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Research article

Effects of drying techniques on bioactivity of ginger (*Zingiber officinale)*: A meta-analysis investigation

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Abstract: Ginger is a spice with various uses for humans, such as flavoring agents and nutraceuticals. Drying is commonly used in the processing and preserving of ginger and affects the characteristics of the final ginger product. This study aimed to review the studies that have evaluated the effects of drying techniques on the bioactivity of ginger. A meta-analysis investigation was conducted to identify a study that evaluated the effects of drying techniques on the levels of bioactivity in ginger. The database search found 113 results. There are 13 articles from 2010 to 2020 that met the inclusion criteria. The drying techniques have different effects on the optimum levels of ginger characteristics. After drying treatment there were significant different on total flavonoid and antioxidant activity and there were not significant on total phenolic content and 6-gingerol content of ginger. In conclusion, drying has different effects on ginger in terms of bioactivity. Therefore, choosing the best method must be made based on the purpose of the process and the final product criteria.

Keywords: antioxidant; bioactive compound; drying; ginger; meta-analysis

1. Introduction

Drying is one of the most widely that have used in food processing to preserve food products due to reduce water content in plant or animal. Most food products have a water content greater than 50%. After drying, the water content ranges from 5–25%, depending on the product variety [1]. An important factor in drying is the dehydration process with associated with a continuous reduction in water content to inhibit microbial growth and preventing biochemical reaction related to spoilage.

However, it can also cause loss of aroma and changes in nutritional value, physical properties, and antioxidant activity [2–4].

Ginger is a spice that has various benefits for humans such as a raw material for traditional medicine and nutraceuticals, flavoring agent, and preservative in food that can add as flavor agent and give a delicious and distinctive aroma. Previous research has revealed that ginger has therapeutic properties, including antibiotic, antimicrobial, and antioxidant effects, inhibiting the formation of inflammatory compounds and anti-inflammatory effects [6,7]. In addition, ginger is also effective against several types of cancer, stimulates blood circulation, controls blood pressure and hypertension, helps lower cholesterol, and maintains the heart [8,9]. In general, these activities are caused by bioactive compounds that content in ginger [10].

Ginger can be consumed and used in fresh, paste, or powder form. Dried ginger can be used as a substitute for fresh ginger, although the tastes produced by fresh and dried ginger are a bit different. A fresh ginger usually as a complementary ingredient in cooking. In contrast, dried ginger powder is usually applied as a flavoring for recipes, such as bread, cakes, biscuits, cookies, and beer.

Drying significantly affects the antioxidant capacity of ginger and freeze-dried ginger has a higher polyphenol content than fresh ginger or its aqueous extract [11]. Dried ginger and stir-fried ginger are rich in phenolic compounds and strong antioxidant activity compared to fresh ginger and carbonated ginger [12]. The comparison method in drying of ginger showed that ginger dried under the open air have better quality in term of physicochemical and organoleptic properties than a solar dryer [13]. Drying ginger at a high temperature can change protein properties and affect sensory attributes through loss of aroma and colour [12]. Microbiologically, the use of solar dryers is a better choice for safer ginger preservation. A maximum temperature of 40 °C is recommended for solar dryers because this temperature does not change the protein properties and can maintain the microbiological quality of ginger [12].

Out of the four drying techniques, sun, oven, vacuum, and freeze drying, thermal drying methods significantly decrease the total phenolic content (TPC) of the dried ginger samples [14]. On the other hand, freeze-dried ginger samples were found to have higher antioxidant content than other samples. The drying techniques and geographical origin can also affect the ginger characteristics and the acceptability of the product in the market [15].

Dried ginger products come in various forms. Production of both intermediate and finished products are still growing and very profitable. The high market demand offers an opportunity for farmers or industry to develop new product with higher quality in term of physicochemical and organoleptic properties. There is demand for this spice in the food and beverage industry as well as the pharmaceutical industry. The different drying techniques of ginger produce final products with different characteristics. This study aimed to compare the ginger drying techniques with a meta-analysis so that the characteristics of the final product can be known in terms of the content of bioactive compounds, antioxidant activity, and volatile compounds. It will also analyze the known drying techniques that can produce high-quality products.

2. Materials and methods

2.1. Literature search

Meta-analysis is a type of systematic review accompanied by statistical techniques to calculate the conclusions of several earlier studies. A literature search was conducted to identify studies that evaluated the effects of drying techniques (specifically freeze, microwave, air, oven, vacuum, and sun-drying) on the concentration of bioactive compounds, such as TPC, total flavonoid, 6-gingerol, antioxidant activity, and volatile compound in ginger. The flowchart of the research study is shown in Figure 1.

Two strategies were used to search the relevant literature. First, searches were carried on the international electronic database with a high-medium reputation, such as ResearchGate, PubMed, DOAJ (Directory of Open Access Journals), and Google Scholar. The search was performed using the following combination of keywords: ginger, dried ginger, drying, bioactivity, phenolic compounds, flavonoid, antioxidant activity, and volatile. Second, a manual search (i.e. snowball searching) was conducted, checking the references cited by the retrieved articles to maximize the results.

