

Antioxidative Properties of Extract, Fractions of *Curcuma aeruginosa* Roxb. and Curcumin Content Using TLC Method

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Abstract: Black turmeric (BT) (*Curcuma aeruginosa* Roxb.) is valuable for medicinal purposes due to its content of curcumin, essential oils, flavonoids, and saponins. This study aimed to assess the antioxidant properties of BT extract and its fractions following steam blanching. A Completely Randomized Design (CRD) was applied with varying steam blanching durations of 0, 2.5, 5.0, 7.5, and 10 min. Fractionation was conducted using petroleum benzene, chloroform, ethyl acetate, and methanol. The BT rhizomes were peeled, washed, steam-blanching, sliced, and dried in a cabinet dryer at 50-55°C for 8 hours. The dried BT was then ground and sieved to 40 mesh. Methanolic extraction was performed, followed by concentration of extracts using a rotary evaporator. The results indicated that a 5-min blanching time produced BT powder with antioxidant activity of 70.57% RSA (Radical Scavenging Activity), total phenolic content (TPC) of 14.27 mg GAE (Gallic Acid Equivalent)/g, total flavonoid content (TFC) of 0.62 mg QE (Quercetin Equivalent)/g, tannin content of 1.81 ppm ($\mu\text{g/g}$), and beta-carotene content of 70.36 $\mu\text{g/g}$, respectively. The methanol fraction of steam-blanching BT exhibited higher antioxidant activity, phenolic content, flavonoid content, tannins, and beta-carotene than other fractions. The highest antioxidant activity was observed in the methanol fraction (50.27% RSA), followed by the chloroform fraction (45.89% RSA), ethyl acetate fraction (31.46% RSA), and the petroleum ether fraction (8.32% RSA). The curcumin content of the BT methanol fraction prepared by steam blanching for 5 minutes was 1.51 ppm. BT has the potential to be used as a functional supplement to reduce oxidative stress in humans.

Keywords: black turmeric; steam blanching; antioxidative properties; fractionation; curcumin.

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1. Introduction

Spices (traditional Indonesian medicinal plants) provide various health benefits due to their antioxidant content. Antioxidants are compounds that can prevent or slow down cell damage caused by free radicals [1]. One of the widely consumed spices as a traditional

medicine is black turmeric (BT). BT is a species of the *Curcuma* genus, which belongs to the *Zingiberaceae* family. The rhizome of BT has a dark bluish-black color, a bitter taste, and a strong aroma. Essential oil from BT rhizomes has a pleasant camphor-like aroma [2]. The rhizome's essential oil has a pleasant camphor-like odor. BT contains active compounds such as curcumin, flavonoids, and saponins [3]. It also contains alkaloids, terpenes, carbohydrates, tannins, flavonoids, steroids, reducing sugars, proteins, glycosides, and quinones [4]. Traditionally, BT rhizomes have been utilized in the treatment of various illnesses, such as asthma, fever, hemorrhoids, epilepsy, leukoderma, cancer, and HIV/AIDS. Fresh BT rhizome paste (BTS) can relieve migraines, wounds, snake bites, and rheumatic pain, while boiled BT rhizomes (BTB) are used as an antidiarrheal and stomach pain reliever. BT rhizomes and leaves are aromatic due to their essential oil content, such as camphor, ar-turmerone, ar-curcumin, borneol, and bornyl acetate [5,6]. Bioactive compounds from black turmeric have health benefits, including anticancer, anti-inflammatory, cardiovascular, antiviral, and antivenom [7,8].

Blanching is a short-term heat treatment process applied to fruits or vegetables before drying [9]. Proper blanching pretreatment can enhance color, reduce microbial activity, and soften tissue texture. It also helps remove cellular gases, preventing oxidation-related corrosion. Blanching improves texture and preserves carotenoids and ascorbic acid from oxidative degradation during drying and storage [10]. Additionally, blanching can enhance the antioxidant activity of agricultural products. For instance, blanching *Curcuma mangga* Val. increased its antioxidant activity when evaluated using the FRAP (Ferric Reducing Antioxidant Power) [11] and DPPH (2,2-diphenyl-1-picrylhydrazyl) methods [12]. Previous studies reported that the Total Phenolic Content (TPC) and Total Flavonoid Content (TFC) of BT subjected to hot water blanching showed a positive correlation with its antioxidant activity [13]. BT powder treated with hot water blanching in a 0.05% citric acid solution for 5 minutes exhibited the highest antioxidant activity, suggesting its potential as a bioactive compound-rich ingredient in food products [14]. BT extract possesses various bioactive properties, including anticancer, antioxidant, antimicrobial, immunostimulant, anti-inflammatory, antipyretic, and potential uterine relaxant and anthelmintic properties. BT essential oil is effective as an antibacterial and antioxidant, while its methanol extract has been used to treat helminthic infections [15].

Several methods have been used for curcumin analysis, including Thin Layer Chromatography (TLC), based on differences in polarity and solubility of compounds in a mixture. In the TLC process, the extracted sample is initially spotted onto a chromatography plate for development. The analyte spots appear on the TLC plate after separation, which can be identified based on their absorption or fluorescence characteristics. Samples containing multiple components can be differentiated by their retention factor (R_f) values [16,17].

Previous studies have demonstrated the antimicrobial potential of *Curcuma longa* using a TLC-based bioautography method combined with ImageJ image analysis. This approach successfully identified single compounds with antimicrobial activity against various Gram-positive bacterial strains from diethyl ether and methanol extracts. The identified compounds were further confirmed using classical microdilution assays and purified through centrifugal partition chromatography with a heptane-chloroform-methanol-water solvent system (5:6:3:2) (v/v/v/v) [18]. Another study revealed that turmeric waste from extraction processes could be utilized through partial hydrothermal hydrolysis to produce new bioactive-rich products, such as deflavored and depigmented turmeric (PHDDT) and turmeric hydrolysate (TH), which

contain short-chain sugars with potential economic benefits and reduced agricultural waste [19]. Additionally, research has shown that curcumin in turmeric degrades by up to 47% within 60 minutes when heated in water, while at temperatures up to 250°C, curcumin in oil degrades by 25%, and curcumin in turmeric degrades by 70%, as analyzed by TLC [20].

Research on the extract and fractions of BT powder treated with steam blanching (BTB) remains limited. Therefore, this study aims to assess the antioxidant properties of BT extract and its fractions and determine the curcumin content of the selected fractions using the TLC method.

2. Materials and Methods

The samples of fresh black turmeric rhizome (BTF) aged 8–10 months were obtained from CV Windra Mekar, Sedayu, Bantul. The chemicals used for analysis included ethanol (Merck, 96%), BHT (Butylated Hydroxyl Toulene, Sigma), DPPH solution (2,2-diphenyl-1-picrylhydrazyl, Sigma-Aldrich) 0.1 mM, pure Folin-Ciocalteu solution (Merck), Na₂CO₃ (Merck, 20%), NaNO₂ (Merck, 10%), AlCl₃·6H₂O (Merck, 10%), NaOH (Merck, 10%), HCl (Merck), methanol (Merck), acetone (Merck), petroleum benzine (Merck), curcumin, and silica gel 60 F₂₅₄.

