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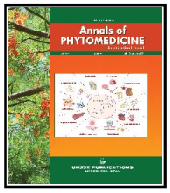

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Impact of desiccation methods on phytochemical composition and profiling in diverse solvent extracts of leaves of *Moringa oleifera* Lam. var. PKM 1

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Abstract

Moringa oleifera Lam. is a common green leafy vegetable used to make traditional soups and stews. The leaves are usually dried and grained into a powder for ease of handling and storage, just as with most green leafy seasonal vegetables. PKM 1 was derived from *M. oleifera* and it is grown for its heavy biomass and tender leaves. Characteristic features of this variety include wide and dark green leaves, long and tender pods, a bushy habit and rapid growth after cropping. This gives the largest yields at the shortest period and the length of each pod is 45-75 cm. Each plant yields 300-400 pods. The effects of drying on the health-promoting effects of the foliage have not yet been fully researched, despite the popularity of this processing method. Therefore, the purpose of this research was to investigate how the biological activities and phytoconstituent composition of Moringa were affected by different drying techniques, including solar cabinet drying, open sun drying, solar tunnel drying and HPD (heat pump drying). The study found that different drying techniques had a significant impact on the leaf's phytoconstituents (flavonoids, alkaloids, terpenoids, steroids, saponins, cardiac glycosides and tannins). The most promising technique for preserving the nutraceutical properties of Moringa leaves was heat pump drying. However, this study shows that the optimal order of drying processes for practical application is heat pump drying, followed by solar cabinet drying, solar tunnel drying, and sun drying. This order ensures optimal preservation of phytoconstituents and potential biological activity of the leaf. The study indicates that the best method to preserve the nutraceutical properties of Moringa leaves is by using heat pump drying, followed by extraction with methanol solvent. This method shows great potential for future commercial exploitation.

1. Introduction

Moringa oleifera Lam. is a hardy tree that is mostly grown in tropical and subtropical climates, with origins believed to be in both Asia and Africa (Lakshmidevamma *et al*., 2021). One of the most important plants in the Moringaceae family, Moringa is a valuable and often-used species of ethnomedicine that is found at the interface of food and medicine (Alavilli *et al*., 2022; Minakshi *et al*., 2021). Plant components including leaves, seeds, stems, roots, flowers, and bark are all regarded as therapeutic (Stevens *et al*., 2021)

This tree is a natural nutritional supplement source for women, infants, and children (Mahato *et al*., 2022). In addition to bioremediation and medicinal properties, it offers a wide range of culinary applications (Gupta *et al*., 2022). Moringa's edible parts, including its leaves and green pods, are abundant in proteins, vitamins, minerals, antioxidants, phenolic compounds, and non-essential and essential amino acids. They are rich in nutrients such as gallic acid, ferulic acid, oleic acid, palmitic acid, linoleic acid, p-coumaric acid, kaempferol, niazimicin, and quercetin. Notable constituents in Moringa extracts include myricetin, glycosides, caffeoylquinic acid, quercetin, hydroxybenzoic acid, coumaroylquinic acid, kaempferol, glucosinolates, zeaxanthin, luteolin, luteoxanthin, apigenin and isothiocyonates. Additionally, Moringa seeds, which contain phenolic compounds like gallic acid, ellagic acid and kaempferol, have significant antioxidant activity (Tahir *et al*., 2020).

Previous research has documented the application of bioactive compounds from Moringa in various commercial food applications as well as functional foods. Because of the plant's high concentration and high-quality bioactive components, it can be used for a variety of food technology applications, including nutrients and technological ones, such as antimicrobial agents, antioxidants, and food fortification (Devisetti *et al*., 2016; Oyeyinka *et al*., 2018; Radka *et al*., 2020).

Plants naturally produce biochemical metabolites called phytochemicals, which are vital to human nutrition. According to Mirzaeian *et al*. (2021), these secondary metabolites include gums, phenols, tannins, alkaloids, flavonoids, steroids, glycosides, and terpenoids. On the other hand, several variables, such as drying techniques, temperature, time, solvent concentration, and solvent polarity, generally influence the extraction and purification of phytochemicals from plant material. It is not possible for a single solvent to reliably extract every phytochemical found in the plant material, so different phytochemicals are extracted in solvents with

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varying polarities depending on their chemical makeup (Lapornik *et al*., 2005).

