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"Solvent-Driven Variations in Moringa Oleifera Extracts: Implications for Diabetes Management"

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KEYWORDS

Moringa oleifera, antioxidant, anti-inflammatory, α-amylase inhibition and maceration,

ABSTRACT: The present study explores the influence of solvent polarity on the phytochemical profile, antioxidant, anti-inflammatory and α-amylase inhibitory activities of *Moringa oleifera* leaf extracts, using a successive maceration method with solvents of increasing polarity—hexane, ethyl acetate, ethanol, and water. Phytochemical screening revealed that the type and concentration of bioactive compounds varied significantly with the solvent used. Ethyl acetate extract (MOLEaE) was particularly rich in flavonoids, phenolic compounds, tannins, and saponins—key phytochemicals associated with therapeutic effects. Among all extracts, MOLEaE exhibited the highest antioxidant activity (IC_{50} = 123.28 mg/ml) and anti-inflammatory activity (IC_{50} = 122.01 mg/ml), as well as notable α-amylase inhibition (64.09%), suggesting its potential utility in oxidative stress reduction and inflammation control, both crucial in diabetes management. Hexane extract (MOLHE), rich in non-polar steroids, showed limited antioxidant activity but moderate anti-inflammatory potential. Water and ethanol extracts displayed moderate activity due to the presence of alkaloids, carbohydrates, and proteins. The findings underscore the critical role of solvent selection in optimising the extraction of therapeutic phytochemicals. Ethyl acetate, a moderately polar solvent classified as Generally Recognised as Safe by the US FDA, emerged as the most effective solvent for isolating bioactive compounds with pharmacological relevance. Additionally, regional and environmental factors may influence the phytochemical composition of Moringa oleifera, necessitating further *in-vivo* studies and clinical trials to validate efficacy, bioavailability, and safety of the extracts for future use in managing diabetes and related metabolic disorders.

I. INTRODUCTION

Moringa oleifera (MO), commonly known as the "drumstick tree" or "miracle tree," is a highly valued plant native to the Indian subcontinent. It has gained significant attention for its rich nutritional profile and therapeutic potential[1]. The leaves, seeds, pods, roots, and flowers of *Moringa oleifera* are enriched with a wide range of bioactive compounds, including flavonoids, alkaloids, vitamins, minerals, and essential amino acids. These compounds contribute to its diverse pharmacological activities, such as antioxidant, anti-inflammatory, antimicrobial, anticancer, antidiabetic, cardioprotective, hepatoprotective, and immunomodulatory effects[2].

The present research article aims to investigate the efficacy of *Moringa oleifera* extracts in reducing oxidative stress and inflammation, which are critical factors in the pathogenesis of diabetes and its complications[2]. Diabetes mellitus is a chronic metabolic disorder characterised by persistent hyperglycemia resulting from defects in insulin secretion, insulin action, or both. It is a global health challenge, contributing to significant morbidity and mortality due to its associated complications, such as

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cardiovascular diseases, neuropathy, nephropathy, and retinopathy. A critical factor in the pathophysiology of these complications is the heightened state of oxidative stress and chronic inflammation, which exacerbates insulin resistance and beta-cell dysfunction.

Oxidative stress plays a pivotal role in the onset and progression of diabetes. The overproduction of reactive oxygen species (ROS) and a simultaneous decline in endogenous antioxidant defence mechanisms lead to cellular damage and impaired insulin signalling. *Moringa oleifera* have rich antioxidant profile, including compounds like quercetin and chlorogenic acid, has been shown to scavenge free radicals and enhance the activity of endogenous antioxidant enzymes such as superoxide dismutase (SOD) and catalase (CAT)[3] Furthermore, inflammation is the mark of diabetes, is driven by elevated levels of pro-inflammatory cytokines such as TNF-α, IL-6, and IL-1β. Studies have demonstrated that *Moringa oleifera* modulates these inflammatory pathways by inhibiting nuclear factor kappa B (NF-κB) signalling and reducing cytokine expression[4]

Preclinical and clinical studies highlight the potential of *Moringa oleifera* in improving glycemic control and mitigating diabetes-related complications. For instance, dietary supplementation with *Moringa oleifera* leaf extracts has been associated with reduced fasting blood glucose levels, improved lipid profiles, and enhanced insulin sensitivity[5.] Moreover, *Moringa oleifera's* nephroprotective and cardioprotective effects further underscore its therapeutic promise in comprehensive diabetes management.

