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Research Article

Differences in oven-drying temperatures change quality and phytochemicals of medicinally potential *Boesenbergia rotunda* (L.) Mansf. rhizomes

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Abstract

Boesenbergia rotunda (L.) Mansf., known for its medicinal properties, holds great potential for the development of both medicinal and nutritional supplements due to its various biological and pharmacological benefits. *B. rotunda* belonging to the Zingiberaceae family, is a rhizomatous perennial herb commonly referred to as "finger root". The rhizome of *B. rotunda* is widely used as a food ingredient in various countries. Additionally, it has been traditionally utilized in folk medicine to treat a range of ailments, including rheumatism, muscle pain, fever, gastrointestinal disorders, flatulence, dyspepsia, and peptic ulcers. Drying is one of the most used technologies in the pharmaceutical industry to prevent spoilage and maintain product quality. The purpose of this study was to investigate the effects of different drying treatments (hot air oven drying at 60, 70, 80, 90 and 100°C) on the quality parameter such as moisture, ash, curcumin, mineral content particle size and phytochemicals like phenol, flavonoid, saponin and tannin of *B. rotunda.* The result reported that Boiling *B. rotunda* at 80°C followed by oven drying at 100°C showed lowest moisture content. Smallest particle size, ash content, highest elements atomic % and maximum retention of pharmaceutically important secondary metabolites like curcumin, phenol, flavonoid, saponin and tannin content were obtained in boiling *B. rotunda* at 80°C followed by oven drying at 100°C. The findings of this study will aid in the development of enhanced techniques for restoring the market-preferred optimal quality of *B. rotunda*. Additionally, they will help improve methods for preserving the active components, offering significant benefits to pharmaceutical industries, farmers, and plant breeders.

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Keywords: Finger root, Curcumin, Flavonoid, Medicinal plant, Phenol, Zingiberaceae

Introduction

Medicinal plants have long served as a crucial source for both curative and preventive treatments in human medicine, and they have also been utilised to extract significant bioactive compounds (1, 2, 3). Approximately 80% of the global population relies on medicinal plants for their health and healing (4). In India, however, the Rig-Veda, which is believed to have been composed between 1600 and 3500 B.C., contains the first mentions of the use of plants as medicine (5). Traditional medicine has continued to be the most affordable and easily accessible treatment option within the primary health care systems of resource-poor communities. In recent years, there has been a growing surge of interest in natural products chemistry research. This heightened interest is driven by several factors, including the need to address unmet therapeutic demands, the impressive diversity in the chemical structures and biological activities of naturally occurring secondary metabolites, and the usefulness of novel bioactive natural compounds as biochemical probes (6). Additionally, advances in sensitive techniques for detecting biologically active natural products, as well as improved methods for isolating, purifying, and structurally characterising these compounds, along with progress in meeting the supply challenges of complex natural products, have all contributed to this renewed focus (7). Many sources indicate that medicinal plants offer numerous uses and benefits, leading to an anticipated increase in their market value in the coming years (8).

The Zingiberaceae family is renowned for its medicinal properties and is widely distributed across the tropics, especially in Southeast Asia. Gingers are significant natural resources that offer a variety of valuable products, including food, spices, medicines, dyes, and perfumes (9). There are around 1200 species in the 53 genera that make up the ginger family (10). India is one of the richest and most diverse regions for Zingiberaceae, boasting around 20 genera and over 200 species (11). *Boesenbergia rotunda* (L.) Mansf. is a rhizomatous herb belonging to the Zingiberaceae family (12). *B. rotunda* is a perennial plant characterised by a short stem that is replaced by pseudostems, created by leaf sheaths that can reach heights of up to 50 cm (Fig. 1). The rhizomes have a light brown exterior and a yellow interior, and the transverse sections are ovoid-globose in shape, that emit a strong aroma. Their appearance resembles fingers extending from a central base. (13). *B. rotunda* is native to Southern China, India, and Southeast Asia (14). It is known by various local names,

