JURNAL SAINS TERAPAN VOL. 5 NO.1 2019 e-ISSN 2477-5525
p-ISSN 2406-8810

Received :	Accepted:	Published :

Effect of Cold Plasma Treatment on Total Dissolved Solids (TDS) Concentration and Functional Groups in Turmeric (*Curcuma longa*) Powder in Water

Dian Mart Shoodiqin[1*], Fadli Robiandi[2], Jesika Br Ginting[3], Angelika Putri Fadilla[4]

[1]Institut Teknologi Kalimantan
[2] Institut Teknologi Kalimantan
[3]Institut Teknologi Kalimantan
[4]Institut Teknologi Kalimantan

[*]dianms@lecturer.itk.ac.id

Abstract

Cold plasma technology (CPT) offers a promising non-thermal approach for surface modification in organic materials, impacting biopolymer physicochemical properties and solubility. Given turmeric's (Curcuma longa) limited aqueous solubility, which restricts its bioavailability and application, this study investigated the effect of CPT on turmeric powder. Specifically, dried turmeric powder was treated with cold plasma at 65 W for 0, 10, and, 20 seconds to assess its impact on total dissolved solids (TDS) and functional group modifications. Results show a significant improvement in aqueous dissolution, with the plasma-treated turmeric achieving a maximum TDS of 25.8 ppm, a 34.4% increase from the untreated sample's 19.2 ppm. Fourier-transform infrared spectroscopy (FTIR) further elucidated these changes, revealing a clear increase in polar O–H (transmittance intensity from 0.956 to 0.973) and C–O groups (transmittance intensity from 0.944-0.974 to 0.968), alongside the appearance of N–H/Amine groups (0.939-0.972 to 0.967) and a reduction in non-polar aliphatic C–H groups (transmittance intensity from 0.958 to 0.917). These modifications collectively demonstrate that cold plasma treatment effectively enhances turmeric's solubility by 34.4%, making it a highly effective technique for expanding its applications in food and pharmaceuticals.
Keywords: FTIR, Cold Plasma, Powder, Functional Groups

Abstrak

Teknologi plasma dingin (CPT) menawarkan pendekatan non-termal yang menjanjikan untuk modifikasi permukaan pada bahan organik, yang memengaruhi sifat fisikokimia dan kelarutan biopolimer. Mengingat keterbatasan kelarutan kunyit (*Curcuma longa*) dalam air, yang membatasi ketersediaan hayati dan aplikasinya, penelitian ini mengkaji pengaruh CPT pada serbuk kunyit. Secara khusus, serbuk kunyit kering diberi perlakuan plasma dingin dengan daya 65 W selama 0, 10, dan 20 detik untuk menilai pengaruhnya terhadap total zat terlarut (TDS) dan modifikasi gugus fungsional. Hasil menunjukkan adanya peningkatan signifikan dalam kelarutan air, dengan kunyit terpapar plasma mencapai TDS maksimum 25,8 ppm, meningkat 34,4% dibandingkan sampel tanpa perlakuan sebesar 19,2 ppm. Spektroskopi inframerah transformasi Fourier (FTIR) lebih lanjut memperjelas perubahan ini, mengungkap peningkatan nyata pada gugus polar O−H (intensitas transmitansi dari 0,956 menjadi 0,973) dan C−O (intensitas transmitansi dari 0,944−0,974 menjadi 0,968), disertai dengan munculnya gugus N−H/Amina (0,939−0,972 menjadi 0,967) serta penurunan gugus non-polar alifatik C−H (intensitas transmitansi dari 0,958 menjadi 0,917). Modifikasi ini secara keseluruhan menunjukkan bahwa perlakuan plasma dingin secara efektif meningkatkan kelarutan kunyit sebesar 34,4%, sehingga menjadi teknik yang sangat efektif untuk memperluas aplikasinya dalam bidang pangan dan farmasi.

Kata kunci : FTIR, Plasma Dingin, Serbuk, Gugus Fungsi

1. Introduction

In the context of rapid technological advancement in the agricultural sector, turmeric (*Curcuma longa*) has emerged as a valuable agricultural product due to its rich content of bioactive compounds. One of the most prominent constituents, curcumin, is widely recognized for its anti-inflammatory and antioxidant properties[1]. While the benefits of turmeric are well established, recent studies have explored the broader potential of cold plasma technology—particularly its ability to modify the functional groups of polymeric or organic materials exposed to plasma. Such modifications may significantly affect the diffusion behaviour of particles in aqueous environments, a key factor in various agricultural and food processing applications [2].