The equipment used included a micropipette (Acura 825), an analytical balance (Ohaus Pioneer PA214, USA), a vortex mixer (Maxi Mix II type 37600, Germany), a rotary evaporator (Buchi, Switzerland), a magnetic stirrer (Thermo Scientific, United States), a centrifuge (Ohaus, USA), a densitometer (Shimadzu, Japan), a chromatography chamber (Biostep, Germany), and a UV-Vis spectrophotometer (Genesys, USA).

2.1. Preparation of black turmeric powder.

The BTF rhizomes were sorted, peeled, washed, and subjected to steam blanching for varying durations (0, 2.5, 5, 7.5, and 10 minutes). They were then sliced (2–3 mm thick), dried in a cabinet dryer at 50–55°C for 8 hours, ground, and sieved to a 40-mesh size. The steam blanching method was adapted from [21]. The resulting powder was tested for antioxidative properties in the extracts (BTB 0, 2.5, 5, 7.5, and 10 minutes) and fractions (derived from the selected BTB extract). The selected fraction was further analyzed using TLC to determine curcumin content.

2.2. Extraction of BT powder for antioxidative property analysis.

BT powder subjected to steam blanching (0, 2.5, 5, 7.5, and 10 minutes) was weighed (1 g) and dissolved in 10 mL of ethanol. The mixture was vortexed (Maxi Mix II type 37600) and macerated for 18 hours following a modified method by [22]. The macerated samples were filtered using Whatman No. 42 filter paper and analyzed for antioxidative properties, including DPPH radical scavenging activity, TPC, TFC, β-carotene, and tannin levels. The modification in this study involved an 18-hour maceration time.

2.3. Fractionation of BT powder.

50 g of the selected BT powder (BTB 5 minutes and BTF 0 minutes as the control) was placed in a 1000 mL Erlenmeyer flask and mixed with 500 mL of methanol. The mixture was homogenized using a magnetic stirrer (Thermo Scientific, United States) for 30 minutes at 430 rpm and then macerated for 24 hours. The filtrate was filtered using Whatman No. 2 filter paper

and concentrated with a rotary evaporator (Buchi, Switzerland) at 40°C under vacuum conditions until the condensed solvent stopped dripping.

The extraction product was fractionated using a liquid-liquid method [23], as shown in Figure 1. A total of 1 g of concentrated extract (paste) was mixed with 10 mL of hot distilled water at 70°C while stirring until homogeneous. The solution was then placed in a separating funnel and mixed with 10 mL of petroleum benzine, followed by further homogenization. The solution was left to settle until two layers formed, which were then separated. The residue was further mixed with 10 mL of petroleum benzine, stirred, and separated. This step was repeated three times, yielding 30 mL and 40 mL fractions. Fractionation using chloroform, ethyl acetate, and methanol followed the same procedure, resulting in corresponding fractions. The obtained fractions included 30 mL of petroleum benzine, chloroform, and ethyl acetate, and 40 mL of methanol. The fractions were stored in dark vials at 10°C and tested for antioxidative properties.

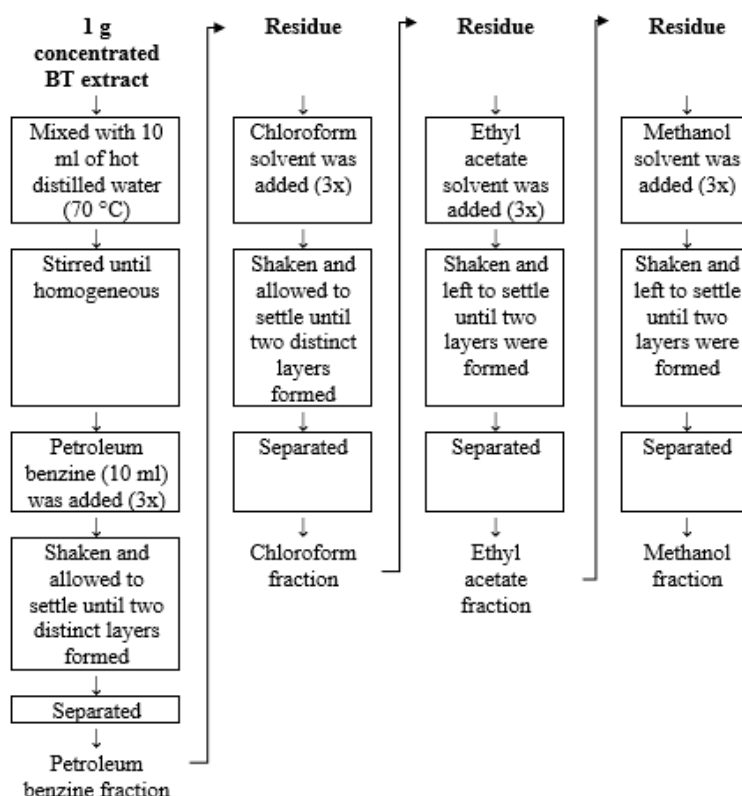


Figure 1. Fractionation method of BT powder.

2.4. Antioxidant activity analysis.

2.4.1. DPPH radical scavenging method.

A total of 0.2 mL of the sample was added to 3.8 mL of 0.1 mM DPPH solution. The mixture was then vortexed (Maxi Mix II type 37600) and left to stand for 30 minutes in a dark room at room temperature (27°C). Absorbance was determined using a spectrophotometer (Genesys, USA) at a wavelength of 517 nm, with ethanol used as the blank [24]. BHT was used as the positive control since BHT is reported to have potent antioxidant activity.

2.4.2. TPC analysis using the Folin-Ciocalteu method.

A total of 50 µL of the sample was added to 250 µL of Folin-Ciocalteu reagent, followed by the addition of 750 µL of 20% Na₂CO₃. The mixture was vortexed (Maxi Mix II

type 37600) and then diluted with distilled water to a final volume of 5 mL. The sample was incubated for 2 hours at room temperature (27°C), and its absorbance was measured at 760 nm using a spectrophotometer (Genesys, USA) [25].

2.4.3. TFC analysis.

A total of 50 µL of the sample was taken and mixed with 4 mL of distilled water and 0.3 mL of 10% NaNO₂. The mixture was left to stand for 6 minutes before adding 0.3 mL of 10% AlCl₃.6H₂O. After standing for 5 minutes, 4 mL of 10% NaOH was added. The solution was diluted to 10 mL with distilled water, vortexed (Maxi Mix II type 37600), and its absorbance was measured at 510 nm using a spectrophotometer (Genesys, USA). Quercetin was used as the standard, and the total flavonoid content was expressed as mg Quercetin Equivalent (QE)/g [26].

2.4.4. β-carotene analysis.

β-Carotene analysis was conducted using a modified method [27]. The modification applied was a total homogenization time of 10 minutes for the sample. A total of 1 g of the sample was placed into a 100 mL test tube, followed by the addition of 5 mL of 95% ethanol, and then vortexed (Maxi Mix II type 37600). A total of 20 mL of petroleum benzine was added, and the mixture was vortexed again. The mixed sample was separated into residue and filtrate using a separatory funnel. A total of 1 mL of the yellow layer (filtrate) containing β-carotene was transferred into a tightly closed test tube. Then, 2 mL of petroleum benzine was added, and the sample was vortexed. Absorbance was measured at 450 nm using a spectrophotometer (Genesys, USA).