The data extracted from each paper included the following: study authors, year of the study, drying techniques, evaluated polyphenols, evaluated methods for antioxidant activity analyses, pre-and-post-processing concentrations of polyphenols and flavonoid, standard deviation (SD), and the number of samples (n). Only studies with at least three samples that presented the standard deviation were included.

2.2. Meta-analysis calculation

The data obtained were analyzed using descriptive methods and Confidence Interval (CI) with the principle of mean difference as the effect size. CI analysis was performed to identify differences using a significance level of 95%. This significance level means that it can be trusted 95% that the data used is within the interval calculated based on the CI. The interval has a related level of confidence that the actual parameter is within the specified range [16]. Microsoft Excel was used for CI analysis, and the data is presented in the form of histograms. STATA 16.0 for Windows 64-bit x86-64 (2019) was used to test for heterogeneity between studies. The significance of the data was presented in the form of a forest plot graph.

3. Results and discussion

3.1. Literature search and data collection

A database search for literature regarding the effect of drying techniques on bioactivity and volatility of ginger was found in 113 articles published between 2010 and 2020. Of 113, only 40 articles passed the inclusion criteria. Articles presenting mean values, standard deviations, or raw data that could be used for further calculations were included. In contrast, articles that only evaluated a single sample or did not define the sample number were excluded. Furthermore, 13 articles were selected for the CI analysis.

There were 12 drying techniques uncovered from 40 included articles based on the criteria used in drying ginger (Figure 2). There are four method that most widely applied technique, starting from freeze-, microwave-, air and oven-drying. The other methods are vacuum-, sun-, convective-, shade-, infrared-, solar-, silica gel- and spray-drying techniques. Each drying technique has advantages and disadvantages that can affect the characteristics and quality of the final product. Furthermore, there are different financial costs associated with each method.

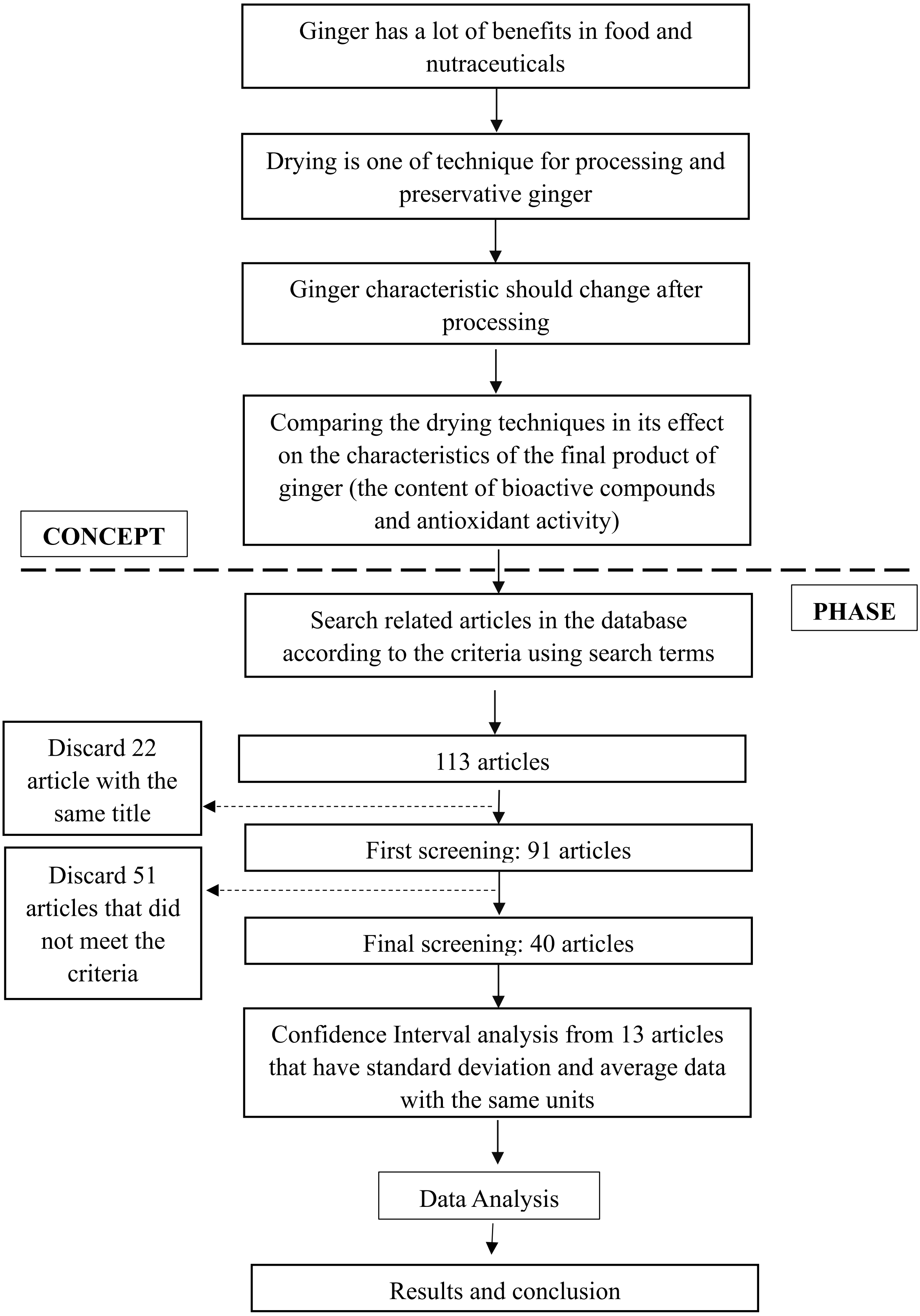

Figure 1. Flow chart of the research study.

