus, Escherichia coli, Lactobacillus spp* and azithromycin at 50 µg/mL were used as positive controls for *Salmonella typhimurium*, while sterile distilled water and 20% DMSO were used as negative controls.

Antimicrobial activity was determined by measuring the diameter of the inhibition zones around each well using Vernier callipers. A clear zone around the well signified antimicrobial activity. All experiments were performed in triplicate, and the average diameter of the inhibition zones was calculated.

Results and Discussion

Estimation of Antioxidant Potential of Berries

Antioxidants play a crucial role in neutralizing free radicals, thereby reducing oxidative stress. This study evaluated the antioxidant capacity of different berries using the DPPH assay. The findings show that the antioxidant activity in fresh berries ranges from 20 to 60 µg/mL, while in frozen berries, it ranges from 20 to 80 µg/mL. (Table 1&2)

When comparing the antioxidant potential of fresh and dried berry extracts, it was found that fresh berry extracts typically exhibit higher antioxidant activity than their dried counterparts. Among the fresh berries, blueberries showed the greatest antioxidant potential, with a value of 75.78 µg/mL. In contrast, the antioxidant potential of dried blueberry extract was 45.78 µg/mL, which is still higher than that of most other dried berry extracts. The lowest antioxidant activities were recorded for dried mulberry and blackberry extracts, with values of 30.39 µg/mL and 31.94 µg/mL, respectively. (Figure 1)

Antimicrobial Activity of Fresh Berry Extracts

The antimicrobial effects of fresh berry extracts were tested against a variety of microorganisms, including *Bacillus cereus*, *Staphylococcus aureus*, *Salmonella typhimurium*, pathogenic *Escherichia coli*, normal flora *Escherichia coli*, and *Lactobacilli*. The outcomes are detailed in Table 3. Mulberry extract showed inhibition zones ranging from 8 mm to 13 mm across the different microorganisms tested. The highest activity was observed against *Salmonella typhimurium* (13 mm), while the lowest was seen against *Staphylococcus aureus* (8 mm). Indian Blackberry extract showed inhibition zones between 9 mm and 11 mm, with the greatest effectiveness against *Bacillus cereus* and *Staphylococcus aureus* (11 mm), and the least against *Salmonella typhimurium* (9 mm). Gooseberry extract demonstrated the most potent antimicrobial activity among the berries tested, with inhibition zones spanning from 15 mm to 21 mm. It was most effective against *Salmonella typhimurium* (21 mm) and least effective against *Escherichia coli* (15 mm). Star Gooseberry extract exhibited inhibition zones between 8 mm and 11 mm, showing consistent, though lower, antimicrobial activity compared to the other berry extracts. It was most effective against *Bacillus cereus* and *Indian Blackberry* (11 mm) and least effective against *Salmonella typhimurium* (8 mm). (Table 2)

For reference, the positive controls (streptomycin and azithromycin) displayed inhibition zones ranging from 18 mm to 25 mm, confirming their strong effectiveness against the test microorganisms. The negative controls, including sterile distilled water and 20% DMSO, did not show any antimicrobial activity (0 mm), ensuring that the observed effects were due to the berry extracts themselves and not due to external factors or contamination. The antimicrobial efficacy of the fresh berry extracts varied significantly among the different microorganisms and berry types. Gooseberry extracts stood out for their high antimicrobial potential, particularly against *Salmonella typhimurium* (21 mm), suggesting the presence of potent antimicrobial compounds that may be beneficial for therapeutic uses or

as food preservatives. Mulberry and Indian Blackberry extracts showed moderate antimicrobial effects, with Mulberry being more effective against *Salmonella typhimurium* than *Staphylococcus aureus*, potentially indicating specific compounds that target Gram-negative bacteria. Indian Blackberry displayed relatively uniform antimicrobial activity across the different test organisms, suggesting a broad-spectrum antimicrobial effect. Star Gooseberry had the lowest antimicrobial activity among the fresh berries tested, but still demonstrated some level of inhibition, indicating that it possesses antimicrobial properties, though less potent than those of Gooseberry or Mulberry.

The effectiveness of the positive controls, streptomycin and azithromycin, in inhibiting the growth of all test organisms validates the experimental procedure and the susceptibility of the microorganisms used. The lack of activity in the negative controls further confirms that the observed antimicrobial effects were indeed due to the berry extracts. These results underscore the potential of certain fresh berries, especially Gooseberries, as sources of natural antimicrobial agents. Further research to isolate and identify the specific compounds responsible for these antimicrobial effects, as well as exploring their applications in food safety and therapeutic settings, is recommended.