Consequently, the utilization of diverse solvent polarity in this investigation for the phytochemical screening of Moringa leaf samples will aid in both identifying the components of the leaf extracts and which one is predominant over the others, as well as in extracting the maximum quantity of necessary phytochemicals that can be employed in the creation of more effective medications for treating a range of ailments.

2. Materials and Methods

2.1 Sample preparation

The PKM 1 Moringa tender leaves are harvested on an organic farm at Department of Vegetable Science, Horticultural College and Research Institute, Periyakulam (Figures 1, 2). The location of the experiment is being conducted at 10.1283° N, 77.5998° E, and 411 meters above mean Sea level (MSL). The tender leaves were manually separated, washed with running tap water and allowed to drain. Each batch, containing 5 kg of leaves, was subjected to different drying methods, *viz*., cabinet solar drying, open sun drying, tunnel drying and heat pump drying (HPD). For cabinet solar drying, a cabinet tray dryer with 24 trays (each measuring 0.8 m x 0.4 m x 0.03 m) was used, maintaining a temperature of 50°C. In open sun drying, the leaves were placed outside in the open environment, following the common sun drying practice. It was dried to a constant weight and then milled into powder (Foline *et al*., 2011). The solar tunnel dryer had a floor area of 6 m x 3 m and a height of 2.7 m. It featured a galvanized iron frame covered with a UV-stabilized polyethylene sheet (200 µ size). Moringa leaves were placed in trays (0.8 m x 0.4 m x 0.03 m) on a platform measuring 2.7 m x 1 m x 0.96 m. Two 50 W exhaust fans removed moisture-laden air from the dryer, which was oriented north-south with temperatures ranging between 30°C and 43.2°C (Kumar *et al*., 2020). The HPD unit consisted of a compressor, evaporator, condenser and expansion valve, with the drying chamber dimensions being 0.90 m x 1.80 m x 1.70 m. Air flowed over an electric heating coil with a maximum capacity of 1800 W and the compressor, with a capacity of 300 W, moved back and forth. Air was passed into the drying chamber to dry the materials on inner trays (each holding 25 kg) and the drying temperature was regulated by a thermostat. The dried samples were then powdered using a laboratory-type steel blade blender and analyzed for phytochemical profiling (Pandidurai *et al*., 2022).

Figure 1: Moringa tree PKM 1.

Figure 2: Moringa leaves.

2.2 Preparation of leaf extract

For solvent extraction of *M. oleifera* leaves, three different solvents, namely methanol, ethyl acetate and n-hexane, with increasing polarity were used in the sequential cold extraction method. 100 g of the powdered leaves were separately soaked in 250 cm^3 of solvent in a closed glass jar for 48 h and filtered with the Whatman filter paper. The process was repeated with each solvent, evaporated to dryness, and stored in the refrigerator at 4°C for further studies.

2.3 Phytochemical screening of different solvent extracts of Moringa dried leaves

Phytochemical profiling of various extracts from Moringa leaves was done according to the procedures described by Amano *et al*. (2023), Poonam *et al*. (2023), Indumathi *et al*. (2014) and Omokpariola *et al*. (2021).

2.3.1 Test for alkaloids

10 ml of the extract was completely evaporated. 2 ml of 2 % HCL acid was added to the dry residue. Wagner's reagent was added to the mixture in small drops. The appearance of a reddish-brown precipitate suggested the presence of alkaloids.

2.3.2 Test for terpenoids

10 ml of the crude extract and 5 ml of concentrated (H_2SO_4) were carefully added to 4 ml of chloroform. A positive result for the presence of terpenoids is indicated by the formation of the reddish-brown coloration at the interface.

2.3.3 Test for steroids

2 ml of the extract and 3 ml of concentrated sulfuric acid were combined. Sterol presence was indicated by the formation of a red precipitate.

2.3.4 Test for saponins

1 ml of extract in a graduated cylinder was mixed with 20 ml of distilled water. After shaking the mixture for 5 to 15 min, stable foam formed, indicating the presence of saponins.

2.3.5 Test for glycosides

1 ml of concentrated sulfuric acid was added after adding 6 ml of the plant extract to 3 ml of glacial acetic acid containing one drop of ferric chloride ($FeCl_3$) solution. The presence of cardenolide deoxy sugar was indicated by the formation of a brown ring at the interface. In the acetic acid layer, a greenish ring may also form gradually throughout the layer, but a violet ring may also emerge beneath the brown ring.

