

Exhaustive Extraction Compared To Soxhlet
Extraction from Ginger (*Zingiber officinale* R.)

المقارنة بين الاستخلاص الشامل و إستخلاص سوكلشليت من
الزنجبيل



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الملخص

يُعد الزنجبيل (*Roscoe officinale Zingiber*) من التوابل الغذائية والنباتات الطبية ذات القيمة العالية، حيث تُعد مركبات الجنجرولات والشوجولات مكوناته الحيوية الرئيسية. ورغم أهميتها، ما تزال الدراسات المقارنة حول كفاءة طرق الاستخلاص محدودة، خصوصاً في الظروف المناسبة للتطبيقات الصناعية. تهدف هذه الدراسة إلى مقارنة طريقتين للاستخلاص: الاستخلاص الشامل باستخدام نظام مائي-جليسريني، والاستخلاص بطريقة سوكلشليت باستخدام الإيثانول. لتحديد الظروف المثلى من حيث المردود والتركيب وقابلية التطبيق الصناعي. تم استخلاص الريزومات باستخدام مزيج ماء:جليسرين (50:50) عند 60 °م مع التحريك المستمر وبدونه. إضافة إلى استخلاص بطريقة سوكلشليت باستخدام إيثانول 99% لمدة 17 ساعة. جرى تحليل المستخلصات باستخدام كروماتوغرافيا السائل عالية الكفاءة (HPLC) مع الكابسيسين كـمقياس خارجي. حقق الاستخلاص الشامل مردوداً بلغ 5.1 ملغم/غم من الجنجرولات والشوجولات بعد 11 دورة متتالية مع التحريك أو 17 دورة من دون تحريك. في المقابل، أعطى استخلاص سوكلشليت مردوداً بلغ 2.54 ملغم/غم (ما يعادل 9% من الوزن الجاف). أي بزيادة نسبتها 166% مقارنة بالطريقة المائية-جليسرينية. ورغم أن استخلاص سوكلشليت أظهر مردوداً أعلى، فإن اعتماده على المذيبات العضوية، واحتياجه إلى تسخين مطول وخطوات معقدة لاسترجاع المذيب، يحد من ملاءمته للتطبيق الصناعي في مجالات الأغذية والمنتجات الصيدلانية. في المقابل، وفر الاستخلاص الشامل بالماء-جليسرين، وخاصة مع التحريك المستمر، ظروفاً أكثر أماناً وأقل تكلفة مع تحسين الكفاءة وتقليل عدد دورات الاستخلاص اللازمة. كما أن دمج الحورات الثلاث الأولى أدى إلى رفع كفاءة المردود. توضح النتائج أن استخلاص سوكلشليت مناسب للأغراض البحثية والمقارنة التحليلية، بينما يُعد الاستخلاص الشامل المحسن الطريقة الأكثر عملية للإنتاج واسع النطاق، حيث يوازن بين المردود والأمان والجودى الاقتصادية، مع تجنب عيوب المذيبات العضوية. وتقدم هذه الدراسة دليلاً علمياً داعماً لتوحيد المستحضرات المشتقة من الزنجبيل، بما يساهم في تعزيز تطبيقها الصناعي وجهود التوحيد العالمي لمعايير الجودة والسلامة.

ABSTRACT

Ginger (*Zingiber officinale Roscoe*) is widely valued as a culinary spice and medicinal plant, with gingerols and shogaols identified as its principal bioactive compounds. Despite their importance, comparative studies on extraction efficiency remain limited, particularly under conditions suitable for industrial applications. This study investigated two extraction techniques: exhaustive extraction with a water-glycerin solvent system and Soxhlet extraction with ethanol to determine optimal methods for yield, composition, and scalability. Ginger rhizomes were extracted using a 50:50 water-glycerin mixture at 60 °C with and without continuous stirring, and by Soxhlet extraction with 99% ethanol for 17 hours. Extracts were analyzed by reversed-phase HPLC, with capsaicin serving as the external standard. Exhaustive extraction produced up to 15 mg/g of total gingerols and shogaols after 11 consecutive cycles with stirring, or 17 without. In comparison, Soxhlet extraction yielded 2.54 mg/g (equivalent to 9% dry weight), representing a 166% higher recovery than the hydroglycerin method. Although Soxhlet extraction achieved superior yields, its reliance on organic solvents, extended heating, and complex recovery steps limits its feasibility for industrial food and pharmaceutical production. Conversely, exhaustive extraction using water-glycerin, particularly under continuous stirring, reduced the number of required extraction cycles, enhanced mass transfer, and provided safer and more cost-effective processing conditions. Combining the first three extraction cycles further improved yield efficiency. The findings demonstrate that while Soxhlet extraction is effective for analytical comparisons and research purposes, optimized exhaustive extraction represents a more practical method for large-scale production. It balances yield, safety, and economic considerations while avoiding solvent related drawbacks. This study provides evidence-based guidance for standardizing ginger-derived products, offering a scalable approach that supports both industrial application and international efforts to harmonize quality and safety standards.

