FOOD
RESEARCH

Review on ginger (*Zingiber officinale* Roscoe): phytochemical composition, biological activities and authentication analysis

[1,2]Styawan, A.A., [1]Susidarti, R.A., [1]Purwanto, [3]Windarsih, A., [4]Rahmawati, N., [4]Sholikhah, I.K.M. and [1,*]Rohman, A.

[1]Faculty of Pharmacy, Universitas Gadjah Mada, Yogyakarta, 55281, Indonesia.
[2]Faculty of Health and Technology, Universitas Muhammadiyah Klaten, Central Java, Indonesia
[3]Research Center for Food Technology and Processing (PRTPP), National Research and Innovation Agency (BRIN), Yogyakarta, 55861, Indonesia
[4]Research Center for Pharmaceutical Ingredients and Traditional Medicine, National Research and Innovation Agency, Indonesia

Abstract

Zingiber officinale Roscoe, known as ginger has been widely used as a spice in food application and as a herbal component in traditional medicine. Its rhizome is known to have bioactive compounds such as phenolic compounds, flavonoid compounds, and essential oils which are responsible for pharmacological activities. Gingerol is the major phenolic compound in the ginger rhizome which consist of gingerol, shogaol, paradol, zingerol, gingerones, and gingerdiones. Other compounds such as polysaccharides, amino acids, organic acids, and minerals are also present. Ginger provides health advantages for humans because of its biological activities such as antioxidant, antiinflammation, antibacterial, antiviral, antifungal, antihyperlipidemic, antiobesity, and hepatoprotective activities. Products developed from ginger rhizomes were used in foods, beverages, and herbal medicine. Due to its functional values and its wide application, it is very important to ensure its authenticity. Authentication is important for quality control because it is related to the safety, efficacy, and quality of the products. The high-performance liquid chromatography (HPLC), DNA-based method, and vibrational spectroscopy combined with chemometrics of multivariate analysis have been successfully used for ginger authentication. This review highlighted the phytochemical compositions, biological activities, and authentication analysis of ginger rhizome. Based on its biological activities, ginger is a good source of pharmaceutical and nutraceutical products.

1. Introduction

The family of Zingiberaceae includes about 53 genera with more than 1200 species. Zingiberaceae is distributed across south and southeast Asia. Some plants within this family commonly used in herbal medicines are *Zingiber officinale* (ginger), *Zingiber zerumbet* (bitter ginger) and *Curcuma longa* (turmeric) (Koga *et al.*, 2016). Currently, some members of the Zingiberaceae family have attracted enormous interest among researchers due to their popularity as spices and herbal components in traditional medicine. One of the most well-known members of the Zingiberaceae family is the common ginger, namely *Zingiber officinale* Roscoe or known as *Jahe Emprit*, Zingiber officinale Roscoe var. officinale, known as *Jahe Gajah* and Zingiber officinale Roscoe var. rubrum or called as *Jahe Merah* (Seow *et al.,* 2017). The rhizomes of these three gingers are depicted in Figure 1. The name ginger comes from the

Middle English *gingivere*, but this spice dates back over 3000 years to the Sanskrit word *srngaveram* (horn root) (Benzie and Wachtel-Galor, 2011).

The rhizome of ginger, the horizontal stem from which the roots grow, is a medicinal plant that has been widely used in Ayurvedic, Chinese, and Tibb-Unani herbal medicines for more than 3000 years in the Asian regions including Indonesia, Sri Lanka, Japan, Burma, China, India, and others such as the Arab nations, Congo, Germany, Greece, Tibet and the United States of America due to its beneficial characteristics such as its pungency, aroma, nutrients and pharmacological activity with negligible side effects all over the world (Kiyama, 2020). The rhizomes contain two groups of materials, volatile compounds constituting the essential oil and non-volatile compounds, including oleoresin (a source of pungency) and other phytochemicals having biological activities which are beneficial to human health such as

*Corresponding author.
Email: abdulkimfar@gmail.com

Figure 1. Rhizome of (A) Zingiber officinale Roscoe (*Jahe Emprit)*, (B) Zingiber officinale Roscoe var. Officinale (*Jahe Gajah)* and (C) Zingiber officinale Roscoe var. rubrum (*Jahe Merah)*

phenolics and flavonoids (Motawi *et al.,* 2011). With the development in science and modern technology in food products, ginger has been formulated into several products including ginger tea, ginger beer, ginger powder, ginger candies, and ginger juice (Krüger *et al.,* 2018).

The health benefits of ginger for human health are mainly attributed to bioactive compounds such as phenolic compounds, flavonoids, terpene and some volatile compounds contained in the essential oils of ginger, therefore in the first section, some phytochemicals present in ginger are highlighted in Table 1. Ginger has been reported to treat or prevent a wide array of ailments including nausea and vomiting after chemotherapy (Crichton *et al.,* 2019), reducing blood pressure (anti-hypertension) (Hasani *et al.,* 2019), antidiabetic activity by reducing the levels of blood glucose (Hajimoosayi et *al.,* 2020), anti-hyperlipidemic (Pourmasoumi *et al.*, 2018) and other activities. In addition, ginger is widely used to prevent some chronic diseases through its capability to act as an antioxidant by suppressing reactive oxygen species (Mao *et al.*, 2019). Some biological activities of ginger were depicted in Table 2.

The widespread application in the medicinal field and culinary uses of gingers increases its market value, as a consequence, ginger can be the target of adulteration with other herbal components to obtain economical profit (Wang and Yu, 2015). Some problems are frequently met in herbal authenticity which include the incorrect identification (mislabeling of herbal products), the substitution and adulteration of a higher-priced herb with lower-priced herb, dilution of high-quality herbal components with lower grade ones, and labelling the herbal from different origins (Rohman *et al.*, 2014). The ginger authentication remains a difficult task due to some reasons, namely the heterogeneity of plant material sources, the contamination of ginger with similar plant materials and the intentional adulteration of ginger in commercial herbal products. Therefore, the authentication of ginger used in herbal products is essential to assure that ginger either as raw material or in herbal products is authentic (Wu *et al.*, 2018). The objective of this review was to highlight some

phytochemicals responsible for certain health beneficial effects, explore the biological activities of ginger by either preventing or curing diseases and discuss the analytical methods used for the authentication of ginger.

2. Methodology

Throughout this review, the strategy of literature selection consisted of searching and studying the literature using several databases SciFinder, Web of Knowledge, Scopus, PubMed, and Google Scholars which appear in several publishers including American Chemical Society, Science Direct, Springer, Francis and Taylor, Wiley, and BioMed Central. The keywords used are Ginger or (*Zingiber officinale* Roscoe) or (*Zingiber officinale* Roscoe var. officinale) or (*Zingiber officinale* Roscoe var. rubrum) + phytochemicals or chemical composition + biological activities or pharmacological activities + authenticity or authentication analysis. After that, the obtained literature was subjected to screening by removing the redundant articles appearing in several databases. The selected articles were critically evaluated by applying inclusion and exclusion criteria and critical assessment and then used for making a review in logical structure according to the journal's guidelines. The inclusion criteria of selected papers were: (1) studies regarding phytochemical compositions, biological activities and authenticity analysis of ginger; (2) year of publication of 2000-2020, while the exclusion criteria used are all papers written in non-English.

