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Impact of Processing Techniques on Antioxidant, Antimicrobial and Phytochemical Properties of Curry Leaves (Murraya koenigii Spreng)

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***Abstract*—** *Curry leaves (Murraya koenigii Spreng) are widely valued for their nutritional and therapeutic properties, primarily due to their rich phytochemical composition, including flavonoids, alkaloids, essential oils, and also exert several pharmacological activities such as antifungal, antimicrobial, antidiabetic, etc. Although curry leaves are an economical source of nutrients, and generally consumed as seasoning. Various researchers observed that cooking has impact on many of the nutrients therefore, it is necessary to find out the best cooking method to minimise the nutrient loss. In this study, the impact of five common household processing techniques (boiling, pressure cooking, steaming, sautéing & microwave cooking) on in vitro antioxidant activity, vitamin C, β-carotene, antimicrobial efficacy and phytochemical profiles (both qualitative and quantitative) was determined on curry leaves. Steaming (74%) and sautéing (81%) were the most effective in preserving radical scavenging activity, while boiling (612%) and pressure cooking (157%) led to considerable losses. All cooking methods resulted in a reduction of ascorbic acid content (82-93%) and β-carotene (3-38%), while they had a positive effect on the total phenol (16-65%) and flavonoids (54-413%). Boiling had the highest negative impact on the antimicrobial activity of curry leaves. After processing of curry leaves, no zone of inhibition was observed against E. coli. These findings suggest that milder cooking methods, particularly steaming and sautéing, are preferable for retaining the functional quality of curry leaves in culinary applications. Integrating such practices into daily cooking could help maximize the preventive health benefits of this medicinally important plant.*

Keywords*— *Antimicrobial activity, Antioxidant activity, Curry leaves, Microwave cooking, Phytochemical, Processing techniques

I. INTRODUCTION

Curry leaves (*Murraya koenigii* Spreng), widely recognized for their distinctive aroma, flavor, and medicinal value, hold a prominent place in South Asian cuisine and traditional healing practices. According to the WHO, for primary health care up to three fourth population in developing countries and more than half globally depend on plant-based medicines [1]. Rich in bioactive compounds such as alkaloids, flavonoids, phenolics, essential oils, ascorbic acid, and carotenoids, curry leaves exhibit a strong presence of pharmacological characterstics, including antioxidant, antimicrobial, anti-inflammatory, antidiabetic, and hepatoprotective prpperties. As a medicinal plant, *Murraya koenigii* (commonly known as curry leaves, *kadhi patta*, or *mitha nimba*) has been reported to offer therapeutic benefits for a range of health conditions such as indigestion and gastritis [2], cancer [3], diabetes [4], cardiovascular diseases [5], and hyperlipidemia [6]. While curry leaves have been extensively studied for their therapeutic potential in treating various diseases through leaf extracts but their inclusion in the regular diet as a food ingridients may serve as an effective preventive measure due to their rich phytochemical and antioxidant profile.

In typical culinary practice, curry leaves are primarily used in seasoning in small quantities and usually in cooked form. However, increasing their incorporation into various recipes, while minimizing nutrient loss, could enhance their health benefits. Therefore, it is important to investigate how different cooking methods affect their nutritional and phytochemical properties. While antioxidant activity, antimicrobial efficacy, and phytochemical content of curry leaves have been documented by several researchers [7,8,9], there is still limited research on how common domestic processing techniques influence these functional attributes. Understanding these effects is essential for optimizing the dietary use of curry leaves to maximize their therapeutic potential.

This study aims to investigate the effect of boiling, pressure cooking, microwave cooking, sautéing, and steaming on the functional attributes of curry leaves. By analyzing the changes in antioxidant capacity, ascorbic acid and beta-carotene content, antimicrobial efficacy and phytochemical characteristics, the study seeks to provide valuable insights into how common processing techniques affect the health-promoting qualities of curry leaves. The findings are expected to advice to retain or enhance the therapeutic potential of this underutilized yet powerful medicinal plant.

II. MATERIALS AND METHODS

2.1 Sample procurement and Preparation

Fresh curry leaves (*Murraya koenigii* Spreng) were collected from the kitchen garden of Kurukshetra University campus and washed thoroughly to remove dust and impurities. The leaves were air-dried to remove surface moisture before subjecting them to different processing treatments.

2.2 Processing Techniques

The curry leaves were divided into six groups: one unprocessed (raw) and five groups subjected to different processing techniques. For every processing technique, quantity of water, temperature and time of cooking was standardized after many trials.

- Boiling: Adding 50 ml of water leaves were boiled at 100°C for 5 minutes in a covered stainless-steel utensil.
- Pressure Cooking: Leaves were pressure-cooked using 20 ml of water at 121°C (15 psi) for 5 minutes.
- Microwave Cooking: Leaves were microwaved in 10 ml of water at 900 W for 4 minutes.
- Sautéing: Leaves were sautéed in minimal oil (2 tsp/20 g leaves) for 3 minutes.
- Steaming: Leaves were steamed for 10 minutes in a closed vessel.

After processing, the leaves were cooled to room temperature immediately and used for extraction

2.3 Extraction of samples for further analysis

Raw and treated samples, were weighed, grounded manually using pestle and mortar, added 80 % methanol and acidified to pH with 6N HCl and kept for 30 minutes in mechanical shaker at room temperature. After 30 minutes, the extract was centrifuged at 10,000 rpm for 10 minutes, supernatant was collected. Aliquot was filtered with whatman no. 1 filter paper and evaporated on hot plate at 60˚C.

