Impact of Solvent Type on Total Phenol and Flavonoid Content and Sun Protection Factor of Crude Cashew Nutshell Liquid

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Abstract: Cashew nutshell liquid (CNSL) is a cheap source of natural phenolic compounds that have numerous applications. These phenolic compounds have chemical structures with chromophores similar to those found in synthetic chemical UV-filters, which are present in commercial sunscreen products (SSPs). Thus, this study investigated the impact of solvents on the yield, total phenol content (TPC), total flavonoid content (TFC), and the sun protection factor (SPF) of crude CNSL. The percent yield ranged from (30.4 ± 0.7% to 49.3 ± 3.2%); hexane recorded the lowest yield, while ethanol recorded the highest. Acetone (101.2 ± 2.5 mg GA/g), methanol (99.5 ± 0.10), and chloroform (95.4 ± 3.7 mg GAE/g), recorded the highest TPC respectively, while hexane (33.3 ± 0.7 mg QE/g) recorded the highest TFC. The SPFs ranged from (22.1 ± 1.1 to 16.4 ± 0.8), chloroform (22.1 ± 1.1), acetone (21.5 ± 1.1), and methanol (19.3 ± 1.0) again recorded the highest values respectively, while hexane (16.4 ± 0.8) recorded the lowest. Our results revealed that extracting solvents have a significant impact on the yield and SPF of CNSL. Therefore, we propose that acetone, chloroform, and methanol, either alone or as mixtures, could be the best solvents for extracting CNSL with a good TPC and SPF.

Keywords: cashew nutshell liquid; phenols; flavonoids; sun protection factor; skin cancer

1. Introduction

Recently, chemical industries around the globe have been negatively hit by the erratic supply of raw materials due to the gradual depletion of fossil fuel reserves [1,2]. This has resulted in an increase in the demand for raw materials, consequently causing the prices of fuels and petroleum chemical products to also increase exponentially [1,3]. Research has also shown that the indiscriminate use of petroleum-based chemicals over the years has been associated with environmental pollution, global warming, human health, and ecological system problems [4]. Therefore, global research has focused on finding new and sustainable renewable resources, which can supplement or entirely replace fossil fuels with similar or competitive results.

At present, a great majority of researchers worldwide suggest that biomass feedstocks, such as sugars, starches, and vegetable oils, could be the best alternative to fossil fuels in the production of desirable chemical products. To this end, vegetable oil has received great attention because of its versatility, affordability, inherent biodegradability, excellent environmental credentials, and low toxicity to ecological systems and humans [5]. In addition, the processing of edible oils into desirable chemical products leaves a low carbon footprint; hence their contribution to the emission of greenhouse gasses is minimal as compared to fossil fuels [6].

Nonetheless, the utilization of edible feedstocks, such as vegetable oils for the large-scale production of desirable chemical products, is associated with several important issues, such as competition with the human food supply chain and land use [7]. Many people fear that if this is unchecked, it will cause havoc to the global food economy [8]; the conflict between the demand for edible feedstocks for human food and the supply for fuel/chemical
production led to a sharp increase in food prices during the 2007/2008 global financial market [6]. Moreover, the world is not ready to adopt edible oils as the sole raw material for the production of desirable chemical products, given that the demand for edible oils for food in developing countries is extremely high. At the same time, developed countries are failing to completely harness the large-scale production of desirable chemicals from edible feedstocks due to poor yields and high costs of production [8].

Therefore, to supplement or replace fossil hydrocarbons in the production of desirable chemical products, but without impinging on the human food supply chain, other forms of vegetable oils need to be exploited. Non-edible oils have the same interesting physical, chemical, and economic characteristics as edible oils (e.g., environmentally friendliness, biodegradability, affordability, and versatility), except they are not suitable for human consumption due to the presence of some toxic components [8–11]. As a result, they are off the table as human foods, and this ultimately cuts them off the human food supply chain. Hence, it is logical to presume that they would be a better alternative to supplement or replace edible oils in the generation of desirable chemical products. CNSL is a non-edible oil derived from waste cashew nutshell (CNS) (Anacardium Occidentale). It is a readily available natural resource, and unlike edible oils, it does not interfere with the human food supply chain, nor compete for land use, as it is a non-edible oil and originates from agricultural waste (cashew nutshell) [7,12]. In addition, cashew trees are capable of thriving in very poor environments; hence competition with the main food crops can be avoided by setting-up plantations in areas that do not support traditional crops [13]. Furthermore, CNSL is a versatile natural resource that has great potential to be converted into almost any desired chemical product with ease and at a low cost [14–16]. Crude CNSL exhibit a broad spectrum of biological activities against a wide range of microorganism and insects, including bacteria, fungi [17], viruses [18], termites [19], weevils [20], Mollusca [21], and nematodes [22]. It has also found wide application in industries as a raw material for the production of paints and coating agents, dyestuffs, brake-lining, adhesives, polymers, surfactants, and drugs [14]. Constituents from CNSL can also undergo a series of chemical modifications, such as decarboxylation, hydrogenation, nitration, methylation, epoxidation, ozonolysis, and polymerization [14]. Figure 1 shows the major components of CNSL.