Cold plasma science and technology have increasingly been investigated for their applicability in addressing challenges in the agricultural and food sectors. The diverse mechanisms of action and the flexibility of cold plasma—as a standalone or integrated technology—provide a promising platform for sustainable innovation [3]. Recent developments in understanding the long-term effects of reactive plasma species and their interactions with biological systems suggest that cold plasma can be applied optimally across multiple stages in agriculture and food production [4].

Several driving factors have contributed to the growing demand for sustainable and innovative technologies in agriculture, including increasing global population, pressure on food, water, and energy resources, and stricter regulations concerning safety and long-term ecological sustainability [5]. Microbial contamination remains a persistent problem in agricultural and food systems, exacerbated by the growing concern over antimicrobial resistance [4]. Therefore, alternative approaches to microbial control—alongside strategies to reduce food allergenicity—are urgently needed. Cold atmospheric plasma has demonstrated efficacy in mitigating various biological and chemical risks and represents a transformative and sustainable intervention technology [6][7].

Addressing these challenges, this study focuses on the application of cold plasma specifically to turmeric powder, aiming to investigate changes in solubility and particle behaviour in water after plasma treatment. Cold plasma is generated by applying electrical energy, which accelerates free electrons that subsequently collide with gas molecules, initiating ionization processes [8]. The reactive plasma species formed then interact with surrounding air and the target sample—in this case, turmeric powder.

Over the past five years, various lab-scale cold plasma systems with different application modes have been tested for surface decontamination of agricultural seeds such as carrot, parsley, wheat, pepper, alfalfa, onion, radish, water grass, and maize [9]. The efficiency of microbial inactivation varies depending on the type of target microorganisms, with higher inactivation rates observed in mono-species inoculations compared to native multi-species microflora residing both on the surface and within seed structures [10].

Cold plasma has also shown potential in enhancing physicochemical properties (e.g., hydrophobicity, wettability, moisture content, enzyme activity, protein and chlorophyll levels, nitrogen content, and soluble phenolics) and physiological traits (e.g., germination rate, biomass, and overall yield) during early plant development stages [5]. Optimizing plasma parameters—such as gas type, power input, and treatment time—is crucial, with treatment duration being one of the most influential variables. Depending on system design and voltage levels, effective durations may range from 5 seconds to 30 minutes, with shorter treatments generally improving seed performance and longer exposures possibly causing negative effects [3].

Turmeric rhizomes are widely used in traditional herbal medicine and have demonstrated therapeutic benefits for inflammation, and cancer prevention [11]. Ethanol extracts of turmeric have been shown to contain high levels of phenolics and flavonoids, with phytochemical screening revealing the presence of alkaloids, tannins, saponins, and flavonoids. Quantitative analysis using the Folin-Ciocalteu method and colorimetry (with quercetin standard) found total phenolic content to be 229.0894 mg GAE/g and total flavonoid content to be 140.0666 mg QE/g extract [12].

Currently, most commercial herbal and traditional medicine preparations rely on conventional techniques [13]. In this study, turmeric powder is exposed to cold plasma for 10 seconds. To evaluate the effectiveness of this treatment, changes in particle concentration in water are assessed through Total Dissolved Solids (TDS) measurements and dissolution time analysis [14]. Linear regression is used to describe the rate of change. The concentration changes are then correlated with chemical modifications in the functional groups, analyzed using Fourier-transform infrared spectroscopy (FTIR) [15].

FTIR analysis provides insights into the chemical structure and functional group alterations in the turmeric samples, revealing shifts in transmittance intensity that indicate changes induced by plasma treatment. These findings are expected to contribute to the broader application of turmeric in the food and pharmaceutical industries, while also advancing the development of cold plasma-based technologies for processing herbal materials. Therefore, this research aims to offer an effective and efficient solution to improve turmeric solubility, with broader implications for product development and industrial applications.

