

Development and Characterization of Fenugreek (*Trigonella foenum-graecum*) Seed Extract-Loaded Nanoparticles for Anti-Inflammatory Therapy in Chronic Kidney Disorder

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ABSTRACT

Chronic Kidney Disease (CKD) is a progressive disorder characterized by persistent inflammation, oxidative stress, and gradual loss of renal function. Natural products rich in bioactive phytochemicals have gained considerable attention as potential therapeutic agents for the management of CKD-associated complications. *Trigonella foenum-graecum* (fenugreek) seeds are known to possess antioxidant, anti-inflammatory, and nephroprotective properties owing to their diverse phytochemical composition. The present study aimed to investigate the phytochemical profile of fenugreek seed extracts and evaluate their suitability for nanoparticle-based anti-inflammatory therapy in CKD. Methanolic and ethanolic extracts of fenugreek seeds were prepared and subjected to preliminary phytochemical screening, GC-MS analysis, and LC-MS/MS profiling. The phytochemical screening confirmed the presence of alkaloids, flavonoids, phenolic compounds, saponins, tannins, glycosides, carbohydrates, and amino acids. GC-MS analysis identified 26 compounds in the methanolic extract and 17 compounds in the ethanolic extract, including dihydroxyacetone, pyrogallol, benzoic acid derivatives, fatty acids, and alcohols. LC-MS/MS profiling further revealed the presence of several bioactive metabolites associated with antioxidant and anti-inflammatory activities. Among the investigated extracts, the methanolic extract exhibited greater phytochemical diversity and bioactive potential. These findings suggest that fenugreek seed extract represents a promising natural source of bioactive compounds and may serve as a suitable candidate for the development of nanoparticle-based drug delivery systems for CKD management.

Keywords: *Trigonella foenum-graecum*, Fenugreek, Chronic Kidney Disease, Nanoparticles, Phytochemical Screening, GC-MS, LC-MS/MS, Nephroprotection, Anti-inflammatory Activity.

INTRODUCTION

Chronic Kidney Disease is a problem for people's health all around the world. It is when the kidneys get worse and worse over time. This cannot be changed. Chronic Kidney Disease gets worse because of long term inflammation stress on the body damage to cells and scarring of the kidneys. All these things together make the kidneys not work properly and make people very sick. Even though we have some treatments that can slow down the disease they do not always. It can have bad side effects. So people are looking for better ways to treat Chronic Kidney Disease using things that come from nature. [1] Fenugreek is an important

plant that is used to help people in many different ways. The seeds of the fenugreek plant have good things in them like trigonelline, diosgenin, quercetin, kaempferol, galactomannan and 4-hydroxyisoleucine. These things, in fenugreek seeds can help with health problems because they have antioxidant, anti-inflammatory, antidiabetic, hypolipidemic and nephroprotective effects. Many studies have shown that fenugreek seeds can help reduce stress on the body control inflammation and protect the kidneys from getting hurt. Fenugreek is used in traditional and modern ways to help people and Chronic Kidney Disease is one of the things that fenugreek may be able to help with.[2] New things are happening in nanotechnology. It is helping us make better ways to give people medicine. We can use particles to help the body absorb medicine better keep it from breaking down and make sure it gets to the right place. This is really helpful because it can make the medicine work better. So putting fenugreek seed extracts into these particles might be a good way to help people with kidney disease who have a lot of inflammation.[3] This study is about taking fenugreek seeds pulling out the stuff and then figuring out what is in it and how it works. We want to find out if we can use these extracts to make a kind of medicine that uses tiny particles to help reduce inflammation in people, with kidney disease. Despite the reported nephroprotective and anti-inflammatory activities of *Trigonella foenum-graecum*, limited studies have investigated its application in nanoparticle-based drug delivery systems for chronic kidney disease. Furthermore, comprehensive phytochemical profiling to identify bioactive constituents suitable for nanoformulation remains insufficient. Therefore, the present study aims to characterize fenugreek seed extracts and evaluate their suitability for nanoparticle-mediated anti-inflammatory therapy in CKD.[4] The novelty of this work lies in the integration of phytochemical screening, GC-MS, and LC-MS/MS profiling to identify bioactive compounds from fenugreek seeds and establish their potential for development of nanoparticle-based nephroprotective formulations [5]

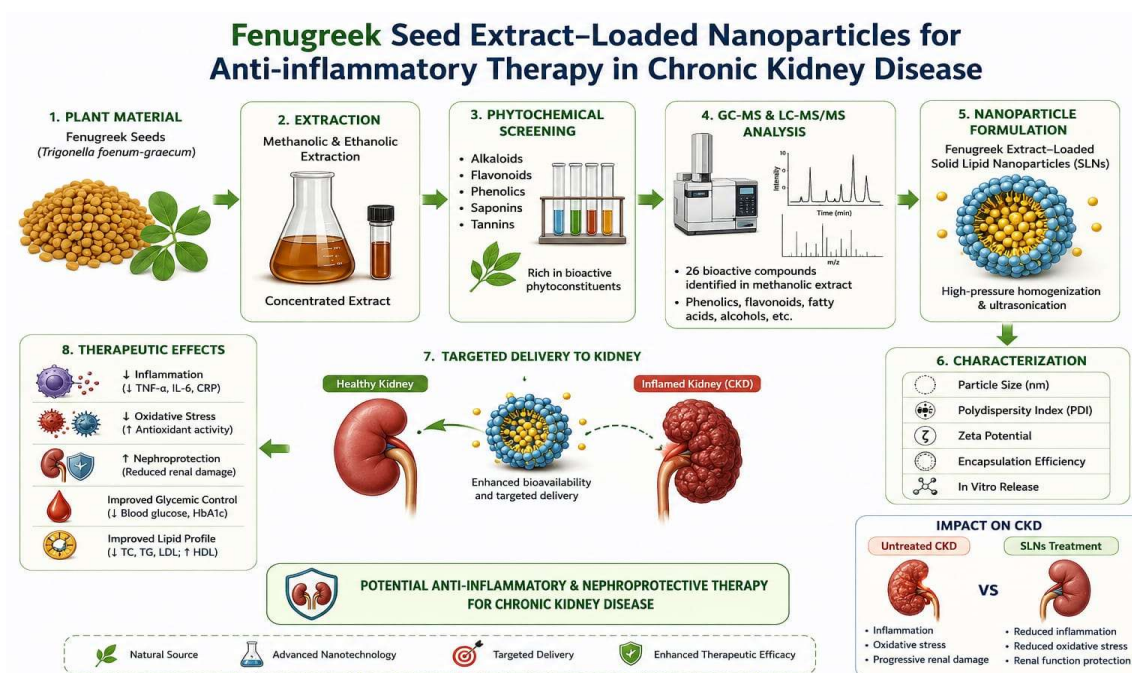


Figure 1. Graphic Representation of Fenugreek seed Extract

II. MATERIALS AND METHODS

Plant Material and Extraction

We got some fenugreek seeds cleaned them well and dried them in the shade. This helped keep the stuff in the seeds from getting damaged. We then ground the dried seeds into a powder. We used methanol and ethanol to extract the stuff from the powder one at a time. After that we removed the solvents by reducing the pressure. This gave us extracts. We called the extract made with methanol Sample 01. The one made with ethanol Sample 02.[6]

Gas Chromatography–Mass Spectrometry (GC-MS) Analysis

We did GC-MS analysis using an Agilent GC-MS/MS machine. This helped us find out what chemicals were in the extracts. We identified each compound by checking its mass spectrum against known databases and libraries.