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Exhaustive Extraction Compared To Soxhlet Extraction From Ginger (*Zingiber officinale* R.)

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Abstract :

Ginger (*Zingiber officinale* Roscoe) is widely valued as a culinary spice and medicinal plant, with gingerols and shogaols identified as its principal bioactive compounds. Despite their importance, comparative studies on extraction efficiency remain limited, particularly under conditions suitable for industrial applications. This study investigated two extraction techniques—exhaustive extraction with a water–glycerin solvent system and Soxhlet extraction with ethanol—to determine optimal methods for yield, composition, and scalability. Ginger rhizomes were extracted using a 50:50 water–glycerin mixture at 60 °C with and without continuous stirring, and by Soxhlet extraction with 99.9% ethanol for 17 hours. Extracts were analyzed by reversed-phase HPLC, with capsaicin serving as the external standard. Exhaustive extraction produced up to 1.5 mg/g of total gingerols and shogaols after 11 consecutive cycles with stirring, or 17 without. In comparison, Soxhlet extraction yielded 2.54 mg/g (equivalent to 9–11% dry weight), representing a 166% higher recovery than the hydroglycerin method. Although Soxhlet extraction achieved superior yields, its reliance on organic solvents, extended heating, and complex recovery steps limits its feasibility for industrial food and pharmaceutical production. Conversely, exhaustive extraction using water–glycerin, particularly under continuous stirring, reduced the number of required extraction cycles, enhanced mass transfer, and provided safer and more cost-effective processing conditions. Combining the first three extraction cycles further improved yield efficiency. The findings demonstrate that while Soxhlet extraction is effective for analytical comparisons and research purposes, optimized exhaustive extraction represents a more practical method for large-scale production. It balances yield, safety, and economic considerations while avoiding solvent-related drawbacks. This study provides evidence-based guidance for standardizing ginger-derived products, offering a scalable approach that supports both industrial application and international efforts to harmonize quality and safety standards.

Keywords: Gingerols, Shogaols, Exhaustive extraction, Soxhlet, *Zingiber officinale*, HPLC.

Introduction

Around the world, ginger rhizome has been utilized as a spice and food flavoring. Furthermore, for thousands of years, ginger has been highly prized as a herbal remedy. (Pratoko, 2018; Yulianti et al, 2018). Ginger has common medicinal uses in humans including carminative, antiemetic, anti-nauseant, and anti-inflammatory applications (Mao et al, 2019). The most pungent components, the gingerols, which are a group of homologues with a variety of unbranched alkyl chain lengths, are among the many physiologically active substances found in the rhizome of ginger (*Zingiber officinale*), a member of the Zingiberaceae family of plants. (Sharifi-Rad et al, 2017). 6-gingerol is the most prevalent component in the gingerol series, which were found to be the main active ingredients in the fresh ginger rhizome (Li et al, 2012a). However, the main pungent ingredient in dried ginger powder is shogaol, which is a dehydrated form of gingerol. A number of pharmacological and physiological effects, including as analgesic, antipyretic, gastro-protective, cardio-tonic, and anti-hepatotoxic properties, have been discovered for gingerol (Kou et al, 2018; Putra et al, 2018). This study balances yield, cost, and safety by offering scalable insights into ginger extraction. Additionally, it offers evidence-based recommendations for standardizing products made from ginger around the world.

Statement of Problem

Ginger is valued for its medicinal compounds, but current extraction methods face challenges. Traditional Soxhlet extraction achieves high yields but uses harmful solvents and complex processes, while greener water–glycerin systems are safer but efficiency data lacks. A comparative study is needed to find the ideal method that balances yield, cost, safety, and industrial practicality.