2. Research Method

In this study, turmeric (*Curcuma longa*) powder was prepared by drying fresh turmeric slices using a food dehydrator at 70 °C for 12 hours, followed by grinding and sieving to obtain a uniform particle size of 200 mesh [16]. The resulting powder was then subjected to cold plasma treatment using a plasma reactor operating at 65 watts for 0, 10, 20 seconds under atmospheric conditions [2]. During treatment, the generated plasma interacted with the surrounding air and subsequently with the surface of the turmeric particles. After plasma exposure, 1 gram of both treated and untreated turmeric powder was dissolved in a fixed volume of distilled water, stirred, and filtered to obtain an aqueous extract. The Total Dissolved Solids (TDS) concentration was measured using a digital TDS meter to evaluate the effect of plasma treatment on the solubility of turmeric in water. In addition, Fourier Transform Infrared (FTIR) spectroscopy was performed on both treated and untreated samples to analyze changes in functional groups, using a spectral range of 4000–500 cm^{-1}. The resulting spectra were compared to identify shifts in peak positions and intensities that indicate chemical modifications induced by plasma exposure.

Table 1. Sample specification

No.	Detail	Notes
1	Turmeric powder without plasma treatment	200 mesh
2	Turmeric powder with plasma treatment	200 mesh with 0, 10, and 20 seconds treatment

3. Result

Total Dissolved Solids (TDS) is a critical parameter used to measure the overall concentration of dissolved substances within a solution. In the context of turmeric (Curcuma longa), TDS analysis provides valuable insights into the extractability of bioactive and soluble compounds, such as curcumin, and their implications for product quality in food and pharmaceutical applications [17]. This study aimed to compare TDS variations in plasma-treated and untreated turmeric powder samples by employing a linear regression model to describe the rate of change over time.

The linear regression analysis of the collected data yielded two distinct models corresponding to the plasma-treated and untreated turmeric samples. The regression equation for the untreated turmeric was $y = 0.0471x - 2.811$, while for the 10 seconds plasma-treated turmeric it was $y = 0.02731x + 6.61085$, and for the 10 seconds plasma-treated turmeric it was $y = 0.03282x - 1.9127$. The regression coefficients, 0.0471, 0.02731, and 0.03282 respectively, represent the rate of TDS change per second. These results indicate that the rate of TDS increase was higher in the plasma-treated sample, suggesting that plasma treatment enhances the dissolution process of turmeric's soluble constituents [7].

An additional significant observation concerns the time at which a notable increase in TDS begins. In the untreated turmeric sample, a marked change in TDS was observed starting at approximately 160 seconds (Figure 1), whereas in the plasma-treated sample, the shift occurred much earlier, at around 60 seconds (Figure 2). This time difference implies that plasma treatment accelerates the onset of dissolution, likely due to more efficient physicochemical interactions between the plasma-modified particles and water [18]. The rapid onset of solubilization suggests improved hydrophilicity and water dispersibility of the treated powder, reinforcing the potential of cold plasma treatment to enhance the extraction efficiency of turmeric’s soluble compounds [19].

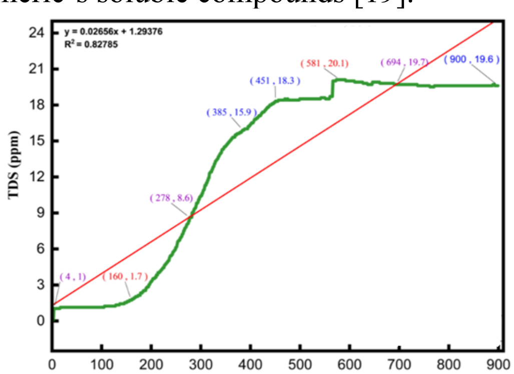

Figure 1. Time-TDS graph of turmeric powder without plasma treatment

Furthermore, the analysis also considered the maximum TDS values attained for each sample. The untreated turmeric sample reached a peak TDS value of 19.2 ppm, while the plasma-treated sample achieved a higher maximum of 25.8 ppm (for 10 seconds treatment) although reached at lower point when treated with 20 seconds plasma (22.4 ppm). This further supports the hypothesis that cold plasma treatment facilitates increased solubility and promotes the release of dissolved substances from turmeric powder.

