Synthesis & Characterization of Sudan I -A Dye from Organic Waste: Green Approach

Rati Trivedi Nair[1], Anubha Vijay Pandya[2], Dr Shirin Imam[3], Dr Aparna Gandhe[4]

[1]Assistant Professor, Department of Biosciences, Acropolis Institute of management Studies & Research, Indore.
Email: ratitrivedi@acropolis.edu.in
[2]Professor & Head, Department of Chemical Sciences, Christian Eminent College, Indore.
Email: dranubhavpandya@gmail.com
[3]Professor, Department of Chemical Sciences,Christian Eminent College, Indore.
[4]Professor & Head, Department of Chemistry, Govt. Holkar Science College, Indore

Abstract
The valorization organic waste into valuable chemicals, provide raw materials for industries. It can be integrated with renewable energy sources, creating a more sustainable energy system. It helps in reducing greenhouse gas emissions by avoiding the release of methane from decomposing organic waste and generating cleaner energy alternatives. It opens up new markets for bio-based chemicals and fuels, potentially creating jobs in the green economy. Converting organic kitchen waste to chemical compounds represents an innovative and sustainable approach to waste management. Kitchen waste contains proteins, amino acids, lignin fragments, natural dyes, and other nitrogenous bimolecular, during natural biodegradation these nitrogenous biomolecules liberates aromatic amines. These aromatic amines can be extracted from waste using green solvents, mild conditions, and aqueous chemistry & serve as a precursor for its conversion into value-added derivatives such as Sudan I which is also known as Phenyl-azo beta naphthol a yellow dye. This research paper focuses on converting organic kitchen waste into valuable chemical products by chemical methods rather than biological methods.

Keywords: Waste valorization, Sudan dye, Green synthesis, Organic waste recycling, Phenyl-azo beta naphthol synthesis, GC-MS characterization, Sustainable waste recycling

1. Introduction

The rapid increase in urbanization, industrial growth, and population expansion has led to a substantial rise in municipal solid waste generation across the world [1]. Among the various categories of municipal waste, organic wet waste constitutes a major fraction, primarily originating from households, food processing industries, agricultural activities, and commercial establishments. According to recent environmental assessments, biodegradable organic waste accounts for nearly 45–60% of total municipal solid waste generated globally, creating significant environmental management challenges when improperly handled [2]. Traditional waste disposal practices such as open dumping, uncontrolled landfilling, and incineration contribute substantially to environmental degradation. Organic waste deposited in landfills undergoes anaerobic decomposition, resulting in the release of methane gas, a greenhouse gas possessing nearly twenty-eight times greater warming potential than carbon dioxide over long-term atmospheric cycles [3]. In addition, improper waste disposal causes groundwater contamination, foul odor generation, pathogen proliferation, and ecosystem disturbance. In recent decades, the concept of circular economy has emerged as a transformative approach toward sustainable waste management. Circular economy principles and conversion of discarded materials into economically valuable products. Within this framework, waste-to-chemical conversion technologies have attracted considerable scientific interest due to their potential to transform waste streams into renewable chemical feedstocks capable of replacing petroleum-derived industrial chemicals [4].

The increasing accumulation of municipal organic waste has become a significant environmental challenge worldwide, demanding the development of innovative and sustainable waste management strategies. In recent years, waste valorization technologies have emerged as promising approaches for converting organic waste streams into economically valuable chemical products while simultaneously reducing environmental burden [5,6].

Organic wet waste represents a chemically rich substrate containing carbohydrates, proteins, lipids, amino compounds, aromatic precursors, fatty acids, and nitrogen-containing organic compounds. Advanced analytical techniques have demonstrated that such waste streams contain multiple chemically recoverable intermediates capable of serving as precursor molecules for synthetic organic reactions. Recovery of these chemical constituents offers an opportunity to develop environmentally sustainable pathways for the synthesis of commercially valuable chemical compounds [7,8]. Green chemistry principles advocate the design of chemical processes that minimize hazardous reagent use, reduce waste generation, maximize resource efficiency, and promote sustainable manufacturing systems. Integrating waste valorization strategies with green organic synthesis provides a novel pathway for simultaneously addressing environmental pollution and chemical production demands [9]. The present investigation explores an innovative waste-to-value approach involving the utilization of domestic organic wet waste as a precursor source for the synthesis of Phenyl-azo beta naphthol. Chemical screening techniques were employed to identify suitable aromatic precursor compounds present within collected wet waste samples. Subsequently, experimental synthesis routes were designed to convert waste-derived organic constituents into Phenyl-azo beta naphthol under controlled laboratory conditions. The synthesized product was characterized using physicochemical analytical methods including melting point

determination and Gas Chromatography–Mass Spectrometry (GC-MS) to confirm molecular identity and structural integrity. The study demonstrates the feasibility of transforming biodegradable domestic waste into industrially relevant chemical products while establishing a sustainable model for circular chemistry-based waste management systems. This work contributes toward the growing field of waste valorization technologies and presents a promising alternative approach for environmentally sustainable chemical manufacturing in the context of global resource conservation and green industrial development.