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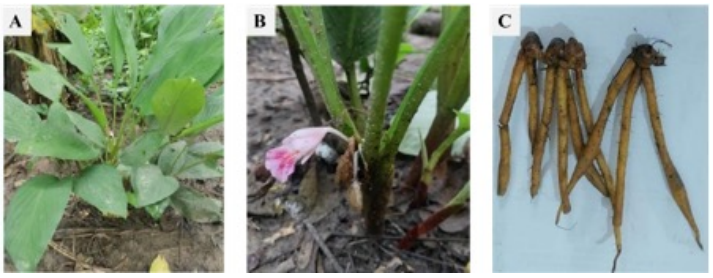
including Chinese key, Chinese ginger, Fingerroot in English. In Assam it is locally known as "Darik ada" in Assamese. The rhizomes of *B. rotunda* have been utilized as spices, flavouring agents, dyes, and as ingredients in numerous traditional medicines. This plant is traditionally used in folk medicine to treat various ailments, including rheumatism, muscle pain, fever, gastrointestinal disorders, flatulence, dyspepsia, and peptic ulcers (14). In Indonesia, *B. rotunda* is commonly utilized to make "jamu," a well-known traditional tonic for women post-childbirth. It also serves as a beauty treatment for teenage girls and helps in preventing leukorrhea (15). Fresh rhizomes of *B. rotunda* are utilized to treat inflammatory conditions such as dental caries, dermatitis, dry cough, colds, tooth and gum diseases, swelling, wounds, diarrhoea, dysentery, and are also used as a diuretic (16, 17). Over the years, researchers have successfully isolated a wide range of bioactive compounds from *B. rotunda* using various approaches and technologies. Nearly a hundred compounds have been identified and characterized from the rhizomes of this plant including flavonoid derivatives, chalcone derivatives, esters, kawains, terpenes, and terpenoids compounds which have demonstrated significant medicinal potential (14).

Drying is a widely used technology in food processing that extends the shelf life of plant products by removing water. By reducing water activity, it helps prevent the growth of most yeasts, moulds, and bacteria (18). Plant parts are dried using either natural or artificial methods. Conventional techniques, such as open sun-drying and shade-drying at ambient temperatures, are still commonly used as affordable and convenient methods of drying (19). Alternatively, various artificial drying methods, such as microwave drying, freeze-drying, and conventional air oven drying, are also used (1). Currently, conventional air oven drying is a standard technique for drying plant-based food and medicinal materials; however, it often affects the nutritional value, flavour, texture, and pharmaceutically important qualities of the plant materials and may cause oxidative degradation of heat-sensitive polyphenols (20, 21, 22). The moisture level in aromatic and medicinal plants influences their bioactivity by altering their physical and chemical properties (22). However, the drying process significantly alters the phytochemical composition and oil content of aromatic and medicinal plants (23). The advantages of using drying technology include reduction of microbial spoilage and product's weight, making storage and distribution easier, which offers a significant profit opportunity for the food, and pharmaceutical industries. Nevertheless, the choice of carrier agents as well as drying method and temperature plays a crucial role in determining the final products' quality. Previous report on *Curcuma caesia*, another rhizomatous medicinally important genus of Zingiberaceae family, suggested that boiling at 80°C for half an hour before drying could restore the pharmaceutically important qualities more favourably (22). Obviously, by reducing chances of contamination due to less exposure to open air and minimising drying duration, oven drying can offer more commercial advantage over other conventional open air-drying methods like sun and shade drying. However, there is lack of information on optimization of oven drying temperatures for maximum retention of pharmaceutically important quality parameters of *B. rotunda* boiled rhizomes. Therefore, this study aims to compare and analyse the effects of oven drying treatments at different temperatures on quality parameters including moisture, ash, and curcumin contents and pharmaceutically potential phytochemicals like phenol, flavonoid, saponin, and tannin of boiled *B. rotunda* rhizomes. Other two key pharmaceutical aspects viz. elemental composition and particle size of *B. rotunda* rhizome have also been examined following oven drying methods. This analysis aims to scientifically recommend the ideal drying conditions for this medicinal plant rhizomes, which will be helpful for pharmaceutical industries, farmers, and entrepreneurs.

Figure 1: The whole plants (A), flower (B), rhizome (C) of *B. rotunda*



Materials and methods

Sample collection

B. rotunda rhizomes were collected from Khat Tetelia, Namgaon, Assam, India (26^0 8/ N latitude and 91^0 40/ E longitude).

Sample preparation

Collected *B. rotunda* fresh rhizomes were washed thoroughly to remove dust and dirt. After cleaning, the rhizomes were boiled at 80 °C for 30 minutes in a water bath as per the previously reported methodology (22). Boiling process ensures full starch gelatinization and even curcumin distribution as well as helps to eliminate raw odour, shortens drying time, and results in a uniformly coloured final product. Afterwards, boiled finger root rhizomes were sliced into small pieces and spread on Petri plates, and then dried in a hot air oven at 5 different temperature such as 60, 70, 80, 90 and 100°C.