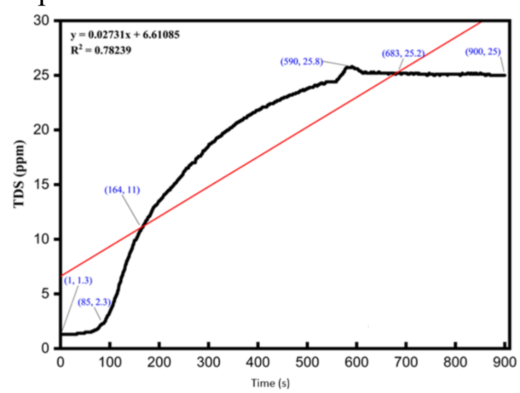

Figure 2. Time-TDS graph of turmeric powder with 10 seconds plasma treatment

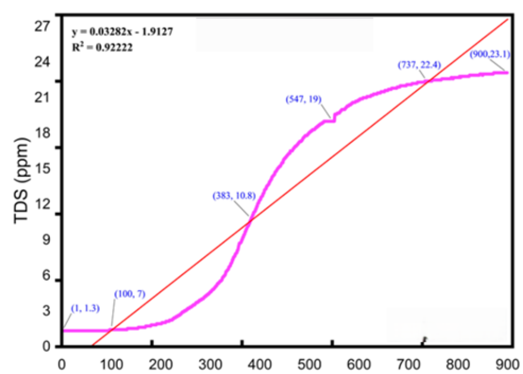

Figure 3. Time-TDS graph of turmeric powder with 20 seconds plasma treatment

The comparison of functional groups of turmeric powder before and after plasma treatment is presented in the table below.

Table 2. List of Wavenumbers in Turmeric without Plasma and Turmeric with Plasma Treatment

Functional Groups	Wave Number (cm⁻¹)	Transmittance Intensity of Turmeric without Plasma	Transmittance Intensity of Turmeric with Plasma

		Treatment	Treatment
O-H Stretching	3237 - 3283	0.956	0.973
C-H Stretching (Alkane)	2914 - 2915	0.958	0.917
C=O Stretching (Carbonil)	1742	0.976	No significant peak
C=C (Aromatic atau Alkene)	1596 - 1624	0.946 - 0.970	0.968
C-O Stretching	1277 - 1280	0.944 - 0.974	0.968
C-H Bending (Alkane)	1373	0.953 - 0.978	0.968
N-H / Amine	1507 - 1509	0.939 - 0.972	0.967
C≡N or C=O Carbonate	2356	-	0.941
O-H Stretching (Alcohol)	3687 - 3912	0.972 - 0.973	-

The variation in water solubility between untreated turmeric powder (hereafter referred to as the first sample) and plasma-treated turmeric powder (second sample) can be elucidated through an analysis of functional groups using Fourier Transform Infrared Spectroscopy (FTIR). Functional group identification and corresponding transmittance intensities, summarized in the comparative table. 2 and figure 3, reveal key modifications in the chemical structure induced by plasma exposure. These changes offer insights into how plasma treatment affects the physicochemical properties of turmeric, particularly its solubility in water [2].

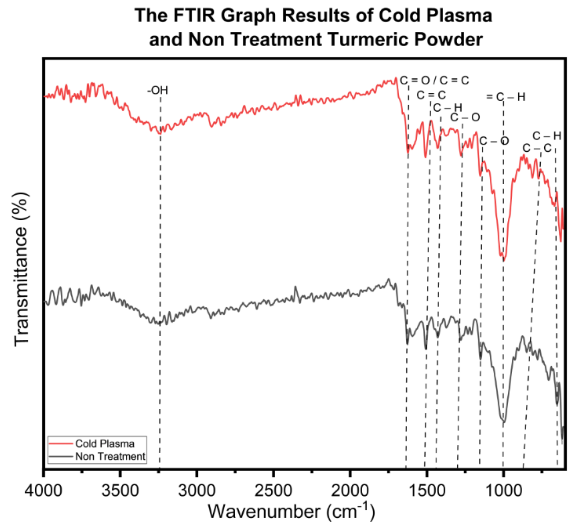

Figure 3. FTIR graph result of cold plasma and non-Plasma treatment

The O–H stretching vibrations, detected at 3237–3283 cm^{-1}, exhibited a transmittance intensity of 0.956 in the first sample and 0.973 in the second. Due to their high polarity, O–H groups significantly enhance water solubility through hydrogen bonding interactions. The increased intensity in the second sample suggests a higher concentration of hydroxyl groups following plasma treatment. This enhancement may result from plasma-induced ionization processes that introduce new hydroxyl groups or oxidize existing moieties into hydroxyl functionalities. Thus, the observed increase in O–H groups is a primary contributor to the improved aqueous solubility of the plasma-treated sample[20].