2.4.5. Tannin content analysis.

Condensed tannin content was analyzed by adding 50 µl of the sample to 3 mL of 4% methanolic vanillin solution and 1.5 mL of concentrated HCl. The mixture was vortexed (Maxi Mix II type 37600) for 2 minutes, and its absorbance was measured at 500 nm using a spectrophotometer (Genesys, USA). Condensed tannin content was expressed as mg Catechin Equivalent (CE)/g dry basis using a calibration curve (8.9–44.4 mg/l) with $r = 0.99$ [28].

2.5. Curcumin analysis of methanol fraction using the TLC method.

Curcumin analysis began with the preparation of a curcumin standard. A total of 1 mL of the selected fraction was taken, and 20 µl was spotted onto a TLC plate coated with silica gel 60 F₂₅₄ using a microsyringe. The plate was placed into a chamber (Biostep, Germany) pre-filled with a mobile phase consisting of toluene: glacial acetic acid (8:2) and was eluted until reaching the limit. The plate was removed and left to dry, and the curcumin content was determined using a densitometer (Shimadzu, Japan) at 425 nm [29].

2.6. Statistical analysis.

A Completely Randomized Design (CRD) was applied, considering variations in steam blanching time (0, 2.5, 5, 7.5, and 10 minutes) and different solvents used for fractionation (petroleum benzine, chloroform, ethyl acetate, and methanol). Data were analyzed using

Analysis of Variance (ANOVA), and if significant differences were found, Duncan's Multiple Range Test (DMRT) was performed using SPSS software.

3. Results and Discussion

3.1. Extract analysis of black turmeric.

Table 1 showed a significant difference ($P < 0.05$) in the antioxidant activity of BT powder with steam blanching treatment (BTB). The BTB for 5 minutes exhibited the highest antioxidant activity, which was 70.57% RSA. Blanching beyond the optimal time (5 minutes) showed a decrease in antioxidant activity. The preliminary blanching treatment can deactivate the polyphenol oxidase enzyme. A study by Dewanto *et al.* [26] reported that blanching increases the antioxidant activity of white turmeric compared to unblanched turmeric. The study showed that a 5-min blanching process significantly inactivates polyphenol oxidase in white turmeric [25]. The polyphenol oxidase enzyme in white turmeric causes browning, which impacts the product quality. This is in line with the findings of [31], which reported that blanching lily tubers at 95-100°C can reduce browning. Blanching using the microwave method for 3-5 minutes can preserve antioxidant activity and reduce browning in the peels of mango, apple, orange, and banana [32].

Table 1. The results of chemical analysis of black turmeric powder.

Steam blanching treatment (min)	Antioxidant activity (% RSA)	Total phenolics (mg EAG/g bk)	Flavonoids (mg QE/g)	Tannins (ppm (μ /g))	Beta-carotene (μ g/g)
BTF 0	64.01 \pm 0.46 ^b	9.69 \pm 0.04 ^b	0.59 \pm 0,00 ^{bc}	1.60 \pm 0.01 ^c	66.95 \pm 1.23 ^a
BTB 2.5	66.43 \pm 0.15 ^c	11.03 \pm 0.00 ^c	0.61 \pm 0,00 ^{cd}	1.81 \pm 0.00 ^d	70.31 \pm 0.00 ^b
BTB 5	70.57 \pm 0.15 ^c	14.27 \pm 0.16 ^d	0.62 \pm 0,00 ^d	1.81 \pm 0.00 ^d	70.36 \pm 1.25 ^b
BTB 7.5	68.71 \pm 0.31 ^d	11.15 \pm 0.04 ^c	0.58 \pm 0,01 ^{ab}	1.57 \pm 0.01 ^b	74.94 \pm 1.27 ^c
BTB 10	61.38 \pm 0.15 ^a	8.56 \pm 0.02 ^a	0.56 \pm 0,01 ^a	1.44 \pm 0.01 ^a	76.56 \pm 1.27 ^c

Different letter notations in the column indicate significant differences at a 95% significance level; BTB: BT powder from steam blanching; BTF: fresh BT powder.

The total phenolic content in Table 1 shows that BTB is significantly higher than that of the fresh sample. BTB treated for 5 minutes exhibited the highest total phenolic content of 14.27 mg GAE/g dry weight. This is likely because the steam blanching process can cause cell wall rupture, allowing bound phenolic compounds to be released and easily extracted. The study by [33] showed that the total phenolic content in elephant apple fruit increased due to high-temperature treatment (30-50°C).

The total flavonoid content of BT is expressed in mg quercetin equivalent (QE)/g sample, ranging from 0.56 to 0.62 mg QE/g. Research conducted by Tien *et al.* [34] also showed that broccoli that was blanched had a greater total phenolic value than broccoli without blanching. The highest flavonoid content was found in BTB treated for 5 minutes. The steam blanching treatment of BT powder resulted in a higher total flavonoid content than the fresh sample. This aligns with previous research stating that blanching *the bangle rhizome extract with 0,05% citric acid increases* antioxidant activity compared to non-blanching [35].

The condensed tannin content in BT powder ranged from 1.44 to 1.81 ppm (μ g/g). The condensed tannin content increased up to 5 minutes of blanching, but beyond that, it decreased. Since tannins are water-soluble, their levels decline with extended blanching. According to Pujimulyani *et al.* [14], heat treatment of tannins in black turmeric prepared using hot water blanching showed a significant increase in antioxidant activity compared to non-blanching black turmeric.

The beta-carotene content in steam-blached BT powder ranged from 66.95 to 76.56 µg/g. The highest beta-carotene content was observed in BTB treated for 7.5 minutes and 10 minutes, with no significant difference between them. The lowest beta-carotene content was found in the untreated BTB sample, measuring 66.95 µg/g. Table 1 shows that beta-carotene content tends to increase as the blanching time increases. This is consistent with the findings of Okhoca *et al.* [36], providing that blached cassava abacha has higher beta-carotene content than non-blached cassava abacha.

3.2. Color analysis of black turmeric.

The research data on BT color analysis are presented in Table 2. In color analysis, the highest L* (lightness) value was observed in the BTS sample, while the lowest value was recorded in the BTB 10-minute sample. The L* value represents the brightness or the lightness-darkness level on a scale from 0 (black) to 100 (white). The L* values of BT powder ranged from 67.18 to 69.81. A higher L* value indicates a brighter color. The steam blanching treatment significantly influenced the brightness of BT powder. Blanching in black turmeric aims to improve physical properties, including increasing brightness.

Table 2. Data on BT powder color analysis.