Quality analysis

Determination of moisture content

The moisture contents of finger root rhizomes were determined using a standard method described by Llano et al., 2022 (24). The finger root rhizome slices were dried in a hot air oven at 105°C until reached a constant weight, and the moisture content was then calculated using the following formula:

$$\text{Moisture content (\%)} = \frac{W1-W2}{W1} \times 100$$

Where, W1= Weight of the sample before drying (g); W2= Weight of the sample after drying (g)

Determination of ash content

Ash content of finger root rhizomes was determined by using a standard protocol described by AOAC, 1990 (25). The finger root rhizomes powders were heated in porcelain basins at 550°C in a muffle furnace for three hours. The ash content was then calculated using following formula:

$$\text{Ash content (\%)} = \frac{\textit{Weight of the basin with ash} - \textit{weight of the empty basin}}{\textit{Gram of sample taken}} \times 100$$

Determination of curcumin content

Curcumin content was determined using a standard protocol described by Geethanjali et al., 2016 (26). A volume of 5 mL acetone extract of rhizome powder was placed in a round flask

wrapped with dark-colored tape to maintain darkness, as curcumin is light-sensitive. The absorbance of the extract was measured at a wavelength of 420 nm using a UV-Vis spectrophotometer (Agilent Cary 60 UV-Vis). The curcumin content was then calculated based on a standard curve created using commercial curcumin powder obtained from SRL.

Estimation of mineral element

Elemental analysis was conducted on dried powdered samples of *B. rotunda* rhizomes using a scanning electron microscope (SEM) equipped with an energy dispersive X-ray (EDX) spectrometer. The SEM employs a high-energy electron beam to generate various signals from the specimen's surface, providing detailed information on both external morphology and chemical composition. SEM combined with EDX is a modern, widely used technique for both qualitative and quantitative analysis of trace and essential elements (27).

Particle size determination

SEM images for particles of various granulometries were captured. The particle sizes in the micrographs were measured using the Image software (28). Due to the irregular shapes of the particles, the measurement was based on the widest dimension. Micrograph were recorded at 500x magnification under SEM (SIGMA VP FESEM, ZEISS).

Phytochemical analysis

Determination of total phenolic content (TPC)

TPC was determined by a method described by Fattahi et al., (2014) (29) with slight modification. For this, 0.5 g of plant sample was taken in 80% ethanol and centrifuged at 10000 rpm for 20 min. The supernatant was saved and the residue was re-extracted with 5 mL of 80% ethanol and again centrifuged. Both the supernatants were mixed and ethanol was evaporated from the supernatant to dryness. Dried extract was dissolved in 5 mL of distilled water and aliquots from 0.1 to 1.0 mL were taken in test tubes. The volume in each tube was adjusted to 3 mL with water. Then 0.5 mL of Folin-Ciocalteu reagent was added to each tube. After 3 minutes, 20% Na^2CO^3 was added to each tube, mixed thoroughly, and placed the tubes in boiling water for one minute, cooled and measured the absorbance at 725 nm against a reagent blank. TPC was calculated by using a gallic acid standard curve.

Determination of Total flavonoid content (TFC)

TFC was measured by a method described by Fattahi et al., 2014 (29). About 0.2 g of sample was weighed and soaked in 10 mL methanol and centrifuged at 20000 rpm for 20 min. From the supernatant different aliquots were taken and 5% sodium nitrite was added to each aliquot. After 5 min, 10% aluminium chloride was added. Then, after 6 minutes, 2 mL of 1 M sodium hydroxide was added to the mixture. The absorbance was determined at 510 nm. TFC content was determined using a quercetin standard curve.

Determination of saponin content

The saponin content was determined using a protocol described by Obadoni and Ochuko (2002) (30) with slight modification. Accordingly, 5 g of the sample was soaked in 20% aqueous ethanol in a conical flask. The sample was then heated in a water bath at 55 ºC for 4 hours with continuous stirring. After heating, the mixture was filtered, and the residue was re-extracted with 20% ethanol. The combined extracts were reduced to 10 mL over a water bath at around 90 ºC. The concentrated extract was then transferred to a 250 mL separating funnel, where 5 mL of diethyl ether was added and shaken vigorously. The aqueous layer was collected while the diethyl ether layer was discarded. This purification process was repeated three times. Next, 15 mL of n-butanol was added, and the combined n-butanol extract was washed three times with of 5% NaCl. Finally, the solution was transferred to a beaker and heated in a water bath to evaporate the solvent, then dried in an oven to a constant weight. The saponin content was calculated using the following formula:

$$\text{Saponin (\%)} = \frac{W2-W1}{W} \times 100$$

Where, W= Weight of sample; W1= Weight of empty beaker; W2= Weight of beaker with saponin