The C–H stretching region, appearing at 2914–2915 cm^{-1}, showed a decrease in transmittance from 0.958 (first sample) to 0.917 (second sample). These peaks correspond to alkane structures, which are inherently non-polar and hydrophobic. The reduced intensity in the second sample indicates a decrease in alkane content, likely due to structural modifications induced by plasma[2]. Such a reduction in non-polar content enhances the hydrophilic character of the material, thereby improving solubility.

In the first sample, a distinct peak at 1742 cm^{-1} with an intensity of 0.976 indicates the presence of carbonyl groups. This peak was absent in the second sample, suggesting the transformation or degradation of C=O groups due to plasma treatment. The disappearance of this functional group could indicate oxidation into more hydrophilic groups (e.g., hydroxyls), contributing to an overall increase in material polarity and solubility[2].

The C=C stretching bands, associated with aromatic or alkene structures, appeared within 1596–1624 cm^{-1}. The first sample showed transmittance intensities ranging from 0.946 to 0.970, while the second exhibited a slightly elevated intensity of 0.968. These groups are less polar and have limited influence on solubility. The minor variations observed suggest minimal structural alteration due to plasma, with only a modest impact on water interaction properties.

The C–O stretching vibrations observed at 1277–1280 cm^{-1} increased in intensity from 0.944 (first sample) to 0.968 (second sample). These groups, typically present in alcohols, esters, and ethers, support water solubility through dipole–dipole and hydrogen bonding interactions. The increase in C–O content following plasma treatment indicates molecular restructuring that enhances the hydrophilicity of the turmeric powder[21].

N–H stretching vibrations, found at 1507–1509 cm^{-1}, showed an increase in intensity from 0.939 in the untreated sample to 0.967 in the plasma-treated one. As polar functional groups capable of hydrogen bonding, the increased presence of N–H groups suggest successful chemical modification by plasma. This modification promotes enhanced molecular interactions with water molecules, further supporting increased solubility[21].

A peak at 2356 cm^{-1} was observed exclusively in the second sample, with a transmittance intensity of 0.941. This region may correspond to the formation of nitrile (C≡N) or new carbonyl (C=O) groups as a direct result of plasma exposure. Although these groups are less influential than O–H and N–H in solubility enhancement, their presence indicates substantial chemical alterations that contribute to increased material polarity.

At 1373 cm^{-1}, C–H bending vibrations showed intensities of 0.953 in the first sample and 0.968 in the second. This suggests a decrease in non-polar alkane bonds and supports the hypothesis of conversion into more polar structures, contributing to an overall increase in hydrophilicity.

The high-wavenumber O–H stretching region (3687–3912 cm^{-1}), which was clearly present in the first sample with intensities between 0.972–0.973, was absent in the second sample. This disappearance suggests possible conversion of specific alcohol-based O–H groups into other functional groups during plasma treatment, likely contributing to the broader chemical transformation of the material.

The comparative FTIR analysis demonstrates that plasma treatment induces significant chemical modifications in turmeric powder, leading to increased water solubility. These modifications are primarily characterized by the enhancement of polar functional groups such as O–H, C–O, and N–H, as well as the reduction or transformation of non-polar groups such as alkane C–H and carbonyl C=O. Specifically, the observed increase in O–H stretching (3237-3283 cm^{-1}) and C–O stretching (1277-1280 cm^{-1}) corresponds to the hydroxyl and methoxy groups abundant in curcumin's phenolic and enol structures, indicating an enhanced presence or accessibility of these hydrophilic sites on the turmeric surface. Concurrently, the reduction in aliphatic C–H stretching (2914-2915 cm^{-1} and 1373 cm^{-1}), characteristic of the hydrophobic alkyl chains within curcumin and related compounds, further supports a shift towards a more hydrophilic surface. The significant reduction or absence of the C=O stretching peak at 1742 cm^{-1} in the treated sample, which can be attributed to ketone groups in curcumin, suggests a modification of these carbonyl functionalities by the plasma. Furthermore, the increased transmittance intensity for N–H/Amine groups (1507-1509 cm^{-1}) after plasma treatment points to the formation of new nitrogen-containing polar functionalities on the surface. These observed changes in key functional groups, consistent with the molecular structure of curcumin, elucidate how plasma treatment alters the surface chemistry to enhance interaction with water, thereby improving the overall solubility of turmeric. The resulting increase in hydrophilicity highlights the effectiveness of plasma treatment as a surface engineering technique to improve the solubility of turmeric-based materials[21]. These findings have promising implications for applications in the pharmaceutical and food industries, particularly for enhancing the bioavailability and functional performance of turmeric-derived compounds.

