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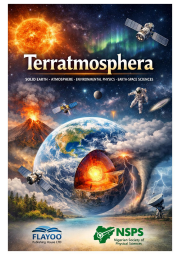

Synthesis, optimization, and evaluation of polyurethane from underutilized vegetable oils

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ABSTRACT

Biodegradable polyurethane can be produced from sustainable feedstocks such as waste sunflower cooking oil, which is often used for biodiesel production. This work describes the synthesis, characterization, and optimization of sustainable, mixed petroleum-sunflower polyol alongside their optimization. Polyol production was studied at a fixed sodium hydroxide catalyst concentration (1.0% w/w), reaction times of 40, 60, and 80 min, and oil-to-glycerol molar ratios of 3:1 and 4:1. Fourier transform infrared (FTIR) spectroscopy was used for polyol characterization. Polyurethane synthesis used a fixed amount of toluene diisocyanate (TDI), variable mixed-polyol ratios, and stannous octoate catalyst (2.0% w/w). The polyurethanes were evaluated for physical properties, mechanical and structural performance, chemical resistance, and stress–strain behavior. The highest polyol yield was 60.1% at an oil-to-glycerol molar ratio of 4:1, a reaction time of 80 min, a fixed sodium hydroxide catalyst concentration of 1.0% w/w, and 250 °C. SuPU-30:20 showed the best overall balance, with a tensile strength of 14 kPa, elevation of 52 mm, porosity of 16, weight of 14.9 g, 40% compression of 36.5, and good resistance to chemical attack. These results suggest that waste sunflower cooking oil is a promising sustainable feedstock for polyurethane, with SuPU-30:20 approaching the performance range of commercial flexible foams in tensile strength and density, although porosity and elevation remain below typical values.

1. INTRODUCTION

Polyurethane (PU) is a linear polymer in which the linkages are either urethane or carbonate ester. Its chemical structures enable it to exhibit both thermosetting and elastomeric properties, and it can occur in various forms. Foams [1, 2] are among the most widely used thermosetting polyurethanes for cushioning and thermal insulation.

In addition, thermoplastic polyurethanes are used in adhesives, paints, sealants, shoe soles, protective gear, textile fibers, and automobile parts. Polyurethane is considered the sixth most widely used polymer in the world, with its 2016 value estimated at 53 billion euros per annum [3]. The European Association of Plastics Manufacturers reported that 27 million metric tons of polyurethanes were manufactured in 2015, representing 8% of the total production of 323 million metric tons [4]. Toluene diisocyanate (TDI) and conventional polyols, usually obtained

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from petrochemical sources, react to form polyurethanes. However, polymer production from petrochemicals is not sustainable because of fluctuating prices, environmental considerations, and uncertainty regarding existing oil reserves [5–7]. Therefore, novel extraction procedures have recently been developed for vegetable oils [6]. These polymers are biodegradable and also promote the production of polyurethanes from renewable sources.

Vegetable oils contain a large proportion of triglycerides (93–98% by weight), which are triesters of glycerol and fatty acids, as well as diglycerides, monoglycerides, and phospholipids (both unsaturated and saturated) [8]. The three fatty acids are esterified to form triglycerides, which are lipids derived from fatty acids. These are normally fatty acids containing 12–22 carbon atoms. Double bonds determine whether the carbons at positions 9, 12, and 15 are saturated or unsaturated. Reactivity is enhanced by the fact that triglycerides constitute approximately 95% of the total weight [9]. In addition, fatty acids may contain several functional groups, including ester, hydroxyl, epoxy, and double-bond functionalities, which increase their reactivity [5]. Various studies have examined the use of vegetable oils as alternatives to petroleum-derived raw materials. Castor oil is particularly preferred because its fatty acid composition contains hydroxyl groups. However, some vegetable oils do not contain hydroxyl groups and are therefore less desirable until their fatty-acid chains are modified to introduce hydroxyl groups (polyols). Echeverri *et al.* [10] described a laboratory process involving soybean oil and catalysts such as sodium hydroxide or sodium methoxide to obtain a 3:1 glycerol-to-oil molar ratio, resulting in 48.6% monoglycerides [11].

The use of vegetable oils as raw materials for petroleum alternatives also has disadvantages, including the relatively high cost of virgin vegetable oils and the possibility of diverting land from food cultivation or forest reserves. One alternative is to reuse cooking oils, which are estimated to generate approximately 27 million tons of waste oils globally each year and can be purchased at two to three times less than the cost of virgin vegetable oils. Recycled oil can nevertheless provide an accessible and relatively inexpensive feedstock for producing petroleum alternatives.

Recent studies have produced flexible polyurethane foams with high bio-based content and systematically investigated crosslink density and mechanical properties using polyols derived from waste cooking oils [8–11]. The present work further evaluates their fundamental characteristics in terms of stress–strain behavior and chemical resistance. It aims to contribute to the development of environmentally friendly processes for producing polyurethanes from vegetable oils.