Determination tannin content

The tannin content was determined by Folin-Ciocalteu method described by Chandran and Indira (2016) (31). About 1 g of the powder sample was added to a 10 mL of distilled water and centrifuged at 20000 rpm for 20 min. From the supernatant different aliquots were taken and 0.7 mL of Folin-Ciocalteu phenol reagent, as well as 1 mL of 35% sodium carbonate solution was added to each aliquot and the volume was adjusted up to 10 mL with distilled water. The mixture was shaken well and kept at room temperature for 30 minutes and the absorbance was measured against the blank at 700 nm in an UV/ Visible spectrophotometer. Tannin content was calculated by using tannic acid standard curve.

Statistical analysis

All determinations were carried out in triplicates, and the results were presented as mean ± standard deviation (SD). The data were analysed statistically using MS Excel.

Results and Discussion

Moisture content

Moisture content of *B. rotunda* rhizome powders varied between 3.99% and 8.47%. Highest moisture content was found in “Sample A” which was boiling of rhizome at 80°C followed by oven drying at 60°C and lowest moisture content was obtained in “Sample E” which was boiling the rhizome at 80°C followed by drying at 60°C (Fig. 2A). This result aligns with previous findings, which showed that higher drying temperatures led to lower moisture content and reduced water activity in *Curcuma caesia* rhizome powder (22). Another previous study also corroborated with our findings, rhizome sample of *B. rotunda* that was spray-dried at 190 °C exhibited lower moisture content compared to those spray-dried at 150 °C. This condition caused by high temperature gradient in the process when the temperature was set to high, resulting in a rapid water evaporation and produced a powder with low moisture content (32). For dried herbs, it's essential to maintain moisture content below 10% to prevent fungal growth (33). Other results indicated that the freeze-dried *Curcuma amada* at 0 °C followed by a final heating at 50°C had the lowest moisture content of 3.11 ± 0.04%, while the sun-dried sample had the highest moisture content at 8.94 ± 0.77% (34). Previous findings suggested that, in *Curcuma longa* the lowest moisture content was found in the sample oven-dried at 60 °C, followed by sun-dried, blanched oven-dried, and finally cooked oven-dried samples (35). Previous work reported that, the lowest moisture content was observed in the solar-dried sample, while higher moisture content was found in the shade-dried and

microwave-dried ginger powder (36). Another research reported that, in *Zingiber officinale* conventional oven drying at 50°C showed the lowest moisture content compared to solar box drying, sun oven plus solar box drying, and microwave oven drying treatments (37). Various studies have shown that mechanical dryers provide better results in terms of moisture content and functional properties compared to the sun-drying method.