4. Conclusion

Turmeric subjected to plasma treatment exhibits a higher rate of TDS (Total Dissolved Solids) increase, more rapid and significant changes, and reaches a greater maximum TDS value compared to untreated turmeric. FTIR analysis reveals that plasma treatment enhances the presence of polar functional groups such as O–H, N–H, and C–O, while reducing non-polar groups such as C–H, thereby increasing the hydrophilicity and water solubility of the turmeric powder. These findings demonstrate that plasma treatment is an effective method for improving the solubility of turmeric.

5. Suggestion

Further research is needed on the treatment of turmeric powder using ball milling to evaluate the effectiveness of cold plasma in comparison. Such studies would allow for a direct assessment of the relative impact of cold plasma treatment versus mechanical modification through ball milling on the physicochemical properties and solubility of turmeric powder.

6. References

[1] B. Jyotirmayee and G. Mahalik, "A review on selected pharmacological activities of Curcuma longa L," *Int. J. Food Prop.*, vol. 25, no. 1, pp. 1377–1398, 2022, doi: 10.1080/10942912.2022.2082464.

[2] R. C. P. Jawaharlal Nehru Garimella, "Effect of (multi pin) atmospheric cold plasma treatment on curcumin extraction and investigating phytochemicals, antioxidants, physical and morphological properties of turmeric (Curcuma longa L.) powder," *Food Chem.*, vol. 449, 2024, doi: https://doi.org/10.1016/j.foodchem.2024.139233.

[3] N. N. Misra, X. Yepez, L. Xu, and K. Keener, "In-package cold plasma technologies," *J. Food Eng.*, vol. 244, no. September 2018, pp. 21–31, 2019, doi: 10.1016/j.jfoodeng.2018.09.019.

[4] P. Bourke, D. Ziuzina, L. Han, P. J. Cullen, and B. F. Gilmore, "Microbiological interactions with cold plasma," *J. Appl. Microbiol.*, vol. 123, no. 2, pp. 308–324, 2017, doi: 10.1111/jam.13429.

[5] A. Dey, P. Rasane, A. Choudhury, J. Singh, D. Maisnam, and P. Rasane, "Cold plasma processing: A review," *J. Chem. Pharm. Sci.*, vol. 9, no. 4, pp. 2980–2984, 2016.

[6] D. A. Laroque, S. T. Seó, G. A. Valencia, J. B. Laurindo, and B. A. M. Carciofi, "Cold plasma in food processing: Design, mechanisms, and application," *J. Food Eng.*, vol. 312, no. July 2021, 2022, doi: 10.1016/j.jfoodeng.2021.110748.

[7] S. K. Pankaj, Z. Wan, and K. M. Keener, "Effects of cold plasma on food quality: A review," *Foods*, vol. 7, no. 1, 2018, doi: 10.3390/foods7010004.

[8] P. Pedrow, Z. Hua, S. Xie, and M. J. Zhu, *Engineering principles of cold plasma*. Elsevier Inc., 2019. doi: 10.1016/B978-0-12-814921-8.00001-3.

[9] F. F. Anastasia, I. R. Aziz, V. Oktaviola, and A. Iswara, "ANTIBACTERIAL ACTIVITY of COMBINATION COLD PLASMA and PARIJOTO (Medinilla speciosa) against Staphylococcus aureus and Pseudomonas aeruginosa on DIABETIC ULCER," *El-Hayah*, vol. 7, no. 4, pp. 133–138, 2020, doi: 10.18860/elha.v7i4.10313.