Antimicrobial Activity of Frozen Berry Extracts

The antimicrobial activity of frozen berry extracts was evaluated against a selection of microorganisms, including *Bacillus cereus*, *Staphylococcus aureus*, *Salmonella typhimurium*, pathogenic *Escherichia coli*, normal flora *Escherichia coli*, and *Lactobacilli*. The findings are summarized in Table 4.

Fresh Blackberry extracts displayed inhibition zones between 9 mm and 12 mm across the tested microorganisms. The largest zone of inhibition was observed against *Staphylococcus aureus* and *Lactobacilli* (12 mm), while the smallest was against pathogenic *Escherichia coli* (9 mm). Fresh Blueberry extracts showed inhibition zones ranging from 10 mm to 16 mm, with the highest activity against *Salmonella typhimurium* (16 mm) and the lowest against *Escherichia coli* (10 mm). Fresh Raspberry extracts exhibited inhibition zones between 11 mm and 13 mm, with the greatest effect against *Staphylococcus aureus* (13 mm) and the least against *Lactobacilli* (11 mm). Fresh Mulberry extracts produced inhibition zones ranging from 8 mm to 14 mm, showing the most significant effect against *Salmonella typhimurium* (14 mm) and the least against pathogenic *Escherichia coli* (8 mm).

In comparison, dried berry extracts showed varied antimicrobial effectiveness. Dried Blackberry extracts exhibited inhibition zones from 15 mm to 22 mm, showing significant activity against normal flora *Escherichia coli* (22 mm) and *Staphylococcus aureus* (18 mm). Dried Blueberry extracts had inhibition zones between 9 mm and 25 mm, with the greatest activity observed against normal flora *Escherichia coli* (25 mm) and the least against *Bacillus cereus* (9 mm).

Dried Raspberry extracts showed inhibition zones ranging from 12 mm to 25 mm, with the most substantial inhibition noted against normal flora *Escherichia coli* and *Lactobacilli* (25 mm) and the least against *Bacillus cereus* (12 mm). Dried Mulberry extracts displayed inhibition zones between 12 mm and 20 mm, with the highest activity against *Salmonella typhimurium* (20 mm) and the lowest against *Lactobacilli* (12 mm).

The positive controls, streptomycin and azithromycin, demonstrated significant antimicrobial activity with inhibition zones ranging from 14 mm to 26 mm, validating the assay and confirming the susceptibility of the microorganisms. Negative controls, including sterile distilled water and 20% DMSO, showed no inhibition (0 mm), affirming that the observed effects were due to the berry extracts.

The antimicrobial activity of frozen berry extracts varied notably between their fresh and dried forms. Generally, dried extracts exhibited stronger antimicrobial effects compared to fresh extracts, possibly due to the concentration of bioactive compounds during the drying process. Among the dried extracts, Raspberry demonstrated the highest overall antimicrobial activity, particularly effective against normal flora *Escherichia coli* and *Lactobacilli* (25 mm), indicating that drying may retain or even enhance the potency of certain antimicrobial compounds.

Similarly, Dried Blackberry and Dried Blueberry showed significant inhibition against multiple microorganisms, highlighting their potential as sources of antimicrobial agents. On the other hand, fresh berry extracts showed variable effectiveness, with Fresh Blueberry exhibiting the highest inhibition against *Salmonella typhimurium* (16 mm), while Fresh Mulberry and Fresh Raspberry

displayed moderate to high activity against specific microorganisms. These variations could be due to differences in the concentration of bioactive compounds between fresh and dried forms.