Non-Targeted LC-MS/MS Analysis

We also did a metabolite profiling test using a SCIEX QTRAP 4500 LC-MS/MS system. This test helped us detect and characterize different metabolites and phytochemicals in the fenugreek seed extracts. It was a -targeted approach, which means we did not specifically look for certain things but instead looked at a wide range of stuff that was present in the extracts.[7]

The test gave us an idea of what was, in the extracts. Preliminary Phytochemical Screening

We did some tests to see what kinds of good stuff was in the extracts. We used tests to check for things like alkaloids, flavonoids, saponins, tannins, phenolic compounds, glycosides, carbohydrates and amino acids.

- We checked the extracts to see if they had alkaloids, flavonoids and other compounds.
- The tests helped us know what was in Sample 01 and Sample 02.
- We found out what major compounds were present, in both the methanolic and ethanolic extracts.
- The methanolic extract, Sample 01 had compounds.
- The ethanolic extract, Sample 02 had some compounds too.
- We identified the compounds in both extracts.

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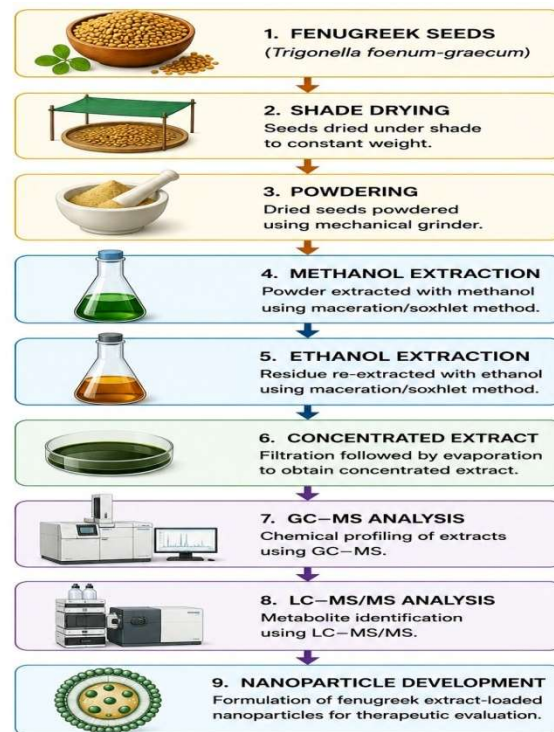


Figure 2. Flowchart of Fenugreek Seed Extraction Process

III. Results and Discussion

A. Phytochemical Screening and Relevance to Chronic Kidney Disease

When we look at the seeds of *Trigonella graecum* we find that they have a lot of good things in them. These things are called phytochemicals. The seeds have alkaloids, flavonoids, saponins, tannins and other things that are good for us. These phytochemicals help keep us healthy by fighting against things that can hurt us like radicals and things that cause inflammation. They also help protect our kidneys.[8] We did some tests to see what was in the seeds. We found that they have alkaloids, flavonoids, saponins, tannins and other things. Some of the phytochemicals in fenugreek are trigonelline, diosgenin, yamogenin, quercetin, kaempferol luteolin, gallic acid and 4-hydroxyisoleucine.[9] Diosgenin and some other phytochemicals in fenugreek are good at reducing inflammation. They do this by stopping things that cause inflammation like TNF- α , IL-6 and NF- κ B. Flavonoids like quercetin and kaempferol are good at fighting against radicals. They do this by catching them and making our bodies own antioxidant enzymes work better. Trigonelline is a phytochemical that helps protect our kidneys from damage caused by radicals. It does this by changing the way some signals work in our bodies. 4-Hydroxyisoleucine is another phytochemical that helps control blood sugar levels. This can help reduce damage to our kidneys caused by diabetes. All of these phytochemicals together make fenugreek seed extract a thing to use to help manage chronic kidney disease. We have done some studies to see how well fenugreek works to protect our kidneys. We used fenugreek seed extract on animals with kidney damage caused by gentamicin, streptozotocin and ethylene glycol. We found that the extract helped reduce the damage to their kidneys. It also reduced the amount of waste products in their blood and the amount of stress they had. This is news for people, with chronic kidney disease. Fenugreek seed extract might be a tool to help manage the disease.

B. Statistical Analysis

All experiments were carried out in triplicate (n=3). Results are presented as mean \pm standard deviation. Statistical analysis was performed using one-way ANOVA followed by Tukey's post hoc test, and $p < 0.05$ was considered statistically significant.[10]

The Physical Characteristics of Extracts

After the solvent was gone the methanolic and ethanolic extracts looked like semi-solid masses. This showed that the extraction of phytoconstituents from the fenugreek seeds was successful.

Phytochemical Analysis

When we did a phytochemical screening we found that the extracts had several important bioactive constituents, including:

- Alkaloids
- Flavonoids
- Saponins
- Tannins
- Phenolic compounds
- Glycosides
- Carbohydrates
- Amino acids

These phytochemicals, like the flavonoids and phenolic compounds are known for being antioxidants. The saponins and alkaloids are also good for reducing inflammation and protecting the kidneys. The fenugreek seeds extracts have these phytochemicals, which have antioxidant and antiinflammatory properties. The phytochemicals in the fenugreek seeds extracts are also good, for protecting the kidneys.[11]

C. GC-MS Analysis

Methanolic Extract (Sample 01)

When we looked at the methanolic extract we found 42 peaks. We were able to identify 26 of these compounds. The main things we found were dihydroxyacetone acid derivatives, tetradecanoic acid derivatives, fatty acid esters, alcohols and some other compounds that are good for us. The methanolic extract had a lot different types of phytochemicals than the ethanolic extract.