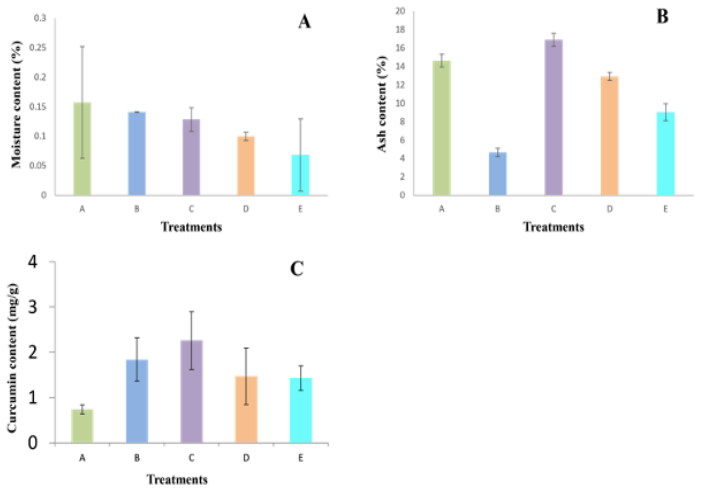
Ash content

In the present study on *B. rotunda*, highest ash content was found in "Sample C" which is boiled *B. rotunda* rhizome at 80°C followed by oven dried at 80°C and lowest ash content was found in "Sample B" which was boiled *B. rotunda* rhizome at 80°C followed by oven drying at 70°C (Fig. 2B). Study revealed that, in *C. longa* the highest total ash content was found in the oven-dried at 60°C samples, measuring 7.38%. and the sun sample exhibited the lowest ash content measuring 7.03% (35). In previous study on *C. caesia*, the rhizome sample that was oven-dried at 70°C after being boiled at 80 °C had the highest ash content of 11.5% and the lowest ash content of 3.23% was observed in samples which was boiled at 100 °C followed by oven-dried at 100°C (22). Another finding on *C. longa*, where the finger rhizomes boiled at 80 °C for 30 minutes showed the highest total ash content, whereas the rhizomes boiled at 100 °C for 75 minutes exhibited the lowest ash content (38). The solar drying method resulted in the highest total ash content in *Z. officinale*, suggesting that solar drying could be an effective technique for retaining maximum minerals in this species. This also highlights the variation in optimal preservation methods across different species (39). On the other hand, in *C. longa* the ash contents showed no significant variations with different oven drying temperatures, viz. 45, 55, 65 and 75 °C (40). In another study, *Z. officinale* microwave drying showed highest ash content followed by shade, solar and oven drying at 50°C (36). In another study, when *Curcuma xanthorrhiza* Roxb. was oven dried at 70 °C, the maximum ash content was achieved, as opposed to 80 °C and 90 °C (41). Therefore, the amount of ash in the rhizomes of various Zingiberaceae species varies depending on the treatment, which indicates the necessity of drying technique optimization from species to species to improve the quality restoration parameters.

Curcumin content

In the present study, highest curcumin content was found in "Sample C" which was boiling *B. rotunda* rhizome at 80°C followed by oven drying at 80°C and lowest curcumin content found is "Sample A" which was boiling *B. rotunda* rhizome at 80°C followed by oven drying at 60°C (Fig. 2C). In previous study on *C. caesia*, the highest curcumin content was observed in the sample that was shade dried and then boiled at 80 °C for 30 minutes. Conversely, the lowest curcumin content was found in the sample that was oven-dried at 100 °C and subsequently boiled at 100 °C (22). In another study, three distinct drying techniques were used on *C. xanthorrhiza*, with oven drying at 70, 80, and 90 °C. The curcumin concentration significantly decreased when the drying temperature was raised from 80 to 90 °C (41). Another study on *C. longa* revealed that shade-net drying was preferable over cabinet and sun drying for better retention of curcumin content (42). Previous study also indicated that in *C. longa* significant reduction in curcumin during heat processing, with the most substantial loss occurring during pressure cooking for 10 minutes (43). In previous study, the cooked/oven-dried and sun-dried samples of *C. longa* showed the highest curcumin content, with no significant difference between the two methods. On the other hand, the blanched/oven-dried and oven-dried specimens had the lowest curcumin content, also with no notable difference between these treatments (35). Previous studies have suggested that drying *C. longa* rhizomes with hot air at 70 °C is the most effective way to maximize curcumin content. Furthermore, several earlier studies have observed that extended boiling times lead to a reduction in curcumin content (44).

Figure 2: Effect of various drying processes on phytochemicals of rhizomes: [A] Moisture content; [B] Ash content content; [C] Curcumin content



[Boiling at 80°C +oven drying at 60°C (A), Boiling at 80°C +oven drying at 70°C (B), Boiling at 80°C +oven drying at 80°C (C), Boiling at 80°C +oven drying at 90°C (D), Boiling at 80°C +oven drying at 100°C (E)]

Mineral content

SEM-EDX analysis of a differently treated sample of *B. rotunda* rhizome powder revealed the presence of elements such as carbon (C), oxygen (O), magnesium (Mg), aluminum (Al), silicon (Si), phosphorus (P), potassium (K), and calcium (Ca). In present study, highest C, P, K, Ca, Mg found in content found in "Sample C" (Boiled at 80 °C followed by oven drying at 80 °C) Highest O, Si content found in "Sample B" (Boiled at 80 °C followed by oven drying at 70 °C) and lowest C, P, K, Ca amount found in "Sample B"; Lowest Mg content found in "Sample A". Lowest O, Al, Si was obtained in "Sample C" (Table 1). The atomic percentages of carbon (C) and oxygen (O) are abundant in all treatments compared to other elements. This result aligns with previous findings, where the atomic percentages of C and O were also higher than other elements (22). Previous studies on shade-dried samples of *C. caesia* rhizome have shown a similar pattern, indicating a higher atomic percentage of C, O, Mg, Si, P, K, Ca (27, 45). Therefore, boiling at 80°C followed by drying at the 70-80°C temperature is recommended as the most favourable treatment for preserving the maximum important mineral elements in *B. rotunda* rhizomes. This provides a valuable insight for identifying the optimal preservation method for the species' pharmaceutical applications. While extensive research has been conducted on the medicinal properties of plants focusing on organic components such as alkaloids, glycosides, essential oils, vitamins, and other active compounds, there is limited information regarding the medicinal properties of plants based on their elemental or mineral nutrient content. However, essential to recognize that various elements play crucial roles in combating different human diseases. The mineral elements found in

medicinal plants, even in small doses, possess both therapeutic and prophylactic properties (46, 45).