II. MATERIALS AND METHODS

Plant Collection and Sample Preparation

Fresh *Moringa oleifera* leaves were collected from Viruveedu village, Nilakottai Taluk, Dindigul District. The plant materials were identified and authenticated by a botanist. The leaves were thoroughly washed with distilled water to remove dirt and debris, and defective leaves and stems were discarded. The cleaned leaves were air-dried at ambient room temperature for 10 days to ensure minimal loss of bioactive compounds. Once dried, the leaves were ground into a coarse powder using a mechanical grinder and stored in airtight containers at room temperature for further use.

Fig.1 *Moringa* leaf, Drying and Powder

Preparation of *Moringa* Leaf Extracts

Maceration and Soxhlet extraction are widely employed methods for extracting bioactive compounds from plant materials such as *Moringa oleifera*. Each method has unique advantages, but maceration is often considered better for certain applications, especially in preserving thermolabile and bioactive compounds. Below is an analysis of maceration as a preferred method of extraction for *Moringa*.

Maceration Method:

Maceration involves soaking plant material in a solvent at room temperature for a specific duration to dissolve bioactive compounds. This process is gentle and requires minimal equipment.[15,16] In this method absence of high temperatures ensures that heat-sensitive compounds, such as polyphenols, flavonoids, and vitamins, remain intact. Continuous exposure to fresh solvent avoids compound degradation, unlike prolonged heating in Soxhlet. This process facilitates the softening and breaking of the plant cell walls, allowing the release of soluble phytochemicals.[6]

Extraction Process Using Successive Maceration Method

The successive maceration technique was employed for extracting bioactive compounds from the *Moringa oleifera* leaf powder using four different solvents in increasing order of polarity by hexane (non-polar), ethyl acetate (medium-polar), ethanol (polar), and water (highly polar). The principle behind this method is that different phytochemicals dissolve preferentially in solvents of varying polarities, allowing for selective extraction. *Moringa oleifera* is known to contain diverse phytochemicals with immense therapeutic potential, including flavonoids, polyphenols, alkaloids, terpenoids, tannins, saponins, and glycosides.[17-19]

Journal of Chemical Health Risks

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JCHR (2025) 15(3), 1361-1370 | ISSN:2251-6727

Stepwise Extraction Using Different Solvents

1. **Extraction with Hexane (MOLHE):** The first extraction was carried out using hexane, a non-polar solvent, to isolate non-polar compounds such as fatty acids, terpenoids, and certain alkaloids. The powdered leaves were soaked in hexane for 24–48 hours with intermittent stirring to enhance extraction efficiency. The extract was then filtered using Whatman No. 1 filter paper, and the solvent was evaporated under reduced pressure using a rotary evaporator. The resulting extract was stored in an airtight container at 4-8°C for further analysis.

2. **Extraction with Ethyl Acetate (MOLEaE):** The residue obtained after hexane extraction was subjected to ethyl acetate extraction to isolate flavonoids, polyphenols, and medium-polarity alkaloids. The maceration and filtration steps were repeated, followed by solvent evaporation.

3. **Extraction with Ethanol (MOLEE):** Ethanol was used next to extract polar compounds such as flavonoids, phenolic acids, tannins, and glycosides. The ethanol extract was obtained following the same procedure and stored for further phytochemical analysis.

4. **Extraction with Water (MOLWE):** Finally, aqueous extraction was performed to isolate water-soluble phytochemicals like saponins, polysaccharides, and certain alkaloids. The water extract was obtained following the same procedure and stored for further phytochemical analysis.

Fig 2. Maceration of *MO with various solvents*

Phytochemical Screening

Phytochemical analysis was conducted to detect the presence of bioactive compounds, including alkaloids, tannins, saponins, carbohydrates, reducing sugars, proteins, flavonoids, and other phenolic compounds. Standard qualitative methods were used to identify these phytoconstituents. The tests included[7] Alkaloids: Dragendorff's test, Tannins: Ferric chloride test, Saponins: Frothing test, Flavonoids[6]: Shinoda test, Carbohydrates and Reducing Sugars: Benedict's and Fehling's tests, Proteins: Biuret test, Phenolic Compounds: Ferric chloride test. The results were carefully recorded, providing insight into the therapeutic potential of the extracts for further bioactivity evaluation.