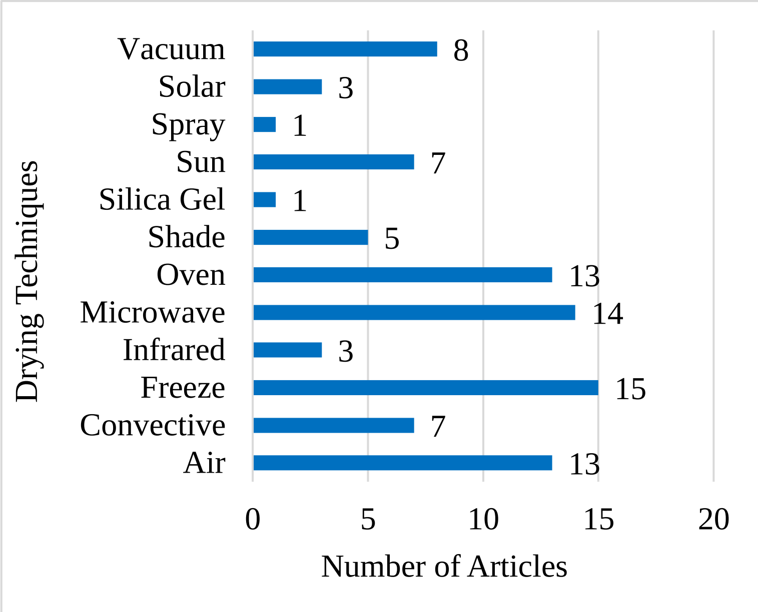

Figure 2. Number of articles based on ginger drying techniques.

Freeze-drying is the most popular technique because many studies have been conducted on foodstuffs and reported that the resulting product has good quality [17]. In addition, there is no change in colour and aroma with stable material structure, indicating a low risk of material damage [17]. Microwave drying is in the second position; this technique has a high drying rate with fast and uniform heating to produce goods with high quality and low energy consumption, making this technique a widely used one [18]. Finally, air- and oven drying are in the third position. These techniques are used because they are easy to operate and low in cost, but the product quality is not high as three other methods [18].

3.2. Impact of drying on bioactive compound

3.2.1. Total Phenolic Content (TPC)

Six drying techniques could be compared for the TPC of fresh ginger and dried ginger. There are freeze, sun, microwave, air, infrared, and convective drying (Figure 3). The average results showed that the increase in TPC occurred in ginger after drying by freeze, sun, convective, and air-drying techniques. On the other hand microwave and infrared drying showed decrease in TPC.

Freeze-dried ginger has effects on the increase in TPC compared to fresh ginger, while other drying techniques (air-, infrared-, microwave- drying) significantly reduced TPC [17]. Another study reported that freeze-drying was in the first position, followed by the relative humidity-convective drying, infrared, and microwave drying techniques [18]. The increase in TPC should be due to the inactivation of the browning enzyme response to reducing phenolic compounds. Meanwhile, another study reported that sun drying is the drying technique with the highest level of increase, but freeze-drying has the highest TPC value of ginger compared to the sun- and oven-drying techniques [19].

Microwave drying is a technique that typically results the lowest content of bioactive compounds compared to other methods. The heat that spreads quickly and intensely from microwaves causes damage to bioactive compounds that can change the chemical structure and degradation of polyphenols content during drying process [20]. Infrared drying applied to ginger also decreases the TPC of the final product. A study conducted [21] showed that this drying technique changed the TPC of ginger.