3. Discussion

3.1 Phytochemical composition and stability

It is reported that the rhizome of ginger contains carbohydrates (60–70%), protein 9%, crude fibre of approximately 3-8%, ash 8%, fatty oil 3–6% and volatile oil 2–3%. The carbohydrates consist of polysaccharides, soluble sugar, and cellulose (Kikuzaki and Nakatani, 1996). Table 1 shows some of the phytochemical compounds of the ginger rhizome. The protein contains a variety of amino acids namely aspartic acid, serine, glutamate, alanine, glycine, threonine, methionine, cysteine, valine, tyrosine, leucine, isoleucine, histidine, lysine, phenylalanine proline, tryptophan, and arginine

(Liu *et al.,* 2019). Some compounds namely zingerone, shogaols, gingerols, and volatile (essential) oils account for up to 3% (mainly alfa-zingiberene, β-sesquiphellandrene, β-phellandrene, camphene, cineol, geraniol, citral) contributed to the characteristic flavor of ginger (Srinivasan, 2017). The chemical structures are depicted in Figure 2.

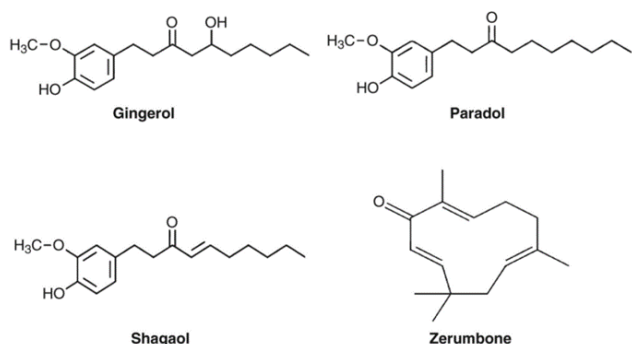Some phenolics reported in ginger that contribute to

Figure 2. Gingerol compounds in Zingiber officinale consist of gingerol (23-25%), shagaol (18-20%), paradol (1-3%) and zerumbone (1-3%)

biological activities include gingerols, shogaols, and paradols. Gingerol is the component responsible for the spicy taste of ginger. It consists of several compounds such as gingerol, shogaol, zingerones, paradols, gingerdiols, and gingerdiones which all of them having a functional group of 3-methoxy-4-hidroxyphenyl. The difference of each compound is based on the different fatty chains connected by the functional group (Liu *et al.,* 2019). Gingerols such as 6-gingerol, 8-gingerol, and 10-gingerolin are the major polyphenols found in fresh ginger. During storage or heat treatment, the levels of gingerol can be decreased and can be transformed into corresponding shogaols. Furthermore, shogaols can be transformed into paradols after hydrogenation. Besides, the other phenolics present in ginger are zingerone, gingerenone-A, 6-dehydrogingerdione and quercetin (Schadich *et al.,* 2016).

Microencapsulation has been reported to protect bioactive compounds and to improve the stability of

ethanolic extract of red ginger extracts, with a ratio of rhizomes and ethanol (1:6). Three compositions consisting of encapsulant materials (maltodextrin and gum arabic with a ratio 10:0, 8:2, and 5:5) has been evaluated. The concentrations of gingerol, phenolic content, essential oils and antioxidant activities were evaluated and then correlated with the encapsulants used. The encapsulant materials produced different stability of gingerols in ethanolic extract of red ginger, and the increased amount of gum arabic offered better protection toward bioactive compounds and greater stability during storage (Nurhadi *et al.,* 2020). Several terpenes are also present in ginger rhizome such as α-curcumene, zingiberene, α-farnesene, β-sesquiphellandrene, and β-bisabolene (He and Li, 2010). These compounds are widely found in ginger essential oils and they are considered to be the main components in ginger essential oils (Yeh *et al.,* 2014). Ginger is also reported to have polysaccharides, organic acids, raw fibres, and lipids (Prasad and Tyagi, 2015). The major organic acids found in ginger are oxalic and tartaric acid while curcumin is also found as a bioactive in the ginger rhizome (Yeh *et al.,* 2014). Other organic acids present in ginger rhizome are acetic acid, lactic acid, citric acid, malonic acid, formic acid, and succinic acid (Liu *et al.*, 2019). The rhizome of ginger also contains vitamins and minerals. The mineral content of ginger is reported as more than 20 elements and the common minerals found are K, Mg, Mn, Ga, P, Al, Ba, Fe, and Zn. The most common vitamins presented in ginger are nicotinic acid and vitamin A (Prasad and Tyagi, 2015).

The evaluation of antioxidant activities, as determined by DPPH radical scavenging and FRAP, of ginger stored at different temperatures (5 and 15°C) and times (4 and 8 months) were performed to determine the optimal storage conditions for ginger rhizomes. Some phytochemicals namely total flavonoid content (TFC), Total phenolic content (TPC), Individual phenolic acids and flavonoids, 6-gingerol and 6-shogaol as determined using ultra-high-performance liquid chromatography (UHPLC) were measured. The results revealed that the contents of dry matter, total phenolic, total flavonoid, 6-

Table 1. Some phytochemical compounds isolated from *Zingiber officinale* reported from some literature

Class of compounds	Compounds	Plant part	References
Glucosides (6-gingerdiol)	1-(4-O-β-D-glucopyranosyl-3-)-5-O-β-D-glucopyranosyl-3-hydroxy-1-(4-hydroxy-3-	Fresh ginger	Sekiwa *et al*. (2000)
Terpene	α-terpinene, α-terpineol, 4-terpineol, terpinolene, γ-terpinolene	Rhizome	Chang *et al*. (2013)
Alcohol	Cineol, β-eudesmol, borneol, geraniol, farnesol, zingiberol	Rhizome	Raina *et al*. (2005); Liu *et al*. (2019)
Acid	L-Bornyl acetate, geranic acid, undecanoic acid	Rhizome	Raina *et al*. (2005; Liu *et al*. (2019)
Gingerols	Gingerol, Shogaol, isoshogaol, paradol, gingerdione, zingerine, β-sitosterol	Rhizome	Raina *et al*. (2005); Nurhadi *et al*. (2020)

gingerol, 6-shogaol, individual phenolics (gallic acid, ferulic acid, cinnamic acid, tannic acid) and individual flavonoids content (quercetin, rutin, catechin, epicatechin, kaempferol) were noticeably decreased at 5 and 15°C during the storage times from 4 to 8 months. The highest contents of these phytochemicals are observed in fresh samples, and the storage of ginger at 15°C for 4 months could reduce significantly the phytochemical contents (Ghasemzadeh *et al.,* 2016).

3.2 Biological activities

The rhizome of *Zingiber officinale* has been reported for its biological activities. Table 2 displays the biological activities of the ginger rhizome.

3.2.1 Antioxidant

The *in vitro* antioxidant assays of different extracts of ginger have been studied using different methods which can be categorized into radical scavenging assay, reducing power, chelating agent, and lipid peroxidation inhibition using linoleic-thyocyanate or beta carotene bleaching. The natural antioxidants extracted from rhizome were frequently correlated with the presence of phenolics, flavonoid and carotenoid contents. The antioxidant activities along with total phenolics contents of ethanolic extract of ginger have been evaluated by Stoilova (Stoilova *et al.,* 2007). The ginger extract had a phenolics content of 870.1 mg/g dry extract, while antioxidant activities as determined by DPPH radical scavenging assay, linoleic acid/water emulsion system and chelating activities revealed strong activities. Including the capability to inhibit hydroxy radical, the ethanolic extract (IC_{50} of 1.90 µg/mL) showed higher activity than the positive control of quercetin (IC_{50} of 2.78 µg/mL).