Significance

This study promotes sustainable, standardized extraction of plant bioactives by comparing exhaustive and Soxhlet methods of extraction. It aims to balance yield and sustainability, develop safer solvent-free protocols, define scalable extraction parameters, and support global quality standards for ginger products, bridging laboratory research with industrial application.

Objectives

The study aims to compare water–glycerin and ethanol Soxhlet extraction methods for ginger in terms of yield and bioactive composition, assess how stirring and extraction cycles affect yield and stability, determine optimal extraction conditions balancing efficiency and feasibility, and establish standardized parameters for large-scale production.

Literature Review

The number of commercial ginger products with gingerols and/or shogaol as the primary active ingredients has increased recently. These products are used to treat chronic arthritis and travel sickness (Mohd Yusof, 2016; Li et al, 2012b). These chemicals' total bioavailability may be influenced by their stability in the gut, especially in the stomach. The stability of gingerols and shogaols in an acidic environment, like the stomach, is thought to be crucial for comprehending their pharmacological function in a variety of medications that contain ginger or ginger preparations.

It is probable that gingerols and shogaols have different pharmacological actions due to their different chemical structures (Kukula-Koch and Czernicka, 2019; Semwal et al, 2015; Sang et al, 2020). This seems to rely on biochemical processes or biological targets. In mice's isolated mesenteric veins, gingerols have been shown to enhance PGF_{2a}-induced muscle contraction, while under the same experimental settings, shogaols have been shown to decrease muscle contraction. In mice's isolated mesenteric veins, both substances prevented noradrenaline-induced muscular contraction; however, 6-shogaol was more effective than 6-gingerol.

In a different biological test, gingerols were more effective than their counterparts at shielding primary cultured rat hepatocytes from galactosamine or carbon tetrachloride-induced cytotoxicity (Bak et al, 2012). Because gingerol loses a hydroxyl group as it dehydrates to shogaol, 6-shogaol has significantly greater lipophilic qualities than 6-gingerol.(Kou et al, 2017). The bioavailability and pharmacokinetic characteristics of these two drugs *in vivo* would differ significantly due to their differing lipophilicity. One important characteristic of gingerols that renders them thermally labile and easily dehydrated at high temperatures and in acidic environments is the presence of a β -hydroxyketo functional group in their structure. The dehydration of 6-gingerol was studied kinetically at 120 °C throughout a pH range of 2.4 to 7.2. (Kukula-Koch and Czernicka, 2019; Semwal et al, 2015). These investigations demonstrated that gingerol dehydration followed first-order kinetics and was dependent on temperature and pH. Previous research examined the process of gingerol degradation, which included a retro-aldol reaction that produced zingerone and aliphatic aldehydes as well as dehydration to shogaol. Shogaol polymerization was also shown to occur in 12 hours at a higher temperature of 120 oC (Kou et al,2018). According to a different study, gingerol can undergo reversible dehydration to produce shogaol when it is in balance with gingerol. A range of temperatures (37 to 100 °C) and pH values were investigated in order to determine the kinetic profile of gingerol degradation in aqueous solutions (Pratoko, 2018; Sharifi-Rad et al, 2017; Putra et al, 2018). The study's new discoveries for the reversible reaction kinetics and activation energies for the hydration and dehydration processes (Putra et al, 2018). While others focused on temperature and pH, two of our researchers had investigated the possibility of adding antioxidants such as ascorbic acid and citric acid to improve stability, in a prior study (Al Jafari and Alkhalaf, 2022).

Method of Research

The active principles were extracted by maceration at 60 °C with and without stirring, with concentration of water and glycerin KKK (50:50), to which were added 0.2% of sodium benzoate Merck (NaC₇H₅O₂) under the E number E211 for 4 hours. The determination of total content of gingerols and shogaols were done by reversed-phase HPLC using capsaicin (C₁₈H₂₇N₃) USP RS11 (USP 41-NF36) as external reference to calculate the concentration of gingerols and shogaols, the solvents were HPLC grade, methanol 99.9%, acetonitrile 99.9% and phosphoric acid (Fisher Chemical) and the purified water was HPLC grade provided by The Jordanian Pharmaceutical Manufacturing Co.