Steam blanching treatment (min)	L*	a*	b*
BTF 0	69.81±0.06 ^c	3.56±0.02 ^b	20.48±0.55 ^a
BTB 2.5	68.83±0.15 ^b	3.86±0.01 ^d	21.78±0.13 ^{bc}
BTB 5	69.64±0.11 ^c	3.76±0.02 ^c	21.36±0.10 ^b
BTB 7.5	69.46±0.09 ^c	3.86±0.14 ^d	22.38±0.10 ^c
BTB 10	67.18±0.24 ^a	2.35±0.04 ^a	20.62±0.02 ^a

Different letter notations in the column indicate significant differences at a 95% significance level; BTB: BT powder from steam blanching; BTF: fresh BT powder.

The a* (redness) value represents the position of color on a scale from green (negative) to red (positive). A negative value indicates a greenish hue, while a positive value signifies a reddish hue. The a* values of BT powder ranged from 2.35 to 3.86. The data showed that prolonged blanching decreased redness intensity. This was due to heat exposure during blanching, which triggered oxidation of red pigments, resulting in a reduction in color intensity.

The b* (yellowness) value indicates the yellowish tendency of black turmeric rhizomes. The b* values of BT powder ranged from 20.48 to 22.38. The data showed that longer blanching times enhanced the yellow color up to 7.5 minutes of blanching. This occurred because blanching helps to brighten the color. The yellow color in BT powder is attributed to the presence of curcumin, a natural pigment. Curcumin is a natural yellow-orange colorant found in turmeric [37].

3.3. Fractionation analysis of black turmeric.

The fractionation analysis of BT powder was based on the best chemical analysis results, specifically BT powder subjected to steam blanching for 5 minutes, with fresh samples as the control, as presented in Table 3.

The data indicate that antioxidant activity in BT fractions ranged from 3.56% to 50.27% RSA, with BHT standard 65.27%. The FBTF fraction ranged from 3.56% to 32.32% RSA, while the FBTB fraction ranged from 8.32% to 50.27% RSA. The results showed that antioxidant activity was higher in FBTB compared to FBTF. This was due to the blanching process, which inactivated polyphenol oxidase enzymes. Blanching is known to enhance the

availability of antioxidant compounds by breaking down cell walls and facilitating the extraction of bioactive compounds.

Table 3. Antioxidant analysis and its compounds in BT powder fractionation.

Steam blanching treatment (min)	Antioxidant activity (% RSA)	Total phenolics (mg GAE/g bk)	Flavonoids (mg QE/g)	Tannins (ppm (μg/g))	Beta-carotene (μg/g)	Curcumin Content (ppm)
Benzine FBTF	3.56±0.64 ^a	2.62±0.08 ^a	0.46±0.01 ^a	1.06±0.06 ^a	65.93±1.28 ^a	ND
Chloroform FBTF	20.73±1.06 ^d	2.71±0.00 ^a	0.51±0.02 ^b	1.32±0.10 ^b	73.16±1.27 ^b	ND
Etil Asetat FBTF	15.13±0.07 ^c	2.55±0.02 ^a	0.49±0.01 ^b	1.12±0.01 ^a	66.84±2.56 ^a	ND
Metanol FBTF	32.32±0.35 ^e	6.10±0.00 ^e	0.57±0.01 ^c	2.58±0.08 ^d	64.13±1.27 ^a	1.55
Benzine FBTB	8.32±0.00 ^b	3.90±0.08 ^c	0.49±0.01 ^b	1.37±0.04 ^{bc}	73.16±3.83 ^b	ND
Kloroform FBTB	45.89±0.23 ^f	4.85±0.01 ^d	0.51±0.01 ^b	1.48±0.01 ^c	87.62±1.28 ^c	ND
Etil Asetat BTB	31.46±0.16 ^e	3.45±0.08 ^b	0.52±0.01 ^b	1.42±0.01 ^{bc}	73.16±1.27 ^b	ND
Methanol FBTB	50.27±0.31 ^g	6.64±0.33 ^f	0.58±0.00 ^c	3.10±0.06 ^e	63.68±0.64 ^a	1.51

Different letter notations in the column indicate significant differences at a 95% significance level; BTB: BT powder from steam blanching; BTF: fresh BT powder. ND = not detected with a detection limit of 0.1 ppm.

The methanol fraction in both FBTB and FBTF exhibited the highest antioxidant activity among the fractions. This is attributed to methanol's high efficiency in extracting antioxidant compounds. According to Alara *et al.* [38], methanol is frequently used as a solvent for extracting phenolic compounds due to its ability to dissolve polar compounds, such as phenolic acids, flavonoids, and tannins, which possess high antioxidant activity.

The ranking of antioxidant activity from highest to lowest was as follows: methanol fraction > chloroform fraction > ethyl acetate fraction > petroleum benzine fraction in both FBTB and FBTF. This confirms that polar solvents, such as methanol, are more effective at extracting strong antioxidant compounds than non-polar solvents, such as benzene.

Table 3 shows that the total phenol content in BT fractions ranges from 2.62 to 6.64 mg GAE/g dry basis. FBTF ranges from 2.22 to 9.52 mg GAE/g dry basis, while FBTB ranges from 2.62 to 6.10 mg GAE/g dry basis. The data indicate that the total phenol content in FBTB is significantly higher than in FBTF. This aligns with the study by Rosa-Martínez *et al.* [39], which found that boiling tomatoes at 98°C for 10 minutes significantly increased the total phenol content. This may be due to the blanching process, which enhances the extraction of phenolic compounds. Blanching can inactivate enzymes that oxidize phenols during drying, leaving more phenolic compounds in the extract. Additionally, blanching can break down rhizome cell walls, making phenolic compounds more easily extractable. Previous research has shown that blanching can increase the availability and extraction of phenolic compounds by more efficiently releasing them from plant matrices. The lowest phenolic content was found in the petroleum benzine fraction of both FBTF and FBTB. This is because this solvent is generally non-polar, while phenolic compounds are usually polar, making them less soluble in non-polar solvents like petroleum benzine. The amount of phenolic compounds extracted in the petroleum benzine fraction was very low. The methanol fraction showed the highest phenolic content in both FBTB and FBTF due to methanol's ability to dissolve polar phenolic compounds. According to Allay *et al.* [40], polar solvents like methanol are often superior in extracting phenolic compounds compared to non-polar solvents.

The flavonoid content in BT fractions ranges from 0.47 to 1.19 mg QE/g (Table 3). The flavonoid content in FBTB was higher than in FBTF. The blanching process helps to enhance the release of flavonoids from plant tissues. Blanching can inactivate enzymes that degrade flavonoids and break down cell walls, making flavonoid compounds more easily extractable. According to [41], blanching can increase the bioavailability of compounds, such as flavonoids,