Some extracts (methanol, ethyl acetate, and hexane) were evaluated for *in vitro* antioxidant assays using radical scavenging of DPPH, ABTS, and nitric oxide. The methanolic extract of ginger (MEG) revealed the highest radical scavenging activities toward DPPH, ABTS and nitric oxide assays with inhibition percentages of 86.26%, 91.04% and 86.72%, respectively. Using GC-MS, some bioactive compounds are responsible for radical scavenging in MEG, such as 6 -gingerol, zingiberene, dihydrocapsaicin, zingerone, curcumene, beta bisabolene and 8-gingerol (Murugesan *et al.,* 2020).

The drying methods also affect the antioxidant activities of ginger. A study conducted by Ghafoor *et al.* (2020) revealed that ginger dried with oven, microwave, freeze, and room-air drying revealed different phenolic contents and compositions, total carotenoid contents, and antioxidant activities as determined by DPPH-radical

scavenging assay. Among these drying techniques, freeze-dried ginger rhizomes showed higher total phenolics (931.94 mg GAE/100 g), total carotenoids (13.17 µg/g), and antioxidant activity (82%) significantly ($p < 0.05$) than those dried using other techniques. Ginger dried by oven showed higher levels of individual phenolic compounds, as determined by HPLC using the diode-array detector in which (+)-catechin, gallic acid, and 3, 4-dihydroxy-benzoic acid. This result indicated that ginger dried by freeze-drying and oven methods yielded increased contents of phenolic compounds which correlate with antioxidant activity ($R^2 = 0.973$) *(Ghafoor et al.,* 2020).

Besides the extract of ginger to be evaluated, some phytochemical compounds isolated from ginger was also assessed for antioxidant activities. Two glucosides from 6-gingerdiol, namely 1-(4-O-β-D-glucopyranosyl-3-) (compound 1) and 5-O-β-D-glucopyranosyl-3-hydroxy-1 -(4-hydroxy-3-methoxyphenyl) decane (compound 2) have been evaluated for antioxidant activities using DPPH-radical scavenging and lipid peroxidation using linoleate-thiocyanate systems, compared to gingerdiol and gingerol. Compound 1 had no antioxidant activities, either using DPPH radical- scavenging or linoleate-thiocyanate method, while compound 2 revealed the same strong antioxidant activity as 6-gingerdiol and 6-gingerol using both methods. The free phenolic OH in compound 2 is suggested to have strong antioxidative activity, meanwhile phenolic OH in compound 1 was blocked by glucose (Sekiwa *et al.,* 2000). The essential oils extracted from fresh and dried gingers as well as methanol and hexane extracts were also evaluated for antioxidant activities using DPPH-radical scavenging assay and Ferric Reducing Antioxidant Power (FRAP). The total phenolic contents were observed in the methanol extract of fresh ginger (95.2 mg gallic acid equivalent (GAE)/g dry extract) followed by hexane extract of fresh ginger (87.5 mg GAE/g dry extract). The essential oils isolated from dried ginger revealed antioxidant activities followed by essential oils from fresh ginger using DPPH and FRAP methods. The major compounds in fresh ginger essential oils, as determined by GC-MS, were camphene, R-terpineol, farnesene, p-cineole, β-mycrene, pentadecanoic acid, zingiberene, geranyl isobutyrate, 3,7- dimethyl-1,3,7-octatriene, 9,12-octadecadienal, 9,12,15-octadecatrienal, nerolidol and R-phellandrene, while essential oils in dried ginger were camphene, R-terpineol, p-cineole, 9,12,15-octadecatrienal, zingiberene, pentadecanoic acid, farnesene, geranyl isobutyrate, limonene, 9,12-octadecadienal, 3,7-dimethyl- 1,3,7-octatriene, nerolidol, and R-phellandrene (El-Ghorab *et al.,* 2010).

Two compounds namely 6-gingerol and 6-shogaol

Table 2. Biological activities of *Zingiber officinale* rhizome

No.	Biological activities	Sample	Results	References
1	Antioxidant	Methanol extract	Good antioxidant activities measured using reducing power assay, superoxide anion, nitric oxide, hydroxide and DPPH radical, and hydrogen peroxide method.	Amir *et al.* (2011)
2	Antioxidant	Methanol, ethyl acetate and hexane extract	Good antioxidant activity measured using DPPH, ABTS, and nitric oxide method.	Murugesan *et al.* (2020)
3	Antioxidant	Methanol extract	Restore the normal antioxidant system (glutathione and catalase) in rats with liver injury in dose dependent manner.	Oke *et al.* (2019)
4	Antiinflammation	Ginger supplementation	Reducing CRP, hs-CRP and TNF-α levels.	Morvaridzadeh *et al.* (2020)
5	Antihyperlipidemic	Fresh ginger rhizome	Reducing the level of total cholesterol, LDL-C (bad cholesterol), triglycerides levels and increasing the level of HDL cholesterol (good cholesterol).	Paul *et al.* (2013)
6	Antimicrobial	Essential oil of ginger	EOs exhibited the inhibition of mycelial growth in all tested fungal pathogens (*Fusarium oxysporum Pyricularia oryzae Colletotrichum falcatum, Ganoderma boninense*, etc.) after 5-dayincubation with the minimum fungal inhibition of were in the	Abdullahi *et al.* (2020)
7	Antidiabetic	Ginger powder	Reducing some parameters which are related to T2DM, namely body mass index, the levels of fasting blood glucose fasting insulin, 2-hour postprandial blood glucose, glycated hemoglobin, triglycerides, total cholesterol, LDL-cholesterol and homeostasis model	ˉEl-Gayar *et al.* (2019)
8	Hepatoprotective	Supersaturable self-emulsifying drug delivery systems (S-SEDDS) of	Provided a hepatoprotective effect in a rat model of CCl_4-induced hepatotoxicity.	Ogino *et al.* (2018)
9	Anti-obesity	Steamed ethanolic extract	Anti-obesity effects as indicated by the losses of body weight and body fat in patients	Park *et al.* (2020)

(Figure 2) contributing to the antioxidant activities have been isolated in Zingiber officinale var. rubrum (Jahe Merah, red ginger) using an experimental design approach. Response surface methodology (RSM) was used for optimum extraction of 6-gingerol and 6-shogaol. The optimum condition was achieved using reflux at 76.9 °C for 3.4 hrs. The values of IC_{50} of 6-gingerol and 6-shogaol as determined using DPPH radical scavenging activity were 20.9 and 38.4 μg/mL, respectively (Ghasemzadeh *et al.,* 2015).

A clinical study on capsules of standardized ginger extract (containing referenced as (1.4% w/w of ginger extract 1.4% equivalent to 5 mg 6-gingerol) and placebo containing the similar ingredient except ginger extract has been performed for newly diagnosed cancer patients receiving adjuvant chemotherapy. Patients were randomized to receive either two capsules of standardized ginger extract (19 patients) or two capsules of placebo (24 patients). Some parameters include the activities of enzymatic antioxidants such as superoxide dismutase (SOD) and catalase (CAT) as well as levels of glutathione peroxidase (GPx), total glutathione (GSH/GSSG), and lipid peroxidation products as evaluated by malondialdehyde (MDA) and plasma concentrations of nitrite/nitrate (NO_2^-/NO_3^-) were investigated. The results showed that antioxidant parameters of SOD, CAT, GPx, and GSH/GSSG were increased significantly at day 64 in patients treated with the ginger group compared to those given by placebo, while the levels of MDA and (NO_2^-/NO_3^-) were decreased significantly ($p < 0.0001$). The daily supplementation of ginger extract started 3 days prior to chemotherapy increased the antioxidant parameters (SOD, CAT, GPx) significantly and reduce the oxidative marker levels (MDA and NO_2^-/NO_3^-) in patients who received moderate to high emetogenic potential chemotherapy (Danwilai *et al.,* 2017).