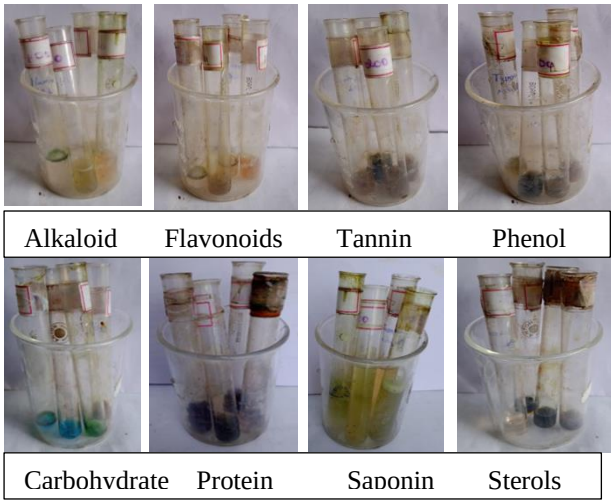

Fig.3. Phytochemical Screening test

Anti-oxidant test

The DPPH (2,2-diphenyl-1-picrylhydrazyl) method is a simple and widely used way to measure the antioxidant activity of plant extracts, like *Moringa* leaves. It is based on the ability of antioxidants to neutralise free radicals. DPPH is a stable free radical. It has a deep purple colour in its radical form because it absorbs light at 517 nm (a specific wavelength). When an antioxidant (from the plant extract) is added, it donates an electron or hydrogen atom to DPPH. This neutralises the free radical, converting it to a non-radical form that is yellow. The reduction in the purple colour of DPPH shows how strong the antioxidant activity of the plant extract is. The more the colour fades, the higher the antioxidant capacity.

***In vitro* Antioxidant activity of extracts:**

A solution of 0.1 millimolar DPPH in methanol was prepared, and 2.4 ml of this solution was mixed with the extract in different concentrations (100, 200 &300 mg/ml). The reaction mixture was vortexed thoroughly and left in the dark at room temperature for 30 min. The

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JCHR (2025) 15(3), 1361-1370 | ISSN:2251-6727

absorbance of the mixture was measured spectrophotometrically at 517 nm. Ascorbic acid was used as a reference.[8] Percentage DPPH radical scavenging activity was calculated by the following equation:

$$\text{Free Radical Scavenging Activity (\%)} = \frac{Abs\ of\ Control - Abs\ of\ Test\ sample}{\text{Abs of Control}} X100$$

A control: Absorbance of DPPH solution without the extract. A sample: Absorbance of DPPH solution with the extract.

IC_{50} (50% inhibitory concentration) determination is a critical step in assessing the antioxidant properties of plant extracts, aiding in product development, therapeutic applications, and scientific research. It provides a standardised way to measure and compare biological activity. A higher value of IC50 indicates a lower antioxidant activity and vice versa.[9,20]

MOLHE MOLEE MOLEaE MOLWE Std Vit

Fig.4 Anti-oxidant activity of *MO,* various Extracts

***In vitro* Anti-Inflammatory Activity Evaluation**

The Inhibition of Albumin Denaturation test is a simple and common method to measure the anti-inflammatory activity of a substance, such as plant extracts. It mimics the way inflammatory processes occur in the body. Here's the concept of the experiment:

Denaturation in Inflammation: During inflammation, proteins in the body (like albumin) can become denatured, meaning they lose their natural shape and function due to stress, heat, or chemicals. This process contributes to tissue damage and inflammatory responses. Anti-inflammatory substances can prevent or reduce protein denaturation**,** thus alleviating inflammation.

Albumin as a model protein: Albumin, a type of protein, is used in this test because it is sensitive to denaturation and behaves similarly to proteins involved in inflammation in the body.