2. MATERIALS AND METHODS

The following standard reagents were used: hexane, chloroform, ethanol, potassium hydroxide, sulfuric acid, sodium hydroxide, sodium methoxide, potassium iodide, activated charcoal, sodium sulfite, sodium chloride, glacial acetic acid, ethyl alcohol, acetone, dichloromethane, diethyl ether, sodium thiosulfate, acetic anhydride, toluene diisocyanate (TDI), phenolphthalein, potassium hydrogen phthalate, filter paper (12.5 mm), and petroleum ether. These materials were provided by LGC Standards (UK) and Sigma-Aldrich (UK). Hydrochloric acid (HCl), methanol (MeOH), and ammonium hydroxide (NH_4OH), all of analytical grade, were purchased from Cerrilliant (USA). Sunflower frying oil was donated by a restaurant in Ilorin, Kwara State. The activated carbon, sulfuric acid, orthophosphoric acid and hydrogen peroxide (30%) were supplied by Merck (India). Phenol and aqueous formaldehyde (37%) were supplied by Hexion Specialty Chemicals.

The apparatus used included a magnetic hotplate/stirrer, burette, retort stand, digital moisture meter, funnel, box-type resistance furnace, pycnometer (ASTM D941) for density measurement, three-neck round-bottom flask, measuring cylinder, thermometer, pipette, reflux condenser, beaker, and NDJ viscometers for viscosity measurement. Waste sunflower oil (WSFO) was collected from deep-fat fryers in Ilorin Township. Commercial styrene-acrylonitrile (SAN)-based synthetic polyol was supplied by Nigeria Unifoam Limited.

2.1. WSFO PURIFICATION

Several procedures were used to clean the waste oil and remove impurities introduced by thermal degradation during frying. Solid impurities were filtered out, and 50 g of WSFO was diluted with 25 mL of CH_2Cl_2 to reduce viscosity. The washing solution was saturated NaCl at 60 °C. The mixture was allowed to separate into phases, and the organic phase was collected after each of four separations. The crude oil was dried over $MgSO_4$, the drying agent was filtered off, and the solvent was removed using a rotary evaporator. This procedure yielded an opaque dark oil [11].

Activated carbon (5 g) was added to a beaker containing 10 mL of concentrated HNO_3 (70%) at 60 °C and stirred for 1 h. The mixture was filtered, and the solids were washed with water until the filtrate reached pH 7. The resulting black solid was heated in an oven at 110 °C for 1 h. A mixture of 50 mL of WSFO and 3 g of chemically modified activated carbon was stirred in a flask at 50 °C for 1 day. The oil was then filtered to remove the activated carbon, yielding a brownish oil [12].

2.2. OIL CHARACTERIZATION

Waste sunflower oil was supplied by a restaurant. Three samples of the oil were filtered using a vacuum-pump system and filter paper (pore size 5–8 μm, qualitative filter grade 292, BOECO) and stored at room temperature. The following international standards were used for oil characterization: ISO 3961:2018 for iodine value [13], using potassium iodide, Wijs reagent, chloroform, and sodium thiosulfate (Panreac), using potassium hydroxide (Merck), diethyl ether, and 95% pure ethanol; ASTM D4274 (phthalic anhydride method) for hydroxyl number; and ISO 3657:2013 for the saponification value of the hydrolysates [16], using hydrochloric acid and potassium hydroxide (Merck). All reactants were of analytical grade.

2.3. SYNTHESIS OF POLYOL

Polyol synthesis was carried out at 250 °C. Experiments were conducted in a 250-mL glass reactor fitted with three necks: one for the condenser, one for reagent addition, and one for temperature measurement. A standard experimental design was used with two oil-to-glycerol molar ratios (4:1 and 3:1), three reaction

Table 1. Waste sunflower oil (WSFO) characterization using crude castor oil (CCAO) and standards.

Test	WSFO	CCAO*	ASTM standard
Acid value (mg KOH/g)	0.561 ± 0.12	1.3 ± 0.14	≤ 0.6 (ASTM D664-24)
Density (g/mL)	0.918 ± 0.13	0.943 ± 0.032	0.91–0.93 (ASTM D4052-22)
Iodine value (g I_2/100 g)	133.56 ± 0.035	87.56 ± 7.62	120–141 (ASTM D5554-15)
Saponification value (mg KOH/g)	196.39 ± 1.38	179.37 ± 39.99	189–195 (ASTM D5558-95)

*Moreno *et al.* [17]; literature values for castor oil are included only for comparison.

times (40, 60, and 80 min), and a fixed sodium hydroxide catalyst concentration of 1% w/w. In both tests, 70 g of oil was added, and the calculated amount of glycerol was introduced into the reactor [17]. The catalyst was weighed and dissolved in ethanol. The catalyst solution was added to the reactor, which was then heated to 250 °C using a heating mantle. After the reaction, 98% sulfuric acid was used to neutralize the catalyst. The reactor contents were transferred to a separatory funnel, allowed to settle for 1 day, and separated by gravity. The products were subsequently characterized as polyols. Fourier transform infrared (FTIR) spectroscopy (Bruker), over the range 3500–500 cm^{-1}, was used to identify product structures. The estimated average OH functionality of the mixed polyols was reported.