3.2.2 Anti-inflammation

Using approaches of systematic review and meta-

analysis, Morvaridzadeh et al. have evaluated the effect of ginger supplementation on anti-inflammation activities by investigating the concentrations of C-reactive protein (CRP), high sensitivity C-reactive protein (hs-CRP), tumour necrosis factor-alpha (TNF-α), soluble intercellular adhesion molecule (sICAM), and interleukin-6 (IL-6) in randomized controlled trials (RCTs). The increased levels of IL-6, TNF-α and CRP are related to the increased risk of inflammation. These increased markers are coming from the increased expression of immune system factors, such as nuclear factor- kappa-B (NF-κB) and peroxisome proliferator-activated receptor-gamma (PPAR-γ) (Aboonabi *et al.,* 2020). As a consequence, the suppression of the inflammatory response is an important point in the management of some chronic diseases such as cardiovascular diseases. The results revealed that there was a significant reduction in circulating CRP, hs-CRP and TNF-α levels due to ginger supplementation. However, from the meta-analysis, the supplementation of ginger did not show any significant impact on IL-6 and sICAM levels (Morvaridzadeh *et al.,* 2020).

Ginger is also used as an adjuvant of chemotherapy to ameliorate nausea and vomiting induced by chemotherapy through studies of a systematic review and meta-analysis. Ginger supplementation might have the benefit to ameliorate chemotherapy-induced vomiting and fatigue, however, because of the clinical heterogeneity, this systematic review reported that there is no association between ginger supplementation and chemotherapy-induced nausea and vomiting-related outcomes (Crichton *et al.,* 2019).

3.2.3 Antihyperlipidemic activities

A study using an approach of meta-analysis of randomized controlled trials on the effect of ginger intake on lipid concentration in subjects with hyperlipidemia has been evaluated. Weighted mean difference (WMD) and its 95% confidence interval were calculated for lipid concentrations including total cholesterol (TC), triglyceride (TG), low-density lipoprotein cholesterol (LDL-C), and high-density lipoprotein cholesterol (LDL-C). As a result, the treatment of ginger could reduce the concentrations of TG with a WMD value of -8.84 at 95% CI significantly, compared to control. The same results were also observed for TC and HDL-C. The supplementation of ginge in different forms (tablet, capsules, powder or rhizomes) could significantly reduce TG and significantly increased HDL-C, however, these changes were related to the clinical condition (Jafarnejad *et al.,* 2017).

The anti-lipidemic effect of methanolic ginger extract prepared by percolation technique has been evaluated in alloxan-induced diabetes and propylthiouracil-induced hypothyroidism in rats. Rats treated with ginger extract exhibited decreased levels of total cholesterol (TC), low-density lipoprotein (LDL) and increased high-density lipoprotein in rat serum compared to rats in control groups. The ginger extract revealed the combination effects in rats treated with ginger and atorvastatin (Al-Noory *et al.,* 2013).

3.2.4 Antibacterial, antifungal and antiviral activities

Some extracts of dried and processed ginger were reported to have antibacterial activities against some Gram-positive and Gram-negative bacteria as evaluated using the disc diffusion method. Antibiotics were used as a positive control, and minimal inhibitive concentration (MIC) was determined. The extracts had MIC values ranged from 5-50 μg/mL with the least active was against *Escherichia coli* with a MIC value of 50 μg/mL. The organic extracts revealed higher antibacterial activities than aqueous extracts, and there were no significant differences between dried and processed gingers and among organic extracts gingers (Gao and Yingying, 2010). This indicated that the active compounds contained in organic extracts were more active than those in aqueous extracts. Bioactive compounds present in essential oils (EOs) are deduced to be responsible for antibacterial activity. Mesomo *et al*. (2013) have evaluated essential oils extracted from ginger using supercritical CO_2 extraction. Using the agar well method, some Gram-positive (*Staphylococcus aureus* and *Listeria monocytogenes*) and Gram-negative (*Escherelia coli, Pseudononas aeroginosa, Salmonella enterica* serovar Typhimurium and *Shigella flexneri* (ATCC12022) bacteria are inhibited by EOs. The compounds contained in EOs namely alfa-pinene, alfa-terpineol and geraniol affected the efficiencies of antibacterial activity of Eos (Mesomo *et al*., 2013).

The effect of aqueous extracts of fresh and dried gingers on the human respiratory syncytial virus (HRSV) was reported through the ability of ginger to stimulate anti-viral cytokines and to induce plaque formation by blocking viral attachment and internalization. Fresh ginger could inhibit HRSV in a dose-dependent manner, while dried ginger was not dose-dependent. The high concentration of ginger may stimulate the mucosal cells to secrete IFN-β which contributes to the counteracting of viral infection (Chang *et al.,* 2013). The aqueous extract of fresh ginger has been reported to have activities toward Chikungunya virus (CV) as determined using parameters of $TCID_{50}$ (Median tissue culture infective dose) and Maximum non-toxic dose (MNTD)

Vero cell-line (Kaushik *et al.,* 2020).

3.3.5 Antidiabetic activity

Diabetes mellitus (DM) Some studies revealed that ginger possesses anti-diabetic properties. The administration of ginger in animal models revealed that some parameters related to diabetic properties namely the serum levels of glucose, lactate dehydrogenase, aspartate aminotransferase, and creatine kinase were significantly reduced compared to the control group (animals without supplementation of ginger). Gestational diabetes mellitus (GDM), impaired glucose tolerance occurring for the first time during pregnancy, is one of the most common complications during pregnancy. ginger has been evaluated on the blood glucose level of GDM women with impaired glucose tolerance test (GTT) using an approach of the randomized double-blind placebo-controlled clinical trial. The women with GDM (24-28 weeks of pregnancy with impaired GTT) were divided into 2 groups, one group is treated with ginger and another group was given by placebo. During this study, some clinical parameters namely Fast Blood Sugar (FBS), serum Blood Sugar 2 h post-prandial (BS2hpp), insulin, and Homeostasis Model Assessment (HOMA) index were analyzed before and six weeks after intervention. The results showed that FBS, fasting insulin and HOMA index was significantly reduced in patients treated with ginger compared to patients given the placebo, while BS2hpp was not different in patients given ginger and placebo (Hajimoosayi *et al.,* 2020).

Diabetes mellitus can result in neuronal damage caused by increased intracellular glucose leading to oxidative stress. The supplementation of ginger exhibited effects on the diabetic brain by reducing oxidative stress and inflammation. The supplementation of ginger could decrease the levels of blood glucose through the antagonistic activity against serotonin receptors and its blockage. Besides, ginger also inhibits the activities of intestinal glucosidase and amylase enzyme, therefore, the absorption of glucose could be reduced. Speculated the capability of ginger to restore the decreased activities of antioxidant enzymes in diabetic rats (Shanmugam *et al.,* 2011). Some researchers speculated that the hypoglycemic effects of ginger are due to the presence of phenolic compounds, polyphenols and flavonoids, and bioactive compounds which are known as antioxidants. Recently, Zingerone (phenolic compounds) was reported to have antidiabetic effects by scavenging free radicals which cause oxidative stress and by reducing overexpression of cellular nuclear factor (NF)-κB, tumour necrosis factor (TNF)-α and cyclooxygenase (COX)-2 proteins in rats. During diabetes mellitus, the expressions of NF-κB, TNF-α and COX-2 were

overexpressed (Singh *et al.,* 2020).