Table 1: Elements of *B. rotunda* rhizome after different drying treatments obtained from SEM-EDX

Elements (Atomic%)	Treatments				
	A	B	C	D	E
C	58.49	52.83	60.36	59.27	56.92
O	37.43	42.95	34.76	36.52	38.78
Mg	0.06	0.25	0.32	0.11	0.21
Al	0.44	0.69	0.25	0.42	0.49
Si	1.32	1.96	0.59	1.44	1.01
P	0.08	0.05	0.32	0.14	0.20
K	1.16	0.65	2.16	1.45	1.43
Ca	0.41	0.36	0.73	0.20	0.50

Particle size

By analysing the SEM images, the particle sizes of the treated and powdered samples of *B. rotunda* were determined. *B. rotunda* rhizomes boiled at 80°C followed by oven dried at 80°C showed smallest particle size compared to other treatments (Fig. 3). Previous study on *C. caesia* revealed that, oven-dried at 100 °C had the smallest particle size compared to other methods. In contrast, the samples that were boiled showed larger particle sizes than those subjected to other treatments (22). Particles of raw materials at the nano- and microscale are closely examined in the pharmaceutical design of solid dosage forms. This is essential because particle morphology including size, shape, and surface characteristics plays a significant role in influencing both the efficiency of manufacturing processes and the quality attributes of the final pharmaceutical products (47). In pharmacological systems, particle size has a substantial impact on drug absorption, dissolution and crossing the blood brain barrier. Additionally, a tiny particle size of medicinal materials leads to an expanded surface area, which promotes faster dissolution in the bloodstream and improves penetration through biological barriers, hence producing more effective delivery to the target (48). To maintain a tiny particle size, medications are formulated into innovative delivery systems that ensure rapid therapeutic action.

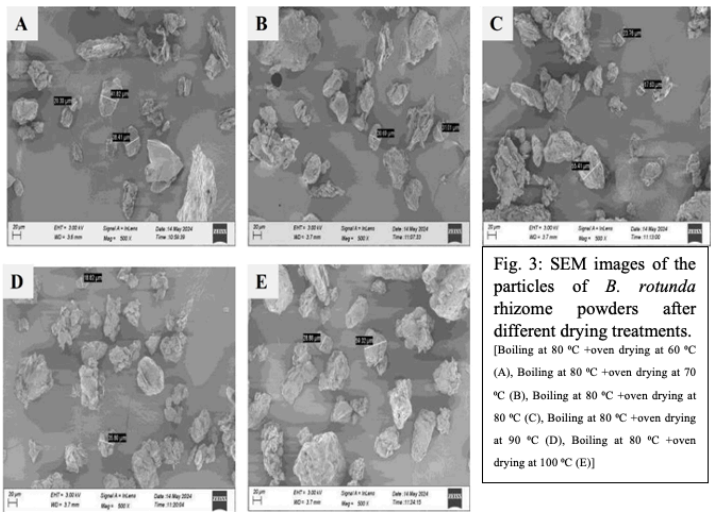


Fig. 3: SEM images of the particles of *B. rotunda* rhizome powders after different drying treatments. [Boiling at 80 ºC +oven drying at 60 ºC (A), Boiling at 80 ºC +oven drying at 70 ºC (B), Boiling at 80 ºC +oven drying at 80 ºC (C), Boiling at 80 ºC +oven drying at 90 ºC (D), Boiling at 80 ºC +oven drying at 100 ºC (E)]