![Figure 1. Major components of CNSL [23].](image-url)

Ultraviolet radiation is one of the major risk factors for human skin cancer, also called melanoma and nonmelanoma cancer. Studies have shown that 90% of skin cancer cases are a result of excessive exposure to sun rays [24]. Skin cancer is a deadly disease, and statistics show that more than 5,400 people worldwide die from nonmelanoma skin cancer alone every month [25]. Ultraviolet radiation causes DNA damage and genetic
mutation in the skin cells, which consequently leads to skin cancer [26]. Thus, limiting the amount of UV radiation that goes on the skin would practically prevent skin cancer [27]. A sunscreen product (SSP) is a substance applied to the skin to protect it from directly receiving damaging radiation from the sun (e.g., UV A and B) [28]. Sunscreen products are made with a wide range of sun protection factors (SPF). The SPF is a value that indicates the effectiveness and efficacy of a sunscreen product. According to the Food and Drug Administration (FDA), a good SSP should have an SPF value of 15 or higher [29]. The higher the SPF value, the greater the protective effect of an SSP. An SSP prevents skin damage by either absorbing, filtering, or scattering damaging sun rays [28]. Two types of SSPs exist and are categorized based on the substance responsible for blocking UV radiation. Physical UV-blockers contain metallic oxides, such as titanium oxide (TiO\textsubscript{2}) or zinc oxide (ZnO). They physically block UV radiation, similar to clothing, and previously, they were made with a particle size ranging from 100 to 300 \( \mu \)m to prevent systemic absorption. However, nowadays, they are micronized, a thing that has sparked public health concerns over possible systemic absorption [30,31]. Chemical UV filters are synthetic organic compounds with either monocyclic, tricyclic, or polycyclic chemical structures. They block UV radiation by having intrinsic chromophores that absorb shorter wavelengths (high energy photons), and spontaneously emit longer wavelengths (low energy photons), which have little or no effect on the skin [30]. Figure 2 below shows some of the basic chemical structures of commonly used UV filters [32]. Interestingly, constituents of CNSL also have these similar chemical structures and chromophores (see Figure 1 above). This suggests that CNSL may have photo-protective abilities just like chemical UV-filters. Besides, CNSL also has other beneficial properties, such as antimicrobial, antioxidant, and antimutagenic effects [17,33].

![Chemical Structures](image)

**Figure 2.** Basic chemical structures for commonly used UV filters [32].

According to a report by the Market Research firm facts (MR), the global market for sun protection products is expected to grow at a compound annual growth rate (CAGR) of 7\% by 2022–2031 [34]. The total market share for sun protection products with organic ingredients is expected to rise in both developing and developed countries, owing to the growing concerns about the side effects of artificial and chemical products [34]. In Europe and East Asia, the total market share for organic SSPs is expected to rise due to an increase in demand for products with anti-aging and anti-pollution ingredients, while in America, the consumption of sun protection products with natural oils as active ingredients is expected to rise due to the convenience of applying the product [35]. At the moment, natural oils extracted from raspberry seeds, wheat germ, avocado, hazelnut, and carrot seeds predominate as active ingredients in organic sunscreen products [34]. However, all these oils are either expensive or originate from edible feedstocks; hence they are economically unsustainable and also interfere with the human food supply chain. Therefore, there is an urgent need to search for new and more sustainable natural resources. Hence, this work aimed to evaluate the potential of crude CNSL (waste products of the cashew industry) as an active ingredient for the formulation of natural sunscreen products. In this work, we simultaneously conducted a preliminary assessment of the impact of extracting solvents on
the yield, total phenol, and flavonoid content, as well as the sun protection factor (SPF), of crude CNSL. Literature sources revealed that the yield and composition of plant extracts are significantly influenced by extracting solvents [36,38].

