Influence of roasting on chemical profile, antioxidant and antibacterial activities of dried chili

Sunida Muangkote^{1,2} · Taweerat Vichitsoonthonkul¹ · Varit Srilaong^{1,2} · Chalermchai Wongs-Aree^{1,2} · Songsin Photchanachai^{1,2}

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Abstract Roasted dried chili, used to improve texture and taste, is important for various cuisines. The effect of roasting at 90 °C for 25 min on the chemical profile and bioactivities of dried chili extracted by petroleum ether was investigated. Based on GC–MS analysis, the crude extracts of roasted dried chili exhibited different chemical profile compared to the control. Roasting of dried chili significantly increased total phenolic compounds. Consequently, the antioxidant activity indicated by 1,1-diphenyl-2-picrylhydrazyl (DPPH) scavenging activity and ferric reducing antioxidant power (FRAP) significantly improved. Conversely, a reduction in the antibacterial agents, capsaicin (32.36%) and dihydrocapsaicin (9.11%), in the roasted sample resulted to a decline in antibacterial activity. The extracts showed a strong activity against *Bacillus cereus* followed by *B. subtilis*, and *Staphylococcus aureus* compared to *Escherichia coli* based on the results of agar disk diffusion, minimal inhibitory concentration (MIC), minimal bactericidal concentration (MBC), and electron scanning microscopy observation.

Keywords Roasting · Chili · Chemical profile · Antioxidant · Bacteria

Introduction

Dried chili (*Capsicum annuum* L.) is an economically important spice, which contributes essential ingredient to foods. Its utilization accounts for about 18% of annual global economic expansion (Food and Agriculture Organization, 2017). Chili is rich in flavor and taste, which originate from various chemical compounds. The dominant chemicals in chili are capsaicinoids, carotenoids, phenolics, and vitamins, which are phytochemicals (Emmanuel-Ikpeme et al., 2014; Lim, 2013). The capsaicinoids are naturally occurring compounds responsible for the pungency of chili. Capsaicin and dihydrocapsaicin are major compounds of the capsaicinoids (Ornelas-Paz et al., 2010). These compounds are powerful free radical scavengers (Hwang et al., 2012) and also are antimicrobial agents on a wide range of bacteria (Cichewicz and Thorpe, 1996) and fungi (Touba et al., 2012).

Chili cv. Jinda, consumed as fresh or dried chili, is a common ingredient in Thai cuisine because of its bright red color and high pungent flavor. In particular, dried chili is an important ingredient in many kinds of ready-to-eat chili paste, salad, and soup; consequently, chili ‘Jinda’ has a high market value in Thailand. Moreover, this cultivar has high productivity and is tolerant to anthracnose disease.

Dried chili is often prepared by roasting and grilling to enhance its flavor and taste as well as texture prior to cook with other ingredients. Roasted dried chili is an important ingredient in many traditional Thai dishes, particularly for ready-to-eat chili paste. Previous studies reported that the cooking process alters the texture, flavor, and taste of food, due to changes in its chemical composition (Toontom et al., 2012) which could potentially affect its biological activities.

✉ Songsin Photchanachai
songsin.pho@kmutt.ac.th

¹ School of Bioresources and Technology, King Mongkut’s University of Technology Thonburi (Bang Khun Thian), Bangkok 10150, Thailand

² Postharvest Technology Innovation Center, Office of the Higher Education Commission, Bangkok 10400, Thailand

Thermal processing of vegetable has different effects on the antioxidant and antibacterial activities (Ornelas-Paz et al., 2013). Total phenolic content (TPC), capsaicinoids, and carotenoids are significantly increased after grilling fresh peppers (*C. annuum* L.) leading to an increase in the antioxidant activities (Ornelas-Paz et al., 2010; Ornelas-Paz et al., 2013). Similarly, Lee et al. (2015) reported that the roasting significantly increased the flavonoid content, phenolic content, and antioxidant activities of roasted soybean (*Glycine max* L. Merrill). Conversely, Hwang et al. (2012) reported that the TPC and antioxidants remain the same after roasting fresh red pepper. Ozgur et al. (2011) and Settharaksa et al. (2012) also reported that the heating process decreases flavonoid content, phenolic content, and DPPH activity. Cichewicz and Thorpe (1996) found that extract of boiled fresh chili has lower antimicrobial activity due to loss of capsaicin and dihydrocapsaicin.