2.4. CHARACTERIZATION OF POLYOL

Biopolyols were characterized using the phthalic anhydride method (ASTM D4274) for polyether and polyester polyols to determine hydroxyl numbers. This method esterifies hydroxyl groups with phthalic anhydride in pyridine and then uses titration with standard NaOH/KOH. Infrared measurements followed a modified established method reported in the literature [18].

2.5. SYNTHESIS OF POLYURETHANE

For polyurethane synthesis, 50 mL of petroleum- and sunflower-based polyol mixtures at ratios of 50:0, 40:10, 30:20, and 20:30 were placed separately in reaction vessels. Each mixed polyol was slowly added to 20 g of TDI. Polymerization began when stannous octoate catalyst (2.0% w/w) was added to accelerate urethane formation. Ethylenediamine (2 mL) was added to promote chain extension, after which the liquid heated and became more viscous. TDI was mixed with a chemical blowing agent (1.0% w/w) and reacted to release carbon dioxide, which caused expansion of the mixture. Silicone (2 mL) was added to produce a consistent foam structure, and the isocyanate index, NCO/OH ratio (13.5), was determined.

2.6. CHARACTERIZATION OF POLYURETHANES

The chemical resistance of the synthesized polyurethanes was evaluated in accordance with ASTM D543-21 [19]. Samples with a surface area of 100 mm^2 were placed in 10 mL of analytical-grade reagents (toluene, HCl, and chloroform) at room temperature for 7 days. The final weight of each sample was then measured. The mass difference was used to determine the effect of each solvent on the polymer surface [20].

3. RESULTS AND DISCUSSION

3.1. PHYSICAL CHARACTERISTICS OF WASTE SUNFLOWER OIL

The physicochemical properties were measured and compared with ASTM standards, as shown in Table 1. After refinement, 44.7 ± 0.18 g of refined sunflower oil (RSFO) was obtained, corresponding to an average yield of 89.4% from four purification replicates. The acid value of WSFO was 0.5611 mg KOH/g, close to the permissible limit of less than 0.6 mg KOH/g according to ASTM. The density of WSFO was 0.918 g/mL, within the ASTM range of 0.91–0.93 g/mL. The iodine value of WSFO was higher (133.56 g I_2/100 g), indicating greater unsaturation. This is advantageous because it provides additional functional groups for chemical modification during polyol preparation. The saponification value, 196.39 mg KOH/g, was close to the ASTM range of 189–195 mg KOH/g. Saponification numbers also provide an approximation of the average molecular weight of triglycerides in oils. Differences in fatty-acid chain length can affect polyol viscosity and reactivity and, consequently, polyurethane properties. Overall, the oil conformed to most ASTM specifications, while the higher unsaturation index and lower acid value of WSFO may favor polyol synthesis. The acid value of oils indicates the free-fatty-acid (FFA) content [21]. In this regard, the marginally lower value for WSFO indicates higher quality and suggests that further processing is appropriate.

3.2. SUNFLOWER OIL USED TO PRODUCE SUN-BASED POLYOL

Table 2 compares the polyol yield from waste sunflower oil with that from castor oil. The results show that production of sunflower-oil-based polyols using NaOH at different molar ratios (3:1 and 4:1) and reaction times was possible. The yield patterns also indicate that both oils are suitable feedstocks for bio-based polyol production, although differences in fatty-acid composition significantly affect reactivity, product yield, and the physical characteristics of the resulting bio-based polyols (Figure 1). However, in all reaction times and molar ratios, the yields for the sun-based polyols were lower than the castor-based values, except at the molar ratio 3:1; at the 40-min sunflower value, it is slightly higher. This finding was attributed to the higher degree of unsaturation and the resulting polyol synthesis. Oils containing high levels of unsaturated fatty acids lead to polyols with higher hydroxyl values and better reactivity [22]. In contrast, WSFO showed slightly lower hydroxyl incorporation and yields because of its lower content of polyunsaturated fatty acids and slower reaction rate.

Table 2. Comparison of polyol yield (%) from waste sunflower oil and castor oil at oil:glycerol molar ratios of 3:1 and 4:1.

Time (min)	Waste sunflower oil		Castor-based polyol*	
	3:1	4:1	3:1	4:1
40	48.2 ± 0.5	53.0 ± 0.3	47.34 ± 1.54	82.12 ± 5.02
60	50.6 ± 0.4	55.0 ± 0.2	79.14 ± 6.17	98.23 ± 1.04
80	53.2 ± 0.3	60.1 ± 0.3	90.55 ± 1.20	87.17 ± 4.06

*Moreno *et al.* [17]; literature values for castor-based polyol are included only for comparison.