3.2.6 Hepatoprotective activity

Ginger is reported to have hepatoprotective activity in rats, in which the rats were made necrosis by treatment of carbon tetrachloride (CCl₄). Some clinical parameters namely antioxidants including the levels of glutathione (GSH), total superoxide dismutase (SOD) and malondialdehyde (MDA), while liver marker enzymes evaluated were succinate and lactate dehydrogenases (SDH and LDH), glucose-6-phosphatase (G-6-Pase), acid phosphatase (AP), 5'-nucleotidase (5'NT), aspartate and alanine aminotransferases (AST and ALT). The cholestatic markers assessed were alkaline phosphatase (ALP), gamma-glutamyl transferase (GGT), and total bilirubin. The administration of ginger significantly increased GSH, SOD, SDH, LDH, G-6-Pase, AP and 5'NT and decreased MDA, AST, ALT ALP, GGT and total bilirubin significantly, therefore, ginger is the potential to be used as a nutraceutical against liver necrosis (Motawi *et al.,* 2011).

The combination of aqueous extracts of ginger (AGE) and rosemary (ARE), either individually or in combination, toward the hepatoprotective activity on rats treated with carbon CCl₄ to induce liver injury, was reported (Essawy *et al.,* 2018). The administration of AGE and ARE can effectively relieve the alterations in a rat's liver induced by CCl₄, and the combination of both extracts was more effective as hepatoprotective than if extracts were administered singly. These results suggested that ginger and rosemary extracts are the potential to be used as an adjunct therapy in liver diseases through antioxidant effects.

3.2.7 Anti-obesity activity

Ginger is reported to have anti-obesity and related metabolic disorders. The anti-obesity effect of ginger associated with energy metabolism in mice has been evaluated. Mice were divided into two groups, namely the control (given with normal diet) and the treated group with a high-fat diet (HFD) with and without ginger at a dose of 500 mg/kg (wt/wt). The results revealed that the administration of ginger could alleviate HFD-induced body weight and fat accumulation. Ginger also reduces the levels of triglyceride, cholesterol and serum glucose. Therefore, it can be deduced that ginger plays a role in preventing obesity and related metabolic disorders (Wang *et al.,* 2019). Previously, it is reported that the anti-obesity of ginger, especially bioactive compounds of 6-shogaol and 6-gingerol, was due to the activation of Peroxisome proliferator-activated receptor δ (PPARδ), a major transcriptional regulator of energy metabolism in

skeletal muscle and adipose pathway. Ginger, also improved the capacity of exercise endurance by increasing the fat catabolism in skeletal muscle. In mice models, the supplementation of ginger also exhibited anti-obesity effects through modulation of the gut microbiota capable of increasing the levels of beneficial bacteria (probiotics) such as Bifidobacterium (Wang *et al.,* 2020).

3.3 Authentication analysis of ginger

Several analytical techniques could be used for authentication analysis of ginger such as polymerase chain reaction (PCR), high-performance liquid chromatography (HPLC), Fourier transform near-infrared (FT-NIR) spectroscopy, and Fourier transform infrared (FTIR) spectroscopy (Wang and Yu, 2015). Analysis using PCR could be used for polymorphism analysis. DNA is extracted from the ginger rhizome using a DNA extraction kit. Different primers are prepared for amplification of samples including from different regions and different varieties. The amplification results are then analyzed for their polymorphism. For analysis based on the chemical compounds, HPLC is widely used to analyze the biochemical compounds in the ginger rhizome. Samples were extracted using suitable HPLC grade solvent and then filtered using 0.22 μm of PTFE membrane filter. HPLC analysis was performed using a reverse-phased C18 column. A binary gradient elution system was used composed of water (A) and acetonitrile (B). The gradient elution as follows: 0.0–2.0 min, 10–55% B; 2.0–8.5 min, 55% B; 8.6–12.5 min, 65% B; 12.6–19.0 min, 100% B. The acquisition of chromatograms used a DAD detector set at the wavenumber of 230 nm. Authentication using FT-NIR was carried out by measuring samples through near-infrared wavelength. Dried powder of ginger sample was used for FT-NIR analysis. Spectra acquisition was carried out using FT-NIR spectrophotometer at the wavenumber region of 4,000-12,000 cm^{-1} (Rohman *et al.,* 2014). The spectra were then pre-processed using normalization, standard normal variate, or mean centring technique. Data analysis was performed using multivariate analysis techniques such as PCA, PLS-DA, OPLS-DA, LDA, and SIMCA. The authentication technique of ginger using FTIR spectroscopy has a similar principle to FT-NIR. The dried powder of ginger was used for FTIR measurement. The sample was measured using an FTIR spectrophotometer at the wavenumber region of 600-4,000 cm^{-1}. The resulted FTIR spectra were extracted for multivariate analysis.

Authentication analysis is important to prevent adulteration or impurities in ginger. The common impurities found in ginger could be insect filth, mould, and mammalian excreta. Moreover, other adulterants commonly found as impurity in ginger are spent ginger, Japanese ginger, beans, and wheat flour. Therefore, a suitable analytical method is required to analyze each type of impurities.

The metabolic profiling and phylogenetic analysis have been reported for authentication of ginger from closely related species in the genus Zingiberaceae namely *Zingiber zerumbet* Smith, *Z. montanum* (Koenig) Theilade, *Z. mioga* (Thunberg) Roscoe, *Zingiber spectabile* Grif, and *Alpinia galanga* (L.) Sw. Phylogenetic analysis exhibited that all *Z. officinale* (ginger) samples from different origins were genetically indistinguishable, while the other Zingiber species were divergent significantly, which allowed that all Zingiber species and *A. galanga* could be clearly differentiated. In addition, using metabolic profiling analysis, ginger samples derived obtained from different geographical origins revealed that the levels of 6]-, 8]-, and 10]-gingerols, as determined by HPLC, are different, even though the qualitative analysis did not show differences in types of phytochemicals (major volatile compounds and non-volatile composition). While, the metabolic profiles of other Zingiber species were very different, either qualitatively or quantitatively (Jiang *et al.,* 2006). The genetic and chemical analyses were also successfully applied for the differentiation of ginger from different origins for authentication analysis.

DNA-based method namely loop-mediated isothermal amplification (LAMP)-based marker has been developed for authentication analysis of *Z. officinale* Roscoe. The RAPD amplification was performed prior to the LAMP assay using 25 random decanucleotide primers. The aim of RAPD was to search DNA polymorphism to define the individuals and to obtain an informative LAMP-based molecular marker. Four specific LAMP primers namely two inner primers and two outer primers were designed for LAMP-based markers. LAMP reaction was carried out using the primers for LAMP and the template of DNA extracted DNA *Z. officinale*. The test was also performed in several species instead of Zingiber. Investigation of the LAMP assay was performed at DNA concentration around 10-15 ng for 30 mins. SYBR-Green was used for visualization. Results demonstrated that LAMP-based assay provided a simple, sensitive, and fast analysis for authentication of *Z. officinale* Roscoe (Chaudhary *et al.*, 2017).