Measuring Inhibition: When albumin is exposed to heat or other stressors, it denatures and forms a turbid solution (cloudy). If the test substance (like *Moringa* extract) has anti-inflammatory properties, it will inhibit this denaturation, keeping the solution clearer.[10]

Determination method: The *In-vitro* anti-inflammatory activity was evaluated using the albumin denaturation inhibition method described by Mizushima et al., with slight modifications. The reaction mixture included the test extract at various concentrations and a 1% aqueous solution of bovine albumin fraction. The pH of the mixture was adjusted with a small amount of 1N HCl. The samples were incubated at 37°C for 20 minutes, followed by heating at 57°C for another 20 minutes. After cooling, the turbidity of the samples was measured spectrophotometrically at 660 nm.[11-13] The experiment was conducted in triplicate, and the percentage inhibition of protein denaturation was calculated using the formula:

$$\text{Percentage inhibition(\%)} = \frac{Abs\ of\ Control - Abs\ of\ Test\ sample}{\text{Abs of Control}} X100$$

Absorbance of Control: Cloudiness of albumin without extract. Absorbance of Test Sample: Cloudiness of albumin with the extract. IC_{50} provides a standardised way to measure and compare biological activity. A higher value of IC_{50} indicates lower activity and vice versa. Although a simple *in vitro test*, it gives an idea of how effective a substance might be in reducing inflammation in the body; however needs to be correlated to *In-vivo* studies. All data of IC_{50} were calculated statistically using https://www.aatbio.com/tools/ic50-calculator last used December 2024.[14]

MOLHE MOLEE MOLEaE MOLWE Std Diclo

Fig. 5. Anti-Inflammatory activity of *MO* Extracts

***In vitro* amylase inhibition test**

In vitro amylase inhibition was studied by the method of Patil SB.[21] In brief, 500 µL of the test Sample was allowed to react with 500 µL of 0.1M phosphate buffer

Journal of Chemical Health Risks

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JCHR (2025) 15(3), 1361-1370 | ISSN:2251-6727

pH 6.9 containing 0.5% α-amylase enzyme (fungal diastase (Research Lab) After 10-minute incubation at 25 degrees Celsius, 500 µL of 1% starch soluble, Extra pure (Loba chemie) in 0.1M phosphate buffer pH 6.8 (Research Lab) was added. Again incubated at 250°C for 10 min. The same was performed for the controls, where 500 µL of the enzyme was replaced by buffer. After incubation, 1000 µL of 3, 5-dinitrosalicylic acid (DNS) (Loba Chemie) was added to both the control and test. Standard acarbose (α-amylase enzyme inhibitor) is used as a standard drug. They were kept in a boiling water bath for 10 min and cooled. The absorbance was recorded at 540 nm using a spectrophotometer, and the percentage inhibition of α-α-α-amylase enzyme was calculated using the formula;

$$\text{Inhibition}(\%) = \frac{Abs\ of\ Control\ -Abs\ of\ extracts}{\text{Abs of Control}} X100$$

Fig.6 Amylase inhibition test of *MO* Extracts

III. RESULT AND DISCUSSION

1. Phytochemical Composition and Extraction Efficiency: Phytochemical screening of *Moringa oleifera* (MO) extracts revealed significant variations in bioactive compounds depending on the solvent used, highlighting the critical role of solvent polarity in selective extraction. The successive maceration method, using solvents of increasing polarity (hexane → ethyl acetate → ethanol → water), facilitated the stepwise extraction of diverse phytochemicals. The study identified alkaloids, flavonoids, tannins, phenols, glycosides, proteins, carbohydrates, steroids, saponins, and terpenoids in different solvent extracts, indicating that *Moringa oleifera* contains a broad spectrum of bioactive compounds with potential pharmacological benefits.

Key Observations:

i. **Alkaloids** were only detected in MOLWE (water extract), suggesting that water is the most effective solvent for extracting these nitrogen-containing bioactive compounds, which have potential hypoglycemic and neuroprotective effects.

ii. **Flavonoids and phenols** were present in all extracts (except hexane), confirming that these compounds are more polar and best extracted with ethyl acetate, ethanol, and water. These phytochemicals contribute to antioxidant and anti-inflammatory activities.

iii. **Tannins** were detected in MOLHE, MOLEaE, and MOLWE, but were absent in MOLEE. Tannins possess anti-inflammatory and anti-diabetic properties, suggesting that moderate-polarity solvents (ethyl acetate, water) are better suited for their extraction.