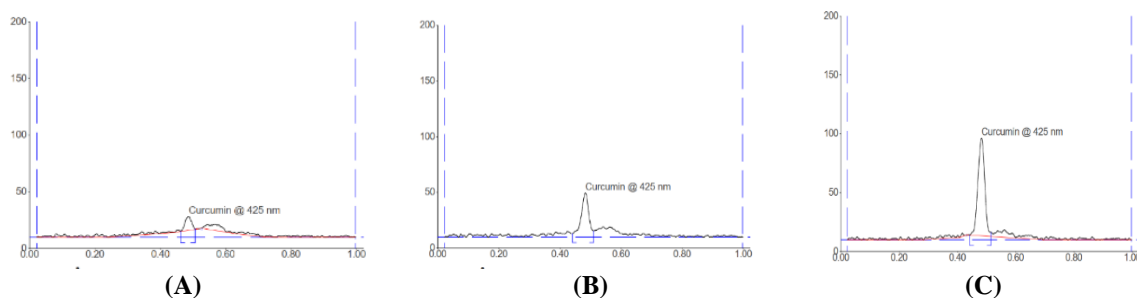
by improving the extraction efficiency from plant matrices. The order of highest to lowest flavonoid content is the methanol fraction, followed by the chloroform fraction, ethyl acetate fraction, and petroleum benzine fraction in both FBTB and FBTF. The petroleum benzine fraction had the lowest flavonoid content due to its non-polar nature, which makes it less effective at dissolving flavonoid compounds, which are generally polar. Flavonoids tend to be more soluble in solvents with moderate to high polarity. The methanol fraction showed the highest flavonoid content because methanol is a polar solvent highly effective in extracting flavonoid compounds. Methanol can dissolve compounds with similar polarity, such as flavonoids, which contain hydroxyl groups that contribute to their polarity.

Table 3 indicates that the condensed tannin content in BT fractions ranges from 0.72 to 2.88 $\mu\text{g/g}$ and shows a significant difference. The tannin content was higher in FBTB than in FBTF. This is because the blanching process can help increase tannin availability by inactivating enzymes that usually break down tannins during drying. Blanching can also disrupt cellular structures, making tannins more easily extractable. According to Magangana *et al.* [42], blanching can enhance the extraction of phenolic compounds, including tannins, by breaking down cell walls and making these compounds more accessible for extraction. The highest tannin content was found in the methanol fraction, followed by the chloroform fraction, ethyl acetate fraction, and petroleum benzine fraction. The methanol fraction had the highest tannin content because methanol effectively extracts polar tannin compounds. The petroleum benzine fraction, which is non-polar, showed the lowest tannin content because tannins tend to be less soluble in non-polar solvents. Therefore, extracting tannins using petroleum benzine is less efficient than using more polar solvents. Tannins are polyphenolic compounds commonly found in various plant parts, including leaves, bark, and roots. Tannins can bind and precipitate proteins, making them useful in various industries, such as leather tanning and food processing. Additionally, tannins are known for their antioxidant, antibacterial, and anti-inflammatory activities, which contribute to the potential health benefits of consuming tannin-rich plants.

The beta-carotene content in BT fractions ranged from 63.68% to 73.16% (Table 3), showing a significant difference. The highest beta-carotene content was found in the chloroform fraction, while the lowest was in the methanol fraction. This is because chloroform is a non-polar solvent that is more effective in extracting non-polar compounds such as beta-carotene. Beta-carotene is hydrophobic and more soluble in nonpolar solvents [43]. The chloroform fraction yielded higher beta-carotene content than the methanol fraction, which is a polar solvent and less effective in dissolving non-polar compounds such as beta-carotene.

3.4. Curcumin analysis using TLC.

TLC densitogram of curcumin standard is presented in Figure 2.



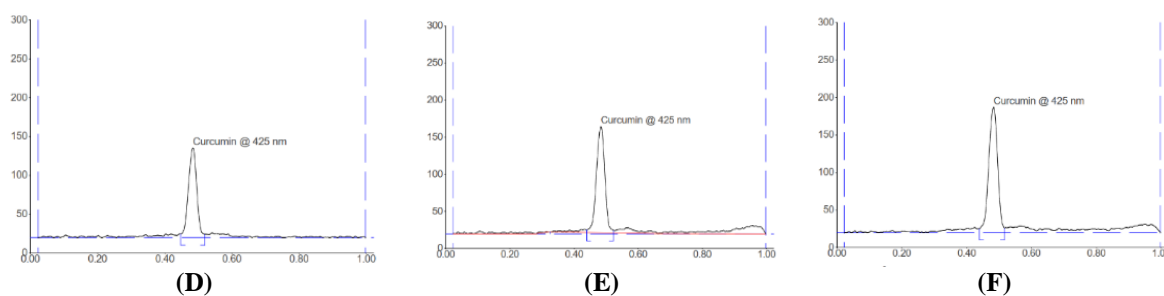


Figure 2. Densitogram of curcumin standards at concentrations: (A) 10 µg; (B) 20 µg; (C) 30 µg; (D) 40 µg; (E) 50 µg; (F) 60 µg.

The densitometric data for curcumin standards, including Rf values and peak areas at different concentrations, are presented in Table 4.

Table 4. Densitometric data of curcumin standards.

Spot	Concentration (µg)	Rf	Peak area (AU)
A	10	0.49	501.11
B	20	0.48	2077.60
C	30	0.48	4008.46
D	40	0.48	5961.62
E	50	0.48	7762.39
F	60	0.48	9524.21

The data were obtained from the TLC-densitometric analysis of curcumin standards at six different concentrations. Each spot (A–F) corresponds to curcumin standards with concentrations of 10, 20, 30, 40, 50, and 60 µg. The Rf value represents the retention factor of the curcumin spot, while the peak area (AU) was recorded from the densitogram at 425 nm and used to construct the calibration curve.

Quantification of curcumin was performed using a calibration curve constructed from TLC-densitometric analysis of curcumin standards. The peak areas of the standards at concentrations of 10–60 µg (Spot A-F) were plotted against their corresponding concentrations to obtain a linear regression equation.

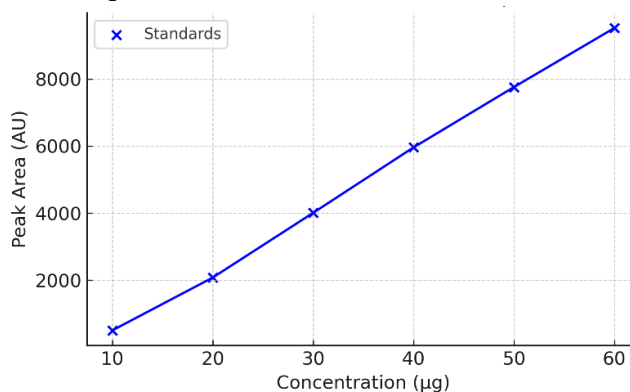


Figure 3. Calibration curve of curcumin standards obtained from TLC-densitometry (Spot A-F).

The curve shows a linear relationship between peak area and concentration of curcumin in the range of 10–60 µg with the regression equation $Y = -1440 + 183.2X$ and a correlation coefficient $r = 0.9996$.

From the fractionation results, the highest antioxidant activity was obtained in the methanol fraction of FBTB, followed by a curcumin content test using the TLC method, with the methanol fraction of FBTF as the control. The Rf value of the sample spot was found to be 0.44–0.46, aligning with the standard curcumin, confirming its presence in the methanol fraction. The densitogram of the curcumin standard and the sample is presented in Figure 3.