To prevent microorganism growth and even resulting aflatoxin, ginger is subjected to sulfur fumigation for post-harvest handling. Fourier transform near-infrared spectroscopy (FT-NIR) combined with chemometrics of principal component analysis and orthogonal projections

to latent structures-discriminant analysis (OPLS-DA) for classification as well as partial least squares (PLS) and counter propagation artificial neural network (CP-ANN) has been applied for authentication of sulfur-fumigated ginger and non- fumigated ginger. PCA and OPLS-DA could classify sulfur fumigation ginger and non-fumigated with clear separation. In addition, using absorbance values of 4000-720 cm^{-1}, PLS and CP-ANN could predict zingerone, 6-gingerol, 8-gingerol, 6-shogaol, and 10-gingerol with acceptable R^2 and error values to differentiate between fumigated and non-fumigated ginger (Yan *et al.,* 2021).

Fourier transform infrared (FTIR) spectroscopy combined with chemometrics of PCA and PLS has been successfully applied for authentication of ginger rhizome in binary mixtures with beans. The samples were prepared in powder form and the concentration of bean used for creating calibration models ranged from 0-30%. Samples were measured using FTIR spectroscopy employing the attenuated total reflectance (ATR) technique in the wavenumber region of 4000-600 cm^{-1}. PCA could be used for checking outliers in calibration samples. Chemometrics of PLS using wavenumber region of 4000-2400 cm^{-1} was successfully used for quantification of beans in binary mixtures with ginger. The PLS model was evaluated using R^2 of calibration as well as validation models. Moreover, the value of root means the square error of calibration (RMSEC) and root mean square error of cross-validation (RMSECV) was also determined. The obtained R^2 was higher than 0.99 for both the calibration model (0.9958) and the validation model (0.9903) indicating the good performance of the PLS model. The RMSEC value was lower than 1.16 and the RMSECV value was lower than 1.751 indicating a low error and good precision of the PLS model. It suggested that a combination of FTIR spectroscopy and chemometrics could be used for the authentication of ginger (Terouzi and Oussama, 2016).

HPLC combined with chemometrics of multivariate analysis was successfully used for the differentiation of ginger based on the geographical origin. HPLC was used to analyze the gingerol derivatives in the ginger rhizome. Chemometrics of hierarchical cluster analysis (HCA) could be used for samples grouped from five different areas namely China, Thailand, India, Malaysia, and Vietnam. Five main clusters were obtained meaning that samples from each country were categorized as a different cluster. Chemometrics of PCA was also successfully used for sample differentiation resulting in five group samples on the PCA score plot. Samples were grouped based on their country of origin. Moreover, chemometrics of linear discriminant analysis (LDA) also corresponded to the results of HCA and PCA. Samples were successfully classified according to their country of origin. It suggested that the composition of gingerol derivatives in ginger rhizome differs among countries and the ginger obtained from one country have similar gingerol derivative compounds (Yudthavorasit *et al.*, 2014).

4. Conclusion

Zingiber officinale Roscoe or ginger is a good source to be used in food, beverage, and traditional medicine products due to some active compounds present such as gingerol, shogaol, zingiberones, gingerdiols, amino acids, organic acids, and minerals. The active compounds are believed to be responsible for some biological activities such as antioxidant, antibacterial, anti-inflammatory, antifungal, antidiabetic, antihyperlipidemic, antiobesity, and hepatoprotective activities. Some of the methods such as high-performance liquid chromatography (HPLC), DNA-based method, FTIR and FT-NIR spectroscopy could be used for authentication of ginger rhizome.

Conflict of interest

The authors declare no conflict of interest.

References

Abdullahi, A., Khairulmazmi, A., Yasmeen, S., Ismail, I.S., Norhayu, A., Sulaiman, M.R., Ahmed, O.H. and Ismail, M.R. (2020). Phytochemical profiling and antimicrobial activity of ginger (*Zingiber officinale*) essential oils against important phytopathogens. *Arabian Journal of Chemistry,* 13(11), 8012–8025. https://doi.org/10.1016/j.arabjc.2020.09.031

Aboonabi, A., Meyer, R.R., Singh, I. and Aboonabi, A. (2020). Anthocyanins reduce inflammation and improve glucose and lipid metabolism associated with inhibiting nuclear factor-kappaB activation and increasing PPAR-γ gene expression in metabolic syndrome subjects. *Free Radical Biology and Medicine*, 150, 30–39. https://doi.org/10.1016/j.freeradbiomed.2020.02.004

Al-Noory, A.S., Amreen, A.N. and Hymoor, S. (2013). Antihyperlipidemic effects of ginger extracts in alloxan-induced diabetes and propylthiouracil-induced hypothyroidism in (rats). *Pharmacognosy Research*, 5(3), 157–161. https://doi.org/10.4103/0974-8490.112419

Amir, M., Khan, A., Mujeeb, M., Ahmad, A., Usmani, S. and Akhtar, M. (2011). Phytochemical analysis and *in vitro* antioxidant activity of *Zingiber officinale*. *Free Radical Antioxidants,* 1(4), 75–81. https://doi.org/10.5530/ax.2011.4.12

Benzie, I.F.F. and Wachtel-Galor, S. (2011). The Amazing and Mighty Ginger In Bode, A.M. and Dong, Z. (Eds.) Herbal Medicine. Biomolecular and clinical aspects. 2nd ed. United Kingdom: CRC Press/Taylor & Francis. https://doi.org/10.1201/b10787

Chang, J.S., Wang, K.C., Yeh, C.F., Shieh, D.E. and Chiang, L.C. (2013). Fresh ginger (*Zingiber officinale*) has anti-viral activity against human respiratory syncytial virus in human respiratory tract cell lines. *Journal of Ethnopharmacology*, 145(1), 146–151. https://doi.org/10.1016/j.jep.2012.10.043

Chaudhary, A.A., Khan, M., Al-Shaqha, W.M., Alharbi, M. and Al-Khamees, O.A. (2017). Rapid and easy molecular authentication of medicinal plant *Zingiber officinale* Roscoe by loop-mediated isothermal amplification (LAMP)-based marker. *Journal of Medicinal Plant Research,* 8(20), 756–62. https://doi.org/10.5897/JMPR2013.5351

Crichton, M., Marshall, S., Marx, W., McCarthy, A.L. and Isenring, E. (2019). Efficacy of ginger (*Zingiber officinale*) in ameliorating chemotherapy-induced nausea and vomiting and chemotherapy-related outcomes: A systematic review update and meta-analysis. *Journal of The Academy of Nutrition and Dietetics*, 119(12), 2055–2068. https://doi.org/10.1016/j.jand.2019.06.009

Danwilai, K., Konmun, J., Sripanidkulchai, B.O. and Subongkot, S. (2017). Antioxidant activity of ginger extract as a daily supplement in cancer patients receiving adjuvant chemotherapy: A pilot study. *Cancer Management Research*, 9, 11–18. https://doi.org/10.2147/CMAR.S124016

El-Gayar, M.H., Aboromia, M.M.M., Ibrahim, N.A. and Abdel-Hafiz, M.H. (2019). Effects of ginger powder supplementation on glycemic status and lipid profile in newly diagnosed obese patients with type 2 diabetes mellitus. *Obesity Medicine,* 14, 100094. https://doi.org/10.1016/j.obmed.2019.100094

El-Ghorab, A.H., Nauman, M., Anjum, F.M., Hussain, S. and Nadeem, M.A. (2010). Comparative study on chemical composition and antioxidant activity of ginger (*Zingiber officinale*) and cumin (*Cuminum cyminum*). *Journal of Agricultural Food Chemistry*, 58(14), 8231–8237. https://doi.org/10.1021/jf101202x