2.4 Nutritional analysis of control and processed samples

2.4.1 Phytochemical Screening

- Qualitative analysis for alkaloids, phenols, and flavonoids. Carbohydrates, and glycosides gums and mucilages Proteins and amino acids, saponin and, fixed oil and fats was conducted using standard protocols [10-23].
- Quantitative estimation included:
  - Total Phenolic Content (TPC): The concentration of total phenolic content of the methanolic extracts was determined by the modified 'Folin-Ciocalteau colorimetric method.' Results were expressed as mg GAE/g FW [24].
  - Total Flavonoid Content (TFC): Using 'aluminum chloride colorimetric method' as reported by Meda *et al*. (2004) [25]. Results were expressed as mg QE/g FW).

2.4.2 Antioxidant activity was assessed using 'DPPH (2,2-diphenyl-1-picrylhydrazyl)' assay

The antioxidant activity of the extract on the basis of the scavenging activity of the stable DPPH free radical was determined by the method followed by Chan *et al*. (2007) [26]. Absorbance was measured spectrophotometrically, and results were expressed as expressed as IC_{50} value µg/100g fresh weight (FW).

2.4.3 Estimation of Ascorbic Acid Content

Ascorbic acid content was determined by 'the 2,6-dichlorophenolindophenol titrimetric method' [27] and expressed in mg/100g FW.

2.4.4 Estimation of β-Carotene Content

β-carotene content was extracted using n-butanol and quantified spectrophotometrically at 440 nm [27]. Results were expressed in μg/100g FW.

2.4.5 Antimicrobial Activity

Antimicrobial efficacy was assessed using the 'agar well diffusion method' [28] against common pathogens (*Escherichia coli*, *Staphylococcus aureus*, and yeast *Candida albicans*). Zones of inhibition were measured in milli meters.

2,5 Statistical analysis

Statistical analysis was conducted using IBM SPSS version 20. Quantitative variables were assessed using measures of central tendency (mean) and dispersion (standard deviation). One-way analysis of variance (ANOVA) was used for comparison involving three or more groups, followed by Tukey's HSD test was used to evaluate significant differences between means, and $p \leq 0.05$ considered as significant.

III. RESULT AND DISCUSSION

3.1 Phytochemical screening

The 'phytochemical screening' of raw as well as cooked curry leaves processed through different household cooking techniques was done to assess the impact of processing on their phytochemical content (Table 1). Results revealed that phenols, and flavonoids were strongly present in all fractions. Carbohydrates, proteins and amino acids, gums & mucilages were present moderately in all the processed sample of curry leaves. Alkaloids, glycosides, saponins, fats & fixed oils were undetected in any of the extracts. Overall different processing techniques used in present research does not seem to have any impact on phytochemical content of curry leaves. Yee et al. (2023) reported a positive test for reducing sugars, which aligns with the findings of the present study [29]. However, on the contrary they reported positive results for alkaloids and saponins, and a negative test for flavonoids in curry leaf extract. This variation may be due to the difference in extraction medium [30].

Table 1: Impact of processing on phytochemical screening of Curry leaves

'S.N.	Phytochemical screening	Raw	Boiling	Pressure cooking	Microwave cooking	Steaming	Sautéing
1.	**Detection of alkaloids**						
A.	Mayer's test	-	-	-	-	-	-
B.	Wagner's test	-	-	-	-	-	-
C.	Hager's test	-	-	-	-	-	-
D.	Dragendorff's test	-	-	-	-	-	-
2.	**Detection of carbohydrates**						
A.	Molish's test	+	+	+	+	+	+
B.	Fehling's test	+	+	+	+	+	+
C.	Barfoed test	+	+	+	+	+	+
D.	Benedict test	+	+	+	+	+	+
3.	**Detection of glycosides**						
A.	Sulphuric acid test	-	-	-	-	-	-
B.	Borntrager's test	-	-	-	-	-	-
C.	Legal's test	-	-	-	-	-	-
4.	**Detection of saponin**						
A	Foam test	**-**	**-**	**-**	**-**	**-**	**-**
5.	**Detection of proteins and amino acids**						
A.	Millon's Test	+	+	+	+	+	+
B.	Biuret test	+	+	+	+	+	+
C.	Ninhydrin test	+	+	+	+	+	+

6.	**Detection of fixed oil and fats**						
A.	Saponification test	-	-	-	-	-	-
7.	**Detection of phenolic compound**						
A.	Ferric chloride test	++	++	++	++	++	++
B.	Lead acetate test	++	++	++	++	++	++
C.	Gelatin test	++	++	++	++	++	++
8.	**Detection of flavonoids**						
A.	Alkaline reagents test	++	++	++	++	++	++
B.	Magnesium and Hydrochloric acid reduction	++	++	++	++	++	++
9.	**Detection of gum and Mucilages**	+	+	+	+	+	+

+Present moderately ++ Present strongly - Absent'

3.2 Total Phenol

Phenol content of curry leaves, both raw and processed, ranged from 450.32 to 801.41 mg/100g GAE (Table 2 Fig 2). The highest phenolic content was observed in the boiled sample, while the sautéed sample exhibited the lowest. Tukey's HSD confirms a clear descending order: Boiled = Steamed > Microwave > Pressure Cooked > Raw > Sautéed. All processing methods, except sautéing, resulted in a significant ($p \leq 0.05$) rise in phenolic content compared to the raw sample. Boiling and steaming led to significantly ($p \leq 0.05$) increase in phenolic levels than the raw sample and other processed treatments. Microwave cooking resulted in a moderate increase (44.26%) in phenolic content, significantly ($p \leq 0.05$) lower than boiling and steaming but higher than pressure cooking and sautéing. Pressure cooking produced an intermediate increase, significantly ($p \leq 0.05$) higher than the raw. Sautéing, however, caused a slight (non-significant) decrease in phenolic content (-6.9%), significantly ($p \leq 0.05$) lower than all treatments that showed enhancement in phenolic content. Overall, all processing treatments had positive impact on phenolic content of curry leaves. This may be attributed to the breaking of cell walls, which promote the release of soluble phenolic compounds that were previously bound to insoluble ester linkages within the cell wall matrix [31]. Şengül *et al*., (2014), Geetha et al., (2018), Chin et al., (2022) also reported significant ($p \leq 0.05$) improvement in phenolic content after cooking process [32,33,34].