[10] E. C. Amalda, F. Alhamidah, Y. Oktanella, and M. Khuzain, "Kajian Artikel: Potensi Plasma Non Termal Sebagai Kandidat Terapi Mastitis Subklinis," *VITEK Bid. Kedokt. Hewan*, vol. 10, no. November, pp.

1–9, 2020, doi: 10.30742/jv.v10i0.41.

[11] A. Purba, "Identifikasi Kadar Fenol dan Flavonoid Ekstrak Etanol Rimpang Kunyit (Curcuma longa L.)," *Herb. Med. J.*, vol. 2, no. 1, pp. 18–24, 2019.

[12] A. Suhardiman, "Uji Antibakteri Rimpang Gandasuli (Hedychium Coronarium) Terhadap Bakteri Staphylococcus Aureus Dan Escherichia Coli Dengan Perbandingan Metode Ekstraksi," *J. Pharmacopolium*, vol. 1, no. 2, pp. 62–68, 2018, doi: 10.36465/jop.v1i2.326.

[13] I. Sitoresmi, S. Sujiman, and A. Maksum, "Aplikasi Keamanan Pangan dan Teknologi Pengemasan Produk Jamu Alona Guna Peningkatkan Kinerja Produk," *J. Ilm. Pangabdhi*, vol. 5, no. 1, 2019, doi: 10.21107/pangabdhi.v5i1.5160.

[14] Z. Affno, A. M. Basri, and B. F. Nore, "Formulation of Naturally Flavoured Mineral Water With Curcuma Longa," *ASEAN J. Sci. Technol. Dev.* , vol. 40, no. 3, pp. 174–180, 2023, doi: 10.61931/2224-9028.1542.

[15] A. Rohman, Sudjadi, Devi, D. Ramadhani, and A. Nugroho, "Analysis of curcumin in curcuma longa and Curcuma xanthorriza using FTIR spectroscopy and chemometrics," *Res. J. Med. Plant*, vol. 9, no. 4, pp. 179–186, 2015, doi: 10.3923/rjmp.2015.179.186.

[16] S. M. Llano, A. M. Gómez, and Y. Duarte-Correa, "Effect of Drying Methods and Processing Conditions on the Quality of Curcuma longa Powder," *Processes*, vol. 10, no. 4, pp. 1–15, 2022, doi: 10.3390/pr10040702.

[17] S. J. Hewlings and D. S. Kalman, "Curcumin: A review of its effects on human health," *Foods*, vol. 6, no. 10, pp. 1–11, 2017, doi: 10.3390/foods6100092.

[18] S. Ahmadian, F. Sohbatzadeh, F. J. Alashti, and R. E. Kenari, "Effect of surface dielectric barrier discharge plasma on the physicochemical properties of soy protein isolate-chia seed gum complex," *Food Chem. X*, vol. 28, no. December 2024, p. 102574, 2025, doi: 10.1016/j.fochx.2025.102574.

[19] A. Shabbir *et al.*, "Applications of cold plasma technique to enhance the safety and quality of different food products," *Meas. Food*, vol. 15, no. July, p. 100183, 2024, doi: 10.1016/j.meafoo.2024.100183.

[20] S. Tahmouzi, J. Sadeghizadeh-Yazdi, F. A. Mohajeri, H. Fallahzadeh, M. Mahmoudzadeh, and S. Khorram, "The Effect of the DBD Cold Plasma Process on the Physicochemical, Mechanical, and Microbial Properties of the Biodegradable Packaging Film (Based on Gelatin-Sodium Alginate) Incorporated with AgNPs to Extend the Shelf Life of Trout Fish in the Refrigerator," *Food Bioprocess Technol.*, vol. 18, no. 1, pp. 701–724, 2025, doi: 10.1007/s11947-024-03485-y.

[21] V. Hemmati, F. Garavand, M. Goudarzi, Z. Sarlak, I. Cacciotti, and B. K. Tiwari, "Cold atmospheric-pressure plasma treatment of turmeric powder: microbial load, essential oil profile, bioactivity and microstructure analyses," *Int. J. Food Sci. Technol.*, vol. 56, no. 5, pp. 2224–2232, 2021, doi: 10.1111/ijfs.14838.

e-*ISSN* 2477-5525
p-ISSN 2406-8810