2.3.6 Test for flavonoids

When 2 ml of the extract was mixed with a few drops of NaOH, a bright yellow hue emerged. The solution became colorless when a few drops of diluted HCL were added, indicating the presence of flavonoids.

2.3.7 Test for tannins

A beaker was filled with 100 cm^3 of water and 2 ml of leaf extract and then allowed to soak for 2 h. Ferric chloride droplets were added to the extracts. Tannins are indicated by the development of a rich blue-black hue.

2.4 Phytochemical analysis of different solvent extracts of Moringa dried leaves

2.4.1 Estimation of alkaloids

To quantify alkaloids, the method outlined by Agoreyo *et al*. (2012) was used. 400 ml of 10% acetic acid in ethanol and 10 g of dry Moringa leaves were combined in a 500 ml beaker. After covering the beaker, it was allowed to stand for four hours. After filtering the mixture, the filtrate was concentrated in a water bath until it was only 25% of its original volume. After the extract began to completely precipitate, concentrated ammonium hydroxide was added dropwise. After allowing the solution to settle, the precipitate was collected, purified with dilute ammonium hydroxide and filtered. The alkaloid-containing residue was then dried and weighed to ensure a uniform mass.

2.4.2 Estimation of terpenoids

10 ml of petroleum ether was added to a 250 ml beaker containing 1g of sample. After 15 min of extraction, it was filtered. At 420 nm, the absorbance was then measured (Awodele *et al*., 2012).

2.4.3 Estimation of steroids

The procedure outlined by Araujo *et al*. (2013) was adapted to determine the gravimetric weight. After cooling the extract to room temperature (25°C), it was filtered through cotton, and the residue (plant material and cotton) was re-extracted with 30 ml of chloroform for 15 min. The two filtrates were combined and evaporated using a rotary evaporator at 40°C under low pressure. Subsequently, the residue was placed in an oven set at 80°C until it reached a constant weight.

2.4.4 Estimation of saponins

The procedure, as described by Gupta (2013), entails filling a conical flask with 100 ml of 15 per cent ethanol and 15 g of plant sample. In a water bath, the mixture is heated to 100°C for 4 h while being continuously stirred at 55°C. The residue is re-extracted using 250 ml of 20% ethanol after filtering. Next, in a water bath, the combined extracts are concentrated to 40 ml. After moving the concentrate to a 250 ml separating funnel, adding 20 ml of diethyl ether, and give it a good shake. After discarding the ether layer, the extraction procedure is repeated. After combining the aqueous layer with 50 ml of n-butanol, 15 ml of 5% NaCl are used twice to wash the mixture. In a water bath, the residual solution is further heated and evaporated. The sample is then dried in an oven at 105°C until it reaches a constant weight.

2.4.5 Estimation of cardiac glycosides

Using 50 ml of water, 2 g of the sample were heated in an oven at 100°C for 10 min following extraction. One drop of iron chloride, 2 ml of H_2SO_4 (dissolved in 10 ml of water), and 3 ml of glacial acetic acid were added to 10 ml of this extract. Later, at 410 nm, the absorbance was determined (Patel *et al*., 2014).

2.4.6 Estimation of flavonoids

Bharathidasan *et al*. (2013) provided a method for extracting 5 g of the sample using 50 ml of 80% aqueous methanol. Paper filter Whatman No. 42 was employed as a filter for the mixture. Next, evaporation was used to dry the filtrate. After that, measurements of the dry residue's weight were made until it stabilized.

2.4.7 Estimation of tannins

Barbosa and Vetter (1995) described the procedure. 2 g of the sample was combined with 100 ml of distilled water. The solution spent an hour in a water bath at 90°C. Whatman's paper No. 1 was used to filter the mixture and the residue underwent another extraction. After being combined, the two filtrates were given time to cool. The filtrates were supplemented with 500 ml of distilled water. A beaker was filled with 100 ml of the solution, to which 10 ml of 40% formaldehyde and 5 ml of concentrated sulfuric acid were added, respectively. After 30 min of refluxing, the entire mixture was allowed to cool. Following filtering, the precipitate was dried and weighed.