3.3 Flavonoid content

Flavonoid content of curry leaves, both raw and processed, ranged from 31.81 to 413.5 mg QE/100g (Table 2 Fig 1). Highest flavonoid content was observed in the pressure-cooked sample, while the raw sample exhibited the lowest flavonoid content. Further Tukey HSD analysis revealed significant ($p \leq 0.05$) increment in all the processed sample than raw. Pressure cooking extremely increased flavonoid levels (1199.91%), significantly ($p \leq 0.05$) different from all other process. Microwave cooking also significantly ($p \leq 0.05$) enhanced flavonoid content over raw while sautéing significantly ($p \leq 0.05$) enhanced flavonoid content compared to boiling and steaming. All the cooking processes increased the flavonoid content in curry leaves. The observed increase in flavonoid content after cooking may be attributed to improved extractability, resulting from the more efficient release of polyphenolic and flavonoid compounds from intracellular protein complexes and modifications in the plant cell wall structure [35]. Similar trends in some vegetables were observed by Hossain et al., (2017), Gunathilake et al. (2018), Alide *et al.*, (2020), Hassan *et al*., (2021), Etu et al. (2024) [36,37,38,39,40].

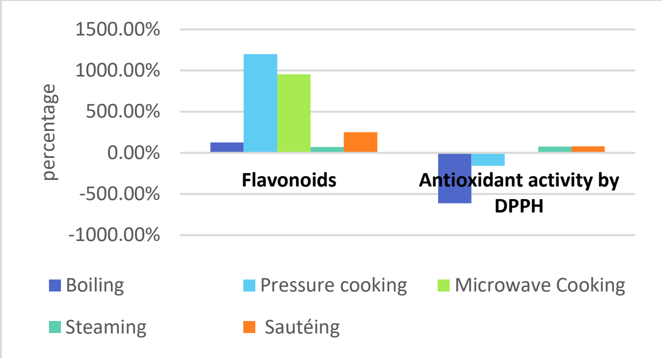

Fig: 1 Impact of different processing on antioxidant activity and flavonoids of curry leaves

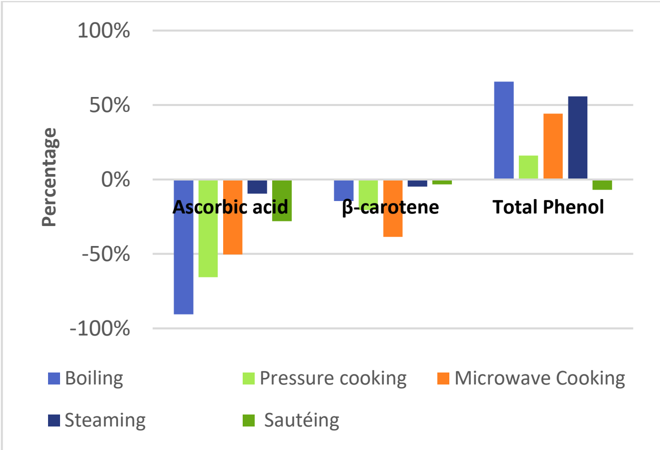

Fig: 2 Impact of different processing on ascorbic acid, β-carotene and total phenol of curry leaves

3.4 Radical scavenging activity

Radical scavenging activity (IC_{50} value) of curry leaves, both raw and processed, ranged from 1714.29 to 45.22 µg/ml (Table 2 Fig 1). All cooking methods had a significant ($p \leq 0.05$) impact on the antioxidant activity of raw curry leaves. Microwave cooking, steaming, and sautéing enhanced the radical scavenging activity, whereas boiling and pressure cooking led to a reduction. Among the treatments sautéed and steamed samples exhibited the highest antioxidant potential, with improvements of 81.19% and 74.75%, respectively, compared to all other samples (raw and processed), and the differences were significant ($p \leq 0.05$). Further Tukey' post hoc test indicated that microwave treatment also significantly ($p \leq 0.05$) enhanced antioxidant activity relative to raw, boiled, and pressure-cooked samples, although its efficacy was lower than that of steaming and sautéing. Boiling resulted in the most substantial loss of antioxidant activity, representing a greater than 600% increase in IC_{50}, and was significantly different ($p \leq 0.05$) from all other processing methods. Among the treatments, sautéed and steamed, samples exhibited the moderate antioxidant potential, with improvements of 81.19% and 74.75%, respectively, compared to all other samples (raw and processed), and the differences were statistically significant ($p \leq 0.05$). The impact of cooking on the antioxidant activity of curry leaves is multifaceted. Microwave cooking, steaming and sauteing enhance the antioxidant activity of curry leaves. Increment after some processing due to breaking down cell walls and releasing bound phenolic compounds [41]. Gunathilake et al. (2018), Chin et al. (2022), and Etu et al. (2024) reported that steaming, microwave cooking, and sautéing enhanced the antioxidant activity in various leafy vegetables, including *Cassia auriculata* and *Centella asiatica*, Chinese kale, and fluted pumpkin and garden egg leaves, respectively [34,37,40]. These findings are consistent with the results of the present study, supporting the positive impact of certain cooking methods on antioxidant potential. In the present study, pressure cooking and boiling significantly ($p \leq 0.05$) reduced the antioxidant activity of curry leaves (*Murraya koenigii*). This reduction may be due to the thermal breakdown of heat-sensitive and water-soluble antioxidants like ascorbic acid through leaching in water and some polyphenol. [42]. These results align with earlier studies (Hwang et al., 2012, El-Hamzy and Ashour,

2017) that reported losses in antioxidant potential in red pepper after boiling [43,44,].