There are only a few studies on the effect of roasting on constituent bioactive agents in dried chili. Thus, this research aimed to analyze the chemical compositions of dried chili, and determine their antioxidant and antibacterial activities after roasting, following the roasting procedures recommended by the producers of ready-to-eat chili paste.

Materials and methods

Dried chilies (*C. annuum* L.) cv. Jinda were prepared from fully ripened, red colored chili. They were harvested from a farm in Sisaket Province, Thailand. The fresh red chilies were washed in tap water and subsequently, dried in a solar greenhouse for 4 days to obtain dried chilies with moisture content (MC) of approximately 8%. The dried chili was stored at room temperature for 3 months before using and their MC was 15.3% (Table 1). Five hundred grams of dried chilies excluding the pedicels, were roasted using an electric frying pan (HGP-14T; Hanabishi, Bangkok, Thailand). The temperature of the heat plate in the electric frying pan was set at 200 °C and was maintained until the

dried chili achieved 90 °C for 25 min. The roasting condition (90 °C for 25 min) was followed the instruction recommended by producers of ready-to-eat chili paste. The temperature of the heat plate and the samples was measured every 2 min using an IR Thermometer (42545; Extech, Nashua, NH, USA). Non-roasted samples were used as control. Roasted and non-roasted dried chili samples were soaked in 98.99% petroleum ether (PE) (Zenith Science Co., Ltd, Bangkok, Thailand) for 7 days at sample to PE solvent (1: 5, w/v) to extract constituent chemical compounds. The residues were re-suspended twice, and the supernatants were subsequently concentrated using a rotary evaporator equipped with vacuum pump and heating bath (R-200; Buchi, Flawil, Switzerland). The percentage of extraction was calculated and then, extracts were dissolved in 99.90% dimethyl sulfoxide (DMSO) (Fisher Scientific UK Ltd., Loughborough, UK) and stored in a freezer (− 18 °C) until analysis.

The Gram-positive bacteria used in this study were *Bacillus subtilis* TISTR 008, *Bacillus cereus* TISTR 687, and *Staphylococcus aureus* TISTR 1466 while the Gram-negative bacteria was *Escherichia coli* TISTR 780. They were obtained from the Microbiological Resources Centre (MIRCEN), Thailand. All strains were grown in a nutrient broth (NB) and incubated at 37 °C for 24 h (INB-500; Memmert, Schwabach, Germany). Bacteria stock cultures were stored on agar medium and kept at 4 °C. Before use, a culture prepared from a colony was transferred into broth and incubated according to the above stated conditions. In this study, all chemicals used were of analytical grade unless indicated otherwise.

Moisture content (MC)

The non-roasted and roasted samples (approximately 3 g) were weighted in aluminum cans, placed in hot air oven (UM-500; Memmert, Bavaria, Germany) at 105 °C for 3 h, allowed to cool and then, re-weighed. The dry weight of samples was used for MC calculation which was expressed on wet weight basis (AOAC, 1995).

Chemical profile analysis

One millimeter of extract was dissolved in 10 mL of DMSO and then filtered using a 0.45 µm polytetrafluoroethylene membrane (Sigma-Aldrich, St. Louis, MO, USA). The extracts were analyzed using gas chromatography–mass spectrometry system (6890N/5973 GC–MS; Agilent Technologies, Santa Clara, CA, USA) equipped with HP-5 MS capillary column (30 m × 0.25 mm; film thickness, 0.25 µm). The mass detector was operated in electron-impact ionization (EI) mode with a mass scan range of 50–550 at 70 eV. The oven was programed such

Table 1 Moisture content and extraction yield of dried chili extract after roasting at 90 °C for 25 min