2. Materials and Methods

Sample Collection

Domestic organic wet waste samples were collected from multiple household sources in Indore, Madhya Pradesh, India. The collected waste primarily consisted of biodegradable kitchen residues including vegetable peels, fruit waste, food leftovers, tea residues, coffee residues, spoiled food material, eggshell fragments, and other decomposable organic matter commonly generated in domestic environments. The collected waste samples were manually segregated to remove inorganic contaminants such as plastic materials, metallic fragments, glass particles, and non-biodegradable components [10]. The segregated organic waste was subsequently homogenized and stored under controlled laboratory conditions at ambient temperature prior to further chemical processing. Moisture-rich samples were partially air-dried to reduce excess water content and facilitate analytical examination. Proper segregation and preparation of organic waste samples were considered essential for improving extraction efficiency and ensuring reproducibility of subsequent chemical analysis procedures.

Sample Preparation

The first step was to prepare the sample for analysis organic kitchen waste sample was spread out on a clean surface and allowed it to dry under the sun in natural conditions. The dried sample was examined visually to check non organic matter like metal fragments, plastic pieces, glass shards, etc, it was then coarsely grind in laboratory mixer grinder to obtain a homogenous mixture & stored in clean, dry & labeled containers. This sample was further used for analysis by dissolving it in a suitable solvent or diluting a concentrated solution to a manageable concentration. The left over part can be converted into organic manure and utilized for agricultural purposes

Chemical screening of Organic kitchen Waste

Preliminary chemical characterization of collected organic waste samples was performed to identify the presence of chemically valuable organic constituents suitable for synthetic transformation. The heterogeneous waste mixture was subjected to preliminary organic screening procedures using solvent-assisted extraction methods. Organic constituents were isolated using suitable solvent extraction techniques in order to separate aromatic organic compounds from the complex biodegradable waste matrix. The extracted fractions were subsequently analyzed for the presence of nitrogen-containing aromatic compounds and organic functional groups that could potentially serve as precursor molecules for synthetic conversion. Initial screening indicated the presence of aromatic amine-containing organic compounds, suggesting the possible occurrence of aniline-based precursors within the waste-derived organic fraction [11].

Fourier Transform Infrared Spectroscopy (FTIR) Analysis

The extracted organic fraction obtained from wet waste samples was subjected to Fourier Transform Infrared Spectroscopy (FTIR) analysis for functional group identification and molecular screening. FTIR analysis was performed over a spectral range of 4000–400 cm^{-1} using standard laboratory analytical conditions. The objective of FTIR characterization was to identify major functional groups present in the extracted organic fraction and determine the presence of aromatic amine functionalities that could act as precursor compounds for further chemical synthesis [12]. The spectral analysis indicated characteristic absorption peaks corresponding to aromatic functional groups and amine-containing organic compounds. The observed spectral pattern suggested the presence of aniline-like aromatic compounds, thereby establishing the feasibility of utilizing waste-derived organic fractions for aromatic amide synthesis. The preliminary FTIR characterization therefore provided the analytical basis for selecting Phenyl-azo beta naphthol synthesis as the target reaction pathway.

Extraction of Organic Precursors from Kitchen Wet Waste

Organic precursor compounds required for synthetic conversion were isolated from chemically screened wet waste fractions using solvent extraction and purification procedures. The biodegradable waste mixture was initially treated with organic solvent systems under controlled laboratory conditions to dissolve chemically active organic constituents. The liquid extract obtained after solvent treatment was filtered to remove insoluble biomass residues and particulate contaminants.

Subsequent purification procedures including filtration, phase separation, and solvent evaporation were performed to concentrate aromatic organic compounds present within the extract. Based on qualitative chemical screening and FTIR characterization, aromatic amine-containing fractions were selected as precursor materials for downstream synthetic reactions. The recovered aromatic fraction containing aniline-based organic molecules was further utilized for Phenyl-azo beta naphthol synthesis.

3. Experimental Procedure

Extraction of Aniline

Approximately 100 g of dried powdered kitchen waste was transferred into a 1000 mL conical flask. 500 mL of

absolute ethanol (95%) was added as the extraction solvent. The mixture was stirred continuously using a magnetic stirrer at 40–50°C for 4–6 hours. After extraction, the mixture was allowed to stand overnight to maximize diffusion of soluble organic compounds into the solvent. The extract was filtered through Whatman No. 1 filter paper. The residue was re-extracted twice using fresh ethanol to improve extraction efficiency. The combined filtrates were concentrated under reduced pressure using a rotary evaporator at 40°C to obtain a crude ethanol extract. The concentrated ethanol extract was transferred to a separating funnel. The extract was acidified to pH 2 using dilute hydrochloric acid (1 M HCl). Under acidic conditions, amines were converted into their corresponding water-soluble ammonium salts. The aqueous acidic layer was separated from the neutral organic fraction. The acidic aqueous layer was gradually neutralized using 2 M sodium hydroxide until pH 10–11. Basification converted the ammonium salts back into free amines. The liberated free amines were extracted using ethyl acetate. Three successive extractions (3 × 50 mL) were performed to maximize recovery. The combined ethyl acetate extracts were dried over anhydrous sodium sulfate to remove traces of moisture. The solvent was removed under reduced pressure to obtain the purified amine-rich fraction [13].