However, contrary findings were reported by Geetha et al. (2018), who observed an increase in antioxidant activity after boiling and pressure cooking of curry leaves [33]. The discrepancy between the current study and Geetha et al.'s findings could be due to differences in cooking duration, leaf maturity, or assay methods used to measure antioxidant capacity.

3.5 Ascorbic acid

Ascorbic acid content of curry leaves, both raw and processed, ranged from 0.2 to 3.18 mg/100g (Table 2 Fig 2). Raw curry leaves had significantly (p≤0.05) more AA than all processed samples statistically. Tukey post hoc analysis showed that no processing method demonstrated significant (p≤0.05) difference over the others. Sautéing was numerically the highest among processed samples, but statistically not different from boiling, pressure cooking, microwaving, or steaming. All processing methods significantly (p≤0.05) reduced ascorbic acid while sautéing preserved the most among them. This loss is mainly attributed to rapid oxidation, which transform AA to dehydroascorbic acid, sunsequently undergoing hydrolysis to 2,3-diketogulonic acid and polymerization. Furthermore, leaching of nutrients into boiling water contributes to the reduction in AA levels [45]. As per present findings, various researchers also reported loss of vitamin C during different cooking technique [46,47,48,49]. 'Vitamin C is a water-soluble and heat-sensitive vitamin, making it prone to degradation during cooking. High temperatures and extended cooking times can lead to significant losses of this nutrient' [50]. This confirms that ascorbic acid is highly vulnerable to thermal and water-based treatments.

Table 2: Impact of different processing techniques on antioxidant activity and phytochemical content on Curry Leaves

Curry leaves	**Raw**	**Boiling**	**Pressure cooking**	**Microwave Cooking**	**Steaming**	**Sautéing**
Antioxidant activity (µg/100g)	240.51±1.54^{c}	1714.29±4.03^{a}	619.98±9.62^{b}	215.01±5.74^{d}	60.72±1.29^{e}	45.22±1.36^{e}
Flavonoid (mg QE/100g)	31.81±0.93^{e}	72.43±1.58^{d}	413.50±1.23^{a}	335.78±7.23^{b}	54.33±2.26^{d}	111.19±5.41^{c}
Phenolic content (mg/100g GAE)	483.81±2.3^{d}	801.41±0.57^{a}	561.79±16.42^{c}	697.95±7.16^{b}	754.15±19.13^{a}	450.32±4.91^{d}
β-carotene (µg/100g)	5912.34±37.55^{a}	5061.02±52.13^{c}	4699.31±44.61^{d}	3631.45±32.31^{e}	5623.46±72.71^{b}	5719.16±45.17^{a} ^{b}
Ascorbic acid (mg/100g)	3.18±0.33^{a}	0.20±0.25^{b}	0.20±0.31^{b}	0.50±0.27^{b}	0.40±0.47^{b}	0.57±0.25^{b}

The mean value having different alphabets are significantly different (p≤0.05) using Tukey's test for different processing treatments

Mean value are presented as mean±SD and referred to the fresh weight

3.6 The β-carotene

The β-carotene content of curry leaves, both raw and processed, ranged from 3631.45 to 5912.34 µg/100g (Table 2 Fig 2). Raw curry leaves had the highest β-carotene content. Tukey post hoc revealed that all the processing methods reduced β-carotene content significantly (p≤0.05) except sauteing. Steaming resulted in to better retention significantly (p≤0.05) higher than boiling, pressure cooking, and microwave cooking**.** Boiling (−14.41%) showed significant (p≤0.05) reduction in comparison to pressure cooking (20.51%) and microwave cooking (38.57%). Overall, sautéing technique preserved β-carotene significantly (p≤0.05) while microwave caused significant (p≤0.05) loss. This study supports findings from previous researchers which showed reductions in carotenoid levels in cooked vegetables compared to their raw counterparts [51,52]. This loss may be attributed to the different intracellular distributions of β-carotene, which is stored within crystalline chromoplasts surrounded by polar lipid-rich membranes in vegetables. As well as thermal processing can alter the physical state of carotenes, making them more soluble as cellular lipids dissolve [53]. Additionally, some carotenoids are lost through leaching during cooking, contributing to the decrease in β-carotene retention. This change is likely a result of heat-induced isomerization, converting trans-carotenes into their more bioavailable cis forms, which have greater solubility in micelles, thereby enhancing their bio accessibility and bioavailability [52].

3.7 Antimicrobial activity

Table 3 and Figure 3 represents the impact of different processing on antimicrobial activity against *Candida albicans* and *Staphylococcus aureus*, *Escherichia coli.* Against *S. aureus*, raw curry leaf extract exhibited a strong inhibitory effect with a zone of 19.56 mm. This is significantly ($p \leq 0.05$) lower than the positive control (ciprofloxacin). However, most thermal processing methods significantly ($p \leq 0.05$) diminished this activity. Significant ($p \leq 0.05$) reduction in antimicrobial activity was found after steaming (9.34 mm), sautéing (8.6 mm), and microwave cooking (5.4 mm). Boiling led to a substantial reduction, showing an inhibition zone of only 4.8 mm. Notably, pressure cooked curry leaves was not effective against Gram-positive bacteria. The positive control (ciprofloxacin) recorded the significantly highest ($p \leq 0.05$) inhibition (22.8 mm), and the negative control (DMSO) showed no activity, confirming the validity of the method. Tukey's post hoc analysis indicated that the raw sample demonstrated significantly ($p \leq 0.05$) higher antimicrobial activity than all processed forms. Sautéed and steamed samples produced a significantly ($p \leq 0.05$) larger ZOI compared to microwave cooked and boiled sample. Maximum inhibitory activity was observed of steamed sample against *S. aureus* among all the processed sample.