Treatments	Moisture content (%)	Extract yield (%)
Non-roasted	15.3 ± 0.01 ^a	3.75 ± 0.02
90 ± 5 °C	3.58 ± 0.02	8.82 ± 0.02
<i>p</i>	* ^b	*

^aValues are mean ± SD (n = 9)

^bSignificant differences between samples are presented as * for *p* ≤ 0.05

that the temperature initiated at 60 °C for 1 min, increased to 108 °C at a rate of 2 °C/min and increased further to 240 °C at a rate of 20 °C/min. The injector temperature was set at 250 °C. Extracts (1 µL) were injected manually in splitless mode, and helium was used as carrier gas at a flow rate of 1 mL/min. The compounds of extracts were identified using data from the National Institute of Standards and Technology (NIST 14.L) mass spectra library as well as data from literature.

Total phenolic content (TPC)

The TPC of extracts were determined using Folin–Ciocalteu reagent based on the method of Gao et al. (2000). Briefly, 0.01 g of extract was added to 0.99 mL of ethanol, from which 0.06 mL portions was obtained. Then, 1.58 mL of distilled water, 0.1 mL of the Folin–Ciocalteu reagent and 0.3 mL of 20% Na₂CO₃ were added to the portion, and then, the mixtures were incubated at 40 °C for 30 min in a water bath (WNB-14; Memmert, Schwabach, Germany). Absorbance was measured at 765 nm (UV-1800; Shimadzu, Kyoto, Japan) using gallic acid as standard. The results were expressed as gallic acid equivalents (GAE).

Antioxidant activities

DPPH (1,1-diphenyl-2-picrylhydrazyl) radical scavenging activity

The DPPH radical scavenging activity was determined using DPPH assay (Brand-Williams et al., 1995) with minor modification. A 0.01 g of extract was added to 0.99 mL of ethanol. Then, 0.6 mL of the diluted extract was mixed with 2.85 mL of DPPH working solution and kept in the dark for 30 min. The working solution was prepared by dissolving 24 mg of DPPH with 100 mL of methanol. Afterwards, 10 mL of the diluted DPPH solution was mixed with 45 mL of methanol. Absorbance was measured at 515 nm and ascorbic acid was used as the standard.

Ferric reducing antioxidant power (FRAP)

The assay was based on the method of Benzie and Strain (1996). First, 0.01 g of extract was mixed with 0.99 mL of ethanol. Then, 0.3 mL of the diluted extract was mixed with 2.85 mL of FRAP reagent and kept in the dark for 30 min. The absorbance was determined at 593 nm. FRAP was freshly prepared by mixing 5 mL of 300 mM acetate buffer (at a pH of 3.6) with 1 mL of 10 mM 2,4,6-tris (2-pyridyl)-s-triazine (TPTZ) solution in 40 mM HCl and 1 mL of 20 mM FeCl₃ 6H₂O. Trolox was employed as

standard and the results were expressed as trolox equivalents (TEAC).

Antibacterial activities

Agar disk diffusion assay

Turbidity of the cell suspensions was measured at 625 nm (optical density range of 0.09–0.10) and adjusted to the required concentration of 10⁸ CFU/mL using the McFarland No. 0.5. The extracts were screened for antibacterial activity using agar disk diffusion method. Extracts were diluted to; 10% when tested with *B. subtilis*, *B. cereus*, and *S. aureus*; and 40% when tested with *E. coli*. Nutrient agar (NA) was used for *B. subtilis*, *B. cereus*, and *E. coli*, while tryptone soya agar (TSA) was used for *S. aureus*. The media used were sterilized in an autoclave (HVE-50; Hirayama, Kasukabe, Japan), cooled to 45 °C and then, poured into petri dishes. On solidifying, sterile filter disks (5 mm in diameter) containing 0.02 mL of each extract were applied to the surface of agar plates that were previously spread with 0.1 mL inoculum suspension. Streptomycin was used as positive control whereas distilled water was used as negative control. The inoculated plates were placed in incubator (INE-500; Memmert, Schwabach, Germany) and incubated at 37 °C for 18 h under dark conditions. The diameter of the inhibition zone was measured using a digital vernier caliper (Mitutoyo, Kanagawa, Japan).