Compound Discovery Report



Sample Information

Name	Sample-1	Data File Path	D:\MassHunter\GCMS\1\data\2026\MAY\040526\A2.D
Sample ID		Acq. Time	07-05-2026 11:21:53 AM
Instrument	GCMSMSQQ	(Local)Method Path(Acq)Version	D:\MassHunter\GCMS\1\methods\FOOD_PEST_SCAN_1_2024.M
MS Type	Q	Path(Acq)Version	MassHunterGC\MSAcquisition10.2.48902_Aug-2022Copyright©1989-2021Agilent
Inj. Vol (µl)	1	IRM Status	
Position	67	Method Path(DA)	D:\MassHunter\Methods\10.0\RAI.m
Plate Pos.		Target Source Path	D:\MassHunter\Library\demo.mslibrary.xml;D:\MassHunter\Library\NIST0.L2
Operator		Result Summary	6 identified (42 found)

Sample Chromatograms

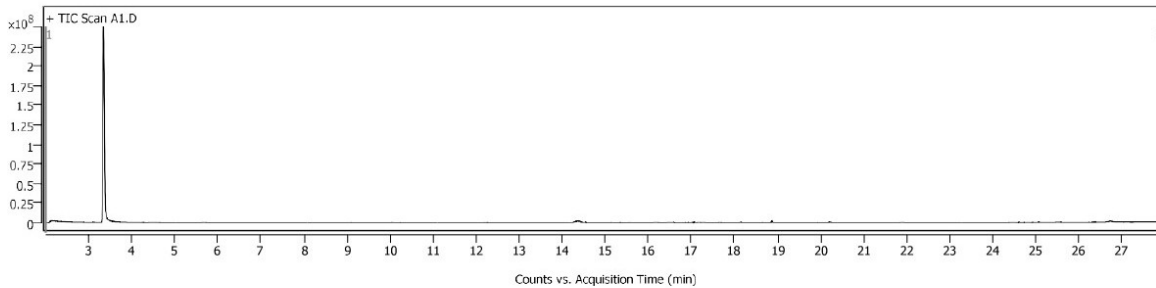
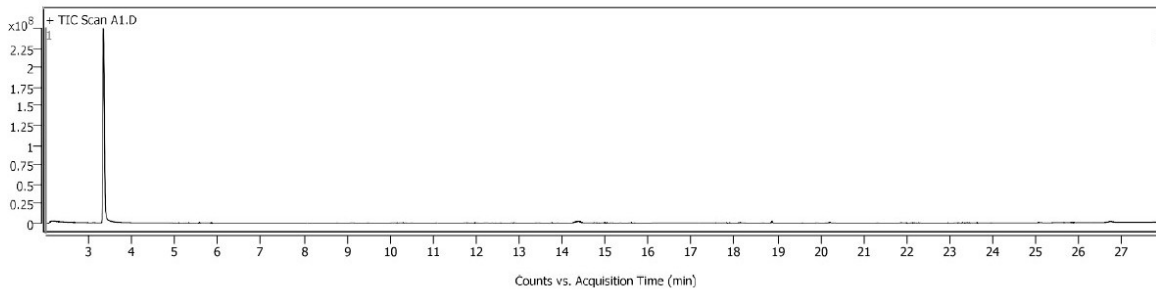
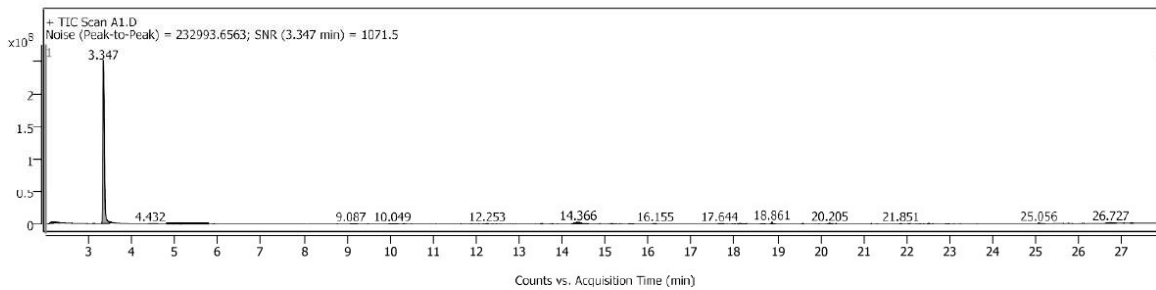
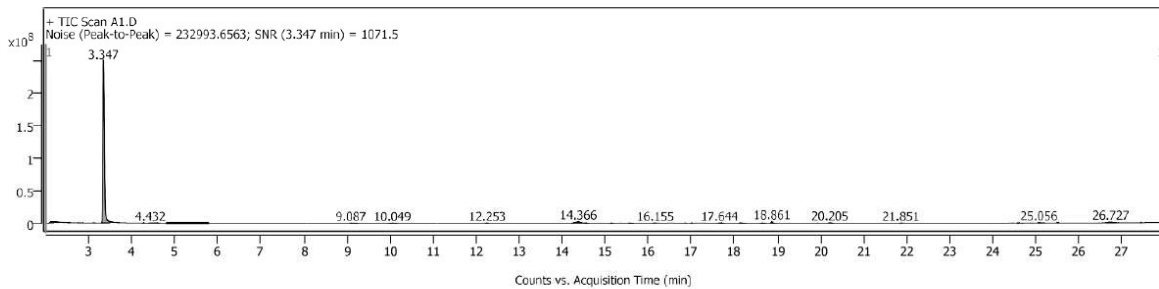
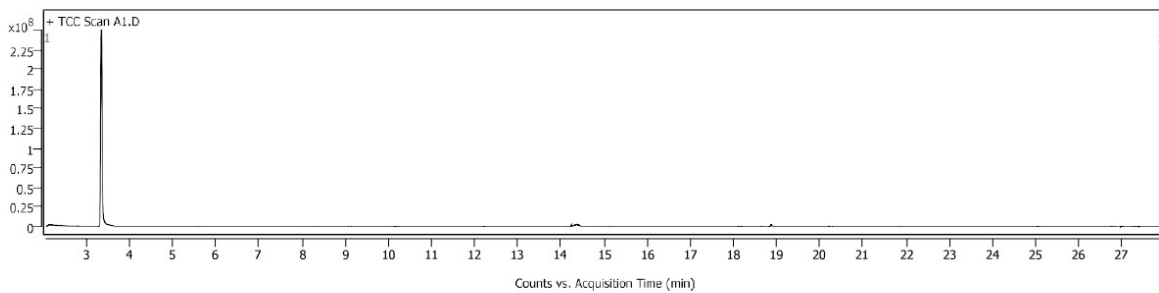
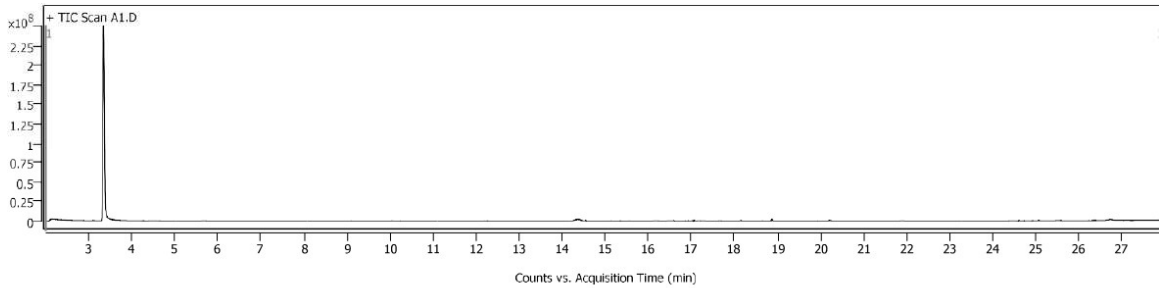
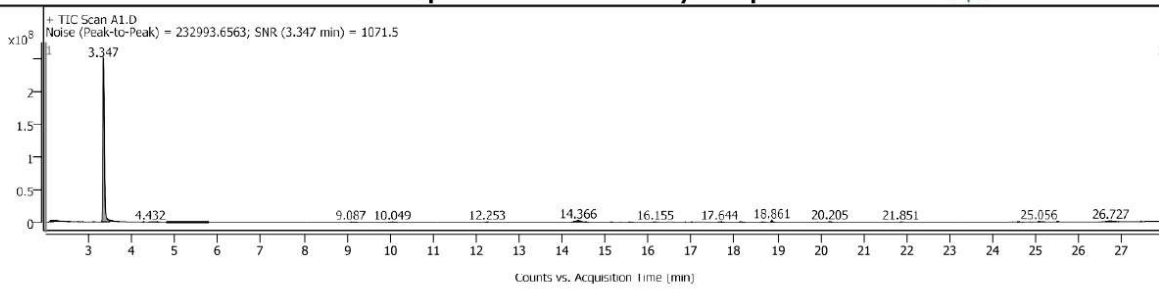