2. Materials and Methods

2.1. Chemicals

Methanol, ethanol, acetone, chloroform, and hexane were purchased from HIMedia. Aluminum chloride, lithium sulfate, sodium molybdate, sodium tungstate, sodium carbonate, bromine, phosphoric acid, and hydrochloric acid were supplied by the Department of Chemistry, University of Zambia. Standard gallic acid and quercetin were purchased from Sigma Aldrich.

2.2. Instruments

Rotavapor (BUCHI RII, Flawil, Switzerland), UV-VIS Spectrophotometer (SHIMADZU UV-2600, Europe), Electronic balance (Scout pro, OHAUS, Parsippany, NJ, USA), and Sonicator (Elmasonic S 40 H, Singen, Germany), Philips blender (Philips Electronics, HR 2061, Koninklijke, Netherlands).

2.3. Sample Collection and Preparation

Cashew nutshells were collected from small-scale cashew processors in Mongu District, Western Province of Zambia. The samples were first washed with tap water to remove all the dirt and debris, then followed by sufficient distilled water. Thereafter, the samples were shade-dried in the air for three weeks. Size reduction was achieved by use of Philips domestic blender (Koninklijke Philips Electronics, Netherlands). The powdered samples were placed in Ziploc bags and placed in the refrigerator at 4°C until required for analysis.

2.4. Extraction of CNSL

Cashew nut shell liquid (CNSL) was extracted from cashew nutshell (CNS) by a method described by [39] and adopted from [40], with modifications. Briefly, two grams of powdered CNS (1.68 mm particle size) were transferred into a 50 mL centrifuge tube containing 20 mL of the respective organic solvents. Then, the mixture was sonicated at room temperature (27 ± 2°C) for five minutes in an ultrasound water-bath device (Elmasonic S 40 H, 37 kHz, 140 W; Elma, Germany). Thereafter, the mixture was vortexed for three minutes and left to stand for 24 h in the dark, at room temperature, to allow maximum extraction of CNSL. On the following day, the mixture was centrifuged at 3000 rpm for 10 min; the supernatant was poured into a storage container while the residual shell was re-extracted further with another 20 mL of fresh solvent and treated as outlined above. The total solvent-to-sample ratio was 20:1, respectively [41]. The supernatant from the first extraction was combined with the second and concentrated on a Rotavapor at 40°C until a constant mass was attained. The percent yield of CNSL was calculated using the formula shown below. All the experiments were done in triplicates, and the values were presented as M ± SEM (mean ± standard error of the mean).

\[
\% \text{CNSL} = \frac{\text{Mass of CNSL (g)}}{\text{mass of dry CNS (g)}} \times 100%
\] (1)

2.5. Determination of Total Phenol Content (TPC)

The TPC of crude CNSL was determined by Folin–Ciocalteau’s method, as described by [42], with modifications. Briefly, a set of working standards of concentrations ranging from (0 to 5 mg/L) were prepared from a stock solution of standard gallic acid (10 mg/L). An aliquot of 0.5 mL of each working standard was pipetted and mixed with 0.5 mL of 10% (v/v) Folin–Ciocalteau’s reagent and incubated for five minutes. Thereafter, the solution was diluted with 3 mL of distilled water and immediately mixed with 2 mL of 20% Na₂CO₃. The mixture was then incubated for 90 min at room temperature in the dark.
The absorbance of the solutions was measured with a UV-Visible spectrophotometer at a wavelength of 765 nm against a blank. For analysis of TPC in crude CNSL, the same procedure for the standards was followed. All the experiments were done in triplicates. The TPC of crude CNSL was expressed as mg of gallic acid equivalent/gram of dry sample (GAE/g). The results were expressed as mean ± standard error (SE) of three replicates.

2.6. Determination of Total Flavonoid Content (TFC)

The total flavonoid content of crude CNSL extracts was determined by the modified aluminum chloride colorimetric method [43]. A variation of the working standard with concentrations ranging from (0 to 5 mg/L) was prepared from a stock solution. An aliquot of 2.0 mL (of either the standard/or CNSL extract) was mixed with 2.0 mL of 2% aluminum chloride solution and incubated at room temperature for 60 min. The absorbance of the solutions was measured at 420 nm against the blank (80% methanol) with a UV-Visible spectrophotometer. The TFC of crude CNSL was calculated from the quercetin standard curve, and the results were expressed as mg of quercetin equivalent (QE)/g of dry sample (QE/g). All the experiments were done in triplicates and expressed as a mean ± standard error (SE) of three replicates.