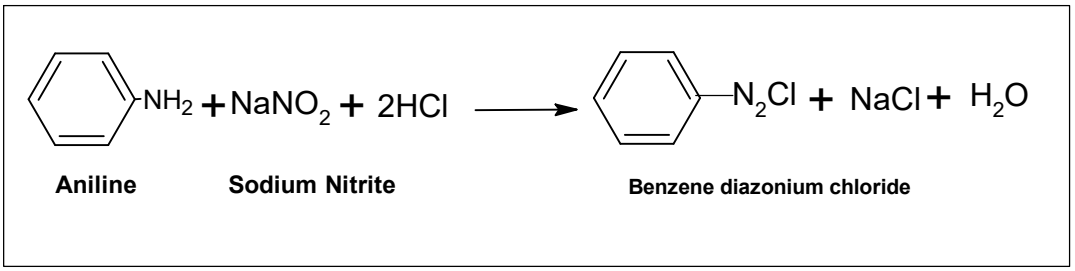
Synthesis of Sudan I

5 ml extracted aniline-rich precursor fraction obtained from OFMSW was dissolved in a mixture of concentrated hydrochloric acid and water in the ratio (16:20) in a 250 ml beaker. The solution was cooled in an ice bath between 0–5°C. To this solution of 4 g sodium nitrite in 15 mL of water was added drop wise with continuous shaking while maintaining the temperature below 5°C.

In another 250 mL beaker 8 gm of beta –naphthol was dissolved in 50 mL10% sodium hydroxide solution & cooled in an ice bath to 0–5°C. Thereafter this solution was added to diazotized solution of aniline dropwise with constant stirring .Stirring was continued for at least half an hour, ensuring that the temperature did not rise above 10°C. A deep red color appeared immediately, and red crystals of 2-naphthol aniline dye rapidly separated out. Allowed the mixture to rest for 30 minutes in a freezing mixture while stirring occasionally & then filtered with the help of Buchner funnel. Dried & recrystallized it with alcohol [14]. The purified crystalline product was subsequently subjected to melting point determination, identified and confirmed using techniques such as FTIR and GC-MS.

Chemical Reaction

Step 1: Diazotization of Aniline



Step 2: Coupling with β –Napthol

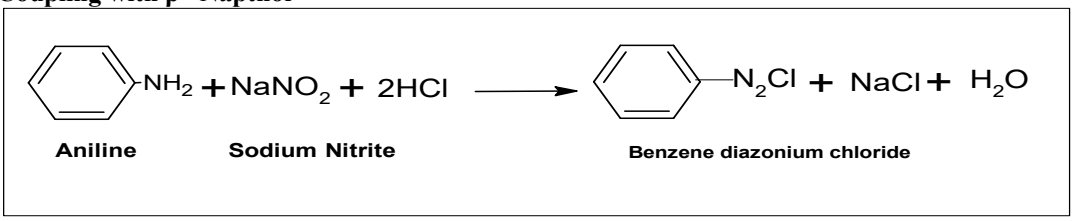


Fig: 1.1 Synthesis of Sudan I

Description of the compound Phenyl azo Beta Naphthol / Sudan I

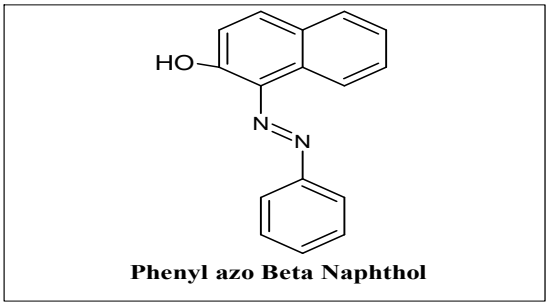


Fig: 1.2 Structure Sudan I

Properties: orange red coloured crystalline solid compound is formed with 85 % yield. It is insoluble in water, highly soluble in alcohol & other organic solvents.

Molecular Formula: C16H12N2O

M.P: 133.5oC, the melting point obtained from analysis was found to be close agreement with the value reported in

the PubChem database.13
1-phenylazo-2-naphthol is used in the chemical industry to color materials such as oils, fats, waxes, plastics, printing inks, shoe and floor polishes, and gasoline.

4. Result and Discussion

Fourier transforms infrared spectrophotometer (FT-IR) & Gas Chromatography –Mass Spectrometry (GCMS) analysis of synthesized chemical compound was done to confirm the synthesis.