Figure 1. Sunflower polyol sample.

3.3. POLYOL MADE FROM SUNFLOWER OIL

The amount of polyol produced was determined in g/mL of oil and expressed as a percentage. The polyol production data are presented in Table 2; the variables included reaction time, oil-to-glycerol ratio (3:1 and 4:1), and percentage yield. The refined oil gave improved polyol results, which are encouraging for the development of an industrial process. The sunflower polyol sample is shown in Figure 1. In general, sunflower-polyol yield increased with reaction time. Yields were comparatively lower at shorter reaction times (40 min), suggesting that the triglycerides were not fully converted to polyols. A longer reaction time (80 min) allowed greater interaction between the oils and NaOH catalyst, leading to higher yields. The 4:1 molar ratio produced higher yields, reaching $60.1 \pm 0.3\%$, at all reaction times compared with the 3:1 molar ratio. This indicates that a higher oil-glycerol molar ratio results in greater transesterification efficiency and polyol production. This may be due to the somewhat higher saponification value and lower fatty-acid unsaturation, which favored more rapid conversion. Sunflower oil is highly unsaturated but may require "ideal conditions" for complete conversion. The results indicate that both catalyst ratio and reaction time are important for efficient polyol synthesis; under the conditions studied, the sunflower-based polyol gave the highest yield of 60.1%.

Table 3. Hydroxyl number and acid value of petroleum-polyol:sunflower-polyol blends determined using the phthalic anhydride method (ASTM D4274).

PetP:SuP ratio (%)	Hydroxyl number (mg KOH/g)	Acid value (mg KOH/g)
50:00	257.2 ± 0.5	0.10 ± 0.02
40:10	254.6 ± 0.4	0.17 ± 0.01
30:20	248.9 ± 0.3	0.73 ± 0.02
20:30	234.5 ± 0.3	0.83 ± 0.04

3.4. CHARACTERIZATION OF POLYOL USING THE PHTHALIC ANHYDRIDE METHOD (ASTM D4274)

Table 3 presents hydroxyl numbers determined by the phthalic anhydride method (ASTM D4274). Hydroxyl values vary among polyol types, and polyols with particular hydroxyl values are selected in polymer formulations to obtain the required properties. Accordingly, the hydroxyl levels of different polyols guide the preparation and refinement of different polyurethane products. The hydroxyl value is particularly important in polyurethane synthesis because it is used to assess polyol reactivity in processes such as polyurethane-foam production. A hydroxyl number of 248.9 ± 0.3 mg KOH/g for PetP:SuP-30:20 indicates the abundance of hydroxyl groups and its reactivity in isocyanate-based polyurethane-forming reactions. Multiple functional hydroxyl groups can increase crosslink density; however, crosslink density also depends strongly on the estimated average OH functionality of the mixed polyol ($f = 2$–3) with a fixed catalyst concentration (NaOH, 1% w/w), enabling polyurethane materials with appropriate properties such as flexibility, hardness, and heat stability.

The associated acid number of 0.73 ± 0.02 mg KOH/g for the PetP:SuP-30:20 polyol blend was low and within the stated range of 0.1–2.0 mg KOH/g for correctly produced sunflower polyols. A low acid value is important to ensure that the polyol is stable and does not impede the crosslinking reaction during polyurethane synthesis.

3.5. CHARACTERIZATION OF POLYOL USING FOURIER TRANSFORM INFRARED SPECTROSCOPY

Sunflower oil was characterized by infrared spectroscopy (Figure 2). At A (3200–3600 cm^{-1}), a signal attributable to O–H stretching vibrations was observed. In polyols, a broad, strong hydroxyl (O–H) stretching band around 3300–3500 cm^{-1} (Fig-