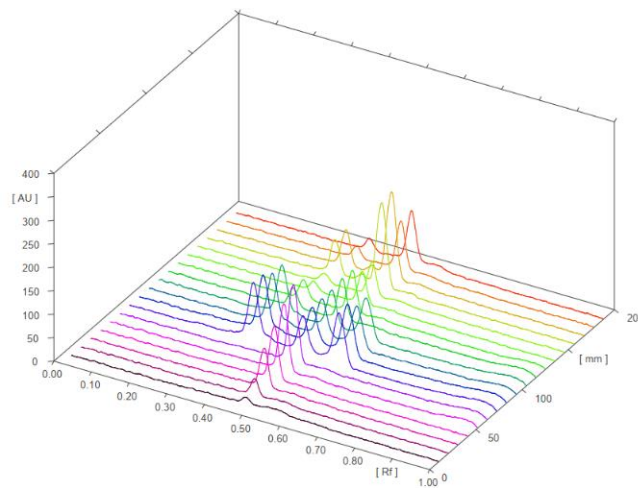


Figure 4. Densitogram of curcumin standard at a concentration of 50 ppm and a sample of BT containing curcumin.

The results of curcumin analysis by TLC on the best black turmeric fraction, as determined by chemical analysis, are presented in the methanol fraction chromatogram (Figure 4).

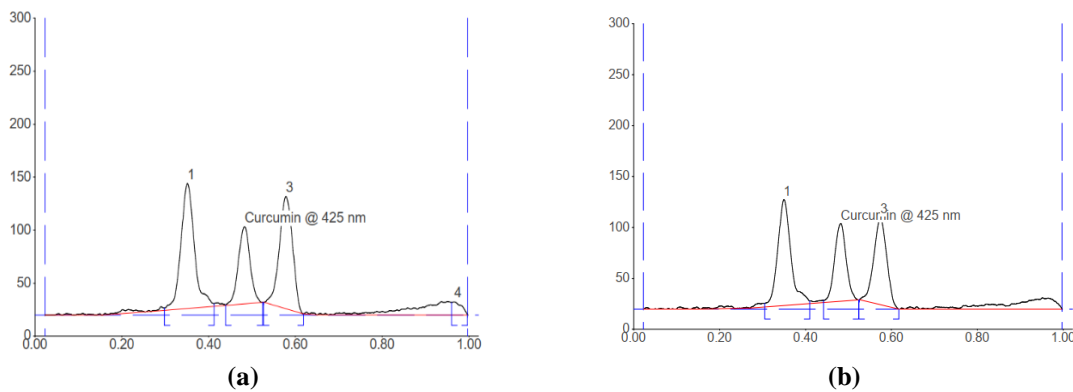


Figure 5. Curcumin chromatogram using the TLC method for the sample (a) BTB; (b) BTF (Note: peak 1: unknown; peak 2: curcumin; peak 3: unknown; peak 4: unknown).

Figure 4 shows the curcumin content in black turmeric using the Thin Layer Chromatography (TLC) method. The curcumin content in methanol FBTB is almost the same (1.55 ppm) compared to FBTB (1.51 ppm). Curcumin has antioxidant properties that are beneficial for the body. Curcumin acts as an antidepressant [44] by preventing oxidative stress and activating the Nrf2-ARE signaling pathway [45]. According to [46], curcumin can be used to treat diabetes by improving insulin resistance and lowering leptin, resistin, and insulin levels.

Methanol FBTB shows an increase in curcumin content compared to methanol FBTF. The blanching process may inactivate enzymes responsible for curcumin degradation. This is in line with [47], who stated that blanching can effectively deactivate polyphenol oxidase and peroxidase in turmeric (*Curcuma longa*). Curcumin has a hydroxyl (-OH) group that is polar, making it more soluble in polar solvents such as methanol [48]. Both fresh and blanched materials produce high curcumin content in the methanol fraction, as blanching does not significantly damage the curcumin compound. As a result, the methanol fraction can extract curcumin with high efficiency.

4. Conclusions

Based on the research results, it can be concluded that blanching for 5 minutes produced BT powder with an antioxidant activity of 70.57% RSA, total phenols of 14.27 mg GAE/g,

flavonoids of 0.62 mg QE/g, tannins of 1.81 ppm ($\mu\text{g/g}$), and beta-carotene of 70.36 $\mu\text{g/g}$. Methanol FBTB showed higher antioxidant activity, total phenols, flavonoids, tannins, and beta-carotene compared to other fractions and FBTF. The highest antioxidant activity was found in methanol FBTB with a value of 50.27% RSA, followed by chloroform FBTB with 45.89% RSA, ethyl acetate FBTB with 31.46% RSA, and petroleum benzene FBTB with 8.32% RSA. Methanol FBTB, tested using the TLC method, showed a curcumin content of 1.51 ppm, which was not significantly different from the control (methanol FBTF).

Author Contributions

Conceptualization, D.P. and B.K.; methodology, N.H.; software, E.W.; validation, A.R., D.P., and B.K.; formal analysis, E.W.; investigation, D.P.; resources, N.H.; data curation, A.R.; writing—original draft preparation, D.P.; writing—review and editing, B.K.; visualization, A.R.; supervision, N.H.; project administration, D.P.; funding acquisition, D.P. All authors have read and agreed to the published version of the manuscript.

Institutional Review Board Statement

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Informed Consent Statement

Declared none.

Data Availability Statement

Data supporting the findings of this study are available upon reasonable request from the corresponding author.

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Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

References

1. Martemucci, G.; Costagliola, C.; Mariano, M.; D'andrea, L.; Napolitano, P.; D'Alessandro, A.G. Free radical properties, source and targets, antioxidant consumption and health. *Oxygen* **2022**, *2*, 48-78, <https://doi.org/10.3390/oxygen2020006>.