In the case of *Escherichia coli*, curry leaves demonstrated significantly ($p \leq 0.05$) lower antibacterial activity, with the raw extract producing a small inhibition zone of 5.78 mm in comparison to positive control. No inhibitory effect was recorded for any of the processed samples highlighting the compound's weak effect against Gram-negative bacteria due to the complete degradation of bioactive compounds during cooking. Nevertheless, the positive control still displayed high efficacy (19.36 mm), emphasizing that the low activity was specific to the curry leaf extracts rather than procedural limitations.

Table 2. Impact of boiling on antimicrobial activity of curry leaves

Plant foods	**Microorganism**	**Zone of inhibition in mm**								
		Raw	**Boiling**	**Pressure cooking**	**Microwave Cooking**	**Steaming**	**Sautéing**	**DMSO**	**Ciproflaxacin**	**Amphotericin**
Curry leaves	Staphylococcus aureus	19.56±0.49^{b}	4.8±0.12^{d}	-	5.4±0.26^{d}	9.34±0.76^{c}	8.6±0.59^{c}	-	22.81±0.31^{a}	nt
	Escherichia choli	5.78±0.23^{b}	-	-	-	-	-	-	19.36±0.42^{a}	nt
	Candida albicans	11.45±0.84^{b}	-	8.7±0.65^{c}	8.8±0.23^{bc}	3.66±0.57^{d}	10.3±0.65^{b}	-	nt	19.57±0.32^{a}

Values are the mean ± SE of three independent determinations;

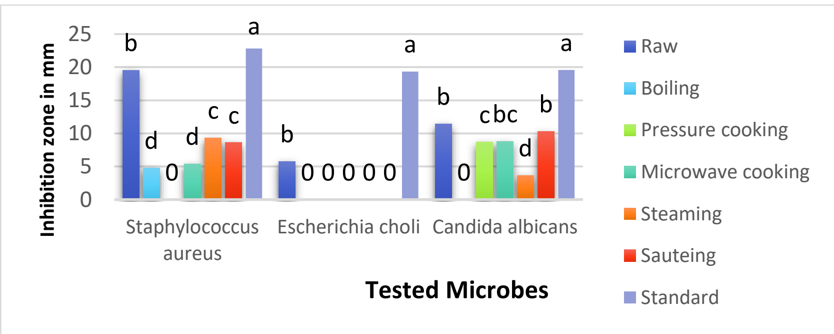

Fig 3: Impact of processing on antimicrobial activity of curry leaves

The column having different alphabets are significantly different ($p \leq 0.05$) using Tukey's test for different processing treatments

For *C. albicans*, the raw extract of curry leaves showed markable antifungal activity (11.45 mm), followed by sautéed (10.3 mm), microwave cooked (8.8 mm) and pressure-cooked (8.7 mm) samples. Steaming produced the significantly ($p \leq 0.05$) least effect (3.66 mm) while no inhibition was observed in boiled sample. This may be due to the leaching of phytochemical in water [54]. Tukey's post hoc analysis indicated that the raw sample demonstrated significantly ($p \leq 0.05$) higher antimicrobial activity than all processed forms. Significant ($p \leq 0.05$) difference was found in the inhibitory activity of pressure cooked, steamed and sauteed sample. These results indicate that curry leaves maintain moderate antifungal activity under certain cooking conditions. The antifungal control (Amphotericin) showed the highest inhibition (19.57 mm). Among all the cooking method, sauteing exhibited minimal reduction in antimicrobial activity of curry leaves against *C. albicans*.

In summary, curry leaves demonstrated strong antimicrobial and antifungal activity in their raw form, especially against *S. aureus* and *C. albicans*. However, most cooking methods particularly boiling and steaming significantly ($p \leq 0.05$) reduced this activity. It is well established that the functional properties of phenolic compounds can be significantly diminished during thermal processing, leading to reduced antioxidant and antimicrobial activities [55]. The extent of this loss may vary depending on factors such as the type of sample, duration of cooking, and the temperature applied [56]. The absence of inhibitory effects against *E. coli* in cooked samples further highlights the structural resistance of Gram-negative bacteria and the importance of processing on bioactive compound retention [57]. These findings underscore the potential of curry leaves as a natural antimicrobial agent, particularly when consumed raw or minimally processed. Similar results were reported by Sutradhar *et al*. (2020) for *Emblica officinalis* [58]. They observed that 5 min boiling reduced the antimicrobial activity due the reduction of vitamin C. Bordoloi *et al*. (2017) also confirmed decreased effectiveness against *S. aureus* after being boiled [59].

IV. CONCLUSION

The study demonstrated that processing methods significantly influence the nutritional and bioactive composition of curry leaves. While all cooking techniques led to some degradation of heat-sensitive compounds like ascorbic acid and β-carotene, they also promoted the release and bioavailability of phenolics and flavonoids. Microwave cooking and steaming emerged as the most favourable techniques, preserving antioxidant and phytochemical properties effectively. Boiling and pressure cooking, though common, may lead to substantial losses in nutrient content. These findings are relevant for optimizing culinary and industrial processing of curry leaves to retain their functional benefits. These findings underscore the importance of selecting appropriate cooking methods to maximize the health benefits of curry leaves.