Plant Material

Air-dried rhizome of ginger *Zingiber officinale*. (Zingiberaceae) were provided by The Jordanian Pharmaceutical Manufacturing Co. (Naor, Jordan). Originally cultivated and dried in Nigeria.

Solutions And Sample Preparation

Control solution: Dissolved 8.0 mg of capsaicin in a 100.0 mL volumetric flask with methanol. Each time, started with 7 replicates of capsaicin as control before the ginger samples, and 2 replicates post each 6 samples of ginger samples in the HPLC.

Ginger Exhaustive Extraction

Ginger rhizome of hydroglycerin extract: In 1000 mL Erlenmeyer flask, introduced 80 g of grinded ginger rhizome with 600 mL of purified water/glycerin (50:50). Warmed up to 60 °C under continuous stirring and without agitation for 4 h, allow to cool and later filtered on an adequate piece of cloth in 1000 mL beaker previously weighted, with manual pressure, expressed all the liquid extract, after the filtration, weighed the resulting extract. That was for

the first extraction, using the resulting amount of the ginger rhizome after the first extraction, the consecutive extractions process was the same for the second, third, fourth, fifth, sixth, seventh, eighth, ninth, tenth, and eleventh, for the extraction under continuous stirring, but for the one without stirring, the extraction continued for other six consecutive extractions to reach the seventeenth extraction.

Optimization Of Ginger Extraction For Production

To achieve the highest yield of the same quantity of ginger, since we can't warm up the extraction because of the oxidation of its component, we tried to reprocess the extraction for more time, to make the extraction with the finest amount of ginger, to make the extraction with continuous stirring and without stirring.

Soxhlet Extraction With Ethanol 99.9%

To achieve the highest yield of the ginger content, we made an extraction using the Soxhlet apparatus, with Ethanol 99.9 % (Fisher Chemical), for 17 hours of continuous percolation, this method has been used to extract the total content of plants for decades. In this experiment the ethanol (850 mL) will continuously boil, evaporate and condense over the sample (100 g of crushed ginger) passing through it, extracting all ingredients which can be extracted by the condensed ethanol. Later on the extract with ethanol was concentrated by evaporating and recovering the ethanol on the Rota-vapor apparatus (DRAGONLAB model RE 100-Pro) water-bath temperature was fixed at 60 °C, coupled to a vacuum pump (TODAY'S Model Chemker 400).

Sample Solution

A 5.0 g portion of the ginger hydroglycerin extract or Soxhlet extract was accurately transferred into a 20.0 mL volumetric flask. Five milliliters of purified water were added, and the volume was made up to the mark with methanol. The mixture was agitated for 2.0 minutes, and, if necessary, the volume was readjusted with methanol. The solution was then filtered through a 0.45 µm syringe filter into an HPLC sample vial.

HPLC Assay

HPLC analysis was performed on Thermo Scientific Dionex UltiMate 3000 UHPLC\HPLC System, formed of (Pump LPG-3400 SD, Autosampler: WPS-3000 TSL, Detector: DAD-3000 RS, Column compartment: TCC-3000 SD). The separation was performed on Thermo reversed phase column Hypersil, BDS, C18 (250 X 4.6 mm, 5 µm). Mobile phase consisting of gradient solution A (acetonitrile 100%) and solution B (Aqueous solution of phosphoric acid at 0.1% v/v), with a flow rate of 1mL/min. Detection was made at 280 nm and the column was maintained at 30 °C. The duration of each injection was 55 min. for all samples including the external reference ones.

Results

Ginger Exhaustive Extraction

The samples were analyzed and the results showed that the maximum yield can be achieved with continuous stirring extraction after 11 consecutive extractions of four hours each one (Table 1), or without stirring after 17 consecutive extractions of four hours each one (Table 2), at 60 °C and the extraction was carried out with water/glycerin 50:50, the final yield was approximately 1.5 mg/g in average. Results shown in (Table 3) correspond to ginger Soxhlet extraction with Ethanol 99.9%.