2.7. Determination of the Sun Protection Factor (SPF)

The SPF of different extracts of crude CNSL was determined as described by [44], with minimal modifications. Briefly, 0.1 g of CNSL was weighed and transferred into a 25 mL centrifuge vial and diluted to 25 mL with absolute ethanol. The mixture was then vortexed for 5 min, followed by centrifugation for another 10 min at 3000 rpm. A 5.0 mL aliquot from the supernatant was transferred to a 25 mL volumetric flask and diluted to volume with ethanol. From this solution, a 5.0 mL aliquot was pipetted and transferred to a 20 mL volumetric flask, and the volume was completed with ethanol to make a final concentration of 0.02 mg/mL. The absorption spectra of CNSL in ethanol solution were obtained in the range of 290 to 450 nm using a 1 cm quartz cell and ethanol as a blank. The absorption data were obtained in the range of 290 to 320, every 5 nm, and 3 determinations were made at each point, followed by the application of the Mansur equation [45].

\[
SPF = CF \times \sum_{\lambda=290}^{320} EE(\lambda) \times I(\lambda) \times Abs(\lambda)
\]

where

- \( CF = \) correction factor (10);
- \( EE = \) erythemogenic effect of radiation with wavelength;
- \( I = \) solar intensity spectrum;
- \( Abs(\lambda) = \) spectrophotometric absorbance values at wavelength.

The values of \( EE(\lambda) \times I(\lambda) \) in Table 1 below are constants, as determined by [46].

Table 1. Relationship between erythemal effect (EE) and radiation intensity (I) at each wavelength (\( \lambda \)).

| \( \lambda \) | EE \( \times I \) (Normalized) |
|-------------|-----------------|
| 290         | 0.0150          |
| 295         | 0.0817          |
| 300         | 0.2874          |
| 305         | 0.3278          |
| 310         | 0.1864          |
| 315         | 0.0839          |
| 320         | 0.0180          |
| Total       | 1               |
2.8. Statistical Analyses

The results of the present study are presented as mean ± SEM \( (n = 3) \). Analysis of variance was performed (one-way ANOVA), and the significant differences between the mean values were determined by a post hoc \( t \)-test (Bonferroni corrected) at a level of significance of \( p < 0.05 \). Statistical analyses were carried out using Microsoft Excel 2013 version.

3. Results and Discussion

3.1. Percent Yield (%)

The efficiency of a solvent to extract phytochemical compounds from plant material depends on several factors, such as polarity of solvent, method of extraction (agitation or heating), extraction time, particle size, as well as ratio of solvent to sample [47]. In this work, all the parameters were kept constant except for the polarity of the solvents. Five organic solvents (hexane, chloroform, acetone, ethanol, and methanol) were chosen based on their different polarities and wide application in the extraction of phytochemical compounds from plant materials [48,49]. The efficiency of these solvents in recovering (yield %) CNSL from CNS is presented in Table 2. In this work, a two-step extraction process comprising sonication and cold solvent maceration was employed to extract CNSL from CNS. Cold solvent extraction, coupled with sonication, was employed because it preserves the natural composition and quality, as well as improves the yield [47,50]. In addition, mild extraction conditions, such as lower temperature (27 ± 2 °C) and sonication time (five minutes), were selected in order to recover natural CNSL as much as possible, as higher temperatures above 100 °C have been reported to degrade natural CNSL (in which anacardic acid is converted, which is the major component of natural CNSL to cardanol via a decarboxylation reaction) [36]. Likewise, prolonged exposure of phytochemical compounds to frequencies above 20 kHz has also been reported to degrade active phytochemical compounds [51]. The percent yields of CNSL increased from nonpolar solvents, hexane (30.8 ± 0.7%), to polar solvents, ethanol (49.3 ± 3.2%), respectively. The average percent yield difference between polar and nonpolar solvents was 16.0%. This huge difference suggested that polar solvents were more efficient in extracting CNSL from CNS than nonpolar solvents. The observed trend can be best explained by understanding the natural composition of the CNS. CNS contains CNSL, which adds about 36% to the total weight of the shell [52]. This CNSL is mainly composed of four major polar alkyl phenolic compounds, viz. anacardic acid (70%), cardol (10%), cardanol (5%), and methyl cardol (5%), and several minor polar phenolic compounds, such as tocopherols, flavonoids, and naphthoquinones [53]. Thus, the higher yields recorded for polar solvents could be because they were extracting a lot more of these compounds [37]. Data based on GC-FID chromatogram from other sources revealed that CNSL has more polar compounds than nonpolar fatty acids; this also could be the reason why nonpolar solvents recorded lower yields [54]. The results obtained in this work agree with what was reported in other works [36,54]. In this work, the percent yields for hexane, acetone, and ethanol were 30.8 ± 0.7%, 33.3 ± 0.4%, and 49.3 ± 3.2%, respectively. While in other works, the percent yields were hexane 30.5% [36], acetone 33.1% [36], and ethanol 40.1% [55]. Despite the difference in the extraction methods employed (in this work, “sonication coupled with maceration,” and in literature, “soxhlet solvent extraction”), the yields were almost the same. Elsewhere, yields of 32.0% and 38.5% percent for hexane and methanol were reported by using the soxhlet method alone, and 58.7% and 62.5% when a two-step soxhlet/supercritical water (SCW) extraction method was employed [54].
Table 2. Percent yield, total phenol and flavonoid content, and sun protection factor of crude CNSL.