REFERENCES

[1] M. S. A. Khan and I. Ahmad, "Herbal Medicine," Elsevier eBooks [Online], pp. 3–13, 2018. Available: https://doi.org/10.1016/b978-0-12-814619-4.00001-x

[2] D. Kiruthika, G. Nandhini, and E. Rakel, "A Study on Murraya koenigii (Curry Leaves) Impact on Gastritis," ScieXplore Int. J. Res. Sci. [Online], vol. 8, no. 1–2, pp. 1, Dec. 2021. Available: https://doi.org/10.15613/sijrs/2021/v8i1-2/217893

[3] S. Aisyah, E. Handharyani, N. Bermawie, and A. Setiyono, "Effects of ethanol extract of curry leaves (Murraya koenigii) on HER2 and caspase-3 expression in rat model mammary carcinoma," Vet. World [Online], pp. 1988–1994, Aug. 2021. Available: https://doi.org/10.14202/vetworld.2021.1988-1994

[4] I. M. Al-Ani, R. I. Santosa, M. H. Yankuzo, A. K. Saxena, and K. S. Alazzawi, "The Antidiabetic Activity of Curry Leaves 'Murraya Koenigii' on the Glucose Levels, Kidneys, and Islets of Langerhans of Rats with Streptozotocin Induced Diabetes," Makara J. Health Res. [Online], vol. 21, no. 2, Aug. 2017. Available: https://doi.org/10.7454/msk.v21i2.7393

[5] J. A. N. Sandamali, R. P. Hewawasam, K. A. P. W. Jayatilaka, and L. K. B. Mudduwa, "Cardioprotective Potential of Murraya koenigii (L.) Spreng. Leaf Extract against Doxorubicin-Induced Cardiotoxicity in Rats," Evid.-Based Complement. Altern. Med. [Online], vol. 2020, Jan. 2020. Available: https://doi.org/10.1155/2020/6023737

[6] R. S. Phatak, C. C. Khanwelkar, S. M. Matule, K. D. Datkhile, and A. S. Hendre, "Antihyperlipidemic Activity of Murraya koenigii Leaves Methanolic and Aqueous Extracts on Serum Lipid Profile of High Fat-Fructose Fed Rats," Pharmacogn. J. [Online], vol. 11, no. 4, pp. 836–841, Jul. 2019. Available: https://doi.org/10.5530/pj.2019.11.134

[7] J. Jelita, B. Wirjosentono, Tamrin, and L. Marpaung, "Phytochemical Screening and Chemical Analysis of Ethanol Extract of Kari Leaves (Murayya koeginii) Using GC-MS Method," J. Phys. Conf. Ser., vol. 1232, p. 012012, 2019.

[8] C. Katariya and R. Arjunkumar, "Antimicrobial effect of curry leaves on Staphylococcus aureus – An In vitro Study," Res. J. Pharm. Technol. [Online], vol. 12, no. 7, p. 3318, Jan. 2019. Available: https://doi.org/10.5958/0974-360x.2019.00559.6

[9] M. A. A. Arif et al., "Phytochemical Analysis of Curry Leaf Extract (Murraya koenigii L.) as a Potential Animal Feed and Medicinal Ingredient," Pharmacogn. J. [Online], vol. 16, no. 2, pp. 471–477, May 2024. Available: https://doi.org/10.5530/pj.2024.16.75