iv. **Glycosides** were absent in all extracts, indicating that *Moringa oleifera* leaves may have a low concentration of glycosides or that the extraction conditions were not optimal for glycoside solubilization.

v. **Proteins** were detected in MOLEaE, MOLEE, and MOLWE, but not in hexane, highlighting that polar solvents (ethyl acetate, ethanol, and water) are essential for protein extraction. These bioactive proteins may contribute to anti-inflammatory and enzyme-regulating properties.

vi. **Carbohydrates** were only found in MOLWE, aligning with the high solubility of polysaccharides in water. Carbohydrates play a role in immune modulation and energy metabolism, which are beneficial in diabetes management.

vii. **Steroids** were exclusively present in MOLHE, indicating that non-polar solvents (hexane) are necessary for extracting steroidal compounds, which are known for anti-inflammatory and hormonal regulatory properties.

viii. **Saponins** were only detected in MOLEaE, suggesting that medium-polarity solvents are most effective in extracting these compounds, which exhibit antimicrobial, cholesterol-lowering, and anti-diabetic properties.

Journal of Chemical Health Risks

www.jchr.org

JCHR (2025) 15(3), 1361-1370 | ISSN:2251-6727

Terpenoids were absent in all extracts, which may indicate that they are either not abundant in *MO* leaves or require specialised extraction methods such as steam distillation.

The above-discussed results are tabulated in Table No. 1, phytochemical analysis test.

Table 1. Phytochemical analysis test

Sl. No	Test	MOLHE	MOLEaE	MOLEE	MOLWE
1	Alkaloids	-	-	-	+
2	Flavonoids	-	+	+	+
3	Tannins	+	+	-	+
4	Phenols	+	+	+	+
5	Glycosides	-	-	-	-
6	Proteins	-	+	+	+
7	Terpenoids	-	-	-	-
8	Saponins	-	+	-	-
9	Carbohydrates	-	-	-	+
10	Steroids	+	-	-	-
(+) Present, (-)Absent					

2. Antioxidant Activity: The antioxidant activity of the extracts was evaluated using the DPPH assay, where lower IC_{50} values indicate stronger antioxidant potential. The order of antioxidant activity (from highest to lowest) was:

MOLEaE > MOLWE> MOLEE > MOLHE

MOLEaE exhibited the highest antioxidant activity because it extracted flavonoids and phenolic compounds more efficiently than other solvents. Flavonoids (quercetin, kaempferol) and phenolic acids (chlorogenic acid, gallic acid) are powerful free radical scavengers, neutralising reactive oxygen species (ROS) that contribute to oxidative stress. Ethyl acetate is a medium-polar solvent, which means it is effective at dissolving polyphenols and flavonoids, but does not extract excessive unwanted polar impurities. Since flavonoids and phenols are directly involved in neutralising DPPH free radicals, the higher concentration in MOLEaE explains its lower IC_{50} value of 123.28 (higher antioxidant activity).

Hexane is a non-polar solvent, which means it primarily extracts steroids, fats, and non-polar terpenoids. These compounds do not have significant antioxidant properties, leading to the highest IC_{50} value (weakest activity). Hexane does not efficiently extract flavonoids or phenolic acids, which are the key antioxidant molecules. This explains why MOLHE had the least radical-scavenging potential and the IC_{50} value (207.41 mg/ml).

MOLWE (IC_{50} = 187.81 mg/ml): Water extracts highly polar compounds like carbohydrates, alkaloids, and tannins, which may contribute to moderate antioxidant activity, but it is not as selective as ethyl acetate in extracting flavonoids. MOLEE (IC_{50} = 198.05 mg/ml): Ethanol extracts a wide range of polar and semi-polar compounds, including phenols, flavonoids, tannins, and saponins. However, it also extracts other polar impurities that may dilute the total antioxidant capacity, leading to slightly lower antioxidant activity than MOLEaE. The above-discussed results are shown in Table No. 2 and Fig. No. 7.