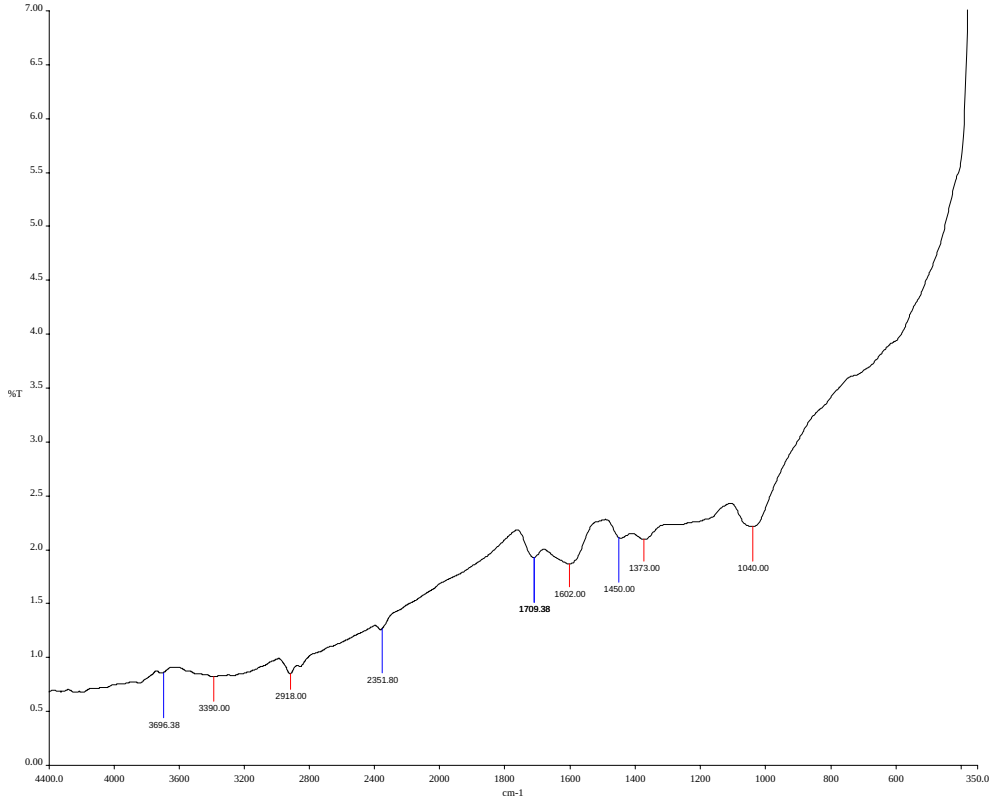


Figure 2. FTIR spectrum of refined sunflower oil.

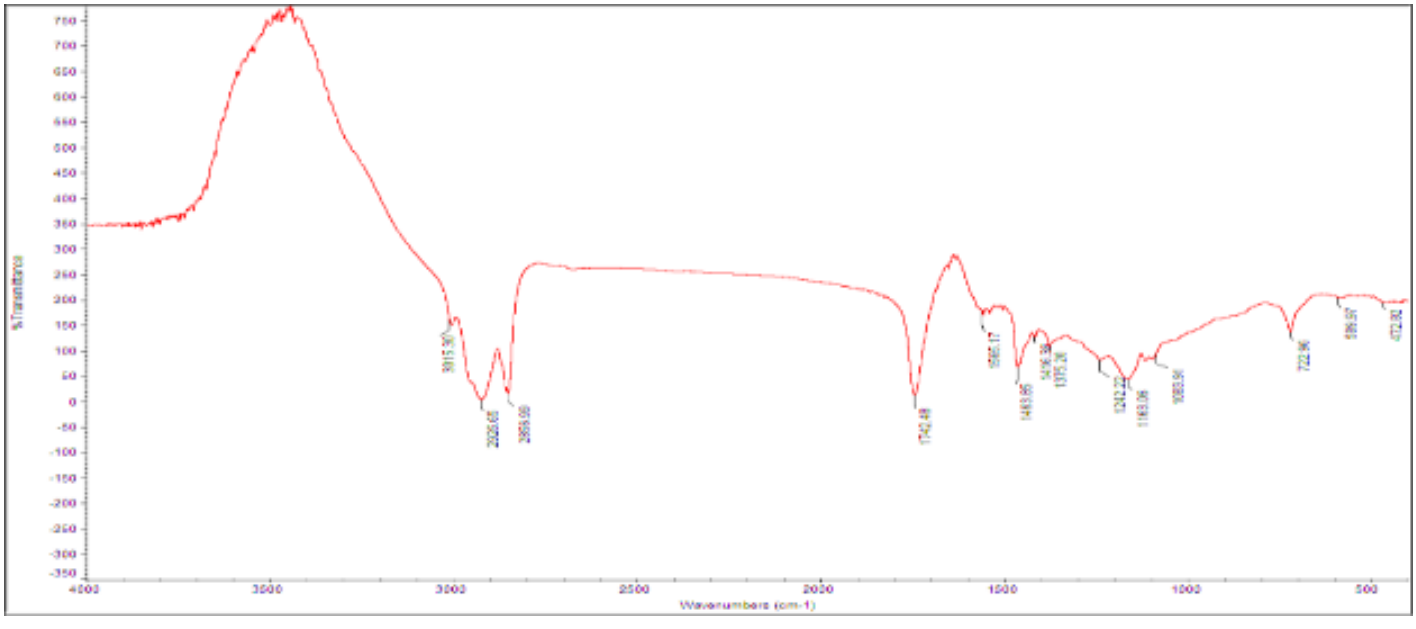


Figure 3. FTIR spectrum of sunflower polyol (bio-based).