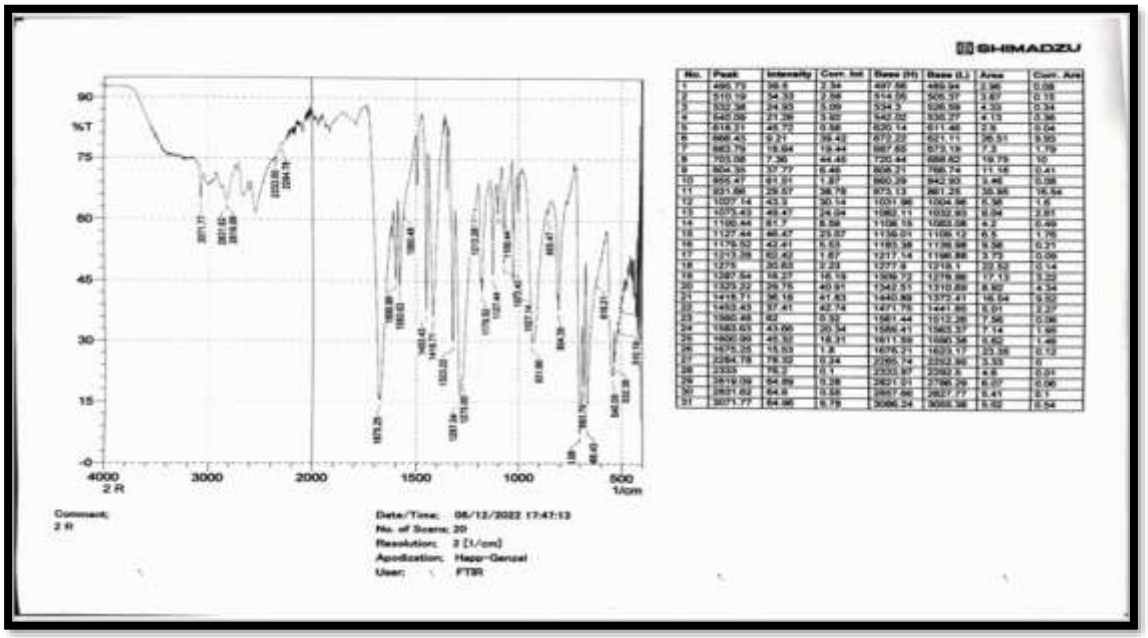


Fig: 3 FTIR of Sudan I with peak intensity table.

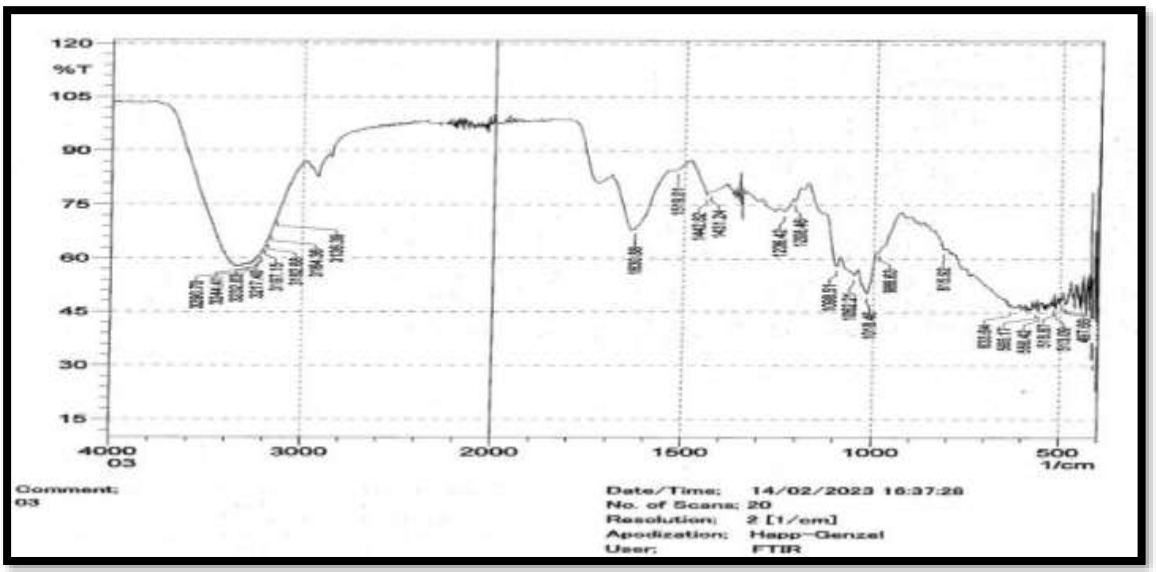


Fig: 4 FTIR of Sudan I (extracted graph)

Table -1 FTIR Peak Intensity Table Sudan I

S.No	Peak	Intensity	Corr. Int	Base (H)	Base (L)	Area	Corr. Are
1	495.73	39.5	2.34	497.66	489.94	2.96	0.08
2	510.19	34.33	2.58	514.05	505.37	3.87	0.15
3	618.21	45.72	0.58	620.14	611.46	2.9	0.04
4	683.79	18.64	19.44	687.65	673.19	7.3	1.79
8	703.08	7.36	44.45	720.44	688.62	19.75	10
10	855.47	61.51	1.87	860.29	842.93	3.46	0.08
11	931.66	29.57	38.79	973.13	861.25	35.95	16.54
12	1027.14	43.3	30.14	1031.96	1004.96	5.36	1.6
13	1073.43	49.47	24.04	1082.11	1032.93	9.04	2.61

15	1127.44	46.47	23.07	1139.01	1109.12	6.5	1.76
16	1179.52	42.41	5.53	1183.38	1139.98	9.56	0.21
17	1213.28	62.42	1.67	1217.14	1196.88	3.73	0.09
18	1275	20.63	2.23	1277.9	1218.1	22.52	0.14
19	1287.54	16.27	16.19	1309.72	1278.86	17.13	3.22
20	1323.22	29.75	40.91	1342.51	1310.69	8.92	4.34
22	1453.43	37.41	42.74	1471.75	1441.85	5.01	2.27
23	1560.48	62	0.32	1561.44	1512.26	7.56	0.06
24	1583.63	43.66	20.34	1589.41	1563.37	7.14	1.95
25	1600.99	45.32	18.31	1611.59	1590.38	5.62	1.46
26	1675.25	15.53	1.8	1676.21	1623.17	23.35	0.12
27	2284.78	78.32	0.24	2285.74	2252.95	3.33	0
28	2333	76.2	0.1	2333.97	2292.5	4.6	0.01
29	2819.09	64.89	0.28	2821.01	2786.29	6.07	0.06
30	2831.62	64.6	0.55	2857.66	2827.77	5.41	0.1
31	3071.77	64.96	6.78	3086.24	3055.38	5.02	0.54