Table 2: *MO* extracts Anti-oxidant activity

Name of extract	Conc (mg/ml)	% of inhibition Average	IC50 (mg/ml)
MOLHE	100	44±3.46	207.41
	200	53±3.88	
	300	65±3.67	
MOLEaE	100	82±4.87	123.28
	200	83± 3.4	
	300	83± 3.2	
MOLEE	100	39±4.4	198.05
	200	47±4.7	

Journal of Chemical Health Risks
www.jchr.org
JCHR (2025) 15(3), 1361-1370 | ISSN:2251-6727

Name of extract	Conc (mg/ml)	% of inhibition Average	IC50 (mg/ml)
	300	54±3.09	
MOLWE	100	58±4.92	187.81
	200	78±4.66	
	300	87±4.64	
Std Vit C	50	91±1.54	81.07
	100	92±1.5	
	150	92±1.54	

Standard Error of the Mean = 6

3. Anti-Inflammatory Activity: The anti-inflammatory activity was measured using the protein denaturation inhibition method, where lower IC_{50} values indicate stronger anti-inflammatory activity. The ranking of extracts from highest to lowest activity was: **MOLEaE > MOLHE > MOLWE > MOLEE**

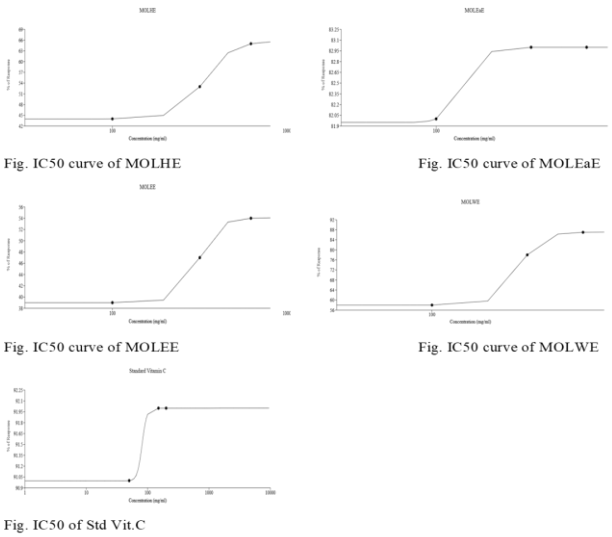

Fig. IC50 curve of MOLHE

Fig. IC50 curve of MOLEaE

Fig. IC50 curve of MOLEE

Fig. IC50 curve of MOLWE

Fig. IC50 of Std Vit.C

Fig. 7 *MO* extracts Anti-oxidant activity IC 50

MOLEaE showed the strongest anti-inflammatory activity (IC 50 is 122.01) because it extracted tannins, flavonoids, and saponins, which are known to inhibit inflammatory pathways. Flavonoids and phenolic acids inhibit inflammatory mediators such as TNF-α, IL-6, and IL-1β, reducing inflammation. Tannins stabilise cell membranes and prevent protein denaturation, a key marker of inflammation. Saponins modulate immune responses and help regulate inflammatory cascades. Ethyl acetate is moderately polar, meaning it effectively extracts flavonoids and tannins without excessive impurities, maximising its anti-inflammatory potency.

Hexane extracted steroids, which have natural anti-inflammatory properties, explain their relatively good anti-inflammatory effect (IC 50 is 197.24). Steroids inhibit pro-inflammatory enzymes (Cyclooxygenase, Lipoxygenase), reducing inflammatory cytokine production. However, MOLHE did not extract flavonoids or tannins, making it less effective than MOLEaE.

Ethanol extracts a broad range of polar compounds, including proteins and carbohydrates, which may have diluted the concentration of active anti-inflammatory compounds. The presence of unwanted plant metabolites could interfere with anti-inflammatory mechanisms, reducing activity (IC 50 is 236.69). Water extracts alkaloids and carbohydrates, which may have some mild anti-inflammatory effects (IC 50 is 202.30). However, water does not efficiently extract steroids or flavonoids, leading to lower anti-inflammatory activity than ethyl acetate extract. The above-discussed results are shown in Table No. 3 and Fig. No. 8.