Table 1: Samples with constant stirring

Sample	Av.mg/g	Ging.%	Shog.%	% G&S	6-G%	6-S%
Ginger 1 st Extract	0.517	77.9	12.3	90.2	60.4	9.8
Ginger 2 nd Extract	0.390	75.0	10.9	85.9	60.4	8.9
Ginger 3 rd Extract	0.227	73.9	10.9	84.8	60.3	8.3
Ginger 4 th Extract	0.133	72.9	10.2	83.1	60.0	9.3
Ginger 5 th Extract	0.081	52.0	10.0	62.0	55.9	11.6
Ginger 6 th Extract	0.051	48.1	10.7	58.8	26.4	12.1
Ginger 7 th Extract	0.030	41.8	14.3	56.1	23.3	13.8
Ginger 8 th Extract	0.024	36.9	19.1	56.0	17.4	18.8
Ginger 9 th Extract	0.021	32.6	20.7	53.3	12.3	20.5
Ginger 10 th Extract	0.015	27.8	23.5	51.3	10.1	23.4
Ginger 11 th Extract	0.012	26.7	22.1	48.8	6.5	22.0
Total	1.501					

Av.mg/g= average of 4 injections in mg of active ingredients for each gram of extract, Ging.%= Percentage of gingerols in 4 injections, Shog.%= Percentage of shogoals in 4 injections, %G&S= Percentage of total gingerols and shogoals in 4 injections, 6-G%= Percentage of 6-Gingerol in 4 injections, 6-S%= Percentage of 6-Shogoals in 4 injections (Note: the remaining percentage to complete to 100% represents other gingerols like 8-Gingerol and 10-Gingerol or other shogoals like 8-Shogoals and 10-Shogoals).

Table 2: Samples without stirring

Sample	Av.mg/g	Ging.%	Shog.%	% G&S	6-G%	6-S%
Ginger 1 st Extract	0.326	72.0	10.9	82.9	61.7	9.3
Ginger 2 nd Extract	0.321	70.2	12.6	82.6	57.3	10.6
Ginger 3 rd Extract	0.295	69.0	13.0	82.0	57.3	11.3
Ginger 4 th Extract	0.259	68.7	14.5	83.2	55.1	12.8
Ginger 5 th Extract	0.230	66.4	17.1	83.5	51.7	14.6
Ginger 6 th Extract	0.204	62.9	17.4	80.3	46.9	15.9
Ginger 7 th Extract	0.184	60.8	19.4	80.2	42.1	19.3
Ginger 8 th Extract	0.166	56.8	22.8	79.6	35.5	21.9
Ginger 9 th Extract	0.147	55.7	23.9	79.6	33.8	23.3
Ginger 10 th Extract	0.138	53.3	26.1	79.4	28.4	26.2
Ginger 11 th Extract	0.128	49.3	30.1	79.4	21.3	29.4
Ginger 12 th Extract	0.119	40.8	31.5	72.3	15.5	30.2
Ginger 13 th Extract	0.111	30.1	32.5	62.6	12.6	31.1
Ginger 14 th Extract	0.104	24.2	33.7	57.9	8.6	17.3
Ginger 15 th Extract	0.099	22.1	34.6	56.7	5.5	14.9
Ginger 16 th Extract	0.093	15.3	34.9	50.2	4.0	10.9
Ginger 17 th Extract	0.089	19.6	25.5	45.1	3.2	10.7
Total	1.474					

Av.mg/g= average of 4 injections in mg of active ingredients for each gram of extract, Ging.%= Percentage of gingerols in 4 injections, Shog.%= Percentage of shogoals in 4 injections, %G&S= Percentage of total gingerols and shogoals in 4 injections, 6-G%= Percentage of 6-Gingerol in 4 injections, 6-S%= Percentage of 6-Shogoals in 4 injections (Note: the remaining percentage to complete to 100% represents other gingerols like 8-Gingerol and 10-Gingerol or other shogoals like 8-Shogoals and 10-Shogoals).