Figure 3. GC-MS Chromatogram of Methanolic Fenugreek Seed Extract (Sample 01)

Compound Discovery Report



Compound Summary

Cpd	Name	Formula	RT	Mass	CAS	ID Source	Score	Score (Lib)	Score (DB)	Score (MFG)	Algorithm
1	Methyl Alcohol	C ₁ H ₄ O	2.151		67-56-1	LibSearch	81.66	81.66			Chrom Decon
2	(E)-2-Ethylidenetetrahydrothiophene 1-oxide	C ₆ H ₁₀ O S	3.118		79496-69-8	LibSearch	55.28	55.28			Chrom Decon
3	Toluene	C ₇ H ₈	3.347		108-88-3	LibSearch	78.26	78.26			Chrom Decon
4			3.832								Chrom Decon
5	Dihydroxyacetone	C ₃ H ₆ O ₃	5.672		96-26-4	LibSearch	45.29	45.29			Chrom Decon
6	Borene, diethyl(dicycloxy)-	C ₁₄ H ₃₁ B O	8.775		1000152-34-3	LibSearch	52.31	52.31			Chrom Decon
7	Tricyclo[3.3.3.0(1,5)]undecane, 2,8,9-trioxo-5-aza-1-bora-	C ₆ H ₁₂ B N O ₃	9.091		15277-97-1	LibSearch	48.75	48.75			Chrom Decon

Compound Discovery Report



Compound Summary

Cpd	Name	Formula	RT	Mass	CAS	ID Source	Score	Score (Lib)	Score (DB)	Score (MFG)	Algorithm
8	Borane, diethyl(decyloxy)-	C14 H31 B O	9.493		1000152-34-3	LibSearch	53.14	53.14			Chrom Decon
9	Propylamine, N,N,2,2-tetramethyl-, N-oxide	C7 H17 N O	10.107		13993-87-8	LibSearch	45.56	45.56			Chrom Decon
10	2,3,1-Benzodiazaborine, 1,2-dihydro-1-methyl-	C8 H9 B N2	10.230		4885-27-2	LibSearch	41.51	41.51			Chrom Decon
11	Borane, diethyl(decyloxy)-	C14 H31 B O	11.058		1000152-34-3	LibSearch	48.69	48.69			Chrom Decon
12	O-Butyl-O-1,2,2-trimethylpropyl methylphosphonate	C11 H25 O3 P	11.722		108202-66-0	LibSearch	41.16	41.16			Chrom Decon
13			12.191								Chrom Decon
14	Borane, diethyl(decyloxy)-	C14 H31 B O	12.251		1000152-34-3	LibSearch	52.53	52.53			Chrom Decon
15			12.897								Chrom Decon
16	2-Methyl-N-(1-methylethylidene)-4-((1E)-1-pentadecenyl)-1,3,2-dioxaborinan-5-amine	C22 H42 B N O2	13.728		60203-39-6	LibSearch	41.88	41.88			Chrom Decon
17	Propanoic acid, 2,2-dimethyl-, rubidium salt	C5 H9 O2 Rb	14.306		70205-79-7	LibSearch	40.27	40.27			Chrom Decon
18	beta-D-Glucopyranosylmethane	C8 H16 N2 O7	14.360		14901-08-7	LibSearch	53.15	53.15			Chrom Decon
19	Phosphonic difluoride	F2 H O P	14.374		14939-34-5	LibSearch	51.09	51.09			Chrom Decon
20	Borane, diethyl(decyloxy)-	C14 H31 B O	15.128		1000152-34-3	LibSearch	47.10	47.10			Chrom Decon
21	Benzoic acid, 4-ethoxy-, ethyl ester	C11 H14 O3	15.555		23676-09-7	LibSearch	53.28	53.28			Chrom Decon
22	Tetradecanoic acid	C14 H28 O2	18.135		544-63-8	LibSearch	62.97	62.97			Chrom Decon
23	3-Hexadecanol	C16 H34 O	18.634		593-03-3	LibSearch	49.37	49.37			Chrom Decon
24	Isopropyl myristate	C17 H34 O2	18.861		110-27-0	LibSearch	58.24	58.24			Chrom Decon
25			18.873								Chrom Decon
26	2-(4-Chlorophenyl)-1,3,2-dioxaborolane	C8 H8 B Cl O2	19.575		69519-09-1	LibSearch	51.96	51.96			Chrom Decon
27			19.930								Chrom Decon
28	Phenazazine, 10,10'-oxybis[5,10-dihydro-	C24 H18 As2 N2 O	20.132		4095-45-8	LibSearch	44.09	44.09			Chrom Decon
29	Decanoic acid, silver(1+) salt	C10 H19 Ag O2	20.202		13126-67-5	LibSearch	60.50	60.50			Chrom Decon
30			20.309								Chrom Decon
31	3,4-Octadiene, 7-methyl-	C9 H16	21.852		37050-05-8	LibSearch	60.30	60.30			Chrom Decon
32			24.933								Chrom Decon
33	Hexadecanoic acid, 2-hydroxy-1-(hydroxymethyl)ethyl ester	C19 H38 O4	25.057		23470-00-0	LibSearch	50.55	50.55			Chrom Decon
34			25.090								Chrom Decon
35			26.634								Chrom Decon
36			26.726								Chrom Decon
37			26.808								Chrom Decon
38			26.825								Chrom Decon
39			26.936								Chrom Decon
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Compound Details