Minimal inhibitory concentration (MIC)

A 0.5 mL of extract was added to a test tube. Two-fold serial dilutions were prepared. For *B. subtilis*, *B. cereus*, and *S. aureus*, the concentration ranged from 0.390 to 100 mg/mL, whereas, for *E. coli*, the concentration ranged from 1.562 to 400 mg/mL in 0.5 mL of double NB. A 0.1 mL of test bacteria suspension (10⁸ CFU/mL) was added to each tube. The negative control tube contained broth and bacteria, whereas the positive control tubes contained, in addition, 0.5 mL of streptomycin. All samples were incubated for 18 h at 37 °C under dark conditions. A 0.1 mL of resazurin was added to the samples and the mixture was incubated for 30 min at 25 °C. Change in the color of resazurin from blue to pink, indicated the growth of bacteria. MIC was defined as the lowest concentration of the extract which resazurin did not change color (Gahlaut and Chhillar, 2013).

Minimal bactericidal concentration (MBC)

The blue tubes from MIC assay were streaked using an inoculating loop on NA and then incubated for 24 h at

37 °C under dark conditions which resulted in the lack of visible bacteria growth.

Scanning electron microscopy (SEM) analysis

Morphological changes in *B. subtilis* and *E. coli* were observed using SEM. The inhibition zones were cut into pieces of approximate size and thickness of 5 cm² and 0.5 cm, respectively. The samples were steamed with 2% osmium tetroxide for 1–2 h. Samples were then dehydrated sequentially with varying ethanol concentrations (30%, 50%, 70%, 95%, and 100%) at 10 min each. They were dried using critical point drying method. The samples were fixed on SEM support and then sputter-coated with gold. Afterwards, microscopic examination was conducted, using SEM (JSM-5410LV; JEOL, Tokyo, Japan) at $\times 30,000$ magnifications and an accelerating voltage of 10 kV.

Statistical analysis

All statistical analyses were performed using the Statistical Package for Social Sciences program (SPSS Inc., Version 17.0, Chicago, IL, USA). The treatments were replicated three times and each replicate sample was measured three times. Differences between treatments were analyzed for statistical significance using t-test ($p \leq 0.05$).

Results and discussion

Moisture content (MC) and extraction yield

After roasting, the MC of the roasted dried chili was significantly reduced compared to its initial MC (Table 1). Generally, roasting markedly accelerates water evaporation in foods and same result was observed in dried chili. The percentage yield of extract for roasted dried chili was significantly higher than for the non-roasted treatment (Table 1). Reportedly, roasting enhances cell damage, resulting in high extractability of chemical compounds in foods (Gaman and Sherrington, 1981). Chirinos et al. (2016) reported that thermal processing such as roasting of sachu inchi (*Plukenetia huayllabambana*) improved extracted yield. Same effect was found in our roasted dried chili. The extract from roasted dried chili was deep-red colored, whereas the extract from non-roasted dried chili was bright-red colored. Roasting induced browning reaction and the occurrence of partial burning in chili (Lee, 1983), which explains the observed color difference.