Table 3: Soxhlet samples

Soxhlet samples	mg/g	Av.mg/g	Av.samples	Ging.%	Shog.%	Total%G&S	6G%	6Sh%
Ging SX Eth smp1 rep1	2.539	2.546	2.542	63.9	15.8	79.7	47.6	12.5
Ging SX Eth smp1 rep2	2.553			63.9	15.8	79.7	47.5	12.5
Ging SX Eth smp2 rep1	2.519	2.537		64.1	15.5	79.6	47.7	12.4
Ging SX Eth smp2 rep2	2.557			63.8	15.7	79.5	47.4	12.6

Ginger SX Ethanol= Ginger extract by Soxhlet apparatus using Ethanol, mg/g= content of active ingredients for each gram of extract, Av.mg/g= average of 2 injections in mg of active ingredients for each gram of extract, Av. Samples= average of 4 injections in mg of active ingredients for each gram of extract, Ging.%= Percentage of gingerol, Shog.%= Percentage of shogaols, %G&S= Percentage of total gingerols and shogaols, 6-G%= Percentage of 6-Gingerol, 6-S%= Percentage of 6-Shogaols (Note: the remaining percentage to complete to 100% represents other gingerols like 8-Gingerol and 10-Gingerol or other shogaols like 8-Shogaols and 10-Shogaols).

Optimization Of Ginger Extraction For Production

The results of all extractions including the exhaustive extraction showed that the highest yield and the practical for handling and filtration was the extraction with crushed ginger and not the fine grinded one, with continues stirring at 60 °C, for four hours with 50:50 water/glycerin, three consecutive extractions and then to be mixed together, to achieve the highest amount of the extraction with high concentration, higher than the required for the industrial needs.

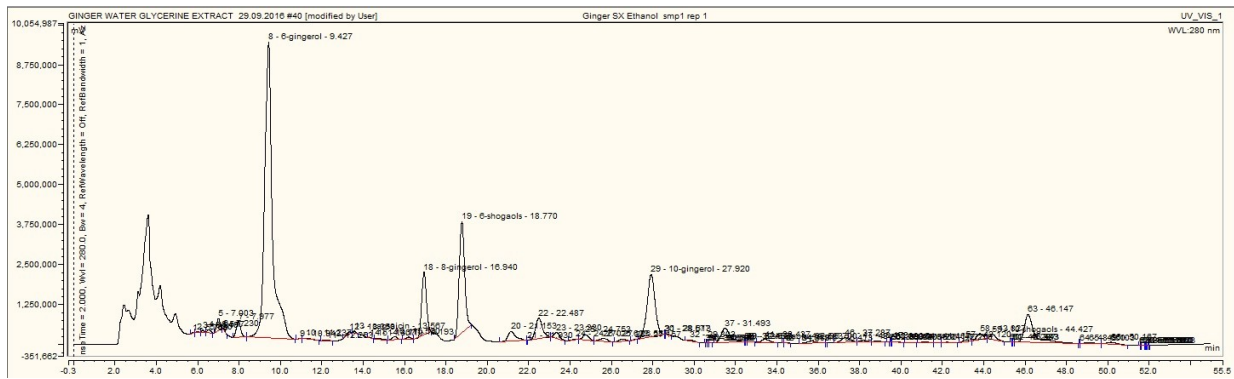
Soxhlet extraction with Ethanol 99%

Results showed that it can be obtained 9 -11 g out of 100 g of ginger dry plant material, this means a yield up to 10% (w/w) of the ginger dry can be extracted by this method, the HPLC results showed that 2.54 mg/g (Ethanol free extract) can be obtained by this method, which is 166% higher than the water: glycerin ratio.

HPLC Analysis

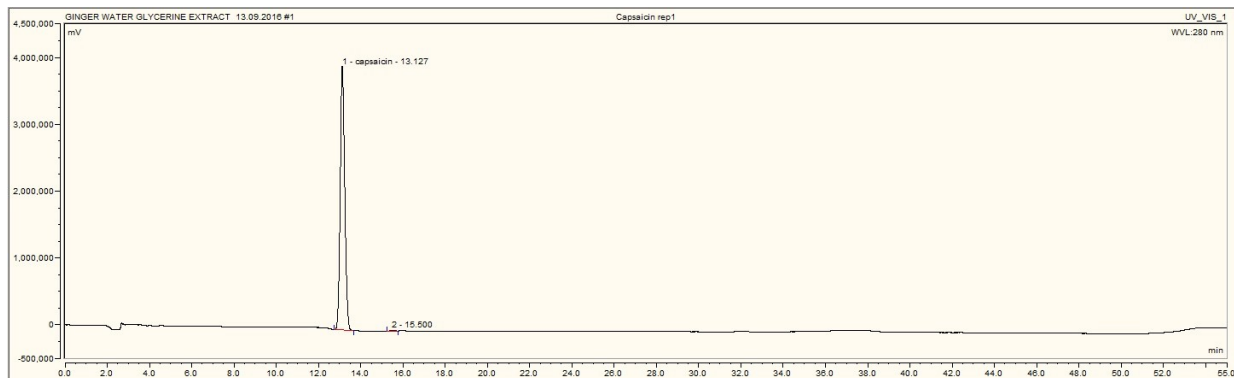
The quantitative analysis of ginger extracts was performed using reversed-phase HPLC with capsaicin as an external reference Figure 1-3. The method allowed accurate determination of total gingerols, shogaols, and their main homologues, 6-gingerol and 6-shogaol.