Table 3: *MO* **extract Anti-inflammatory activity**

Name of the extract	Conc (mg/ml)	% of inhibition Average	IC50 (mg/ml)
MOLHE	100	38	197.24
	200	41	
	300	43	
MOLEaE	100	40	122.01
	200	55	
	300	55	
MOLEE	100	27.6	236.69
	200	27.5	
	300	26.8	

Journal of Chemical Health Risks
www.jchr.org
JCHR (2025) 15(3), 1361-1370 | ISSN:2251-6727

Name of the extract	Conc (mg/ml)	% of inhibition Average	IC50 (mg/ml)
MOLWE	100	43	202.30
	200	51	
	300	60	
Diclofenac	50	84	100.11
	100	82	
	150	80	

Standard Error of the Mean = 6

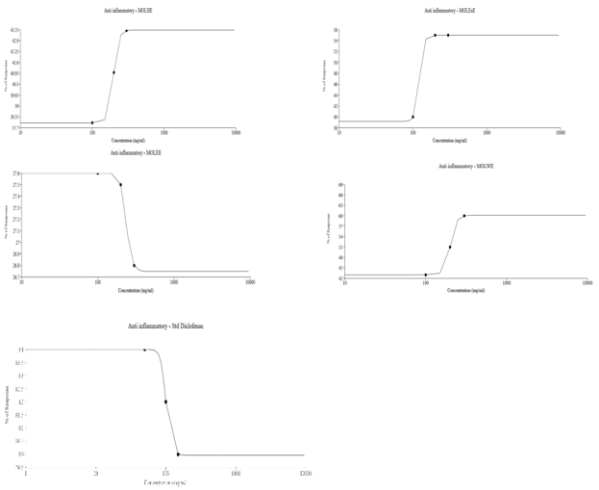

Fig. 8. *MO* and standard Anti-inflammatory IC 50

4. The digestive enzyme (alpha-amylase) inhibition activity: In vitro amylase inhibition was studied by the method of Patil SB, Sample -MOLWE 57.63 %, MOLEaE 64.09%, MOLHE 64.81%, MOLEE 59.78%, was showed inhibition of amylase enzyme when compared to acarbose standard- 91.74%. The results indicate that MOLEaE and MOLHE give better activity compared to others.

Table No. 4 Effect of alpha amylase inhibition assay

Sample code	Conc µg/ml	Absorbance at 540nm	Mean	% inhibition
Control		1.82 1.87 1.88	1.85	
Std Acarbose	250	0.42 0.39 0.39	0.40	78.45
	500	0.35 0.28 0.24	0.29	84.38
	1000	0.15 0.12 0.19	0.15	91.74
MOLWE	100	0.88 0.89 0.91	0.89	51.88
	200	0.82 0.83 0.84	0.83	55.29
	300	0.75 0.76 0.77	0.78	57.63
MOLEaE	100	0.84 0.86 0.87	0.85	53.85
	200	0.78 0.77 0.76	0.77	58.52
	300	0.69 0.65 0.66	0.66	64.09
MOLHE	100	0.84 0.88 0.87	0.86	53.50
	200	0.73 0.75 0.74	0.74	60.14
	300	0.69 0.63 0.64	0.65	64.81
MOLEE	100	0.98 0.99 0.97	0.98	47.21
	200	0.86 0.88 0.87	0.87	53.14
	300	0.76 0.75 0.73	0.74	59.78

Regional Influence on Phytochemical Composition: The phytochemical content of *Moringa oleifera* is known to vary depending on geographical location, climate, soil composition, and environmental conditions. Several studies suggest that *Moringa oleifera* plants grown in different regions exhibit distinct variations in their bioactive compound concentrations.

IV. CONCLUSION

This study highlights that solvent choice significantly affects the extraction of bioactive compounds from *Moringa oleifera*, influencing its antioxidant and anti-inflammatory properties. Among the four solvents tested, Ethyl acetate extract (MOLEaE) showed the highest antioxidant (IC_{50} = 123.28 mg/ml) and anti-inflammatory (IC_{50} = 122.01 mg/ml) activities and showed inhibition of amylase enzyme 64.09 %, making

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JCHR (2025) 15(3), 1361-1370 | ISSN:2251-6727

it the most effective for diabetes management. Further *in vivo* studies and clinical trials are necessary to confirm the efficacy and bioavailability of the active compounds from these extracts. Ethyl acetate is classified as Generally Recognised as Safe (GRAS) by the U.S. FDA when used in controlled amounts. However, it must be completely removed from the final product, and future studies should focus on optimising safe, bioactive-rich extracts for diabetes management.

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