Phytochemicals

Total Phenol content

In present study, highest phenol content obtained in "Sample C" (Boiling *B. rotunda* rhizomes at 80°C followed by hot air oven drying at 80° C). Lowest phenol content found in "Sample A" (Boiling *B. rotunda* rhizomes at 80°C and hot air oven drying at 60°C) (Fig. 4A). Another report indicated that in *C. amada*, the cabinet drying method at 70 °C produced the highest total phenolic content, while the freeze-drying method at 30 °C resulted in the lowest phenolic content (34). This result is partially consistent with other findings on *C. caesia* rhizomes, where hot air oven drying at temperatures between 60 and 80 °C also exhibited the highest phenol content (49). Another study on turmeric, hot air oven drying at 80 °C for 30 minutes resulted in the highest TPC. However, when the drying temperature was raised to 100 °C, there was a significant decrease in TPC due to the non-enzymatic oxidation of polyphenols (50). In previous study, the TPC was found to be higher in freeze-dried samples of *Z. officinale* rhizomes compared to those dried using oven, microwave, freezing, and air-drying methods. However, the oven-dried ginger demonstrated a significantly greater amount of individual phenolic compounds than those processed by the other drying methods (51). In contrast, shade-dried *Z. officinale* rhizome powder exhibited the highest phenolic content, with a measurement of 487.87±2.63 mg GAE/g. On the other hand, oven-dried *Z. officinale* powder had the lowest phenolic content, recorded at 310.74±4.78 mg GAE/g (39). In previous report, the phenolic content of *Z. officinale* rhizome extract was highest when processed using the freeze-drying method, measuring 13.83 mg GAE/g, compared to 9.69 mg GAE/g with the oven-drying method (52). In previous study on *Z. officinale*, the highest TPC was found in samples dried using a vacuum oven at 45 °C, followed by those processed with freeze drying and shade drying methods (53). Study also revealed that the total phenolic content (TPC) of turmeric samples dried using a cabinet dryer at 30 °C was significantly higher than those dried by other methods, including sun drying, cabinet drying at 70 °C, and infrared drying (54). Phenolics are a class of secondary metabolites that are widely distributed throughout plants.

Total flavonoid content

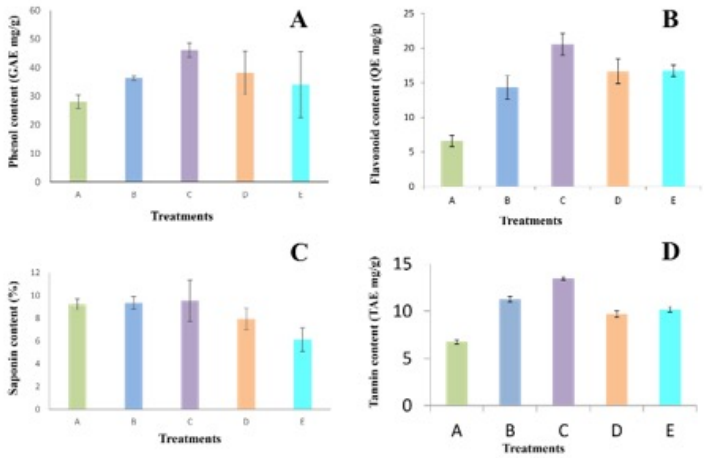
In present study on *B. rotunda*, flavonoid content ranges from 6.59 to 20.56QE mg/g. Highest flavonoid content obtained in "Sample C" which was boiling *B. rotunda* rhizomes at 80 °C followed by oven drying at 80°C (Fig. 4B). This result partially corroborates with other findings on *C. caesia*, where hot-air oven dried at 60 to 80°C showed significantly higher retention of TFC compared to those dried using microwave and sun-drying methods (49). In another study on *Z. officinale,* highest TFC content obtained in vacuum oven dried at 45°C sample followed by freeze drying and shade drying (53). Another report suggested that the TFC of turmeric samples dried using a cabinet dryer at 70 °C was significantly higher compared to other drying methods, including sun drying, cabinet drying at 30°C, and infrared drying (54). Previous study reported that on leaves of *Hibiscus hirsutus*, both aqueous and methanol showed highest flavonoid compound content when dried using hot air drying at 80°C, with measuring of 5.79 ± 0.07 mg CE/g and 4.75 ± 0.36 mg CE/g, respectively (55). Another study suggested that, the highest TFC (10.57 mg CE/g) ginger powder was dried at 100°C. However, the TFC decreased to 5.98 mg CE/g when the drying temperature was reduced to 80°C. Further lowering the drying temperature resulted in even lower TFC values, reaching 2.7 mg CE/g at 40 °C (56).