Essawy, A.E., Abdel-Wahab, W.M., Sadek, I.A. and Khamis, O.M. (2018). Dual protective effect of ginger and rosemary extracts against CCl$_4$-induced hepatotoxicity in rats. *Environmental Science and Pollution Research*, 25(20), 19510–19517. https://doi.org/10.1007/s11356-018-2129-5

Gao, D. and Yingying, Z. (2010). The effect of ginger extracts on gram-positive bacteria. *Pharmacognosy Journal*, 2(15), 41–44. https://doi.org/10.1016/S0975-3575(10)80077-X

Ghafoor, K., Al-Juhaimi, F., Özcan, M.M., Uslu, N., Babiker, E.E. and Mohamed-Ahmed, I.A. (2020). Total phenolics, total carotenoids, individual phenolics and antioxidant activity of ginger (*Zingiber officinale*) rhizome as affected by drying methods. *LWT*, 126, 109354. https://doi.org/10.1016/j.lwt.2020.109354

Ghasemzadeh, A., Jaafar, H.Z.E. and Rahmat, A. (2015). Optimization protocol for the extraction of 6-gingerol and 6-shogaol from *Zingiber officinale* var. rubrum Theilade and improving antioxidant and anticancer activity using response surface methodology. *BMC Complementary Alternative Medicines*, 15, 258. https://doi.org/10.1186/s12906-015-0718-0

Ghasemzadeh, A., Jaafar, H.Z.E. and Rahmat, A. (2016). Changes in antioxidant and antibacterial activities as well as phytochemical constituents associated with ginger storage and polyphenol oxidase activity. *BMC Complementary Alternative Medicines*, 16(1), 25–32. https://doi.org/10.1186/s12906-016-1352-1

Hajimoosayi, F., Sadatmahalleh, S.J., Kazemnejad, A. and Pirjani, R. (2020). Effect of ginger on the blood glucose level of women with gestational diabetes mellitus (GDM) with impaired glucose tolerance test (GTT): A randomized doubleblind placebo-controlled trial. *BMC Complementary Medicine Therapy*, 20(1), 116–122. https://doi.org/10.1186/s12906-020-02908-5

Hasani, H., Arab, A., Hadi, A., Pourmasoumi, M., Ghavami, A. and Miraghajani, M. (2019). Does ginger supplementation lower blood pressure? A systematic review and meta-analysis of clinical trials. *Phytotherapy Research*, 33(6), 1639–1647. https://doi.org/10.1002/ptr.6362

He, Y. and Li, X.R. (2010). Analysis of volatile omponents in rhizome zingibers, *Zingiber officinale* roscoe and ginger peel by gas chromatography-mass spectrometry and chemometric resolution. *Webmed Central Chinese Medicine*, 1(9), 60-66.

Jafarnejad, S., Keshavarz, S.A., Mahbubi, S., Saremi, S., Arab, A. and Abbasi, S. (2017). Effect of ginger (*Zingiber officinale*) on blood glucose and lipid concentrations in diabetic and hyperlipidemic subjects: A meta-analysis of randomized controlled trials. *Journal of Functional Foods*, 29, 127–134. https://doi.org/10.1016/j.jff.2016.12.006

Jiang, H., Xie, Z., Koo, H.J., McLaughlin, S.P., Timmermann, B.N. and Gang, D.R. (2006). Metabolic profiling and phylogenetic analysis of medicinal Zingiber species: Tools for authentication

of ginger (*Zingiber officinale* Rosc.). *Phytochemistry*, 67(15), 1673–1685. https://doi.org/10.1016/j.phytochem.2005.08.001

Kaushik, S., Jangra, G., Kundu, V., Yadav, J.P. and Kaushik, S. (2020). Anti-viral activity of *Zingiber officinale* (Ginger) ingredients against the Chikungunya virus. *Virus Disease*, 31(3), 270–276. https://doi.org/10.1007/s13337-020-00584-0

Kikuzaki, H. and Nakatani, N. (1996). Cyclic diarylheptanoids from rhizomes of *Zingiber officinale*. *Phytochemistry*, 43(1), 273–277. https://doi.org/10.1016/0031-9422(96)00214-2

Kiyama, R. (2020). Nutritional implications of ginger: chemistry, biological activities and signaling pathways. *Journal of Nutrition and Biochemistry*, 86, 108486. https://doi.org/10.1016/j.jnutbio.2020.108486

Koga, A.Y., Beltrame, F.L. and Pereira, A.V. (2016). Several aspects of Zingiber zerumbet: A Review. *Revista Brasileira de Farmacognosia,* 6(3), 385–391. https://doi.org/10.1016/j.bjp.2016.01.006

Krüger, S., Bergin, A. and Morlock, G.E. (2018). Effect-directed analysis of ginger (*Zingiber officinale*) and its food products, and quantification of bioactive compounds via high-performance thin-layer chromatography and mass spectrometry. *Food Chemistry*, 243, 258–268. https://doi.org/10.1016/j.foodchem.2017.09.095

Liu, Y., Liu, J. and Zhang, Y. (2019). Research progress on chemical constituents of *Zingiber officinale* Roscoe. *Biomed Research International*, 5, 5370823. https://doi.org/10.1155/2019/5370823

Mao, Q., Xu, X.Y., Cao, S.Y., Gan, R.Y., Corke, H. and Li, H.B. (2019). Bioactive compounds and bioactivities of ginger (*Zingiber officinale* Roscoe). *Foods*, 8(6), 1–21. https://doi.org/10.3390/foods8060185

Mesomo, M.C., Corazza, M.L., Ndiaye, P.M., Dalla-Santa, O.R., Cardozo, L. and Scheer, A.D.P. (2013). Supercritical CO_2 extracts and essential oil of ginger (*Zingiber officinale* R.): Chemical composition and antibacterial activity. *Journal of Supercritical Fluids*, 80, 44–49. https://doi.org/10.1016/j.supflu.2013.03.031

Morvaridzadeh, M., Fazelian, S., Agah, S., Khazdouz, M., Rahimlou, M. and Agh, F.E.P.S.H. (2020). Effect of ginger (*Zingiber officinale*) on inflammatory markers: A systematic review and meta-analysis of randomized controlled trials. *Cytokine*, 135, 155224. https://doi.org/10.1016/j.cyto.2020.155224

Motawi, T.K., Hamed, M.A., Shabana, M.H., Hashem, R.M. and Aboul-Naser, A.F. (2011). *Zingiber officinale* acts as a nutraceutical agent against liver fibrosis. *Nutrition and Metabolism*, 8, 40–46. https://doi.org/10.1186/1743-7075-8-40

Murugesan, S., Venkateswaran, M.R. and Jayabal, S.S.P. (2020). Evaluation of the antioxidant and anti-arthritic potential of *Zingiber officinale* Rosc. by *in vitro* and *in silico* analysis. *South African Journal of Botany*, 130, 45–53. https://doi.org/10.1016/j.sajb.2019.12.019

Nurhadi, B., Suriati, Tensiska, Saputra, R.A. and Sukri, N. (2020). The role of encapsulant materials on the stability of bioactive compounds of red ginger (*Zingiber officinale* Roscoe. var. Rubrum) extract powder during storage. *Food Chemistry*, 333, 127490. https://doi.org/10.1016/j.foodchem.2020.127490