Table 1.2 FTIR Characterization of Sudan I

S. No.	Observed Wavenumber (cm^{-1})	Reference Range (cm^{-1})	Vibration Mode	Functional Group
1	3294–3253	3200–3500	Hydrogen-bonded phenolic hydroxyl (Ar–OH) stretching vibration	O–H Stretch
2	3186–3052	3000–3100	Aromatic benzene and naphthalene ring stretching vibration	Aromatic C–H Stretch
3	1669–1601	1590–1660	Conjugated aromatic ring skeletal stretching vibration	Aromatic C=C Stretch
4	1587–1531	1500–1560	Conjugated azo linkage stretching vibration (overlapping with aromatic C=C)	Azo (–N=N–) Stretch
5	1399–1309	1280–1380	Aromatic C–N stretching associated with azo conjugation	C–N Stretch
6	1255–1069	1000–1260	Phenolic C–O stretching vibration	C–O Stretch
7	1007–967	950–1050	In-plane aromatic C–H deformation vibration	Aromatic C–H Bending
8	831–687	680–900	Out-of-plane bending vibration of substituted aromatic rings	Aromatic C–H Bending
9	604–504	450–650	Aromatic ring deformation and skeletal vibration	Ring Skeletal Vibration

The FTIR spectrum of the OFMSW-An-C4 (Fig. 3 & 4) and its peak intensity & characterization table (Table-1 & 2) exhibited several characteristic absorption bands corresponded tohydrogen-bonded phenolic hydroxyl group.

A huge absorption band dominated between 3294 and 3253 cm^{-1} was assigned to the O–H stretching vibration of a hydrogen-bonded phenolic hydroxyl group. The broad nature of this absorption indicated the intermolecular hydrogen bonding, which was a characteristic feature of phenolic compounds & hence confirmed that the synthesized molecule contains a phenolic hydroxyl functionality attached to an aromatic ring [15].

Weak absorption bands recorded between 3186 and 3052 cm^{-1} attributed to the aromatic C–H stretching vibrations of benzene and naphthalene rings. These absorptions confirmed the presence of sp^2 hybridized carbon atoms and the synthesized molecule possesses an comprehensive aromatic framework [15].

Intense absorption bands recorded between 1669 and 1601 cm^{-1} corresponds to the skeletal stretching vibrations of conjugated aromatic C=C bonds. The position of these absorptions reflects the extensive π-electron delocalization within the aromatic system, which contributed to the stability of the synthesized molecule [16].

The absorption bands observed between 1587 and 1531 cm^{-1} indicated the azo (–N=N–) stretching vibration. In aromatic azo compounds, this vibration usually appeared as a medium to strong absorption & frequently overlaps with aromatic ring stretching vibrations because of extensive conjugation between the azo linkage and adjacent aromatic rings. The existence of this characteristic band provided important evidence for the successful formation of the azo linkage during synthesis [15].

The medium-intensity absorptions recorded between 1399 and 1309 cm^{-1} were attributed to the C–N stretching vibration related with the aromatic azo system. These bands further confirm the presence of nitrogen-containing aromatic functionality in the molecule.

Strong absorption bands appeared between 1255 and 1069 cm^{-1} indicated the phenolic C–O stretching vibration & this supported the presence of a phenolic hydroxyl group bonded to the aromatic ring and represents one of the characteristic spectral features of aromatic phenols.16
The absorption bands recorded between 1007 and 967 cm^{-1} occurred from in-plane aromatic C–H bending vibrations, while the intense bands between 831 and 687 cm^{-1} assigned to out-of-plane aromatic C–H bending vibrations of substituted benzene and naphthalene rings. These fingerprint absorptions indicated the substituted aromatic nature of the synthesized molecule & are consistent with the expected aromatic substitution pattern.
Finally, weak absorptions appearing between 604 and 504 cm^{-1} are assigned to skeletal deformation vibrations of the aromatic ring system, provided additional evidence for the rigid conjugated aromatic framework [16].
Hence, the FTIR spectrum showed characteristic absorption bands corresponded to phenolic hydroxyl (Ar–OH), aromatic C–H, conjugated aromatic C=C, azo (–N=N–), aromatic C–N and phenolic C–O functional groups, presence of these characteristic absorptions showed the successful incorporation of both the phenolic & azo functionalities into the synthesized aromatic system. The obtained spectral characteristics of the synthesized compound Sudan I were in good agreement with the data reported on PubChem for 1-(phenylazo)-2-naphthol [17]. Hence confirming the successful synthesis of the target compound

GCMS Analysis of Phenyl Azo Beta Naphthol

Sample Introduction (GC STEP) Phenyl azo beta naphthol is injected into the GC and vaporized. It is carried through the column by an inert gas like helium. Separation in GC column The compound separates based on its relatively low volatility and higher molecular weight, giving a distinct retention time (often longer than small molecules). Ionization in MS After separation, it enters the mass spectrometer where electron impact ionization causes the molecule to break into charged fragments. Molecular ion peak (M^+) The total ion chromatogram (TIC) of OFMSW-An-C4 exhibited several chromatographic responses distributed throughout the acquisition-time range, indicating the detection of multiple components under the selected chromatographic conditions. A prominent chromatographic response was observed in the later portion of the chromatogram at a retention time (RT) of 17.3 min. (Fig: 5).