[10] W. C. Evans, Trease and Evans' Pharmacognosy [Online], 1978. Available: http://182.160.97.198:8080/xmlui/handle/123456789/547
[11] M. E. Mace, "Histochemical localization of phenols in healthy and diseased banana roots," Physiol. Plant., vol. 16, no. 4, pp. 915–925, Oct. 1963. Available: https://doi.org/10.1111/j.1399-3054.1963.tb08367.x
[12] J. B. Harborne, Phytochemical Methods: A Guide to Modern Techniques of Plant Analysis, 3rd ed., London, UK: Chapman and Hall, 1998. Available: https://link.springer.com/book/9780412572609
[13] R. L. Whistler and J. N. BeMiller, Eds., Industrial Gums: Polysaccharides and Their Derivatives, 3rd ed., San Diego: Academic Press, 1993.
[14] A. Yasuma and T. Ichikawa, "Ninhydrin-Schiff and alloxan-Schiff staining; a new histochemical staining method for protein," J. Lab. Clin. Med., vol. 41, no. 2, pp. 296–299, 1953. PMID: 13035263.
[15] G. E. Trease and W. C. Evans, Pharmacognosy, 11th ed., London: Bailliere Tindall, 1989, pp. 45–50.
[16] H. Wagner, Pharmazeutische Biology, 5th ed., Stuttgart, Germany: Gustav Fischer Verlag, 1993.
[17] X. S. Wagner, Z. Bladt, and E. M. Suie, Plant Drug Analysis, Berlin, Germany: Springer-Verlag, 1996, p. 360.
[18] D. Waldi, "Spray Reagents for Thin-Layer Chromatography," in E. Stahl, Ed., Thin Layer Chromatography: A Laboratory Handbook, New York, NY, USA: Academic Press, 1965.
[19] S. Ramakrishnan, K. G. Prasannan, and R. Rajan, Textbook of Medical Biochemistry, New Delhi: Orient Longman, 1994.
[20] C. K. Kokate, Practical Pharmacognosy, 4th ed., New Delhi: Vallabh Prakashan, 1999.
[21] D. D. Fisher, "Protein staining of ribboned epon sections for light microscopy," Histochem., vol. 16, pp. 81–96, 1968.
[22] A. C. Ruthmann, Methods in Cell Research, New York: Cornell Univ. Press, 1970.
[23] P. B. Gahan, Plant Histochemistry and Cytochemistry: An Introduction, Florida: Academic Press, 1984.
[24] V. L. Singleton, R. Orthofer, and R. M. Lamuela-Raventós, "Analysis of total phenols and other oxidation substrates and antioxidants by means of folin-ciocalteu reagent," in Methods in Enzymology [Online], 1999, pp. 152–178. Available: https://doi.org/10.1016/s0076-6879(99)99017-1
[25] A. Meda, C. E. Lamien, M. Romito, J. Millogo, and O. G. Nacoulma, "Determination of the total phenolic, flavonoid and proline contents in Burkina Fasan honey, as well as their radical scavenging activity," Food Chem. [Online], vol. 91, no. 3, pp. 571–577, Dec. 2004. Available: https://doi.org/10.1016/j.foodchem.2004.10.006
[26] E. W. C. Chan, Y. Y. Lim, and M. Omar, "Antioxidant and antibacterial activity of leaves of Etlingera species (Zingiberaceae) in Peninsular Malaysia," Food Chem., vol. 104, no. 4, pp. 1586–1593, 2007.
[27] AOAC, Official Methods of Analysis, 17th ed., Gaithersburg, MD: Assoc. of Official Analytical Chemists, 2000.
[28] N. S. Ncube, A. J. Afolayan, and A. I. Okoh, "Assessment techniques of antimicrobial properties of natural compounds of plant origin: current methods and future trends," Afr. J. Biotechnol. [Online], vol. 7, no. 12, pp. 1797–1806, Jun. 2008. Available: https://doi.org/10.5897/ajb07.613
[29] K. T. Yee, M. I. Ibrahim, T. M. Nwe, M. M. Thwin, M. M. Lwin, K. C. Aung, M. S. Oo, S. Z. Raduan, and M. S. Yi, "Bioactive compounds screening, antimicrobial activities of leaf extract from two palatable plants: Piper betle and Murraya koenigii (Curry leaves)," Res. J. Pharm. Technol., vol. 16, no. 3, pp. 1452–1458, 2023.
[30] D. R. Rajwanshi and D. R. Mittal, "Phytochemical analysis of curry leaves," Int. J. Sci. Res., vol. 8, no. 9, 2018. [Online]. Available: https://www.ijsr.net/archive/v8i9/ART2020982.pdf
[31] S. A. Adefegha and G. Oboh, "Cooking enhances the antioxidant properties of some tropical green leafy vegetables," Afr. J. Biotechnol., vol. 10, no. 4, pp. 632–639, 2011. doi: 10.5897/AJB10.875
[32] M. Şengül, H. Yildiz, and A. Kavaz, "The effect of cooking on total polyphenolic content and antioxidant activity of selected vegetables," Int. J. Food Prop. [Online], vol. 17, no. 3, pp. 481–490, Apr. 2013. Available: https://doi.org/10.1080/10942912.2011.619292
[33] K. Geetha, S. Hulamani, and H. B. Shivaleela, "Effect of cooking on total antioxidant activity, polyphenols and flavanoid content in commonly consumed vegetables," Int. J. Curr. Microbiol. Appl. Sci. [Online], vol. 7, no. 2, pp. 1459–1466, Feb. 2018. Available: https://doi.org/10.20546/ijcmas.2018.702.176
[34] L. Chin, N. Therdthai, and W. Ratphitagsanti, "Effect of conventional and microwave cooking conditions on quality and antioxidant activity of Chinese kale (Brassica alboglabra)," Appl. Food Res. [Online], vol. 2, no. 1, Mar. 2022. Available: https://doi.org/10.1016/j.afres.2022.100079
[35] S. Wachtel-Galor, K. W. Wong, and I. F. F. Benzie, "The effect of cooking on Brassica vegetables," Food Chem. [Online], vol. 110, no. 3, pp. 706–710, Apr. 2008. Available: https://doi.org/10.1016/j.foodchem.2008.02.056
[36] A. Hossain, M. A. Khatun, M. Islam, and R. Huque, "Enhancement of antioxidant quality of green leafy vegetables upon different cooking methods," Prev. Nutr. Food Sci., vol. 22, no. 3, pp. 216–222, 2017. doi: 10.3746/pnf.2017.22.3.216
[37] K. D. P. P. Gunathilake, K. K. D. S. Ranaweera, and H. P. V. Rupasinghe, "Effect of different cooking methods on polyphenols, carotenoids and antioxidant activities of selected edible leaves," Antioxidants [Online], vol. 7, no. 9, p. 117, Aug. 2018. Available: https://doi.org/10.3390/antiox7090117
[38] T. Alide, P. Wangila, and A. Kiprop, "Effect of cooking temperature and time on total phenolic content, total flavonoid content and total in vitro antioxidant activity of garlic," BMC Res. Notes [Online], vol. 13, no. 1, Dec. 2020. Available: https://doi.org/10.1186/s13104-020-05404-8
[39] A. B. Hassan, S. A. A. Maiman, G. M. Alshammari, M. A. Mohammed, H. F. Alhuthayli, I. A. M. Ahmed, M. A. Alfawaz, A. E. A. Yagoub, A. Fickak, and M. A. Osman, "Effects of boiling and roasting treatments on the content of total phenolics and flavonoids and the antioxidant activity of peanut (Arachis hypogaea L.) pod shells," Processes

[Online], vol. 9, no. 9, p. 1542, Aug. 2021. Available: https://doi.org/10.3390/pr9091542

[40] R. Etu, B. Offia-Olua, and A. Ukom, "Fermentation and sauteing enhances the physicochemical properties, carotenoids and the antioxidant activity of some food vegetables," Meas. Food [Online], vol. 15, Jun. 2024. Available: https://doi.org/10.1016/j.meafoo.2024.100177

[41] F. Shahidi and A. Hossain, "Importance of insoluble-bound phenolics to the antioxidant potential is dictated by source material," Antioxidants [Online], vol. 12, no. 1, p. 203, Jan. 2023. Available: https://doi.org/10.3390/antiox12010203

[42] E. Sikora, E. Cieślik, T. Leszczyńska, A. Filipiak-Florkiewicz, and P. M. Pisulewski, "The antioxidant activity of selected cruciferous vegetables subjected to aquathermal processing," Food Chem. [Online], vol. 107, no. 1, pp. 55–59, Jul. 2007. Available: https://doi.org/10.1016/j.foodchem.2007.07.023