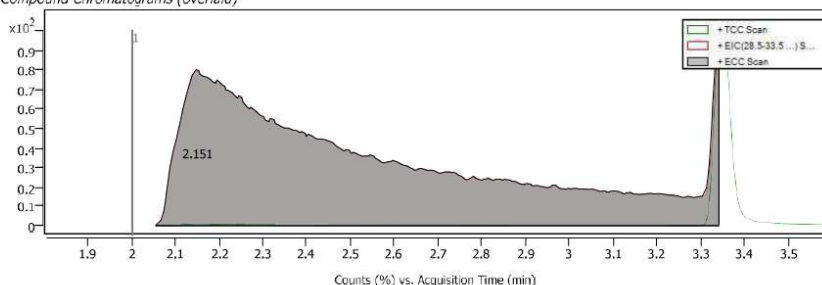
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Species	m/z	Score (Lib)	Num Spectra	Score (DB)	Hits	Score (MFG)	Score (RT)		
		81.66			1				

Compound ID Table

Name	Formula	Species	ID Source	RT	RT Diff	Mass	CAS	Score	Score (DB)	Score (MFG)
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Compound Chromatograms (overlaid)



Structure

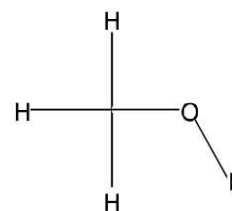


Table 2. Major Compounds Identified in Methanolic Extract by GC-MS
Ethanollic Extract (Sample 02)

We found 25 peaks in the extract and we were able to identify 17 compounds. The main things in this extract were methanol, toluene, pyrogallol, methoxycarbonyl isothiocyanate, dihydroxyacetone and some fatty acid esters.

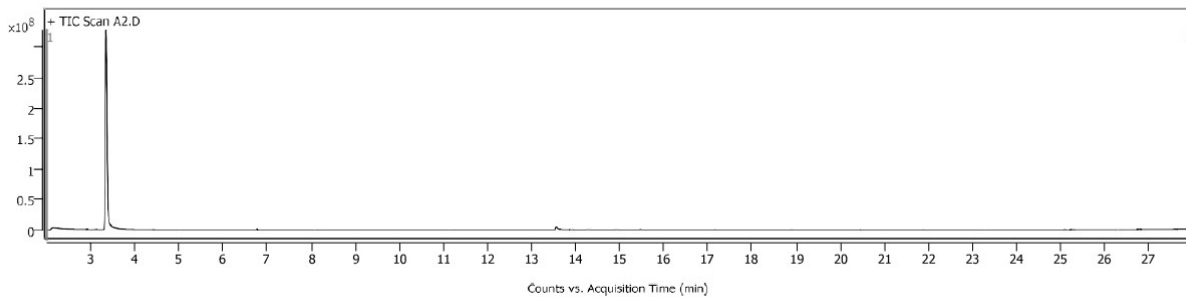
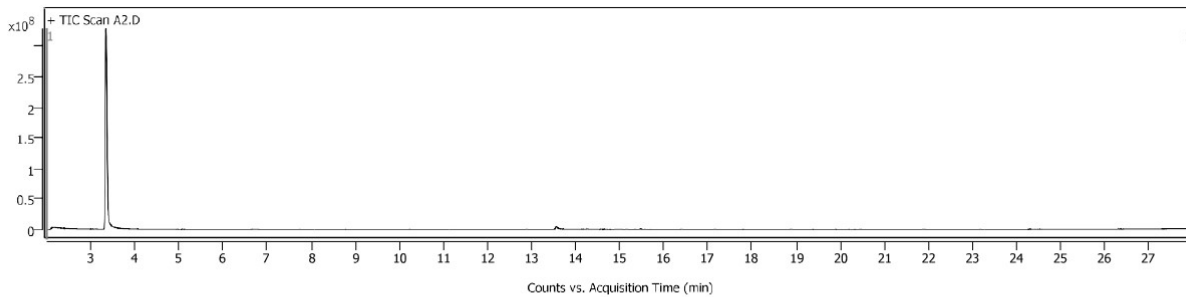
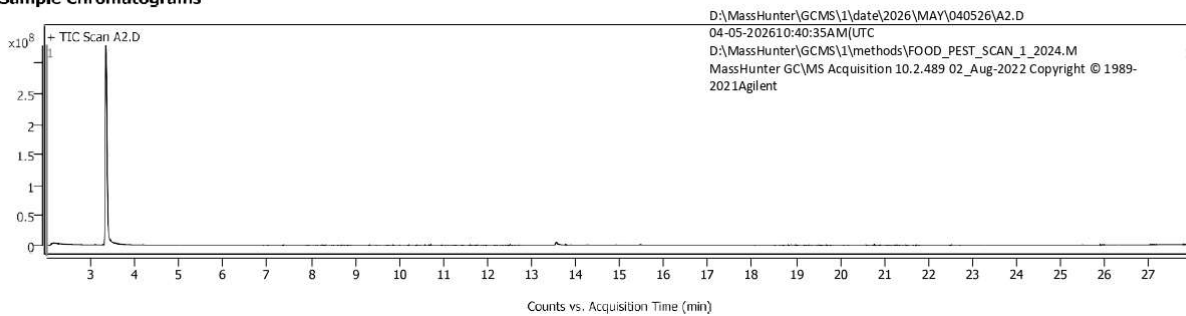
Compound Discovery Report