Ogino, M., Yakushiji, K., Suzuki, H., Shiokawa, K., Kikuchi, H. and Seto, Y. (2018). Enhanced pharmacokinetic behavior and hepatoprotective function of ginger extract-loaded supersaturable self-emulsifying drug delivery systems. *Journal of Functional Foods,* 40, 156–163. https://doi.org/10.1016/j.jff.2017.08.035

Oke, G.O., Abiodun, A.A., Imafidon, C.E. and Monsi, B.F. (2019). *Zingiber officinale* (Roscoe) mitigates CCl_4-induced liver histopathology and biochemical derangements through antioxidant, membrane-stabilizing and tissue-regenerating potentials. *Toxicol Reports*, 6, 416–425. https://doi.org/10.1016/j.toxrep.2019.05.001

Paul, P., Islam, M.K., Mustari, A. and Khan, M.Z.I. (2013). Hypolipidemic effect of ginger extract in vanaspati fed rats. *Bangladesh Journal of Veterinary Medicine,* 10(1-2), 93–96. https://doi.org/10.3329/bjvm.v10i1-2.15652

Park, S.H., Jung, S.J., Choi, E.K., Ha, K.C., Baek, H.I. and Park, Y.K. (2020). The effects of steamed ginger ethanolic extract on weight and body fat loss: a randomized, double-blind, placebo-controlled clinical trial. *Food Science and Biotechnology,* 29(2), 265–273. https://doi.org/10.1007/s10068-019-00649-x

Pourmasoumi, M., Hadi, A., Rafie, N., Najafgholizadeh, A., Mohammadi, H. and Rouhani, M.H. (2018). The effect of ginger supplementation on lipid profile: A systematic review and meta-analysis of clinical trials. *Phytomedicine*, 43, 28–36. https://doi.org/10.1016/j.phymed.2018.03.043

Prasad, S. and Tyagi, A.K. (2015). Ginger and its constituents: Role in prevention and treatment of gastrointestinal cancer. *Gastroenterol Research and Practice*, 9, 142979. https://

doi.org/10.1155/2015/142979

Raina, V.K., Kumar, A. and Aggarwal, K.K. (2005). Essential oil composition of ginger (*Zingiber officinale* roscoe) rhizomes from different place in India. *Journal of Essential Oil-Bearing Plant*, 8(2), 187–91. https://doi.org/10.1080/0972060X.2005.10643442

Rohman, A., Nugroho, A., Lukitaningsih, E. and Sudjadi. (2014). Application of vibrational spectroscopy in combination with chemometrics techniques for authentication of herbal medicine. *Applied Spectroscopy Review*, 49(8), 603–613. https://doi.org/10.1080/05704928.2014.882347

Schadich, E., Hlaváč, J., Volná, T., Varanasi, L., Hajdúch, M. and Džubák, P. (2016). Effects of ginger phenylpropanoids and quercetin on Nrf2-ARE pathway in human bj fibroblasts and HaCaT keratinocytes. *Biomed Research International*, 2016, 2173275. https://doi.org/10.1155/2016/2173275

Sekiwa, Y., Kubota, K. and Kobayashi, A. (2000). Isolation of novel glucosides related to gingerdiol from ginger and their antioxidative activities. *Journal of Agricultural Food Chemistry*, 48(2), 373–377. https://doi.org/10.1021/jf990674x

Seow, S.L.S., Hong, S.L., Lee, G.S., Abd Malek, S.N. and Sabaratnam, V. (2017). 6-shogaol, a neuroactive compound of ginger (jahe gajah) induced neuritogenic activity via NGF responsive pathways in PC-12 cells. *BMC Complementary Alternative Medicine*, 17(1), 230-238. https://doi.org/10.1186/s12906-017-1837-6

Shanmugam, K.R., Mallikarjuna, K., Kesireddy, N., Sathyavelu, and Reddy, K. (2011). Neuroprotective effect of ginger on anti-oxidant enzymes in streptozotocin-induced diabetic rats. *Food Chemistry and Toxicology*, 49(4), 893–897. https://doi.org/10.1016/j.fct.2010.12.013

Singh, B., Kumar, A., Singh, H., Kaur, S., Kaur, S. and Singh-Buttar, H. (2020). Zingerone produces antidiabetic effects and attenuates diabetic nephropathy by reducing oxidative stress and overexpression of NF-κB, TNF-α, and COX-2 proteins in rats. *Journal of Functional Foods*, 74, 10–19. https://doi.org/10.1016/j.jff.2020.104199

Srinivasan, K. (2017). Ginger rhizomes (*Zingiber officinale*): A spice with multiple health beneficial potentials. *PharmaNutrition*, 5(1), 18–28. https://doi.org/10.1016/j.phanu.2017.01.001

Stoilova, I., Krastanov, A., Stoyanova, A., Denev, P. and Gargova, S. (2007). Antioxidant activity of a ginger extract (*Zingiber officinale*). *Food Chemistry*, 102 (3), 764–770. https://doi.org/10.1016/

j.foodchem.2006.06.023

Terouzi, W. and Oussama, A. (2016). Evaluation of Ginger adulteration with beans using Attenuated Total Reflectance Fourier Transform Infrared spectroscopy and multivariate analysis. *International Journal of Engineering and Applied Sciences*, 3(7), 42–46.

Wang, J., Li, D., Wang, P., Hu, X. and Chen, F. (2019). Ginger prevents obesity through regulation of energy metabolism and activation of browning in high-fat diet-induced obese mice. *The Journal of Nutritional Biochemistry,* 70, 105–115. https://doi.org/10.1016/j.jnutbio.2019.05.001

Wang, J., Wang, P., Li, D., Hu, X. and Chen, F. (2020). Beneficial effects of ginger on prevention of obesity through modulation of gut microbiota in mice. *European Journal of Nutrition,* 59(2), 699–718. https://doi.org/10.1007/s00394-019-01938-1

Wang, P. and Yu, Z. (2015). Species authentication and geographical origin discrimination of herbal medicines by near infrared spectroscopy: A review. *Journal of Pharmaceutical Analysis*, 5(5), 277–284. https://doi.org/10.1016/j.jpha.2015.04.001

Wu, X.M., Zuo, Z.T., Zhang, Q.Z. and Wang, Y.Z. (2018). FT-MIR and UV–vis data fusion strategy for origins discrimination of wild *Paris Polyphylla* Smith var. yunnanensis. *Vibrational Spectroscopy*, 96, 125–136. https://doi.org/10.1016/j.vibspec.2018.04.001

Yan, H., Li, P.H., Zhou, G.S., Wang, Y.J., Bao, B.H. and Wu, Q.N. (2021). Rapid and practical qualitative and quantitative evaluation of non-fumigated ginger and sulfur-fumigated ginger via Fourier-transform infrared spectroscopy and chemometric methods. *Food Chemistry*, 341(Part 1), 12–24. https://doi.org/10.1016/j.foodchem.2020.128241

Yeh, H., Yu, Chuang, C.C., Chen, H., Wan, C.J. and Chen, T.L. (2014). Bioactive components analysis of two various gingers (*Zingiber officinale* Roscoe) and antioxidant effect of ginger extracts. *LWT - Food Science and Technology*, 55(1), 329–334. https://doi.org/10.1016/j.lwt.2013.08.003

Yudthavorasit, S., Wongravee, K. and Leepipatpiboon, N. (2014). Characteristic fingerprint based on gingerol derivative analysis for discrimination of ginger (*Zingiber officinale*) according to geographical origin using HPLC-DAD combined with chemometrics. *Food Chemistry*, 158, 101–111. https://doi.org/10.1016/j.foodche**m**.2014.02.086