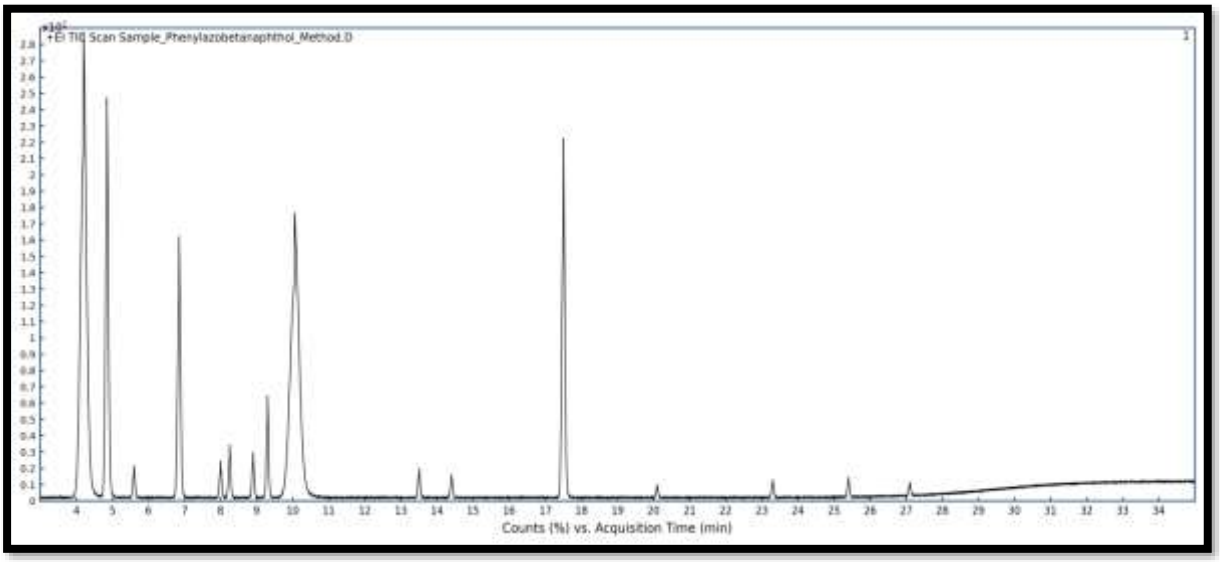


Fig: 5 Total ion chromatogram of Sudan I showing the chromatographic peak at approximately 17.3 min selected for mass-spectral characterization

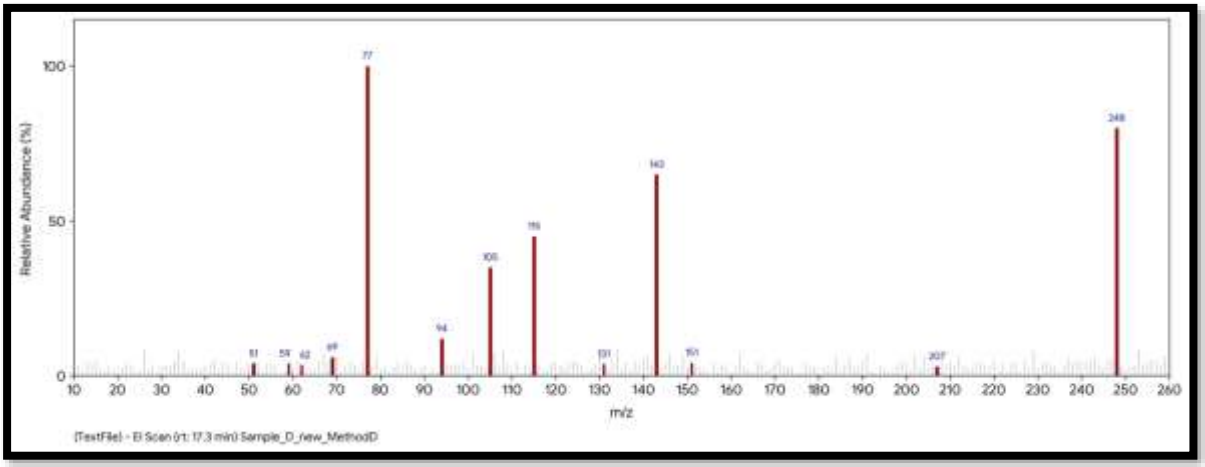
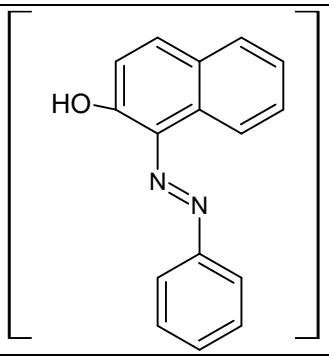
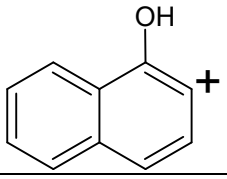
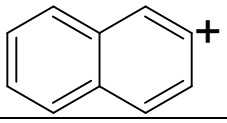
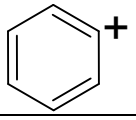