ures 3–5) indicates newly produced hydroxyl groups, distinguishing them from triglyceride ester carbonyls and providing a clearer relationship between spectral changes and reaction conversion. Sunflower polyols commonly show a strong O–H peak around 3400 cm^{-1} and a weaker C=O peak around 1735 cm^{-1} compared with styrene-acrylonitrile (SAN)-based synthetic polyol. Band intensity is associated with the hydroxyl number of the polyol. Characteristic peaks include polyester carbonyl or ether linkages (1720–1750 cm^{-1}, C=O stretching) and aliphatic C–H stretching (2850–3000 cm^{-1}). Ester C–O stretching and a prominent C=O band at 1735 cm^{-1} are characteristic of polyester polyols. Bands at B (2800–3000 cm^{-1}) are related to symmetric and asymmetric stretching vibrations of C–H bonds in methylene groups within aliphatic chains and at chain ends. Signals at

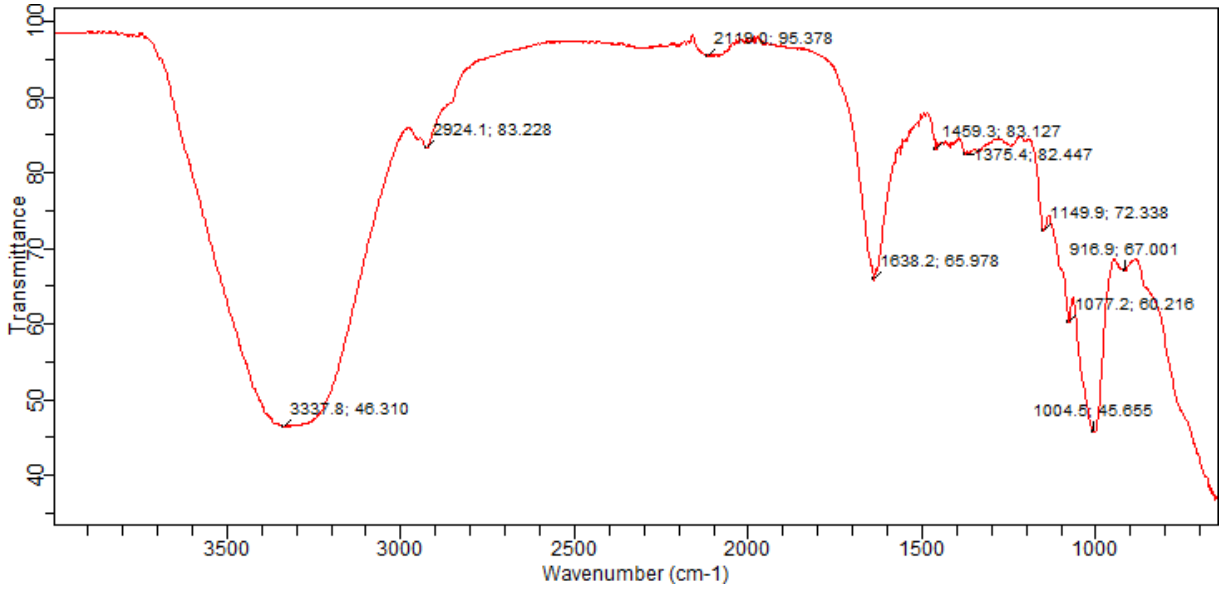


Figure 4. FTIR spectrum of styrene-acrylonitrile (SAN)-based synthetic polyol containing 35% petroleum-based material.

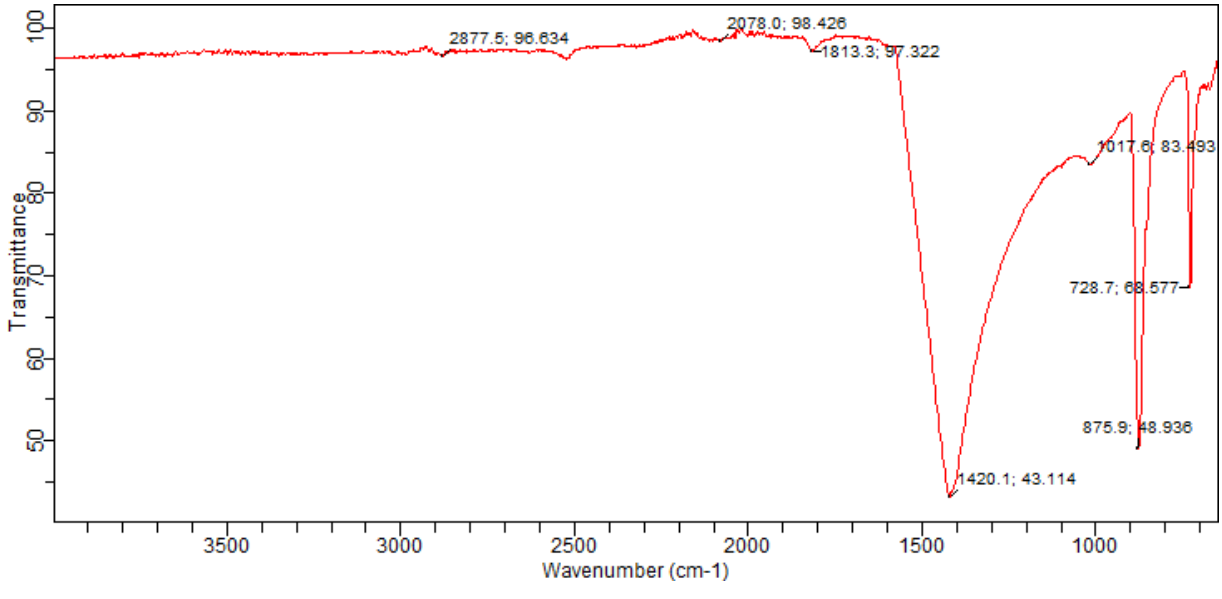


Figure 5. FTIR spectrum of 100% petroleum-based synthetic polyol.