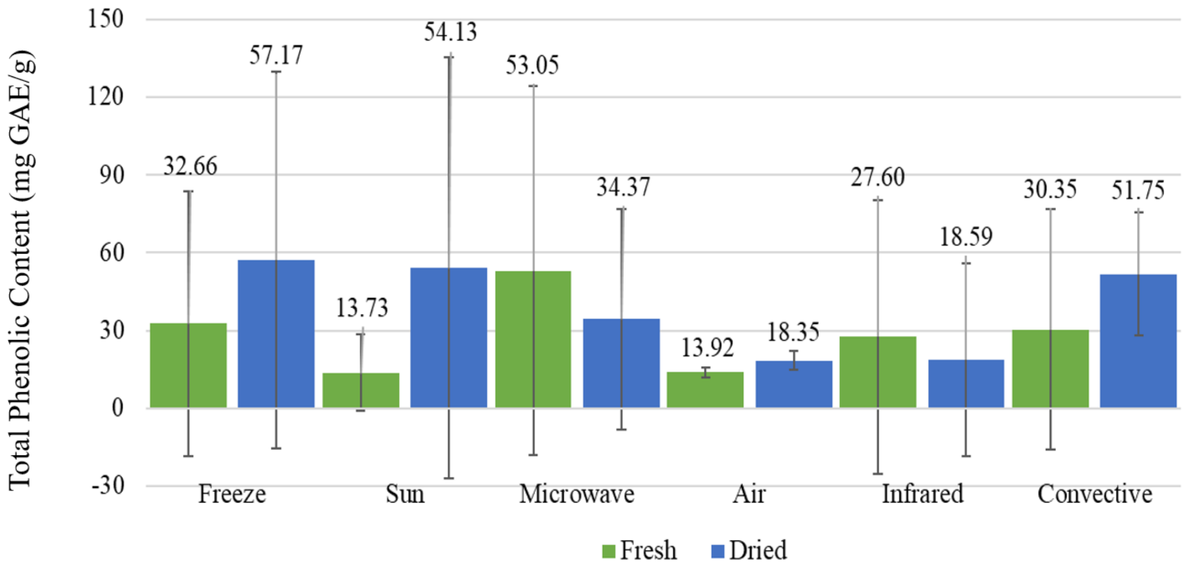

Figure 3. Mean profile of total phenolic content.

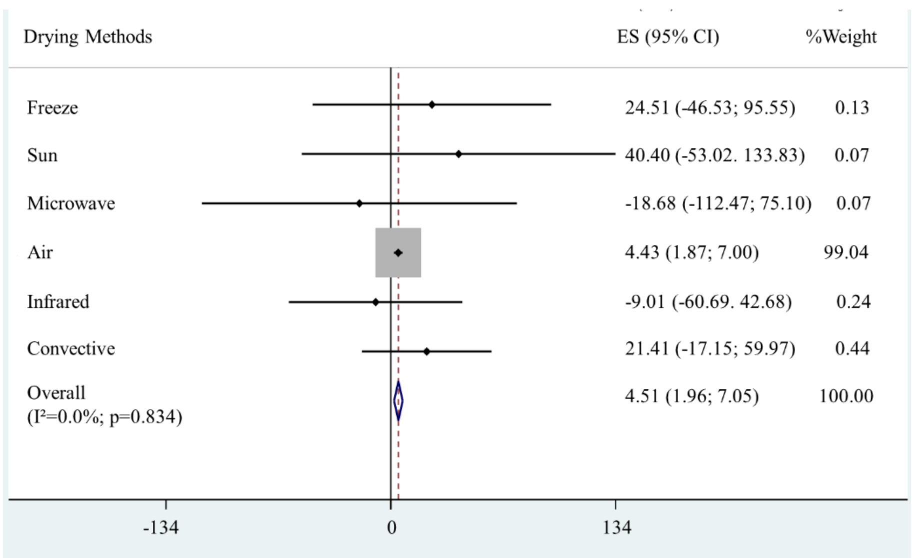

Figure 4. Forest plot graph of drying techniques for TPC (Freeze, n = 6; Sun, n = 3; Microwave, n = 3; Air, n = 10; Infrared, n = 6; and Convective, n = 7).

Many studies have reported that dried plant products have a higher phytochemical content than fresh plants. The stability of bioactive compounds (i.e. phenolic compounds), can be caused by several factors, one of which is the oxidation of polyphenols. This process plays an important role in the degradation of phenolic compounds and plant flavonoids [22]. The activity of polyphenol oxidase (PPO) with its catalytic activity responsible for degradation of bioactive compound in fresh plants.

PPO showed variable activity under different storage conditions and its activity is dependent on the drying method of samples, storage, and processing conditions [22].

The results of comparing drying techniques against TPC on ginger using meta-analysis are presented in Figure 4. The graph shows that the $p > 0.05$ and the CI for the combined effect crosses the vertical line with the effective value, and CI is 4.51 (1.96 to 7.05), which is not statistically significant. Thus, the treatment of different drying techniques did not significantly effect the difference in TPC of dried ginger and fresh ginger.

3.2.2. Total flavonoid

The total flavonoid contents of ginger were consistently increased after drying. Freeze, shade, and vacuum drying techniques can increase the average value of the total flavonoid content of ginger (Figure 5). Vacuum drying gives the highest increase compared to freeze and shade drying techniques.

Freeze-drying can increase the total flavonoid content in ginger, although the level of increase is lower than the sun- and oven-drying techniques [19]. However, one study investigating total flavonoid content in ginger after drying with freeze-drying, relative humidity-convective-drying, infrared-drying, and microwave-drying techniques showed that the freeze-drying technique had yielded the highest level of total flavonoid increase compared to other methods [18]. Another study showed that vacuum drying had the effect of increasing the highest total flavonoid content compared to the sun-drying techniques [23].