2.5 Statistical analysis

Three replicates were performed during each experiment. The data obtained were analyzed using one-way analysis of variance (ANOVA) with a significance level of 5%.

3. Results

3.1 Solvent yield

The percentage yields of ethyl acetate, n-hexane and methanol obtained from the Moringa dried leaves are given as 42.4%, 36.7% and 47.5%. The yields from the various extraction solvents differed significantly from one another.

3.2 Phytochemical screening

Table 1 illustrates the impact of drying methods on the phytochemical screening of the extracts from Moringa leaves. To find their chemical components or secondary metabolites, plant extracts or tissues from different plant parts are essentially subjected to qualitative analysis or phytochemical screening. As part of the current investigation alkaloids, terpenoids, steroids, saponins, cardiac glycosides, flavonoids and tannin were found in the *M. oleifera* leaf extract after preliminary phytochemical screening. In ethyl acetate extract, cardiac glycosides and tannin were present in high amounts whereas alkaloids, terpenoids, steroids, saponin and flavonoids were present in low amount of quantity. The n-hexane extract, saponin and tannin were present in high amounts whereas alkaloids, terpenoids, steroids, saponin, cardiac glycosides and flavonoids were present in low amounts of quantity. In methanol extracts, alkaloids, terpenoids, saponins, cardiac glycosides, flavonoids, and tannins were present in high amounts whereas steroids were present in low amount of quantity.

Table 1: Phytochemical profile of *M. oleifera* from different solvent extracts of PKM 1 Moringa dried leaves

S. No.	Phytochemicals	Ethyl acetate extract	n-hexane extract	Methanol extract
1.	Alkaloids	+	+	++
2.	Terpenoids	+	+	++
3.	Steroids	+	+	+
4.	Saponins	+	++	++
5.	Cardiac glycosides	++	+	++
6.	Flavonoids	+	+	++
7.	Tannin	++	++	++

Note: (++) - Indicate a high amount of active constituents; **(+)** - Indicate a low amount of active constituents.

3.3 Phytochemical analysis of different solvent extracts of Moringa dried leaves

The impact of drying techniques on the phytochemical composition of extracts from Moringa leaves is displayed in Tables 2 to 5. Alkaloids, terpenoids, steroids, saponins, cardiac glycosides, flavonoids and tannins were found to be the main phytochemical components of the Moringa leaf. The findings indicated that the dried Moringa leaf sample extracts' phytochemical composition varied. Heat pump drying has a high quantity of phytochemicals in all three leaf extracts (Figure 3), followed by solar cabinet drying whereas sun-dried leaves have a low quantity of phytochemicals (Figure 4). Among the different extracts, the methanol extract is present in a high quantity of phytochemicals, *viz*., alkaloids (36.67 mg/g), terpenoids (89.75 mg/g), steroids (29.56 mg/g), saponins (241.65 mg/g), cardiac glycosides (245.59 mg/g), flavonoids (196.74 mg/g) and tannin (294.56 mg/g) whereas the n-hexane extract having low quantity of phytochemicals, *viz*., alkaloids (10.54 mg/g), terpenoids (44.74 mg/g), steroids (16.47 mg/g), saponins (167.24 mg/g), cardiac glycosides (101.78 mg/g), flavonoids (84.75 mg/g) and tannin (171.84 mg/g).

Table 2: Quantitative analysis of phytochemicals in leaf extracts of open sun-dried PKM 1 Moringa leaves from different solvent extracts

S. No.	Phytochemicals	Quantity (mg/g)		
		Ethyl acetate extract	n-hexane extract	Methanol extract
1.	Alkaloids (mg/g)	15.46	10.54	27.15
2.	Terpenoids (mg/g)	38.27	44.74	64.78
3.	Steroids (mg/g)	18.57	16.47	21.45
4.	Saponins (mg/g)	115.64	167.24	186.61
5.	Cardiac glycosides (mg/g)	186.47	101.78	192.46
6.	Flavonoids (mg/g)	99.87	84.75	145.74
7.	Tannin (mg/g)	188.57	171.84	198.47
	S.E (d)	2.56	2.62	1.81
	CD at 5%	5.25**	5.47**	4.06**

Note: S.E (d) - Standard error deviation; CD - Critical difference

Table 3: Quantitative analysis of phytochemicals in leaf extracts of solar tunnel dried PKM 1 Moringa leaves from different solvent extracts