[43] I. G. Hwang, Y. J. Shin, S. Lee, J. Lee, and S. M. Yoo, "Effects of different cooking methods on the antioxidant properties of red pepper (Capsicum annuum L.)," Prev. Nutr. Food Sci. [Online], vol. 17, no. 4, pp. 286–292, Dec. 2012. Available: https://doi.org/10.3746/pnf.2012.17.4.286

[44] E. M. El-Hamzy and M. M. Ashour, "Effect of different drying methods and storage on physico-chemical properties, capsaicinoid content, rehydration ability, color parameters and bioactive compounds of dried red Jalapeno pepper (Capsicum annuum) slices," Middle East J. Appl. Sci., vol. 6, no. 4, pp. 1012–1037, 2017. doi: 10.36632/mejasci.2017.6.4.92

[45] V. E. Nambi, R. K. Gupta, S. Kumar, and P. C. Sharma, "Degradation kinetics of bioactive components, antioxidant activity, colour and textural properties of selected vegetables during blanching," J. Food Sci. Technol. [Online], vol. 53, no. 7, pp. 3073–3082, Jul. 2016. Available: https://doi.org/10.1007/s13197-016-2280-2

[46] W. Yang, X. Lu, Y. Zhang, and Y. Qiao, "Effect of cooking methods on the health-promoting compounds, antioxidant activity and nitrate of tatsoi (Brassica rapa L. ssp. narinosa)," J. Food Process. Preserv. [Online], vol. 43, no. 8, May 2019. Available: https://doi.org/10.1111/jfpp.14008

[47] H. W. Kinyi, M. Tirwomwe, H. I. Ninsiima, and C. O. Miruka, "Effect of cooking method on vitamin C losses and antioxidant activity of indigenous green leafy vegetables consumed in western Uganda," Int. J. Food Sci. [Online], Jan. 2022. Available: https://doi.org/10.1155/2022/2088034

[48] Mst. R. Khatun, Mst. K. Khatun, Md. S. Islam, and S. Md. A. Reza, "Effect of different cooking methods on vitamin C content of some selected vegetables," Int. J. Curr. Microbiol. Appl. Sci. [Online], vol. 8, no. 10, pp. 2658–2663, Oct. 2019. Available: https://doi.org/10.20546/ijcmas.2019.810.307

[49] S. Bham, K. Raju, M. Mounica, and M. K. Sukumaran, "Effect of microwave and pressure cooking on stability of vitamin C in some selected vegetables," Int. J. Curr. Microbiol. Appl. Sci. [Online], vol. 6, no. 8, pp. 2391–2397, Sep. 2017. Available: https://doi.org/10.20546/ijcmas.2017.609.293

[50] J. Tian, J. Chen, F. Lv, S. Chen, J. Chen, D. Liu, and X. Ye, "Domestic cooking methods affect the phytochemical composition and antioxidant activity of purple-fleshed potatoes," Food Chem. [Online], vol. 197, pp. 1264–1270, Nov. 2015. Available: https://doi.org/10.1016/j.foodchem.2015.11.049

[51] S. Lee, Y. Choi, H. S. Jeong, J. Lee, and J. Sung, "Effect of different cooking methods on the content of vitamins and true retention in selected vegetables," Food Sci. Biotechnol. [Online], Dec. 2017. Available: https://doi.org/10.1007/s10068-017-0281-1

[52] K. Monalisa, J. Bhuiyan, M. Islam, and A. Sayem, "Boiling-induced changes on physicochemical, bioactive compounds, color, and texture properties of pumpkin (Cucurbita maxima)," Food Sci. Technol. Int. [Online], vol. 26, no. 4, pp. 333–343, Dec. 2019. Available: https://doi.org/10.1177/1082013219894402

[53] T. Mazzeo, D. N'Dri, E. Chiavaro, A. Visconti, V. Fogliano, and N. Pellegrini, "Effect of two cooking procedures on phytochemical compounds, total antioxidant capacity and colour of selected frozen vegetables," Food Chem. [Online], vol. 128, no. 3, pp. 627–633, Apr. 2011. Available: https://doi.org/10.1016/j.foodchem.2011.03.070

[54] P. Nisha, R. S. Singhal, and A. B. Pandit, "A study on degradation kinetics of ascorbic acid in drumstick (Moringa oleifera) during processing," J. Sci. Food Agric. [Online], vol. 84, no. 9, Jun. 2004. Available: https://doi.org/10.1002/jsfa.1864

[55] E. O. Nwaichi, "Effect of heat treatment on the antioxidant properties of Tetrapleura tetraptera, Xylopia ethiopica and Piper guineense," J. Med. Res. Dev., vol. 2, no. 3, pp. 59–63, 2013.

[56] B. V. A. P. Gunasena and R. P. N. P. Rajapakse, "Effect of cooking time and cooking temperature on antioxidant activity and antimicrobial activity of cinnamon, garlic, ginger and turmeric," in Extended Abstracts of the 1st IFSTSL Research Session, Dec. 15, 2015.

[57] Z. Breijyeh, B. Jubeh, and R. Karaman, "Resistance of Gram-Negative bacteria to current antibacterial agents and approaches to resolve it," Molecules [Online], vol. 25, no. 6, p. 1340, Mar. 2020. Available: https://doi.org/10.3390/molecules25061340

[58] P. Sutradhar, S. Ghosh, and B. K. Roy, "Effect of boiling and microwave assisted processing on the antimicrobial efficacy of vitamin–C in Emblica officinalis," Int. J. Curr. Pharm. Res. [Online], pp. 102–105, Sep. 2020. Available: https://doi.org/10.22159/ijcpr.2020v12i5.39780

[59] R. Bordoloi, N. S. Ahmed, K. C. Dora, and S. Chowdhury, "Effect of cooking on antioxidant and antimicrobial property of spices," Biochem. Cell Arch., vol. 17, pp. 361–365, 2017.