The forest plot graph in Figure 6 shows the impact of drying techniques in total ginger flavonoids. The flavonoid content of dried ginger was significantly higher than fresh ginger for all drying techniques. The graph highlights that CI of freeze, shade, and vacuum drying did not cross the vertical line, which is statistically significant because there is a difference in total flavonoids between dried ginger and fresh ginger. Overall, the combined effect was statistically significant because the $p < 0.05$ and the CI of the combined effect did not cross the vertical line, with the effective value of CI being 2.45 (1.77 to 31.3). Thus, the treatment of different drying techniques gave differences in total ginger flavonoids. Vacuum drying gave the largest effect weight of 21.27%, although the CI range (2.89 to 5.82) was not smaller than shade drying.

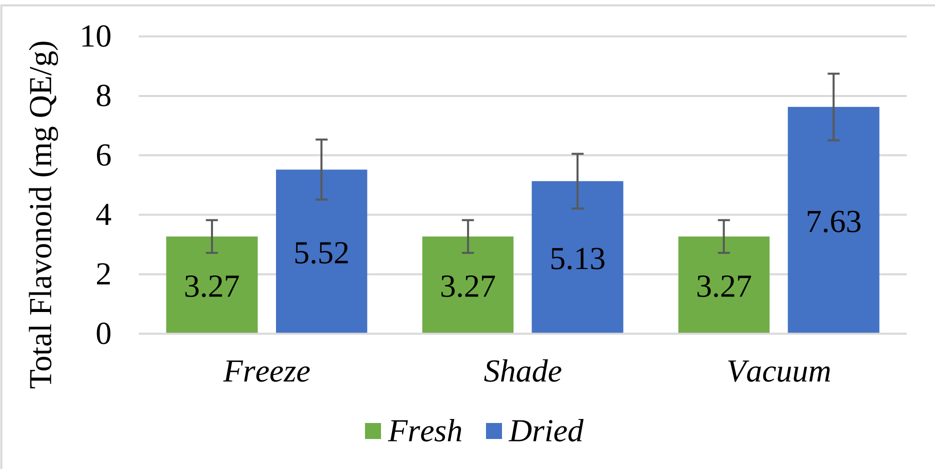

Figure 5. Mean profile of total flavonoid.

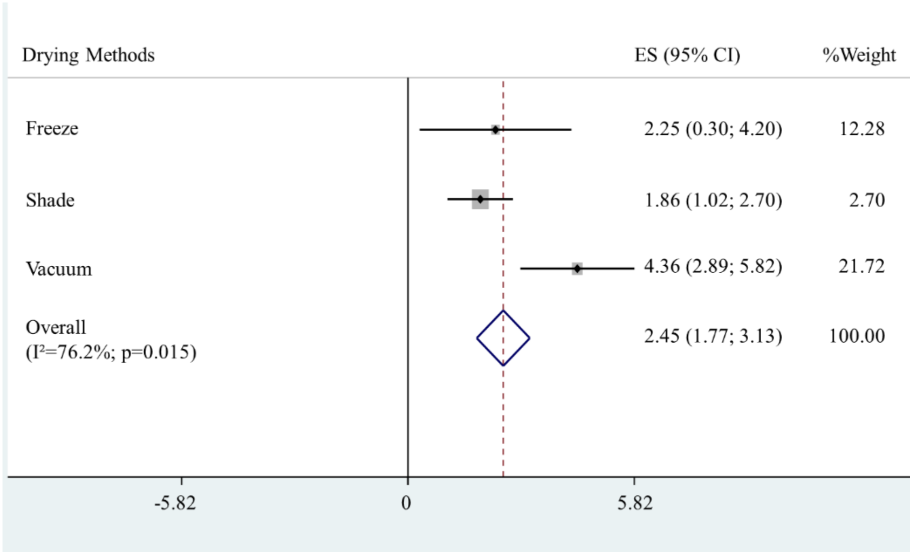

Figure 6. Forest plot graph of drying techniques for total flavonoid (Freeze, Shade, and Vacuum, n = 2).

3.2.3. 6-Gingerol

The content of 6-gingerol in fresh ginger increased from 6.70 mg/g to 8.82 mg/g after being dried using the microwave drying technique, while with the freeze-drying technique, the content of 6-gingerol in dried ginger (4.44 mg/g) was relatively the same as fresh ginger (4.31 mg/g) (Figure 7). The content of 6-gingerol in ginger decreased significantly after being dried using the air-drying technique with a value of 17.34 mg/g down to 10.02 mg/g. Gingerol in dried ginger has a higher content and better flavor quality than fresh ginger. 6-Gingerol is sensitive to temperature and changes to 6-Shogaol at high temperatures due to dehydration of alcohol group on 6-gingerol [24].