S. No.	Phytochemicals	Quantity (mg/g)		
		Ethyl acetate extract	n-hexane extract	Methanol extract
1.	Alkaloids (mg/g)	16.57	12.67	30.47
2.	Terpenoids (mg/g)	41.67	47.68	64.78
3.	Steroids (mg/g)	16.38	15.67	17.94
4.	Saponins (mg/g)	124.67	172.94	193.38
5.	Cardiac glycosides (mg/g)	192.64	129.74	200.37
6.	Flavonoids (mg/g)	108.92	94.87	179.62
7.	Tannin (mg/g)	194.37	186.47	198.64
	S.E (d)	2.74	2.95	1.97
	CD at 5%	5.63**	6.05**	4.15**

Note: S.E (d) - Standard error deviation; CD - Critical difference.

Table 4: Quantitative analysis of phytochemicals in leaf extracts of cabinet solar-dried PKM 1 Moringa leaves from different solvent extracts

S. No.	Phytochemicals	Quantity (mg/g)		
		Ethyl acetate extract	n-hexane extract	Methanol extract
1.	Alkaloids (mg/g)	19.95	15.47	33.14
2.	Terpenoids (mg/g)	43.57	50.54	68.67
3.	Steroids (mg/g)	19.34	18.24	20.64
4.	Saponins (mg/g)	128.74	176.48	198.67
5.	Cardiac glycosides (mg/g)	199.67	134.15	204.65
6.	Flavonoids (mg/g)	119.42	92.67	186.47
7.	Tannin (mg/g)	206.74	202.56	225.67
	S.E (d)	2.89	3.02	2.10
	CD at 5%	5.88**	6.16**	4.43**

Note: S.E (d) - Standard error deviation; CD - Critical difference.

Table 5: Quantitative analysis of phytochemicals in leaf extracts of HPD (heat pump drying) PKM 1 dried Moringa leaves from different solvent extracts

S. No.	Phytochemicals	Quantity (mg/g)		
		Ethyl acetate extract	n-hexane extract	Methanol extract
1.	Alkaloids (mg/g)	22.37	19.45	36.67
2.	Terpenoids (mg/g)	59.34	63.47	89.75
3.	Steroids (mg/g)	25.64	22.64	29.56
4.	Saponins (mg/g)	176.45	234.74	241.65
5.	Cardiac glycosides (mg/g)	226.12	114.67	245.59
6.	Flavonoids (mg/g)	111.24	93.14	196.74
7.	Tannin (mg/g)	284.51	273.87	294.56
	S.E (d)	3.02	3.21	2.31
	CD at 5%	6.48**	6.89**	4.96**

Note: S.E (d) - Standard error deviation; CD - Critical difference.