Chemical profile

Roasting process markedly affected the chemical composition of the dried chili extract (Table 2). Overall twenty-one chemicals were detected in the non-roasted chili extract, while fourteen were found in roasted dried chili extracts. Usually, cooking process affects the chemical components of food, particularly under high temperature (Gaman and Sherrington, 1981). This effect was also found in this research. Our results conform with the study of Toontom et al. (2012) who reported that the chemical profiles, types and concentrations, of dried chilies (*C. annuum* L.) were influenced by the different heating methods. In addition, Ornelas-Paz et al. (2013) found that the bioactive compounds present after grilling of pungent and non-pungent peppers were changed with respect to the fresh peppers. This suggests that various chemical reactions occurred while roasting the dried chili based on the chemical profile shown in Table 2. The dominant chemicals observed in both roasted and non-roasted samples were capsaicin and dihydrocapsaicin. Roasting resulted in 32.36% and 9.11% decreases in the percentage fraction of capsaicin and dihydrocapsaicin, respectively (Table 2). Henderson and Henderson (1992) found that heating pure capsaicin at 200 °C decomposed it into vanillin, methyl-nonenic acid, and ethylnonenamide as well as other 12 minor compounds. Conversely, when capsaicin was heated with oleic acid, 9-octadecenamide and N-vanillyl-9-octadecenamide were markedly observed as well as other 17 minor compounds. From their experiment, capsaicin and dihydrocapsaicin underwent degradation and re-arrangement of decomposition products. These findings corroborate our research wherein the dried chili (15.3% MC) was roasted in an ambient condition using an electric frying pan at 200 °C until it achieved a temperature of 90 °C for 25 min. In this condition, thermal reactions of chemical compounds were induced. The compounds such as capsaicin, dihydrocapsaicin, lipids, free fatty acids, protein, sugar, etc. underwent degradation and/or structural re-arrangement. This leads to a reduction in the initial compounds and an increase in new chemical compounds (Table 2). The chemical profile showed that the main yielding compounds from roasted dried chilies were N-decyl acetamide and methyl-cyclohexane. The N-decyl acetamide was produced from the compounds containing amide group. In the dried chili, the chemicals containing amide group were amino acid, protein, capsaicin, dihydrocapsaicin, and nonivamide. This implies that these compounds could be transformed into N-decyl acetamide by roasting. Our analysis technique (GC–MS) showed that capsaicin and dihydrocapsaicin were reduced by roasting suggesting that capsaicin and dihydrocapsaicin were also degraded. Also, methyl-cyclohexane, was produced in the

Table 2 Chemical compositions of dried chili extract after roasting at 90 °C for 25 min

No.	Retention time (min)	Compounds	Fraction ^a	
			Non-roasted	90 ± 5 °C
1	0.997	2-Methyl-pentane	0.03	0.47
2	1.020	3-Methyl-pentane	0.06	0.50
3	1.214	Cyclohexane	0.19	2.12
4	1.231	3-Methyl-hexane	ND ^b	1.43
5	1.288	1,2-Dimethyl-cyclopentane	0.07	2.08
6	1.317	Heptane	0.10	2.80
7	1.443	Methyl-cyclohexane	0.81	14.36
8	1.494	Ethyl-cyclopentane	0.05	ND
9	1.517	1,2,4-trimethyl-cyclopentane	ND	0.41
10	1.654	2-Methyl-heptane	0.11	ND
11	1.768	1,2-Dimethyl-,trans-cyclohexane	ND	0.70
12	1.774	1,3-Dimethyl-, trans-cyclohexane	0.14	ND
13	2.277	Ethyl-cyclohexane	0.13	ND
14	35.323	Pentadecanoic acid	1.03	ND
15	35.814	Methyl ester hexadecanoic acid	0.37	ND
16	36.009	Palmitoleic acid	0.99	ND
17	36.089	n-Hexadecanoic acid	6.35	5.97
18	36.700	Methyl ester 9,12-octadecadienoic acid (Z,Z)-	0.08	ND
19	37.020	9,12,15-Octadecatrienoic acid (Z,Z,Z)-	9.43	7.00
20	37.077	N-decyl-acetamide	ND	16.15
21	37.569	Vitamin E	0.66	ND
22	37.701	n-Hexadecylacetamide	0.26	ND
23	39.672	Nonivamide	4.03	ND
24	40.758	Capsaicin	31.71	21.45
25	41.067	Dihydrocapsaicin	27.01	24.55

^aFractions of components in dried chili extract (%) = peak area of a component in dried chili extract/total peak area of identified components in dried chili extract

^bNot detected

roasted sample by the thermal reactions of hydrocarbon compounds. Notably, our chemical profile was different from the report of Henderson and Henderson (1992). Perhaps, due to the chemical compounds present in the dried chili and the heating (roasting) condition.