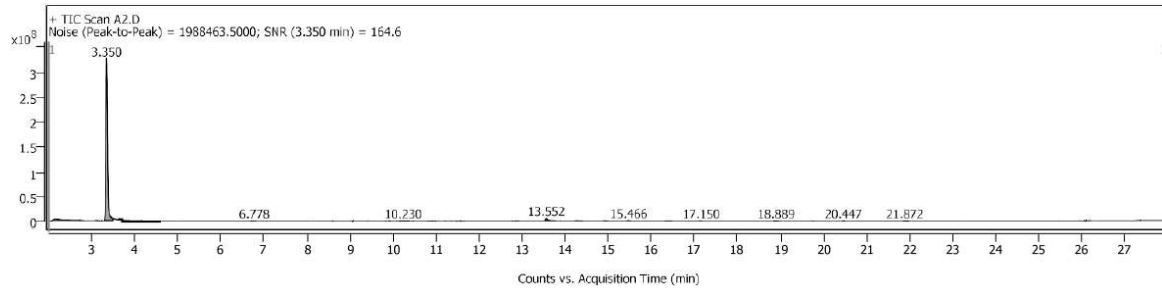
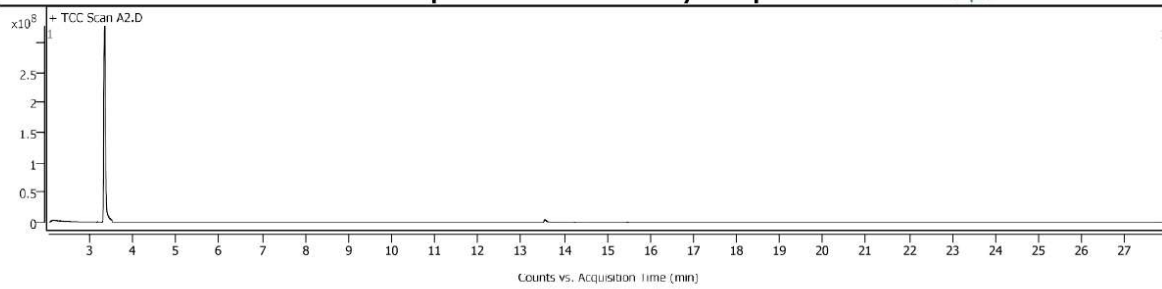
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Inj. Vol(µl)	1	IRM Status	
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Operator		Result Summary	17 identified (25 found)

Sample Chromatograms



Compound Discovery Report



Compound Summary

Cpd	Name	Formula	RT	Mass	CAS	ID Source	Score	Score (Lib)	Score (DB)	Score (MFG)	Algorithm
1	Methyl Alcohol	C H4 O	2.162		67-56-1	LibSearch	79.00	79.00			Chrom Decon
2	(E)-2-Ethylidenetetrahydrothiophene 1-oxide	C6 H10 O S	3.118		79496-69-8	LibSearch	65.00	65.00			Chrom Decon
3	Toluene	C7 H8	3.349		108-88-3	LibSearch	77.91	77.91			Chrom Decon
4	Phosphoric triamide, N,N,N'-tris(hydrazinocarbonyl)-	C3 H12 N9 O4 P	3.374		14795-54-1	LibSearch	45.70	45.70			Chrom Decon
5	Acetic acid, rubidium salt	C2 H3 O2 Rb	3.461		563-67-7	LibSearch	44.30	44.30			Chrom Decon
6	2-Ethylcydohexyl methylphosphonofluoridate	C9 H18 F O2 P	3.583		1000273-28-7	LibSearch	45.87	45.87			Chrom Decon
7	Silacyclopent-3-ene, 3-methyl-	C5 H10 Si	3.839		54077-65-5	LibSearch	45.57	45.57			Chrom Decon
8	Borane, diethyl(decyloxy)-	C14 H31 B O	8.778		1000152-34-3	LibSearch	40.58	40.58			Chrom Decon
9			10.230								Chrom Decon
10	Butylphosphonic acid, di(4-methoxybenzyl) ester	C20 H27 O5 P	10.470		1000315-08-9	LibSearch	47.29	47.29			Chrom Decon
11			11.650								Chrom Decon
12	1,2,3-Benzenetriol	C6 H6 O3	13.554		87-66-1	LibSearch	69.82	69.82			Chrom Decon
13	Methoxycarbonyl isothiocyanate	C3 H3 N O2 S	14.252		35266-49-0	LibSearch	40.54	40.54			Chrom Decon
14	Xylopyranoside, methyl 4-azido-1-deoxy-, .beta.-L-	C6 H11 N3 O1	14.902		20379-31-1	LibSearch	17.97	17.97			Chrom Decon
15	Dodecanoic acid, methyl ester	C13 H26 O2	15.466		111-82-0	LibSearch	60.50	60.50			Chrom Decon
16	Cyclooctasiloxane, hexadecamethyl-	C16 H48 O8 Si8	17.148		556-68-3	LibSearch	55.81	55.81			Chrom Decon
17			17.789								Chrom Decon
18	Cyclononasiloxane, octadecamethyl-	C18 H54 O9 Si9	18.887		556-71-8	LibSearch	54.52	54.52			Chrom Decon
19	Phthalic acid, butyl 3-methylbutyl ester	C17 H24 O4	19.376		1000356-80-4	LibSearch	44.81	44.81			Chrom Decon
20	Propanoic acid, 3-[[bis[(trimethylsilyloxy)phosphoryl], trimethylsilyl] ester	C12 H31 O5 P Si3	21.870		53044-28-3	LibSearch	40.22	40.22			Chrom Decon
21			24.366								Chrom Decon
22			26.731								Chrom Decon
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Compound Details

Cpd. 1: Methyl Alcohol

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Compound Discovery Report

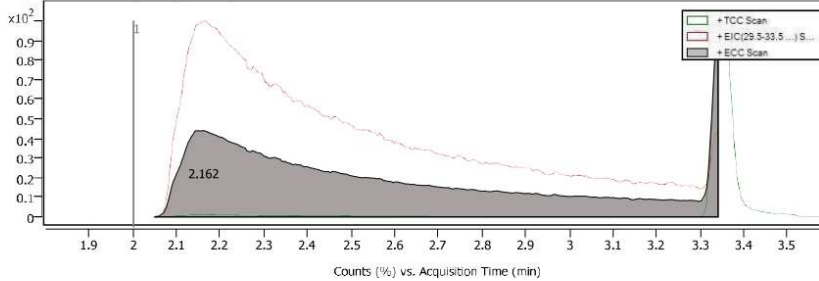


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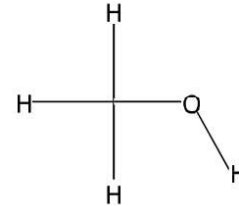
Compound ID Table