Fig: 6 Mass spectra of Sudan I

Table 3 Major mass-spectral ions and their proposed fragmentation

S.No	m/z	Proposed Fragment Ion	Possible fragment of molecule	Description
1	248	Molecular-ion region $C_{16}H_{12}N_2O^{+}\bullet$		Molecular ion of phenylazo-β-naphthol; corresponds to the molecular mass of the proposed compound
2	143	Major fragment		Fragmentation of the molecular framework retaining a substantial portion of the naphthol-derived structure
3	115	Major fragment		Further fragmentation of the naphthalene-derived portion of the molecular ion
4	77	Base peak		Stable phenyl-type aromatic ion formed following fragmentation of the phenyl-containing portion
5	105	Secondary fragment	Aromatic/azo-derived fragment	Secondary cleavage and rearrangement of the molecular framework
6	94	Minor fragment	Secondary aromatic fragment	Further fragmentation of the aromatic molecular system
7	50–70 region	Minor ions	Low-mass aromatic fragments	Secondary fragmentation of phenyl- and naphthalene-containing structures
8	Other low-intensity ions	Minor	Rearrangement/secondary products	Further EI-induced fragmentation of the azo-aromatic molecular framework

The EI–mass spectrum of (Fig. 6) & its proposed fragmentation pattern (Table-3) exhibited a prominent molecular ion at m/z 248. This value is attributed to the molecular mass of phenylazo-β-naphthol. The base peak at m/z 77 showed a highly stabilized phenyl-type aromatic fragment. The prominence of this ion was consistent with fragmentation of the phenylazo portion of the molecule and subsequent stabilization of the resulting aromatic ion.

A prominent fragment observed at m/z 143 is associated with fragmentation of the naphthol-containing portion of the molecule & represents an important secondary structural fragment. The ion at m/z 115 was another significant fragment and was attributed to further fragmentation of the naphthalene-derived fraction of the molecular framework [18].

The spectrum also displayed an ion at m/z 105, together with a lower-intensity ion around m/z 94. These signals were considered secondary fragments resulting from further cleavage and rearrangement of the aromatic azo/naphthol molecular framework.

Several extra low-intensity ions were also present throughout the spectrum. These were considered minor secondary fragmentation & rearrangement products arisied from further breakdown of the aromatic and azo-containing molecular framework and are of lower diagnostic significance than the molecular ion and major fragments.

The molecular ion at m/z 248, together with the prominent ions at m/z 143, 115 and 77, gives a characteristic fragmentation pattern for the analysed compound.

Comparison of the reported mass spectrum with the NIST Mass Spectral Library (NIST17), the result was consistence with 1-benzeneazo-2-naphthol (C16H12N2O) [19].

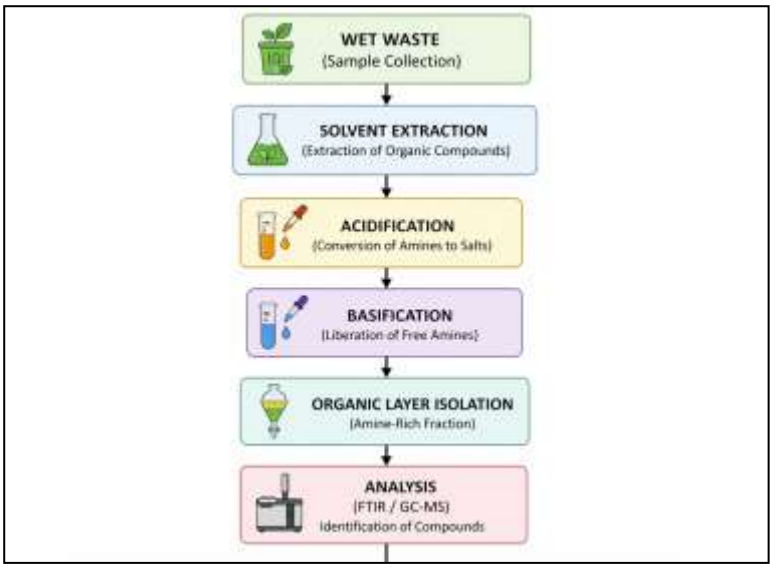


Fig: 7 Flow chart of synthesis

Table 4 Comparison between Conventional and Waste-Derived Chemical Synthesis

Parameter	Conventional Method	Present Study
Raw Material Source	Petroleum-derived chemicals	Domestic organic waste
Environmental Burden	High	Significantly lower
Waste Generation	Moderate	Minimal
Sustainability	Limited	High
Resource Recovery	Absent	Present
Circular Economy Integration	No	Yes

The results indicate significant environmental advantages associated with waste-derived synthesis systems, including lower environmental burden, improved resource recovery, and better alignment with circular economy principles.

Table 5 Material Balance and Product Yield Analysis

Experimental parameter	Quantity / Value
Initial kitchen (dried powder) waste sample	100 grams
Extracted ammonium salt fraction	10 g (Approx)
Extracted amine fraction	6 grams
Extraction solvent	Ethanol
Final Phenyl-azo beta naphthol obtained	5 grams
Product recovery efficiency	40% (based on precursor conversion)

The material balance demonstrates efficient conversion of recovered precursor fractions into Sudan I. The 40% recovery efficiency supports the feasibility of waste-to-chemical conversion for sustainable chemical manufacturing.

Scientific Significance of Waste-to-Chemical Conversion

The successful synthesis of Sudan I from biodegradable domestic waste demonstrates a promising advancement in the emerging field of waste-to-chemical conversion technologies. Traditional waste management systems primarily focus on disposal, composting, or energy generation through anaerobic digestion. However, the conversion of waste into high-value chemical intermediates represents a substantially more advanced approach that combines waste reduction with chemical manufacturing. The present study establishes proof-of-concept evidence that domestic organic waste streams contain chemically recoverable molecular precursors capable of serving as raw materials for synthetic organic chemistry. This approach offers substantial scientific significance by reducing dependency on fossil-based chemical feedstocks while simultaneously promoting circular economy objectives. The results therefore demonstrate that waste materials traditionally regarded as environmental burdens can be transformed into economically valuable industrial chemical resources through appropriately designed green chemistry pathways.