Total phenolic content (TPC) and antioxidant activities

In dried chili, antioxidant activity originates from TPC such as phenols, flavonoids, and capsaicinoids (Lim, 2013). Our results showed that roasting had a positive effect on TPC and antioxidant activities (Table 3). The TPC in dried chili extract was significantly increased after roasting (Table 3). A similar result was reported by Ornelas-Paz et al. (2010) in which grilling fresh hot peppers significantly increased the TPC. Increases in the phenolic content of vegetables by cooking, have been attributed to the dehydration of food matrix and improved extractability of

phenolics from food (Damodaran et al., 2007). Another explanation could be that the thermal process disrupts the plant cell, thus bounded or conjugated phenolics are released in their free form (Choi et al., 2006). The results of the GC–MS analysis showed that the major phenolics compounds in the extract of roasted sample (capsaicin, dihydrocapsaicin, nonivamide, and vitamin E) were decreased (Table 2) whereas the TPC was increased (Table 3). In the roasted sample, the main compound detected was N-decyl acetamide containing an amide group which could also contribute to the high TPC (Table 2). Furthermore, other possible compounds (e.g. melanoidins product of maillard reaction) were produced during roasting which can affect the TPC value, although this compound was not observed in the chemical profile. The extract of the roasted sample revealed significant antioxidant scavenging activity. This result is similar to the finding of Cervantes-Paz et al. (2014) in which grilling (210 °C for 13.23 min) of red peppers exhibited higher

Table 3 Total phenolic content (TPC) and antioxidant activities of dried chili extract after roasting at 90 °C for 25 min

Treatments	TPC (mgGAE/gDW)	Antioxidant activities	
		DPPH (mgAscorbic acid/gDW)	FRAP (mgTEAC/gDW)
Non-roasted	14.38 ^a ± 0.42	0.51 ± 0.04	7.02 ± 0.06
90 ± 5 °C	36.83 ± 2.13	1.89 ± 0.16	17.60 ± 0.25
<i>p</i>	* ^b	*	*

^aValues are mean ± SD (n = 9)^bSignificant differences between samples are presented as * for $p \leq 0.05$ **Table 4** Inhibition zone of dried chili extract against Gram-positive and Gram-negative bacterial, minimal inhibitory concentration (MIC) and minimal bactericidal concentration (MBC) growth after roasting at 90 °C for 25 min

Treatments	Inhibition zone (mm)			Hazy inhibition zone (mm) 40% concentration of extract <i>E. coli</i>
	10% concentration of extract			
	<i>B. subtilis</i>	<i>B. cereus</i>	<i>S. aureus</i>	
Distilled water	NI ^a	NI	NI	NI
Streptomycin (0.01%)	15.37	13.89	10.66	13.80
Non-roasted	7.45 ± 0.09 ^b	7.64 ± 0.23	7.01 ± 0.07	7.18 ± 0.11
90 ± 5 °C	6.03 ± 0.03	6.00 ± 0.00	6.40 ± 0.05	6.95 ± 0.08
<i>p</i>	* ^c	*	*	*
	MIC (mg/mL)			
Distilled water	NI	NI	NI	NI
Streptomycin (0.01%)	0.012	0.012	0.05	0.025
Non-roasted	25 ± 0.00	12.5 ± 0.00	100 ± 0.00	NI
90 ± 5 °C	50 ± 0.00	50 ± 0.00	100 ± 0.00	NI
<i>p</i>	*	*	ns ^d	
	MBC (mg/mL)			
Distilled water	NI	NI	NI	NI
Streptomycin (0.01%)	0.025	0.025	0.05	0.05
Non-roasted	25 ± 0.00	12.5 ± 0.00	100 ± 0.00	NI
90 ± 5 °C	50 ± 0.00	50 ± 0.00	100 ± 0.00	NI
<i>p</i>	*	*	ns	

^aNI, no inhibition^bValues are mean ± SD (n = 9)^cSignificant differences between samples are presented as * for $p \leq 0.05$ ^dNon significant differences between samples at $p \leq 0.05$

antioxidant activity. Likewise, Ornelas-Paz et al. (2010) reported that the grilling of hot peppers also increased the phenolic content about 8 times, leading to an increase in antioxidant activities. It was also observed that the DPPH value of dried chili extracts represented a lesser activity than FRAP value. A possible reason could be that the solvent used was PE. Therefore, the main chemicals in the extracts would be non-polar compounds and would have low solubility in methanol used as a DPPH working solution. Consequently, the compounds in the extract were less sensitive to DPPH.