C (1600–1800 cm^{-1}) may arise from stretching vibrations of unconjugated C=C bonds and C=O groups in the oil molecule. Absorption bands in region D (900–1200 cm^{-1}), characteristic of C–O–C ether and ester group vibrations, are related to the structure of the resulting polyol [23]. A synthetic polyol containing solid acrylonitrile (SAN) and 35% petrochemical base was examined spectroscopically to identify important chemical characteristics and formulation interactions (Figure 4) using FTIR methods.

3.6. SYNTHESIS OF POLYURETHANES USING POLYOLS

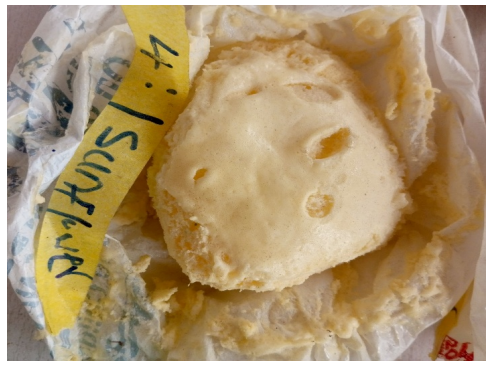
Different polyols were extracted, separated, and then converted to polyurethane at different ratios using the processes described above. The resulting polyurethane samples are shown in Figure 6, and their properties following exposure to several chemical solvents are presented in Table 4.

3.7. PHYSICAL PROPERTIES AND CHEMICAL RESISTANCE OF SUN-BASED POLYURETHANES

Table 4 summarizes the physical properties and chemical resistance of the sunflower-based polyurethanes (SuPUs). The amount of sunflower polyol in the PetP:SuP blends had a significant effect on the physical appearance of the SuPUs.

Samples containing lower levels of sunflower polyol (SuPU-50:00 and SuPU-40:10) ranged from very hard to hard and from pure white to off-white, suggesting a highly crosslinked polymer network dominated by petroleum polyol. As sunflower-polyol content increased (SuPU-30:20 and SuPU-20:30), the materials became cream to pale yellow and their texture became softer and slightly more flexible. This change in color and texture is consistent with the inclusion of vegetable-oil-derived polyols, which can impart flexibility and light chromophores to the final poly-

(a) PetP:SuP (40:10)



(b) PetP:SuP (20:30)

(c) PetP:SuP (30:20)

Figure 6. Polyurethane derived from petroleum-polyol:sunflower-polyol (PetP:SuP) blends.

Table 4. Chemical resistance and physical properties of sun-based polyurethanes.

PetP:SuP ratio (%)	20 g TDI: mixed polyol ratio	Yield (g)	Color	Time (min)	Texture	Chemical attack resistance (mass difference, g)		
						$CHCl_3$	HCl	C_6H_5–CH_3
50:00	SuPU-50:00	53	Pure white	40	Very hard	12.0	30.0	4.0
40:10	SuPU-40:10	55	Off-white	60	Hard	22.0	23.0	3.1
30:20	SuPU-30:20	60	Cream	80	Soft	20.0	18.0	3.05
20:30	SuPU-20:30	53	Pale yellow	90	Slightly flexible	22.0	14.0	2.7

Table 5. Physical characteristics of sun-based flexible polyurethane foams compared with conventional values.

Sample grade	Pre-flex compression (%)	Compression (40%)	Elevation/ height (mm)	Tensile strength (kPa)	Porosity	Hardness CLD (kPa)	Density (kg/m^3)	Weight (g)
SuPU-30:20	70	36.5	52.0	14	16	3.8	29.6	14.9
SuPU-20:30	70	92.2	40.9	11	12	4.3	34.3	13.9
LSPM*	NA	60–70	60–65	5–15	25	3.4–4.0	27.6–28.5	15.9–16.6

*LSPM = Standard Procedure Manual for Polyurethane Laboratories.

mer matrix through their aliphatic chains [24].