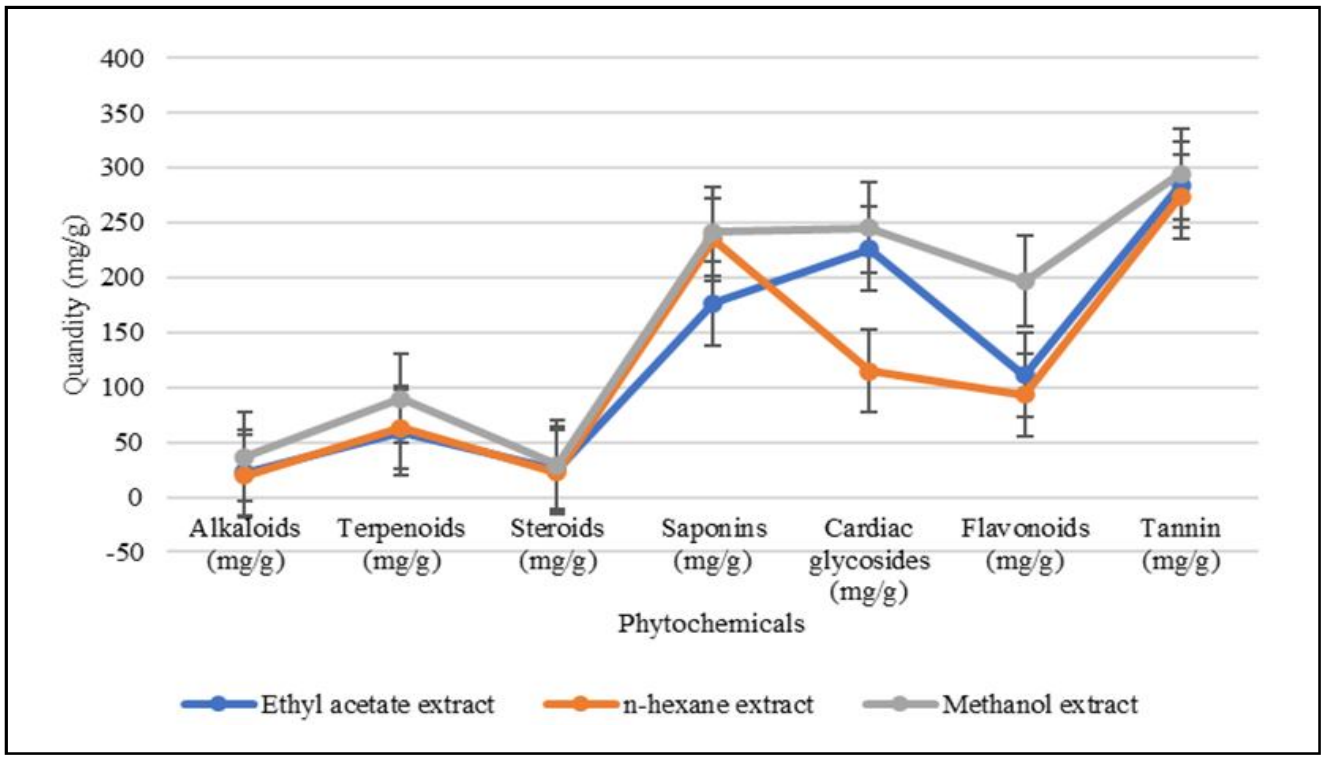

Figure 3: Quantitative analysis of phytochemicals in leaf extracts of HPD (heat pump drying) dried PKM 1 Moringa leaves from different solvent extracts.