2. Mahanta, B.P.; Lahon, D.; Kalita, D.; Lal, M.; Haldar, S. Study on aroma-profile, key odorants and ontogenetic variability of black turmeric (*Curcuma caesia* Roxb.) essential oil: An aroma perspective. *Industrial Crops and Products* **2023**, *193*, 116115, <https://doi.org/10.1016/j.indcrop.2022.116115>.
3. Khotimah, S.N.; Muhtadi, A. Beberapa tumbuhan yang mengandung senyawa aktif antiinflamasi. *Farmaka* **2016**, *14*, 28-40.
4. Donipati, P.; Sreeramulu, S.H. Preliminary phytochemical screening of *Curcuma caesia*. *Int. J. Curr. Microbiol. Appl. Sci.* **2015**, *4*, 30-34.
5. Ibrahim, N.N.A.; Wan Mustapha, W.A.; Sofian-Seng, N.-S.; Lim, S.J.; Mohd Razali, N.S.; Teh, A.H.; Rahman, H.A.; Mediani, A. A Comprehensive Review with Future Prospects on the Medicinal Properties and Biological Activities of *Curcuma caesia* Roxb. *Evid. Based Complement. Alternat. Med.* **2023**, *2023*, 7006565, <https://doi.org/10.1155/2023/7006565>.
6. Paudel, A.; Khanal, N.; Khanal, A.; Rai, S.; Adhikari, R. Pharmacological insights into *Curcuma caesia* Roxb., the black turmeric: a review of bioactive compounds and medicinal applications. *Discover. Plants* **2024**, *1*, 69, <https://doi.org/10.1007/s44372-024-00076-1>.
7. Orellana-Paucar, A.M. Turmeric essential oil constituents as potential drug candidates: a comprehensive overview of their individual bioactivities. *Molecules* **2024**, *29*, 4210, <https://doi.org/10.3390/molecules29174210>.
8. Oriola, A.O. Turmeric–black cumin essential oils and their capacity to attenuate free radicals, protein denaturation, and cancer proliferation. *Molecules* **2024**, *29*, 3523, <https://doi.org/10.3390/molecules29153523>.
9. Sulandari, L.; Bahar, I.A. Modul Dasar-Dasar Pengawetan Pangan. Scopindo Media Pustaka: Surabaya, **2022**.
10. Noreña, C.Z.; Rigon, R.T. Effect of blanching on enzyme activity and bioactive compounds of blackberry. *Braz. Arch. Biol. Technol.* **2018**, *61*, e18180018, <https://doi.org/10.1590/1678-4324-2018180018>.
11. Pujimulyani, D.; Raharjo, S.; Santoso, U. The effect blanching on antioxidan activity and glycosides of White Saffron (*Curcuma mangga* Val.). *Int. Food Res. J.* **2012**, *19*, 617–621.
12. Arvianasari, E.; Setiani, R.A.; Pujimulyani, D. The Effect of Concentration of Citric Acid and Blanching Time on the Antioxidation Properties of White Turmeric (*Curcuma zedoaria* (Berg) Roscoe). *Int. J. Adv. Sci. Technol.* **2020**, *29*, 1647–1653.
13. Pujimulyani, D.; Yulianto, W.A.; Setyowati, A.; Prastyo, P.; Windrayahya, S.; Maruf, A. White saffron (*Curcuma mangga* Val.) attenuates diabetes and improves pancreatic β -cell regeneration in streptozotocin-induced diabetic rats. *Toxicol. Rep.* **2022**, *9*, 1213-1221, <https://doi.org/10.1016/j.toxrep.2022.05.014>.
14. Pujimulyani, D.; Windrayahya, S.; Irnawati, I. The effects of media and blanching time on the antioxidative properties of *Curcuma aeruginosa* Roxb. *Indones. J. Pharm.* **2022**, *32*, 244-250.
15. Kanglom, C.; Singh, Y.A.; Singh, S.H. Evaluation of phytochemical constituent, antioxidant activity and anti-bacterial activity of black turmeric (*Curcuma caesia* Roxb.). *Environ. Ecol.* **2024**, *42*, 821-827, <https://doi.org/10.60151/envec/CZFU3931>.
16. Zhang, S.; Fan, Q.; Guo, J.; Jiao, X.; Kong, X.; Yu, Q. Surface-enhanced Raman spectroscopy tandem with derivatized thin-layer chromatography for ultra-sensitive on-site detection of histamine from fish. *Food Control* **2022**, *138*, 108987, <https://doi.org/10.1016/j.foodcont.2022.108987>.
17. Zhang, S.Q.; Li, J.C. An introduction to traditional Chinese medicine, including acupuncture. *Anat. Rec.* **2021**, *304*, 2359-2364, <https://doi.org/10.1002/ar.24782>.
18. Czernicka, L.; Grzegorzczak, A.; Marzec, Z.; Antosiewicz, B.; Malm, A.; Kukula-Koch, W. Antimicrobial potential of single metabolites of *Curcuma longa* assessed in the total extract by thin-layer chromatography-based bioautography and image analysis. *Int. J. Mol. Sci.* **2019**, *20*, 898, <https://doi.org/10.3390/ijms20040898>.
19. Santana, Á.L.; Meireles, M.A.A. Thin-layer chromatography profiles of non-commercial turmeric (*Curcuma longa* L.) products obtained via partial hydrothermal hydrolysis. *Food Public Health* **2016**, *6*, 15-25.
20. Roy, J.; Leake, M.E.; Barsha, A.S.; Sherpa, T.L.; Adebowale, A.; Heda, G.; Roy, W.; Yarborough, L. Thin layer chromatographic analysis of stability of curcumin and curcumin in turmeric after refluxing in water and using double mobile phase after heating in edible oils. *J. Mississippi Acad. Sci.* **2015**, *60*, 319-326.
21. Pujimulyani, D.; Santoso, U.; Luwihana, S.; Maruf, A. Orally administered pressure-blanching white saffron (*Curcuma mangga* Val.) improves antioxidative properties and lipid profiles in vivo. *Heliyon* **2020**, *6*, e04219, <https://doi.org/10.1016/j.heliyon.2020.e04219>.