Figure 1: Diluted Soxhlet sample



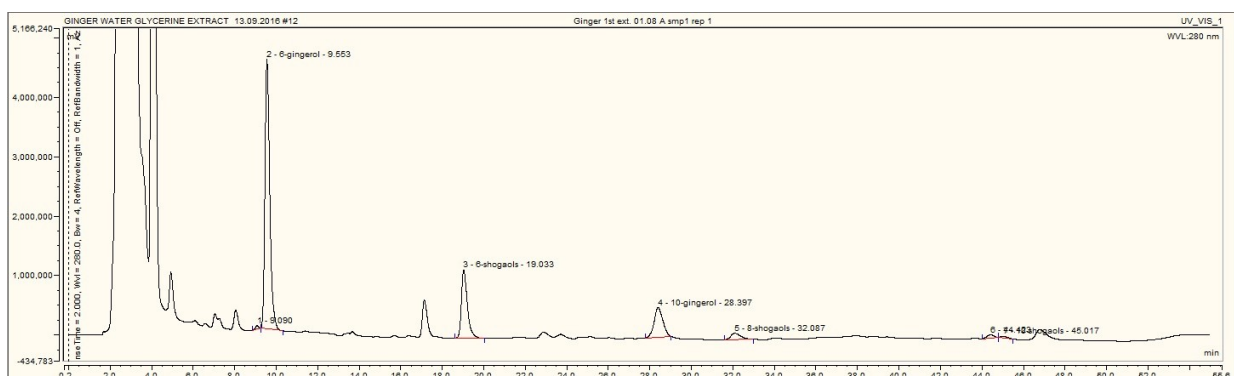
6-gingerol appears at 9.427 minute and 6-shogaol appears at 18.770 minute.

Figure 2: Capsaicin



Capsaicin appears at 13.127 minute

Figure 3: 1st extract



6-gingerol appears at 9.553 minute and 6-shogaol appears at 19.033 minute.

Discussion

Exhaustive extraction with continuous stirring produced the highest cumulative yield of gingerols and shogaols after eleven consecutive extraction cycles, each lasting four hours at 60 °C with a 50:50 water–glycerin solvent system. The total yield reached 1.50 mg/g, with

gingerols consistently comprising the majority of the bioactive fraction (Table 1). Notably, the proportion of gingerols decreased progressively across successive extractions (from 77.9% in the first to 26.7% in the eleventh), whereas shogaols increased relatively, suggesting that repeated heating and extended extraction favored the formation or relative enrichment of shogaols.

When exhaustive extraction was carried out without stirring, seventeen consecutive cycles were required to achieve a comparable cumulative yield of 1.47 mg/g (Table 2). The relative distribution of gingerols and shogaols followed a similar trend; however, the efficiency per cycle was lower compared to stirred extractions, confirming that agitation enhances mass transfer and accelerates compound release.

In contrast, Soxhlet extraction with ethanol (99%) provided a substantially higher yield. After 17 hours of continuous percolation, the method yielded 2.54 mg/g, equivalent to 9–11% (w/w) of the dry plant material (Table 3). This yield was approximately 166% greater than that obtained with water–glycerin exhaustive extraction. The Soxhlet extract also demonstrated a balanced composition of gingerols (63.9–64.1%) and shogaols (15.5–15.8%), with 6-gingerol remaining the dominant component.