Environmental Sustainability Assessment The rapid accumulation of biodegradable municipal waste has become a major environmental concern worldwide, particularly in developing countries where waste segregation and treatment infrastructure remain inadequate. Conventional waste disposal methods such as open dumping, uncontrolled landfilling, and incineration contribute significantly to greenhouse gas emissions, soil contamination, groundwater pollution, and ecosystem degradation. The present study demonstrates an alternative waste management strategy based on chemical valorization of domestic organic waste, transforming biodegradable waste into value-added chemical products rather than treating waste solely as disposable material. One of the major environmental benefits of this approach lies in the reduction of landfill dependency. Organic waste deposited in landfill systems undergoes anaerobic microbial degradation, producing methane gas, which possesses significantly higher global warming potential

compared to carbon dioxide. Redirecting biodegradable waste toward chemical synthesis reduces methane generation and contributes toward climate change mitigation strategies [20-24]. A second major sustainability advantage involves resource recovery efficiency. Organic waste streams contain chemically valuable carbon-based molecules that are often discarded despite possessing significant industrial utility. Recovering these compounds reduces dependence upon petroleum-derived chemical feed stocks traditionally used in industrial organic synthesis. The present waste-to-chemical conversion pathway aligns strongly with circular economy principles, where waste materials are continuously reintroduced into productive industrial cycles rather than being permanently discarded into the environment [25]. In addition, sustainable chemical production pathways such as the present system may contribute toward lowering industrial carbon footprints by reducing extraction and manufacturing requirements associated with conventional petrochemical production systems. The study therefore demonstrates that biodegradable household waste should not merely be considered environmental refuse, but rather a chemically valuable renewable resource capable of supporting sustainable industrial development.

Industrial and Scientific Applications

The synthesized compound Phenyl-azo beta naphthol (Sudan dye) possesses significant industrial relevance and is widely utilized in multiple chemical sectors. Potential applications include: Pharmaceutical Industry

Phenyl-azo beta naphthol derivatives serve as important intermediates in medicinal chemistry and pharmaceutical synthesis pathways used during preparation of biologically active molecules. Polymer and Material Science

Aromatic amides similar to Phenyl-azo beta naphthol contribute to polymer precursor development and advanced material synthesis due to their thermal stability and aromatic structural framework.

Dye and Pigment Industry

Phenyl-azo beta naphthol-based aromatic compounds are frequently employed during synthesis of industrial dyes, pigments, and specialty colorants.

Organic Synthesis Research

The compound serves as a useful model substrate for reaction mechanism studies, aromatic substitution reactions, amide chemistry investigations, and catalytic organic synthesis. Sustainable Chemical Manufacturing

The present study demonstrates potential future industrial pathways where waste-derived precursor compounds may partially replace conventional fossil-based chemical feedstocks.

These industrial applications substantially increase the significance of waste-derived Phenyl-azo beta naphthol synthesis beyond laboratory-scale experimentation.

Future Scope of Investigation

Although the present investigation successfully establishes proof-of-concept evidence for waste-derived Phenyl-azo beta naphthol synthesis, several areas remain open for future scientific development. Future studies may focus on: Optimization of precursor extraction efficiency from heterogeneous organic waste mixtures. Quantitative determination of precursor concentration using advanced chromatographic techniques. Scale-up studies for pilot-scale waste-to-chemical production systems. Investigation of alternative aromatic compounds recoverable from biodegradable waste streams. Development of catalytic reaction systems for improving synthesis efficiency. Comparative life-cycle assessment between waste-derived and petroleum-derived chemical manufacturing systems. Economic feasibility analysis for industrial commercialization of waste-to-chemical conversion technology. Integration of artificial intelligence-assisted chemical screening for rapid identification of valuable precursor compounds within waste streams. Further research in these areas may significantly expand the practical applicability of circular chemistry-based waste valorization systems.

5. Conclusion

The present investigation successfully demonstrates the feasibility of utilizing domestic organic wet waste as a precursor source for the synthesis of Phenyl-azo beta naphthol (Sudan dye) through environmentally sustainable waste valorization pathways. Chemical screening and preliminary analytical characterization indicated the presence of aromatic precursor compounds within biodegradable household waste streams. From an environmental perspective, the study establishes an innovative proof-of-concept model for transforming biodegradable waste into industrially valuable chemical products while reducing landfill dependency, lowering greenhouse gas emissions, promoting resource recovery, and advancing circular economy objectives. The research demonstrates that domestic organic waste represents not only a waste management challenge but also a chemically valuable renewable resource capable of supporting sustainable chemical manufacturing systems. The present work contributes toward the growing scientific field of waste-to-chemical conversion technologies and provides a foundation for future industrial development of circular chemistry-based waste management solutions.

Conflict of Interest

The authors declare that there is no conflict of interest regarding publication of this research work.

Author Contributions

Rati Trivedi Nair: Experimental investigation, laboratory synthesis, data collection, manuscript preparation.

Anubha Vijay Pandya: Conceptualization, methodology development, supervision, manuscript review and final

editing.

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