22. Sujarwo, B.A.; Amanto, B.S.; Siswanti, S. Kinetika Pengeringan Temu Hitam (*Curcuma aeruginosa* Roxb.) menggunakan Cabinet Dryer dengan Perlakuan Pendahuluan Blanching. *J. Teknol. Has. Pertan.* **2015**, *8*, <https://doi.org/10.20961/jthp.v0i0.12788>.
23. Marsono, Y.; Safitri, R.; Noor, Z. Antioksidan dalam kacang-kacangan: aktivitas dan potensi serta kemampuannya menginduksi pertahanan antioksidan pada model hewan percobaan. *Laporan penelitian Hibah Bersaing XII. Lembaga penelitain UGM, Jogjakarta* **2005**,
24. Xu, B.; Chang, S.K. Effect of soaking, boiling, and steaming on total phenolic content and antioxidant activities of cool season food legumes. *Food Chem.* **2008**, *110*, 1-13, <https://doi.org/10.1016/j.foodchem.2008.01.045>.
25. Pujimulyani, D.; Raharjo, S.; Marsono, Y.; Santoso, U. Aktivitas antioksidan dan kadar senyawa fenolik pada kunir putih (*Curcuma mangga* Val.) segar dan setelah blanching. *Agritech* **2010**, *30*, 106162, <https://doi.org/10.22146/agritech.9675>.
26. Dewanto, V.; Wu, X.; Adom, K.K.; Liu, R.H. Thermal processing enhances the nutritional value of tomatoes by increasing total antioxidant activity. *Agric. Food Chem.* **2002**, *50*, 3010-3014, <https://doi.org/10.1021/jf0115589>.
27. Nielsen, S.S. Introduction to the chemical analysis of foods. Jones and Bartlett: **1994**.
28. Xu, B.J.; Chang, S.K. A comparative study on phenolic profiles and antioxidant activities of legumes as affected by extraction solvents. *J. Food Sci.* **2007**, *72*, S159-S166, <https://doi.org/10.1111/j.1750-3841.2006.00260.x>.
29. Windarsih, A.; Rohman, A.; Swasono, R.T. Application of 1H-NMR based metabolite fingerprinting and chemometrics for authentication of *Curcuma longa* adulterated with *C. heyneana*. *J. Appl. Res. Med. Aromat. Plants* **2019**, *13*, 100203, <https://doi.org/10.1016/j.jarmap.2019.100203>.
30. Maila, M.; Tseke, P. Influence of blanching time on the phytochemical and nutritive value of cowpea (*Vigna unguiculata* L. Walp) leafy vegetable. *Int. J. Food Sci.* **2024**, *2024*, 9095035, <https://doi.org/10.1155/2024/9095035>.
31. Wang, R.; Liu, J.; Zhang, J.; Li, G.; Ding, S. Effect of thermal blanching on the inactivation kinetics of polyphenol oxidase and peroxidase in lily bulb, and the functional properties of its flours. *J. Food Meas. Charact.* **2023**, *17*, 615-626, <https://doi.org/10.1007/s11694-022-01658-x>.
32. Dibanda, R.F.; Akdowa, E.P.; Tongwa, Q.M. Effect of microwave blanching on antioxidant activity, phenolic compounds and browning behaviour of some fruit peelings. *Food Chem.* **2020**, *302*, 125308, <https://doi.org/10.1016/j.foodchem.2019.125308>.
33. Nayak, P.K.; Basumatary, B.; Chandrasekar, C.M.; Seth, D.; Kesavan, R.K. Impact of thermosonication and pasteurization on total phenolic contents, total flavonoid contents, antioxidant activity, and vitamin C levels of elephant apple (*Dillenia indica*) juice. *J. Food Process. Eng.* **2020**, *43*, e13447, <https://doi.org/10.1111/jfpe.13447>.
34. Tien, P.-Y.; Yang, P.-F.; Weng, Y.-M.; Yu, Z.-R.; Wang, B.-J. Antioxidant Properties and Sensory Preference of Broccoli Affected by Culinary Practices. *Curr. Res. Nutr. Food Sci.* **2024**, *12*, 1409-1420, <https://doi.org/10.12944/CRNFSJ.12.3.33>.
35. Sari, K.; Rahmadi, A.; Rohmah, M.; Saragih, B.; Salam, I. Antioxidant activities (DPPH and ABTS method) from extract of Bangle rhizome (*Zingiber cassumunar*) using different method of extraction. *Aceh Nutr. J.* **2024**, *9*, 110-119, <https://doi.org/10.30867/action.v9i1.1531>.
36. Okocha, K.; Ezegebe, C.; Victor-Aduloju, A.; Nduka, E.; Orjiakor, S.; Mmuoh, C.; Omologbe, F.; Nnamani, V.; Ishiwu, C. Effect of Blanching Time on the Beta-Carotene and some Chemical Composition of Abacha from Yellow Fleshed Cassava Varieties. *Int. J. Agric. Food Biodivers.* **2023**, *2*, 55-63.
37. Abd El-Hack, M.E.; El-Saadony, M.T.; Swelum, A.A.; Arif, M.; Abo Ghanima, M.M.; Shukry, M.; Noreldin, A.; Taha, A.E.; El-Tarabily, K.A. Curcumin, the active substance of turmeric: its effects on health and ways to improve its bioavailability. *J. Sci. Food Agric.* **2021**, *101*, 5747-5762, <https://doi.org/10.1002/jsfa.11372>.
38. Alara, O.R.; Abdurahman, N.H.; Ukaegbu, C.I. Extraction of phenolic compounds: A review. *Curr. Res. Food Sci.* **2021**, *4*, 200-214, <https://doi.org/10.1016/j.crfs.2021.03.011>.
39. Rosa-Martínez, E.; Bovy, A.; Plazas, M.; Tikunov, Y.; Prohens, J.; Pereira-Dias, L. Genetics and breeding of phenolic content in tomato, eggplant and pepper fruits. *Front. Plant Sci.* **2023**, *14*, 1135237, <https://doi.org/10.3389/fpls.2023.1135237>.
40. Allay, A.; Benkirane, C.; Moumen, A.B.; Rbah, Y.; Fauconnier, M.-L.; Caid, H.S.; Elamrani, A.; Mansouri, F. Enhancing bioactive compound extractability and antioxidant properties in hemp seed oil using a ternary

- mixture approach of Polar and non-polar solvents. *Ind. Crop. Prod.* **2024**, *219*, 119090, <https://doi.org/10.1016/j.indcrop.2024.119090>.
41. Lima, G.; Vanz Borges, C.; Minatel, I.O.; Ferreira, M.I.; Gomez-Gomez, H.; Chen, C.-Y.O. Phenolic Compounds: Functional Properties, Impact of Processing and Bioavailability. In Phenolic Compounds - Biological Activity, Soto-Hernández, M., Palma-Tenango, M., García-Mateos, R., Eds.; IntechOpen: London, **2017**; <https://doi.org/10.5772/66368>.
 42. Magangana, T.P.; Makunga, N.P.; la Grange, C.; Stander, M.A.; Fawole, O.A.; Opara, U.L. Blanching pretreatment promotes high yields, bioactive compounds, antioxidants, enzyme inactivation and antibacterial activity of 'wonderful' pomegranate peel extracts at three different harvest maturities. *Antioxidants* **2021**, *10*, 1119, <https://doi.org/10.3390/antiox10071119>.
 43. Jalali-Jivan, M.; Rostamabadi, H.; Assadpour, E.; Tomas, M.; Capanoglu, E.; Alizadeh-Sani, M.; Kharazmi, M.S.; Jafari, S.M. Recent progresses in the delivery of β -carotene: From nano/microencapsulation to bioaccessibility. *Adv. Colloid Interface Sci.* **2022**, *307*, 102750, <https://doi.org/10.1016/j.cis.2022.102750>.
 44. Ghafouri-Fard, S.; Shoorei, H.; Bahroudi, Z.; Hussen, B.M.; Talebi, S.F.; Taheri, M.; Ayatollahi, S.A. Nrf2-related therapeutic effects of curcumin in different disorders. *Biomolecules* **2022**, *12*, 82, <https://doi.org/10.3390/biom12010082>.
 45. Liao, D.; Lv, C.; Cao, L.; Yao, D.; Wu, Y.; Long, M.; Liu, N.; Jiang, P. Curcumin attenuates chronic unpredictable mild stress-induced depressive-like behaviors via restoring changes in oxidative stress and the activation of Nrf2 signaling pathway in rats. *Oxid. Med. Cell. Longev.* **2020**, *2020*, 9268083, <https://doi.org/10.1155/2020/9268083>.
 46. Ciuca, M.D.; Racovita, R.C. Curcumin: Overview of extraction methods, health benefits, and encapsulation and delivery using microemulsions and nanoemulsions. *Int. J. Mol. Sci.* **2023**, *24*, 8874, <https://doi.org/10.3390/ijms24108874>.
 47. An, N.-n.; Lv, W.-q.; Li, D.; Wang, L.-j.; Wang, Y. Effects of hot-air microwave rolling blanching pretreatment on the drying of turmeric (*Curcuma longa* L.): Physicochemical properties and microstructure evaluation. *Food Chem.* **2023**, *398*, 133925, <https://doi.org/10.1016/j.foodchem.2022.133925>.
 48. Sharma, M.; Pal, U.; Kumari, M.; Bagchi, D.; Rani, S.; Mukherjee, D.; Bera, A.; Pal, S.K.; Dasgupta, T.S.; Mozumdar, S. Effect of solvent on the photophysical properties of isoxazole derivative of curcumin: a combined spectroscopic and theoretical study. *J. Photochem. Photobiol. A: Chem.* **2021**, *410*, 113164, <https://doi.org/10.1016/j.jphotochem.2021.113164>.

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