Table.1 Antioxidant Activity of Fresh Berries

Berry Type	Antioxidant Activity (µg/mL)
Fresh Berries	
Gooseberry (*Phyllanthus emblica*)	51.33± 0.04
Star Gooseberry (*Phyllanthus acidus*)	20.63± 1.53
Indian Blackberry (*Syzygium cumini*)	34.21± 0.21
Mulberry (*Morus nigra)*	22.56± 0.25

Table.2 Antioxidant Activity of Frozen Fresh and Frozen Dry Berries

BERRIES	Blackberry (*Rubus fruticosus*)	Blueberry (*Vaccinium corymbosum*)	Raspberry (*Rubus idaeus*)	Mulberry (*Morus nigra)*
Fresh berries	35.61± 0.84µg/mL	49.51± 1.42 µg/mL	40.02± 0.32 µg/mL	29.90± 0.72 µg/mL
Dry berries	28.57± 1.81µg/mL	26.31± 0.51µg/mL	23.58± 0.46 µg/mL	13.39± 1.82µg/mL

Table.3 Antimicrobial Activity - Zone of Inhibition from Fresh Berries

Berry Type	*Bacillus cereus* NCIM2156	*Staphylococcus aureus* NCIM2079	*Salmonella typhimurium* NCIM2501	*Escherichia coli* NCIM2067 (Pathogenic)	*Escherichia coli* NCIM2032 (Normal Flora)	Lactobacilli (Lactic Acid Bacillus - Sporlac Powder)
Mulberry (F)	11 mm	8 mm	13 mm	8 mm	12 mm	10 mm
Indian Blackberry (F)	11 mm	11 mm	10 mm	9 mm	11 mm	9 mm
Gooseberry (F)	18 mm	17 mm	21 mm	19 mm	15 mm	16 mm
Star Gooseberry (F)	11 mm	11 mm	8 mm	8 mm	8 mm	9 mm
Positive Control	25 mm	18 mm	25 mm	18 mm	23 mm	20 mm
Negative Control	0 mm	0 mm	0 mm	0 mm	0 mm	0 mm

Positive Control: Streptomycin 50 µg/100 mL (forBacillus cereus, Staphylococcus aureus, Escherichia coli, Lactobacilli) and Azithromycin 50 µg/100 mL (for Salmonella typhimurium)
Negative Control: Sterile Distilled Water and 20% DMSO

Table.4 Antimicrobial Activity - Zone of Inhibition from Frozen Berries

Berries	*Bacillus cereus* NCIM2156	*Staphylococcus aureus* NCIM2079	*Salmonella typhimurium* NCIM2501	*Escherichia coli* NCIM2067 (Pathogenic)	*Escherichia coli* NCIM2032 (Normal Flora)	Lactobacilli (Lactic Acid Bacillus - Sporlac Powder)
Blackberry (Fresh)	11 mm	12 mm	12 mm	9 mm	11 mm	12 mm
Blueberry (Fresh)	12 mm	11 mm	16 mm	11 mm	10 mm	14 mm
Raspberry (Fresh)	13 mm	13 mm	12 mm	12 mm	12 mm	11 mm
Mulberry (Fresh)	11 mm	10 mm	14 mm	8 mm	9 mm	13 mm
Blackberry (Dry)	18 mm	18 mm	15 mm	18 mm	22 mm	17 mm
Blueberry (Dry)	9 mm	12 mm	15 mm	9 mm	25 mm	10 mm
Raspberry (Dry)	17 mm	19 mm	12 mm	16 mm	25 mm	18 mm
Mulberry (Dry)	12 mm	14 mm	20 mm	15 mm	15 mm	12 mm
Positive Control	25 mm	22 mm	25 mm	14 mm	26 mm	26 mm
Negative Control	0 mm	0 mm	0 mm	0 mm	0 mm	0 mm

Positive Control: Streptomycin 50 µg/100 mL (forBacillus cereus, Staphylococcus aureus, Escherichia coli, Lactobacilli)and Azithromycin 50 µg/100 mL (for Salmonella typhimurium)
Negative Control: Sterile Distilled Water and 20% DMSO