These findings indicate that while Soxhlet extraction maximizes yield, the requirement for organic solvents and prolonged heating renders it less suitable for industrial food and pharmaceutical applications, where safety, solvent recovery, and regulatory concerns must be considered. On the other hand, exhaustive extraction using water–glycerin provides a safer and more scalable alternative. Continuous stirring not only reduced the number of cycles needed but also improved the relative concentration of active markers, making it more practical for industrial implementation.

Conclusions

The present study focused on the exhaustive extraction of ginger and the optimization of process conditions for potential industrial production. The experimental results demonstrated that up to 1.5 mg/g of total gingerols and shogaols could be obtained using a 50:50 water/glycerin mixture. The optimum conditions for industrial extraction were identified as using crushed ginger at 60 °C for four hours with the same 50:50 water/glycerin solvent system. Moreover, continuous stirring during extraction was found to enhance performance by yielding a higher content of active constituents.

For industrial and economic feasibility, it is recommended that the second and third extraction cycles be combined with the first, as this approach increases the overall yield while maintaining an acceptable ratio of the active markers. Although Soxhlet extraction using ethanol produced a higher total gingerol and shogaol yield, this method is not suitable for industrial application at present. Instead, it serves as a comparative benchmark for evaluating extract quality and plant material performance.

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المستخلص الاستنزافي المتكرر بالمقارنة مع المستخلص بجهاز السوكشليت

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يُعد الزنجبيل (*Zingiber officinale* Roscoe) من التوابل الغذائية والنباتات الطبية ذات القيمة العالية، حيث تُعد مركبات الجنجرولات والشوجولات مكوناته الحيوية الرئيسية. ورغم أهميتها، ما تزال الدراسات المقارنة حول كفاءة طرق الاستخلاص محدودة، خصوصاً في الظروف المناسبة للتطبيقات الصناعية. تهدف هذه الدراسة إلى مقارنة طريقتين للاستخلاص: الاستخلاص الشامل باستخدام نظام مائي-جليسريني، والاستخلاص بطريقة سوكلشليت باستخدام الإيثانول، لتحديد الظروف المثلى من حيث المردود والتركيب وقابلية التطبيق الصناعي. تم استخلاص الريزومات (الجزيمات) باستخدام مزيج ماء-جليسرين (50:50) عند 60 °م مع التحريك المستمر وبدونه، إضافة إلى استخلاص بطريقة سوكلشليت باستخدام إيثانول 99.9% لمدة 17 ساعة. جرى تحليل المستخلصات باستخدام كروماتوغرافيا السائل عالية الكفاءة (HPLC) مع الكابسييسين كمعيار خارجي. حقق الاستخلاص الشامل مردوداً بلغ 1.5 ملغم/غم من الجنجرولات والشوجولات بعد 11 دورة متتالية مع التحريك أو 17 دورة من دون تحريك. في المقابل، أعطى استخلاص سوكلشليت مردوداً بلغ 2.54 ملغم/غم (ما يعادل 9-11% من الوزن الجاف)، أي بزيادة نسبتها 166% مقارنة بالطريقة المائية-الجليسرينية. ورغم أن استخلاص سوكلشليت أظهر مردوداً أعلى، فإن اعتماده على المذيبات العضوية، واحتياجه إلى تسخين مطوّل وخطوات معقدة لاسترجاع المذيب، يجد من ملاءمته للتطبيق الصناعي في مجالات الأغذية والمنتجات الصيدلانية. في المقابل، وُقِر الاستخلاص الشامل بالماء-الجليسرين، وخاصة مع التحريك المستمر، ظروفًا أكثر أماناً وأقل تكلفة مع تحسين الكفاءة وتقليل عدد دورات الاستخلاص اللازمة. كما أن دمج الدورات الثلاث الأولى أدى إلى رفع كفاءة المردود. توّضح النتائج أن استخلاص سوكلشليت مناسب للأغراض البحثية والمقارنة التحليلية، بينما يُعد الاستخلاص الشامل المحسّن الطريقة الأكثر عملية للإنتاج واسع النطاق، حيث يوازن بين المردود والأمان والجدوى الاقتصادية، مع تجنّب عيوب المذيبات العضوية. وتقدّم هذه الدراسة دليلاً علمياً داعماً لتوحيد المعايير العالمية لمعايير الجودة والسلامة. في تعزيز تطبيقها الصناعي وجهود التوحيد العالمي لمعايير الجودة والسلامة.