Another previous Study have also reported that the seeds of *Carica papaya*, when air-dried at room temperature and extracted with diethyl ether, exhibited the highest flavonoid content, measuring 18.27 g RE/100 g, compared to other drying techniques (57). Flavonoids are a significant group of polyphenolic compounds characterized by a benzo-pyrone structure, commonly found in plants. Research indicates that secondary phenolic metabolites, such as flavonoids, contribute to various pharmacological effects (58).

Saponin content

In the present study on *B. rotunda*, highest saponin content (9.54±1.8%) was found in "Sample C" which was boiling at 80°C followed by hot-air oven drying at 80°C and lowest saponin content (6.13±1.03%) was found in "Sample E" which was boiling at 80°C followed by hot-air oven drying at 100°C (Fig 4C). Previous study on *Z. officinale* reported that, highest saponin content was obtained in shade drying (2.67±0.10%) and lowest saponin content was obtained in sun drying (1.68±0.09%) treatment (39). Previous studies have shown that saponin content decreased across all drying methods after the process. However, the highest saponin concentration (11.34 mg/g) was recorded when using the far-infrared drying method at temperatures between 60~ 50ºC for red ginseng (59). Another research on the leaves of *H. hirsuta*, when dried using hot-air drying under vacuum at 50°C with methanol, yielded the highest saponin content compared to other drying techniques (55). Another study indicated that air-dried *Carica papaya* seeds at room temperature, when extracted with diethyl ether, exhibited the highest saponin content (58.91 mg/100 g) compared to other drying techniques (57).

Figure 4: Effect of various drying processes on phytochemicals of *B. rotunda* rhizomes: [A] Phenol content; [B] Flavonoid content; [C] Saponin content; [D] Tannin content



[Boiling at 80°C +oven drying at 60°C (A), Boiling at 80°C +oven drying at 70°C (B), Boiling at 80°C +oven drying at 80°C (C), Boiling at 80°C +oven drying at 90°C (D), Boiling at 80°C +oven drying at 100°C (E)]

Tannin content

In the present study on *B. rotunda*, highest tannin content was found in "Sample C" which was boiling *B. rotunda* rhizome at 80°C followed by oven drying at 80°C and lowest tannin content was obtained in "Sample A" which was boiling *B. rotunda* rhizome at 80°C followed by oven drying at 60°C (Fig. 4D). Previous study found that the tannin content in *Hyphaene thebaica* fruits is higher in oven-dried samples at low temperature of 40 ºC compared to other treatments (60). Tannin is categorized into two types Condensed and Hydrolysable. Condensed tannins are flavonoid units' oligomers (61, 62) while hydrolysable tannins are also recognized today as oligomers of carbohydrates-polyphenol units (63, 64). Previous report indicated that *Betula pubescens* Ehrh. leaves exhibited lower hydrolysable tannin levels when oven-dried at 60°C for 12 hours (11.58 mg/g DW) compared to those dried at room temperature in a fume hood for 4 days (14.14 mg/g DW) and freeze-dried for 48 hours (15.35 mg/g DW) (65). Another study also reported that various drying methods affect the hydrolysable tannin content in *Centaurea cyanus* L. Hot-air convective drying for 3 hours resulted in the lowest tannin content (3.56 mg TAE/g DW), while shade drying treatments yielded the highest tannin content (6.77 mg TAE/g DW) (66).

Conclusion

This study indicates that the quality parameters such as moisture content, ash, curcumin, mineral elements, and particle sizes and phytochemical analysis such as phenol, flavonoid, tannin, saponin of *B. rotunda* rhizomes, vary depending on the drying method used. In this research, boiling at 80°C followed by oven drying at 100°C resulted lowest moisture content. Parameters like highest mineral content, ash content, phenol, flavonoid, saponin, tannin and smallest particle size were obtained in boiling *B. rotunda* rhizome at 80°C followed by oven dried at 80°C, which favourable for drug formulation and restore maximum level of all pharmaceutically important components. This study highlights the potential of *B. rotunda* as a source of nutrition and supplements. It also strengthens the evidence for its medicinal value, suggesting it could serve as an alternative treatment for certain diseases. The active constituents of this medicinal plant, or the metabolic products produced by its cells, are responsible for its various therapeutic properties such as antioxidant, anticancer, antidiabetic, antimicrobial activities etc. This study offers important insights into choosing an enhanced drying method for the commercial and pharmaceutical use of *B. rotunda* rhizome powder. Additionally, it serves as a crucial foundation for future research aimed at identifying, isolation and characterizing the phytochemicals, mineral content, and proximate composition of *B. rotunda*, with the goal of exploring its potential in drug development.

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