The yield of SuPU-30:20 was 60.0 g, followed by SuPU-40:10 (55.0 g) and SuPU-50:00 (53.0 g). This pattern indicates higher overall reactivity of the polymerization system with sunflower-polyol formulation SuPU-30:20. This is most likely related to the availability of reactive hydroxyl groups and their compatibility with isocyanates, which may promote crosslinking. Solvents affected the swelling resistance of SuPU-30:20, with chloroform ($CHCl_3$) causing the greatest change (20.0 g), followed by hydrochloric acid (HCl; 18.0 g) and toluene (C_6H_5–CH_3; 3.05 g). The reductions of 22%, 14%, and 2.7% in all solvents were shown with decreasing content of sunflower polyol for SuPU 20:30. The reduced solvent absorption suggests greater chemical resistance at higher sunflower-polyol SuPU-30:20 replacement rates. Flexible aliphatic chains in sunflower polyol decrease polymer affinity for the solvent, while multiple functional hydroxyl groups increase crosslink density. Vegetable-oil-based polyol additions have been reported to increase the chemical resistance of similar PUs, including soybean- and castor-oil systems [25, 26]. Overall, sunflower polyol can enhance production and chemical resistance while causing some pigmentation and loss of stiffness. These results support sunflower polyol as an alternative to

petroleum-derived polyols in polyurethane formulations.

3.8. CHARACTERISTICS OF SUN-BASED FLEXIBLE POLYURETHANE FOAM COMPARED WITH STANDARDS

The pre-flex value of both foam types, SuPU-30:20 and SuPU-20:30, was 70% and 60–70% under compression (40%), which falls within the allowable range of the Polyurethane Laboratory Standard Procedure Manual, LSPM (ASTM D3574) [28].

The physical characteristics of the sun-based flexible polyurethane foams are compared with conventional values in Table 5. This implies that foam flexibility is strongly affected by the polyol-to-isocyanate ratio; the greater rigidity of SuPU-20:30 can be attributed either to a higher isocyanate concentration or to lower blowing efficiency [27]. Petroleum-to-biopolyol ratios of 50:00, 40:10, 30:20, and 20:30 were evaluated for mechanical properties, hardness, density, hydroxyl number, acid value, and chemical resistance. The results showed that the maximum yield of PetP:SuP-30:20 polyol (60%) was obtained for sunflower oil under the optimum conditions. Increased reactivity was associated with stronger hydroxyl vibrations, with a hydroxyl number and acid value of 248.9 ± 0.3 and 0.73 ± 0.02 mg KOH/g, respectively. The density of SuPU-20:30 was highest (34.3 kg/m^3), outside the normal range of 27.6–28.5 kg/m^3, and was associated with a compact cellular structure, most likely because of the low foam rise. Similarly, the weights of both foams were slightly below the normal range, indicating lower expansion during foaming.

4. CONCLUSION

In conclusion, the physical parameters evaluated in SuPU-30:20 showed good balance, indicating that the foam is softer and more resilient, with good mechanical and structural properties. The effects of the polyol–isocyanate ratio on foam form and behaviour were shown with SuPU-20:30, which resulted in a stiffer, denser, and less porous foam. The results indicate that sunflower-based polyols have potential in flexible foam production, although the formulation needs to be modified to get closer to the standards. Both oils could react with glycerol, depending on the properties of the oil and the level of saponification. The data revealed that the conversion of the residual sunflower oils to polyol was 60.1% under the optimal conditions of 4:1 (molar ratio of oil/glycerol), 1.0% (w/w) catalyst concentration and 80 minutes reaction time. The presence of the major polyol-related structures in both oils, such as ester, hydroxyl and carboxyl groups, was identified by infrared spectrophotometry. The results demonstrated that under experimental conditions, PetP: SuP-30:20 polyol produced the highest production of polyurethane (60 g), which increased reactivity due to larger hydroxyl vibrations, with hydroxyl number and acid value of 248.9 ± 0.3 and 0.73 ± 0.02 mg KOH/g, respectively. After characterising the SuPU-30:20 polyurethane, it was found that the cooking oil of sunflower was more resistant to chemical attack. HCl was the solvent that had the greatest effect on mass loss, reporting a mass loss of 30% for PetP: SuP-50:00 and 22% was the second largest mass loss observed for PetP: SuP-20:30. The average mechanical resistance values of the medium broken strength values of the piece indicated that the polyurethane obtained from the waste sunflower oils (PetP: SuP-30:20) compared to (PetP: SuP-20:30) has tensile strength 14 kPa, lower compression at 40% (36.5 vs 92.2), higher elevation (52 vs 40.9), lower hardness (3.8 vs 4.3), and lower density (29.6 vs 34.3), has best overall balance of mechanical properties and chemical resistance. From these results, it can be concluded that polyurethane from waste sunflower oil-based polyols has promising mechanical performance and improved chemical resistance. However, limitations include porosity and elevation below standards, and the need for formulation optimisation. Further formulation work is required, and the study suggests that a pilot-scale model can be developed to give enhanced polyurethane quality from sustainable, biodegradable resources such as waste sunflower oil while reducing dependence on petroleum resources.

DATA AVAILABILITY

The data supporting the findings of this study are available from the corresponding author upon reasonable request.

DECLARATION OF COMPETING INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this manuscript.

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