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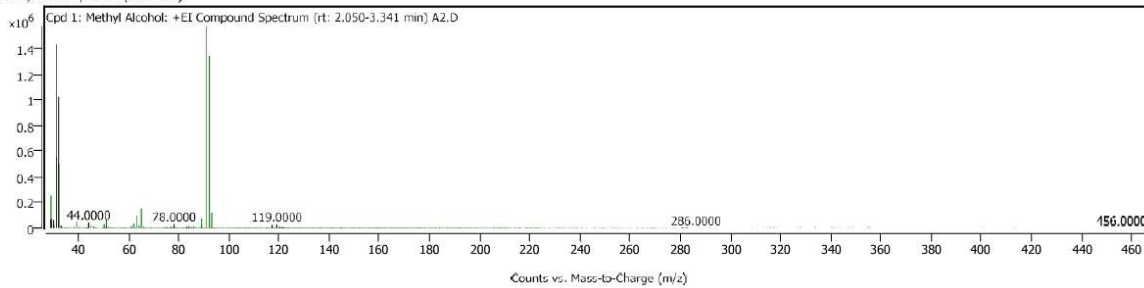
Compound Chromatograms (overlaid)



Structure



Compound Spectra (overlaid)



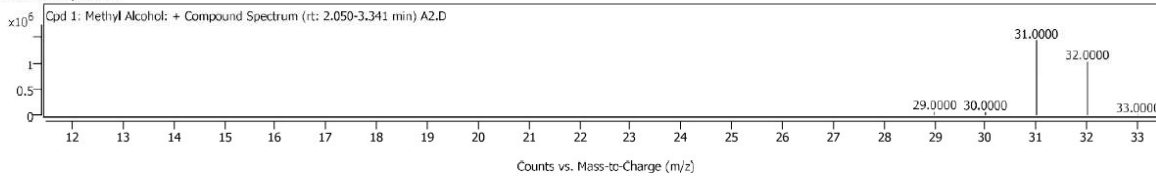
Methyl Alcohol

m/z (prec.)	Species	CE	Score (Lib)	Score (Fwd)	Score (Rev)	Lib/DB
			79.00			NIST20.L

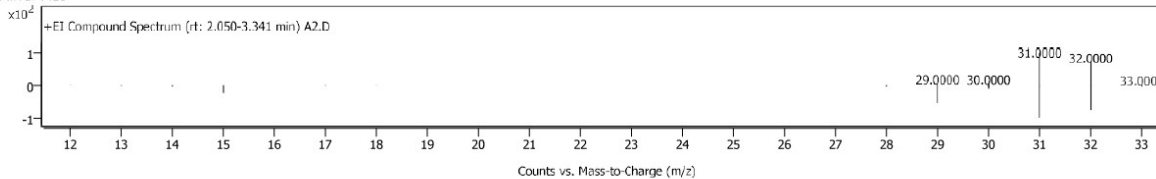
Library Match Details

m/z (prec.)	Species	CE	Score (Lib)	Score (Fwd)	Score (Rev)	Lib/DB
			79.00			NIST20.L

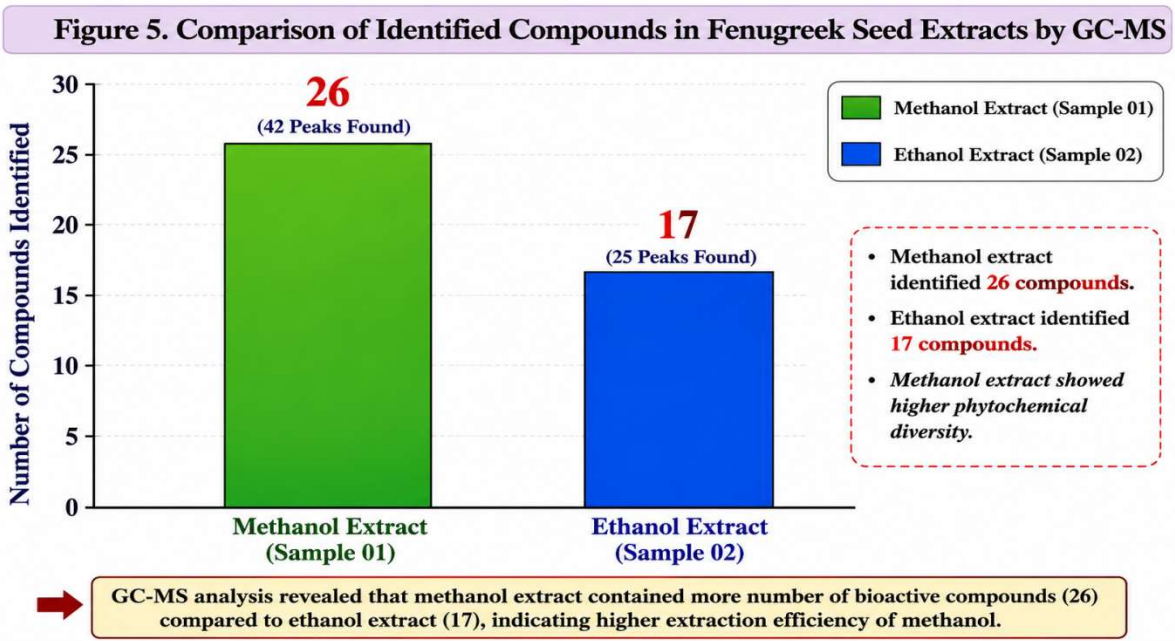
Observed Spectrum



Mirror Plot



Library Spectrum



D. LC-MS/MS Profiling

We used a test to look at the extracts and we found a lot of different metabolites and other compounds in the plants. The test showed that the extracts have a lot of chemicals, which is good because it means that fenugreek seeds could be used to make new medicines. The fenugreek seeds are a choice, for making new medicines because they have so many different compounds that could be useful.[12] The findings of the investigation show that fenugreek seed extracts have a lot of bioactive phytochemicals that can help with inflammation and oxidative stress that people with Chronic Kidney Disease experience. The tests that were done to see what is in fenugreek seeds found that they have compounds that are known to be good at stopping oxidation reducing inflammation helping with diabetes and protecting the kidneys. [13] The extract that was made using methanol had things in it than the one made with ethanol. This means that methanol is better at getting the stuff out of fenugreek seeds.[14] The phytochemicals in fenugreek seeds are really good at helping with things, like oxidation and inflammation. Fenugreek seeds have a lot of phytochemicals that can help with Chronic Kidney Disease. Some parts of the fenugreek plant have been found to have effects on the body. Diosgenin and steroidal saponins can help stop things that cause inflammation, such as tumor necrosis factor-alpha, interleukin-6 and nuclear factor-kappa B. Fenugreek has flavonoids like quercetin and kaempferol which are very good at stopping damage to the kidneys.[15] Trigonelline and 4-hydroxyisoleucine help the body regulate blood sugar and protect the kidneys. Galactomannan also helps with how the body uses fat and may reduce damage to the kidneys. The methanolic extract of fenugreek has a lot of things in it so it was chosen to be used in a special kind of medicine called nanoparticles. Putting fenugreek phytoconstituents into these nanoparticles may help the medicine longer be easier for the body to use and get to the kidneys where it is needed which could make it better, at helping people with kidney disease.