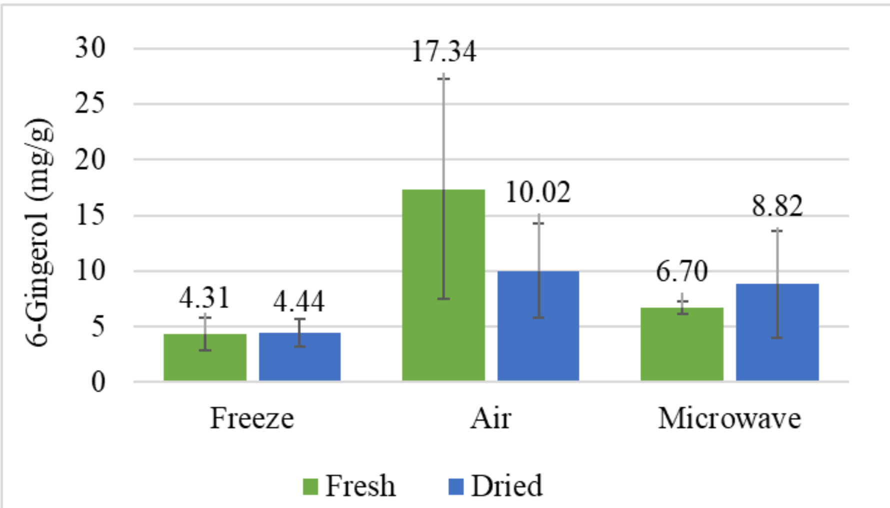

Figure 7. Mean profile of 6-gingerol.

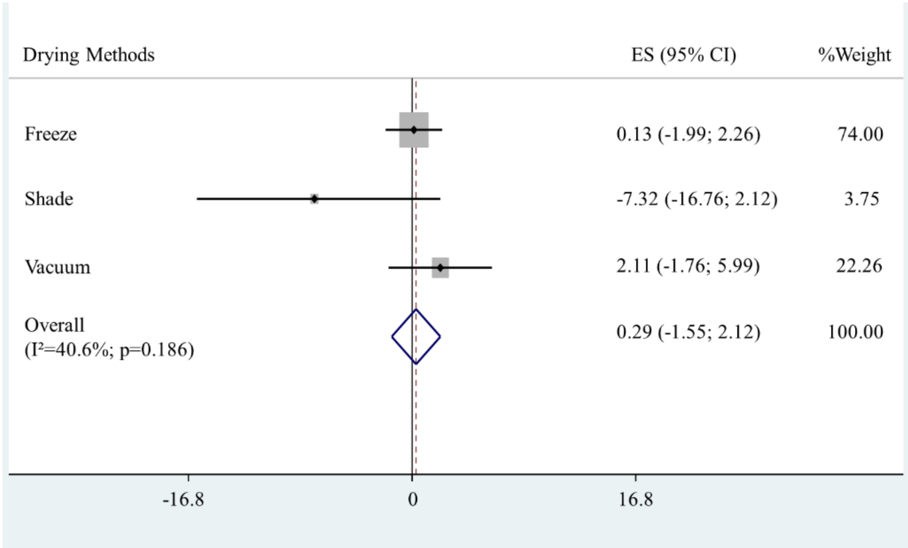

Figure 8. Forest plot graph of drying techniques for 6-gingerol (Freeze, n = 3; Air, n = 5, and Microwave, n = 6).

Gingerol was found as an active compound in fresh ginger. At the same time, shogaol was not identified in fresh ginger because it is a compound formed from the reaction of gingerols undergoing heat processing or after long-term storage. The degradation of gingerols into shogaols can occur in the condition of low pH or high temperature [25].

The results of comparing drying techniques against 6-Gingerol ginger using meta-analysis are presented in the form of a forest plot graphic in Figure 8. The graph shows that the p-value > 0.05 and the combined effect CI crosses the vertical line with the effective value and CI 0.29 (−1.55 to 2.12), which is not statistically significant. Thus, the treatment of different drying techniques had not impact on 6-Gingerol of ginger. The heat-induced conversion of gingerols to shogaols were affected by the heating type, heating temperature, and time. A higher temperature (120 or 130 °C) was advantageous to obtain the ginger products with high quantity of bioactive components of shogaols [26].

3.3. Antioxidant activity

The analysis of the antioxidant activity of ginger was carried out using various methods, as shown in Figure 9. DPPH is the most frequently used analytical method by researchers from the articles that have been obtained. This method is used because it is a fast, simple, sensitive method with low cost. The DPPH free radical is a stable free radical, widely accepted as a tool for estimating antioxidants' free radical scavenging activity. The basic principle of the DPPH method is the ability of antioxidants to inhibit free radicals by donating hydrogen atoms. The DPPH method analyses antioxidant activity used for samples in solids and liquids [27].

Freeze, sun, air, and oven drying had comparable effects (Figure 10) for antioxidant activity. The antioxidant activity of ginger increased after drying in each methods. There were a significant increase occurred in the freeze-drying technique and oven drying as well (Figure 11). Increased antioxidant activity after heat treatment is associated with the release of bound phenolic compound to free phenolic compound due to heating process [28].