Antibacterial activities

The non-roasted and roasted dried chili extracts showed inhibitory effect on the tested bacteria. A clear inhibitory zone of the 10% crude extracts was observed in *B. subtilis*, *B. cereus*, and *S. aureus* and a hazy inhibition zone of the 40% extracts in *E. coli*. The inhibition zone of roasted dried chili extract was significantly lesser than the non-roasted dried chili extract as observed in agar diffusion method (Table 4). The minimal inhibitory concentration (MIC) and minimal bactericidal concentration (MBC) of the extracts showed also the same trend to the results of inhibition zone

Fig. 1 Scanning electron micrographs of *B. subtilis* (A–C) and *E. coli* cells (D–F) treated with dried chili extract after roasting: untreated (A, D); non-roasted (B, E); roasted at 90 °C for 25 min (C, F) (magnification $\times 30,000$)

(Table 4). The non-roasted dried chili extract showed lower MIC and MBC values against *B. cereus*, followed by *B. subtilis* and *S. aureus*. Contradictory, the inhibitory effect on *E. coli* could not be evaluated by the MIC and MBC techniques meaning that *E. coli* is tolerant to the extract of dried chili. Consequently, the extracts contained compounds that were able to inhibit the growth of bacteria, particularly, the Gram-positives. Capsaicin and dihydrocapsaicin in *Capsicum* species were identified as the major compounds that played an important role against food-borne pathogenic bacteria (Cichewicz and Thorpe, 1996). However, the roasting reduced these two compounds in the dried chili extract (Table 2). Consequently, the efficacy of the extract against bacteria was reduced. There was also an increase in the quantity of some chemicals but they did not improve the antimicrobial efficacy. This means the roasting process had a negative impact on the antibacterial efficacy. The present results are in agreement with the finding that boiling red peppers (*C. annuum* L.) leads to loss of capsaicin, an antimicrobial agent (Cichewicz and Thorpe, 1996; Toubia et al., 2012). In addition, scanning electron

microscopy (SEM) showed that the *B. subtilis* cells treated with 10% extracts showed a larger cell wall surface collapse, and membranes rupture (Fig. 1B, C) when compared to the untreated cell which had regular normal shape (Fig. 1A). Conversely, *E. coli* cell exhibited an irregular shape, but had rupture-free cell wall structure when treated with 40% dried chili extracts (Fig. 1E, F). This is due to the difference in the cell wall structure between Gram-positive and Gram-negative bacteria. The multi-layered cell wall of Gram-negative bacteria prevents the diffusion of hydrophobic compounds through its lipopolysaccharide conversion (Benz, 2004). This finding is similar to that reported by Cichewicz and Thorpe (1996) who observed that hot chili extract was more effective against the *Clostridium sporogenes*, *B. subtilis*, *B. cereus*, and *S. aureus* than *E. coli*. Moreover, a similar trend was also presented in crude extracts of other crop species such as onion (Ye et al., 2013).

The MC, extraction yield, antioxidant activities, and antibacterial activities of dried chili were affected by roasting. The MC in roasted dried chili was decreased,

whereas the percentage of yield extract was increased. The roasting slightly decreased capsaicin and dihydrocapsaicin contents, but increased the TPC estimation value and antioxidant activities, indicated by DPPH and FRAP assays of the extract. The extracts showed more potential antibacterial effect against *B. subtilis*, *B. cereus*, and *S. aureus* than *E. coli*, indicated by the inhibitory clear and hazy zone as well as MIC and MBC values. As confirmed by SEM, the cell morphology of the *B. subtilis* treated with the extracts exhibited severe damage, while the treated *E. coli* showed abnormal cells only.

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Compliance with ethical standards

Conflict of interest The authors declare no conflict of interest.

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