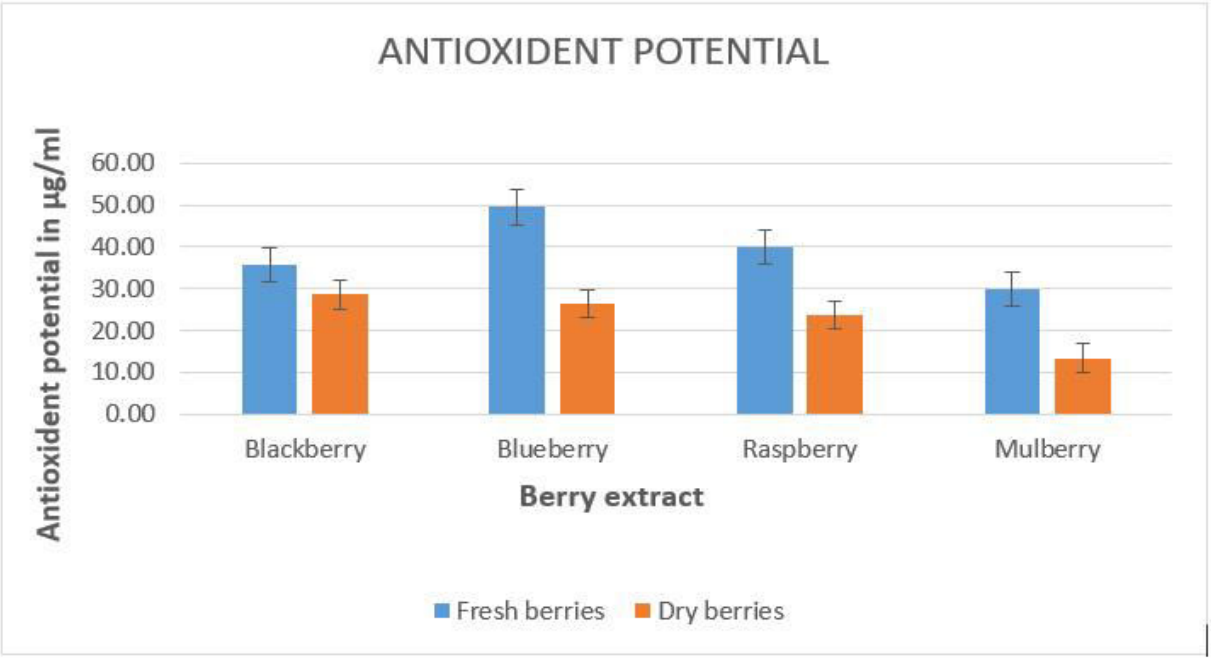

Figure.1 Comparative Analysis of Antioxidant Potential in Fresh vs. Frozen-Dried Berries

Overall, the results suggest that both fresh and dried berry extracts could serve as promising sources of natural antimicrobial agents. Further research should aim to isolate and characterize the specific bioactive compounds responsible for these effects and explore their potential applications in food safety and therapeutic contexts. (Table 3)

Antimicrobial activity results were observed where frozen dried blackberry, blueberry, raspberry, mulberry are showing good results against all the test organisms. From the selected fresh berries gooseberry showed good results against all the test organisms.

Escherichia coli NCIM2067 (pathogenic) was showing highest zone of inhibition against gooseberry amongst selected fresh berries and *Escherichia coli* NCIM2032 (normal flora) was showing highest zone of inhibition against blueberry and raspberry amongst frozen dried berries.

This study demonstrates the notable antimicrobial and antioxidant properties of various berry extracts, emphasizing their potential as natural sources of bioactive compounds. The extracts showed significant inhibitory activity against several microbial strains, even in their unpurified forms, indicating that these berries possess effective antimicrobial agents. The efficacy observed, despite the lack of purification, suggests that these extracts could be further developed into phytomedicines or used as natural food preservatives. The results encourage further investigation and isolation of specific phytoconstituents from these berries, which may result in novel antimicrobial agents with fewer side effects compared to synthetic alternatives.

In addition to their antimicrobial effects, the berries also displayed strong antioxidant activities, highlighting their potential role in mitigating oxidative stress and related diseases. However, the antioxidant potential is not solely linked to polyphenol content, as factors such as bioavailability and digestion may affect the actual antioxidant capacity in vivo.

Therefore, future research should focus on assessing bioavailability and isolating individual compounds to fully understand their therapeutic potential. While the in vitro results are promising, additional studies are needed to confirm these effects in vivo and to explore other parts of the plants. Moreover, examining the efficacy of these extracts against a wider range of pathogens, including mycobacteria, viruses, and parasites, could pave the way for developing effective natural antimicrobial agents.

The application of these extracts as natural preservatives in the food industry also deserves further investigation, especially considering the increasing concerns regarding the safety of synthetic preservatives.

Author Contributions

Shruti A. Satashia: Investigation, formal analysis, writing—original draft. Nileshkumar Pandya: Validation, methodology, writing—reviewing.

Data Availability

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

Declarations

Ethical Approval Not applicable.

Consent to Participate Not applicable.

Consent to Publish Not applicable.

Conflict of Interest The authors declare no competing interests.

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