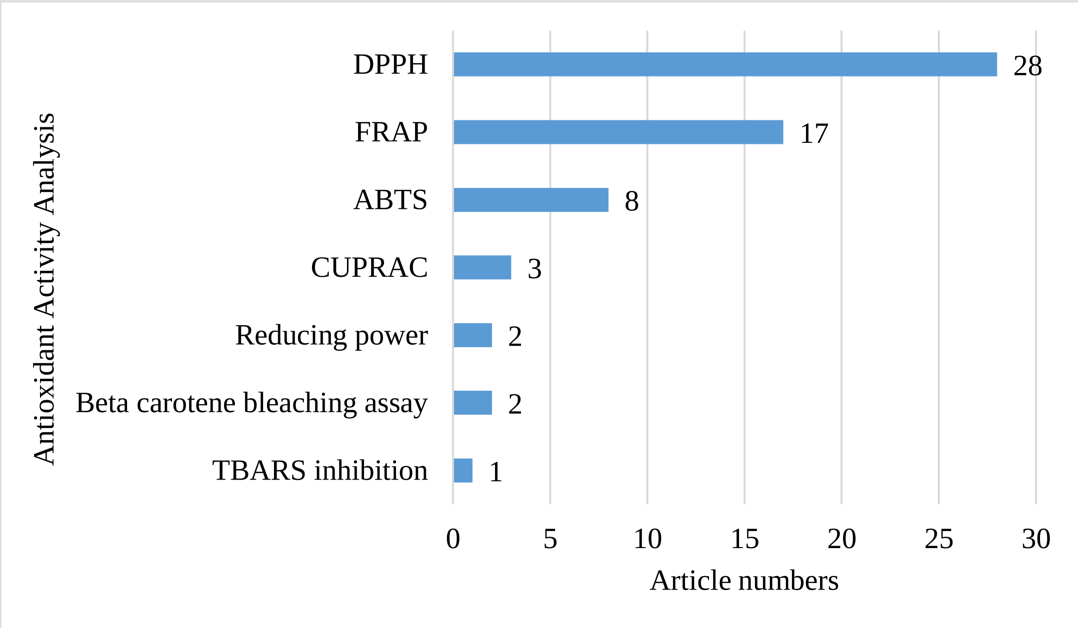

Figure 9. Number of articles based on the methods used for antioxidant activity analysis.

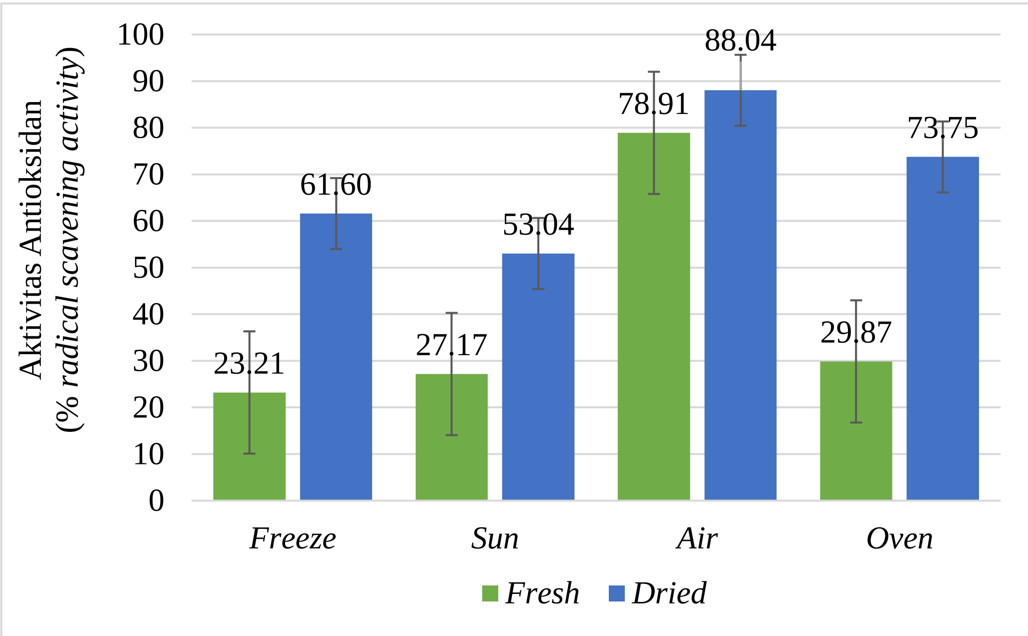

Figure 10. Mean profile of antioxidant activity.

Ginger dried by the freeze-drying technique had the highest antioxidant activity [17]. In contrast, air-drying resulted in fresh ginger having the lowest activity and relative value. The freeze-drying technique leads to the highest increase in antioxidant activity compared to relative humidity-convective drying, infrared- and microwave-drying techniques [18]. The value of antioxidant activity highest with oven drying compared to the sun and freeze drying [28].