#	Library confidence	Sample name	Component name	Component type	Area	Retention time	Ion ratio	Library Hit
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11	●	Sample01	475.3772 / 0.68	Quantifiers	18968618	0.49	N/A	Sildenafil Smart Confirmation
41	●	Sample01	577.1252 / 6.76	Quantifiers	104322400	6.77	N/A	Tulathromycin Marker Smart Confirmation
59	●	Sample01	501.6620 / 7.44	Quantifiers	52670875	7.44	N/A	Tritoqualine Smart Confirmation
196	●	Sample01	784.2000 / 8.74	Quantifiers	118745308	8.90	N/A	Beauvericin Smart Confirmation
244	●	Sample01	784.6800 / 9.09	Quantifiers	178373951	8.90	N/A	Beauvericin Smart Confirmation
289	●	Sample01	760.6800 / 9.35	Quantifiers	50052559	9.40	N/A	Spinetoram B Smart Confirmation
492	●	Sample01	340.0800 / 11.69	Quantifiers	142808053	11.69	N/A	Papaverine Smart Confirmation
508	●	Sample01	576.1200 / 12.00	Quantifiers	123133959	11.91	N/A	Ergocryptine Smart Confirmation

Table 4. LC-MS/MS Metabolites Identified in Methanolic Extract (Sample 01)

#	Library confidence	Sample name	Component name	Component type	Area	Retention time	Ion ratio	Library Hit
11	●	Sample02	475.3772 / 0.68	Quantifiers	191547071	0.67	N/A	Sildenafil Smart Confirmation
8	●	Sample02	453.4214 / 0.65	Quantifiers	212347594	0.66	N/A	Diphenoxylate Smart Confirmation
22	●	Sample02	425.2672 / 5.48	Quantifiers	79420798	5.49	N/A	Eprosartan Smart Confirmation
27	●	Sample02	358.4400 / 6.21	Quantifiers	128723545	6.21	N/A	Oxybutynin Smart Confirmation
28	●	Sample02	358.5816 / 6.29	Quantifiers	130909947	6.21	N/A	Oxybutynin Smart Confirmation
68	●	Sample02	609.2400 / 7.53	Quantifiers	166673039	7.87	N/A	Reserpine Smart Confirmation
93	●	Sample02	609.3600 / 7.86	Quantifiers	151987139	7.89	N/A	Reserpine Smart Confirmation
204	●	Sample02	770.6400 / 8.81	Quantifiers	75421226	8.81	N/A	Selamectin Smart Confirmation
244	●	Sample02	784.6800 / 9.09	Quantifiers	270378876	9.11	N/A	Beauvericin Smart Confirmation
246	●	Sample02	576.0000 / 9.14	Quantifiers	149990690	8.87	N/A	Ergocryptine Smart Confirmation

Table 5.LC-MS/MS Metabolites Identified in Ethanolic Extract (Sample 02)

Fenugreek phytochemicals such as diosgenin, trigonelline, quercetin, kaempferol, and gallic acid may exert nephroprotective effects through suppression of pro-inflammatory mediators including TNF- α , IL-1 β , IL-6, and NF- κ B while enhancing antioxidant defense mechanisms through activation of Nrf2 signaling pathways. These mechanisms collectively reduce oxidative stress and inflammation associated with CKD progression. [16]

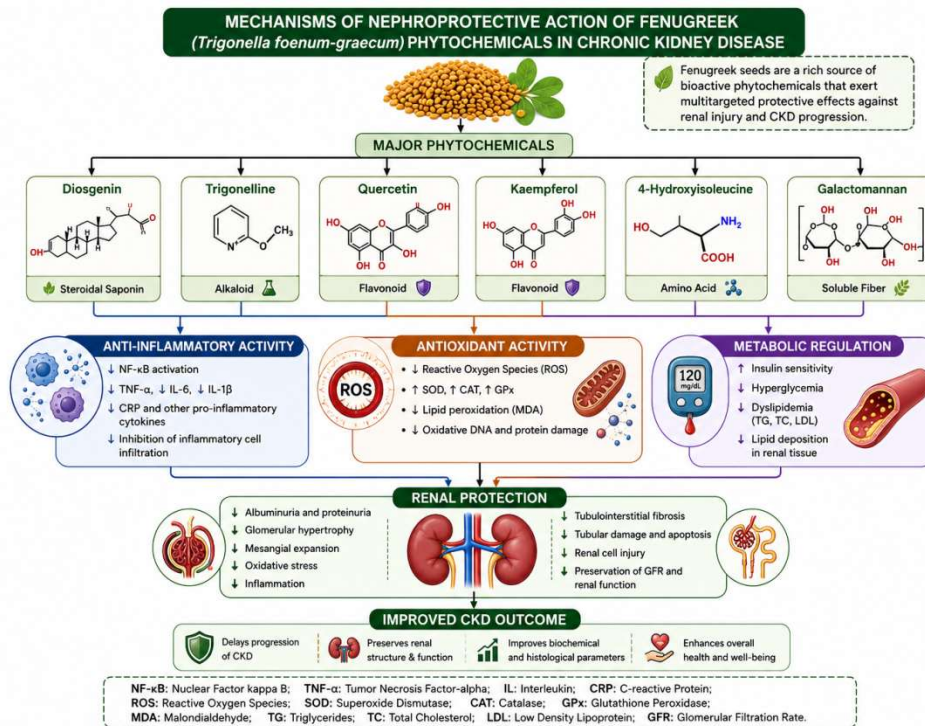


Figure: Proposed Mechanism of Fenugreek Phytochemicals Against Chronic Kidney Disease

IV. CONCLUSION

This study shows that fenugreek seed extracts have good things in them. These things help fight stuff in the body and protect the kidneys. We checked what was in the extracts using a machine. We found 26 things in the methanolic extract and 17 in the ethanolic extract. The methanolic extract has good stuff. The results are news for making new medicines. We think methanolic fenugreek seed extract could be used to make tiny particles. These particles could help deliver medicine to people with kidney disease. The tiny particles could make the medicine work better. We need to do work to make sure these particles are safe and work well. We have to test them before we can use them to help people, with kidney disease. Fenugreek seed extract is a thing to use for this. More studies are needed to see if fenugreek-loaded nanoparticles can help people. These studies will help us understand if it can be used to treat kidney disease.

V. Future Work

Future studies will focus on formulation and optimization of fenugreek extract-loaded nanoparticles, including particle size analysis, zeta potential determination, encapsulation efficiency, controlled drug release studies, cellular anti-inflammatory evaluation, and in-vivo nephroprotective assessment to validate their therapeutic potential against chronic kidney disease.

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