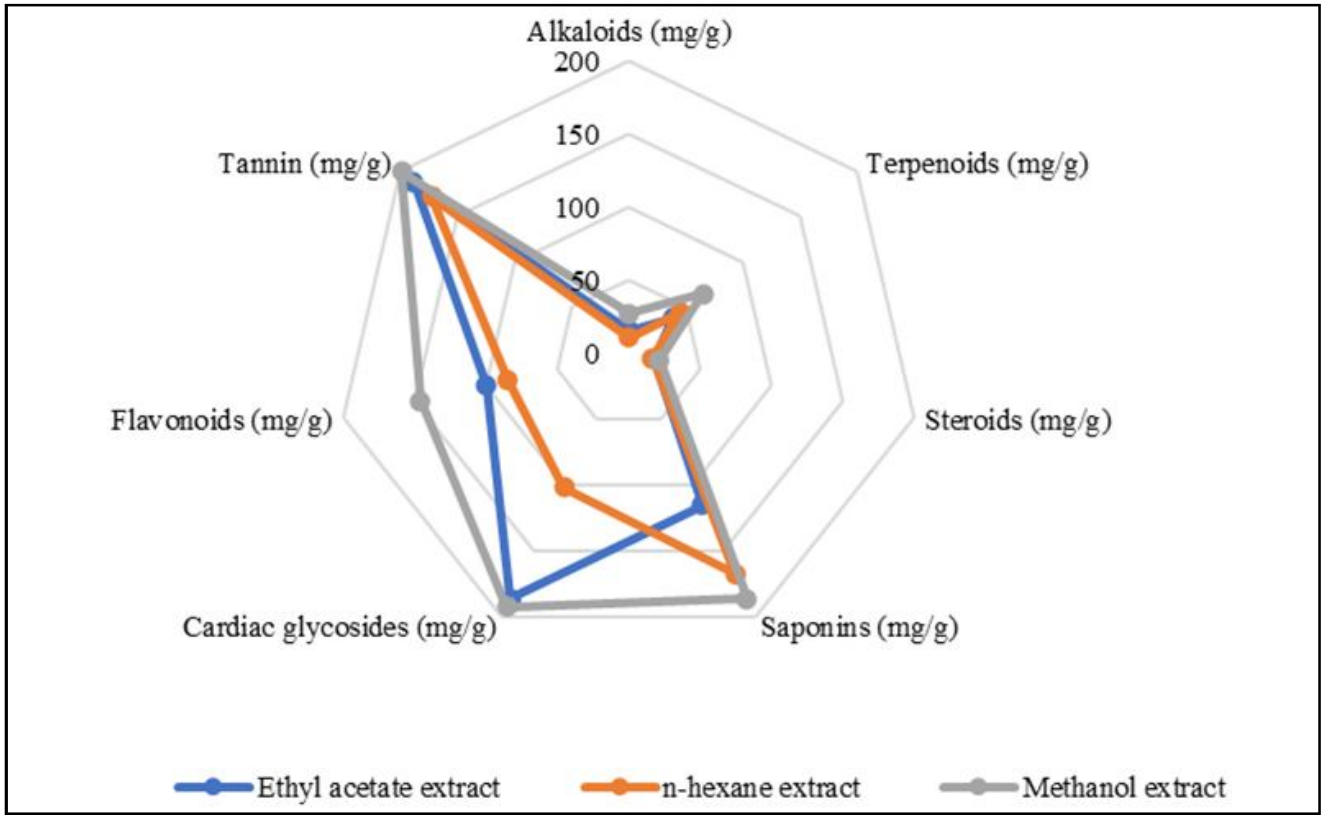

Figure 4: Quantitative analysis of phytochemicals in leaf extracts of open sun-dried leaves from different solvent extracts.

4. Discussion

In many parts of the world, the most popular methods for preserving vegetables for consumption during the dry season are sun drying and shade drying at room temperature; heat pump drying and cabinet solar drying are rarely used (Iwansyah *et al*., 2020). However, the concentration and bioavailability of some crucial food ingredients may be considerably impacted by these processing methods. In addition to demonstrating the presence of alkaloids, terpenoids, steroids, saponins, cardiac glycosides, flavonoids and tannin the phytochemical analysis of the Moringa leaf also demonstrated variations in their concentration following exposure to various drying techniques (Bennour *et al*., 2020). Moreover, the phytochemical composition of the dried Moringa leaf was significantly changed by drying, except for the oxalate content, which remained unchanged (Kumar *et al*., 2024). According to Bakhdir *et al*. (2020), phytochemical screening typically helps to identify the major and bioactive components of plant extracts. Various metabolic, immunological, and neurological disorders in humans can be treated with drugs synthesized using these bioactive constituents.

The present investigation has demonstrated the presence of various compounds identified in Moringa leaf including alkaloids, terpenoids, steroids, saponins, cardiac glycosides, flavonoids and tannin. In our study, the ethyl acetate extract, cardiac glycosides and tannin were present in large amounts, while alkaloids, terpenoids, steroids, saponins, and flavonoids were present in small amounts. The same can be reported by Metri *et al*. (2024). The n-hexane extract, saponin, and tannin were present in large amounts, while alkaloids, terpenoids, steroids, saponin, cardiac glycosides, and flavonoids were present in small amounts. Similar findings observed by Aggarwal *et al*. (2022) In methanol extracts, alkaloids, terpenoids, saponins, cardiac glycosides, flavonoids, and tannins were present in large amounts, while steroids were present in small amounts. The findings agreed by Suman *et al*. (2022). Among the different solvent extracts, the methanol extract has a high number of phytochemicals compared to other extracts.

In our study, various drying methods were employed, including cabinet solar drying, open sun drying, tunnel drying and heat pump drying (HPD). Among these, heat pump drying yielded the highest amount of phytochemicals. Moringa leaves dried using the heat pump method showed high levels of alkaloids, terpenoids, saponins, cardiac glycosides, flavonoids, and tannins, followed by those dried using the solar cabinet dryer. The lowest levels of these phytochemicals were found in leaves dried using the open sun method. Generally, a significant decrease in phytoconstituents was observed in both open sun-dried and solar tunnel-dried samples. This reduction can be attributed to the effects of UV radiation, wind speed, humidity, and the high temperatures involved in sun drying, as well as the moist heat in tunnel drying. These findings are consistent with those of Iwansyah *et al*. (2020), who reported a decrease in the phytochemical content of Moringa with increasing temperatures during drying. Thus, the variations in the phytochemical composition of Moringa leaves can be attributed to heat-induced chemical modifications occurring during the different drying processes.