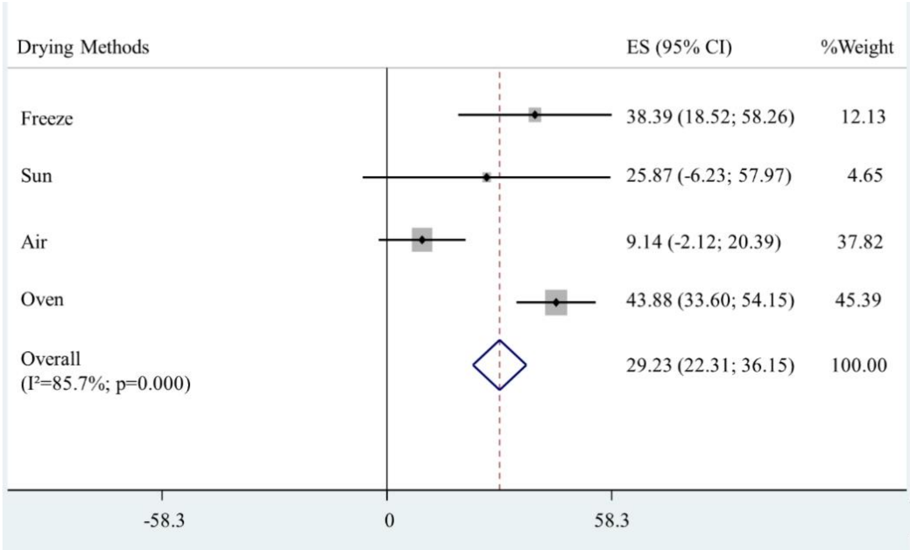

Figure 11. Forest plot graph of drying techniques for antioxidant activity (Freeze, n = 5; Sun, n = 3; Air, n = 13, and Oven, n = 6).

The results of the drying technique's comparison on ginger's antioxidant activity using meta-analysis are presented in the form of a forest plot graph in Figure 11. The graph shows that the CI of the sun and air-drying cross the vertical line, which is not statistically significant because there is no difference in antioxidant activity between dried ginger and fresh ginger. However, the overall result shows that the combined effect was statistically significant because the p-value < 0.05 and the CI of the combined effect did not cross the vertical line with the effective value of the CI was 29.23 (22.31 to 36.15). Thus, the treatment of different drying techniques created differences in the antioxidant activity of ginger. Oven drying had the most significant role in the total effect with a weight of 45.39% and a small CI range (33.60 to 54.15).

3.4. General discussion

The wide range of CI can be caused by the heterogeneity between the data from the articles used. Heterogeneity can occur because the ginger used has different varieties, origins, and pre-treatment presence or absence on ginger samples. This result is in line with [18,21] that fresh ginger's chemical and physical composition varies due to the geographic location of growth, variety, harvest, extraction method, and processing process. The ginger's age at the time of harvest also affects the value of the bioactive compounds and the antioxidant activity. For example, nine-month-old ginger contained higher total phenolic compounds and antioxidant activity than six-month-old ginger [12,19]. According to FAO, the right harvest time for ginger to be dried is when the ginger is eight to nine months old when the plant's leaves turn yellow [29].

Pre-treatment also affects the level of heat-sensitive compounds, including the final product's nutritional quality and sensory properties. Therefore, it can increase energy consumption and efficiency, reduce processing time, and improve product quality [30]. For example, pre-treatment of ginger with osmo-sonication caused a better impact than pre-treatment with osmotic and ultrasound [31]. Osmo-sonication is a good pre-treatment for pre-dehydrating sensitive plants such as ginger before drying by convective-drying technique because of its good quality retention, higher efficiency, and shorter drying time. This treatment can have immense market potential in terms of commercial-scale applications in the pharmaceutical and food industries in the future. Pre-treatment with blanching and soaking with ascorbic acid on ginger before drying by air-drying technique has been shown to increase TPC and antioxidant activity better than ginger without pre-treatment. The increase occurred due to the inactivation of browning enzymes associated with reducing phenolic compounds [32].

Different drying temperatures and settings can also cause heterogeneity. In addition, the size of the material and the temperature used during drying also affect the final characteristics of the dry product. For example, reducing the size of ginger by slicing and then drying in an oven at 50 ℃ was the best quality sample because it had the highest volatile protein, calcium, and magnesium content compared to samples with other treatments [33].

4. Conclusions

The combined mean results show that the freeze-, sun-, convective-, and air-drying techniques increase the average TPC value of ginger, while the microwave- and infrared-drying techniques decrease the TPC value. The average value of total flavonoids in ginger increased after drying by vacuum-, freeze-, and shade-drying techniques. The content of 6-gingerol in ginger increased after being dried by the microwave drying technique. The freeze-drying technique, the content of 6-gingerol in dried ginger was relatively the same as fresh ginger and decreased significantly after being dried by the air-drying technique. Ginger antioxidants showed an increase after drying by freeze-, sun- and air-drying techniques.

The results of the CI analysis showed that different drying techniques did not make a difference to the TPC and 6-gingerol between dried ginger and fresh ginger. Meanwhile, different drying techniques have differences in total flavonoid and antioxidant activity between dried ginger and fresh ginger. This outcome could be due to differences in the geographic location of growth, variety, age at harvest, extraction method, pre-treatment, sample size, temperature, and dryer set.

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Conflict of interest

All authors declare no conflict of interest.

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