Due to their widespread use in ethnomedical practices for analgesic, antispasmodic, and antimicrobial treatments, alkaloids are important for protection against microbiological and pesticide activities (Mavrianingtyas *et al*., 2023). The pharmacological properties of alkaloids include antifungal, antibacterial, antihypertensive, anticancer, and antimalarial properties that can be used to treat various ailments (Goel *et al*., 2022). Antimicrobial, antifungal, antiviral, antihyperglycemic, anti-inflammatory, antiparasitic, and memory-enhancing activities are among the biological characteristics of terpenoids as reported by Xie *et al*. (2021). The presence of terpenoids in Moringa indicates its antifungal and antibacterial activity, which is due to the destruction of the membrane and the inhibitory effect on bacterial cells or fungi (Adekanmi *et al*., 2020). Besides their cardiotonic effects, plant steroids are recognized for their antibacterial and insecticidal properties. They are also used in diets, herbal remedies, and cosmetics. Their extensive biological activities make them valuable in medical applications (Sridewi *et al*., 2024).

According to Omokpariola *et al*. (2021), saponins are used to treat fungal and yeast infections, have hemolytic properties, bind cholesterol, and have an antimicrobial effect against mold. Additionally, saponins stop cancer cells from multiplying, preventing the body from producing unwanted cancer cells (Syahputra *et al*. 2021). The saponin content of the sample, which helps fight infection and microbial invasion, could be the reason for it being used as a natural antibiotic (Oladeji *et al*. 2020).

The known mechanism of action of cardiac glycosides is inhibition of the Na^+ / K^+ pump. This increases the concentration of sodium ions in the myocytes, which in turn increases the concentration of calcium ions. They are used to treat cardiac arrhythmias and heart failure because this inhibition increases the amount of Ca^{2+} ions available for contraction of the heart muscle, which increases cardiac output and reduces cardiac stretch. They are also used to strengthen and improve the function of a failing heart; However, the dosage needs to be carefully monitored as the therapeutic dose is close to the toxic dose (Muhammad and Abubakar, 2022).

Flavonoids are water-soluble polyphenolic compounds with a variety of uses, including cytotoxic antitumor activity, estrogenic activity, enzyme inhibition, antimicrobial, antiallergic, antioxidant, and antiulcerogenic properties (Hassan *et al*., 2021). The duodenal tract contains flavonoids that reduce the risk of heart disease. Furthermore, flavonoids prevent the development of ulcers by promoting the formation of a gastric mucosa cover, enhancing capillary resistance, and enhancing microcirculation, all of which lessen the cellular sensitivity to precipitating factors (Wei *et al*., 2023).

Tannins have important medicinal applications because of their astringent qualities. They encourage the creation of new tissues on wounds and inflammatory mucosa, as well as quick healing. Tannins are used to treat minor burns, varicose ulcers, hemorrhoids, frostbite, and gum inflammation (Hossain *et al*., 2020). Internal administration of tannins is used as an antidote for intestinal catarrh, diarrhea, and heavy metal poisoning. These substances have shown promise in the treatment of viral diseases, such as AIDS, in recent years (Kumari *et al*., 2022).

5. Conclusion

Phytochemicals, which may be important factors affecting antioxidant activity, were present in high concentrations in Moringa leaves. This study concluded that the phytoconstituents of Moringa leaves were significantly altered by the drying techniques, with heat

pump drying being the most promising approach. The observed changes in these parameters can be explained by the possibility that the temperature increase in both the sun and solar tunnel drying processes may have resulted in UV and heat-induced degradation of certain labile phytoconstituents. Therefore, it seemed that the best way to preserve the nutraceutical properties of Moringa leaves was to use heat pump drying. In terms of practical implementation, the drying methods that ensure sufficient preservation of phytoconstituents and potential biological activities of Moringa leaves as mentioned in this study are open sun drying, solar tunnel drying, solar cabinet drying, and drying with heat pump, in ascending order of strength. Among the different solvent extracts, methanol extracts contained high levels of alkaloids, terpenoids, saponins, cardiac glycosides, flavonoids, and tannins, while steroids were present in low quantities. The study suggests that using a heat pump to dry Moringa leaves with methanol solvent extract is the best method to preserve nutraceutical properties. This indicates the potential for future commercial exploitation of this method.

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Conflict of interest

The authors declare no conflicts of interest relevant to this article.

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