| Solvents   | Yield (%)  | TPC (mg GAE/g) | TFC (mg QE/g) | SPF       |
|------------|------------|----------------|---------------|-----------|
| Chloroform | 34.8 ± 0.4 | 95.4 ± 3.7     | 27.2 ± 2.2    | 22.1 ± 1.1 |
| Hexane     | 30.4 ± 0.7 | 74.5 ± 2.7     | 33.3 ± 0.7    | 16.4 ± 0.8 |
| Acetone    | 33.3 ± 0.4 | 101.2 ± 2.5    | 26.1 ± 1.9    | 17.4 ± 0.9 |
| Ethanol    | 49.3 ± 3.2 | 83.3 ± 3.1     | 23.2 ± 0.5    | 19.3 ± 1.0 |
| Methanol   | 47.8 ± 0.9 | 99.5 ± 0.1     | 20.6 ± 2.5    |           |

Each value is expressed as mean ± SEM (n = 3). Means in the same column with different letter superscripts are significantly different, while those with the same letter superscripts are not significant (p < 0.05).

3.2. Total Phenolic Content (TPC)

The TPC of CNSL extracts was analyzed by using the Folin–Ciocalteau method and gallic acid as a standard. The gallic acid standard calibration curve was plotted, and the TPC of the extracts was derived from the standard curve using the following equation: 

\[
Y = 0.0756X + 0.0083, \quad R^2 = 0.9921
\]

The results for TPC were expressed as milligrams of the gallic acid equivalent/gram of dry mass (mg GAE/g) (the results are presented in Table 2). The results obtained are arranged in ascending order and ranged from hexane (74.5 ± 2.7 mg GAE/g), ethanol (83.3 ± 3.1 mg GAE/g), chloroform (95.4 ± 3.7 mg GAE/g), methanol (99.5 ± 0.1 mg GAE/g), and acetone, 101.2 ± 2.5 mg GAE/g, respectively. The highest TPC was recorded in acetone (101.2 ± 2.5 mg GAE/g) and methanol (99.5 ± 0.1 mg GAE/g), respectively. Acetone recorded the highest TPC, possibly because it was able to extract both the polar and minor polar phenolic compounds from CNS. Acetone has the ability to dissolve both polar and minor polar solutes [56]. On the other hand, methanol recorded the second-highest TPC, possibly due to its strong polarity, which allowed it to easily interact with the major polar phenolic compounds in CNS [54]. Both acetone and methanol, either in pure forms or as aqueous mixtures, have been reported to be excellent solvents for extracting phenolic compounds from plant materials [49]. Chloroform (95.4 ± 3.7 mg GAE/g), recorded the third-highest TPC, probably because it was able to extract more of the active minor-polar phenolic compounds, such as flavonoids [48]. On the contrary, hexane (74.5 ± 2.7 mg GAE/g), another highly nonpolar solvent, recorded the lowest TPC; this is possibly because it might have only extracted nonpolar compounds. However, data from literature showed that the composition of nonpolar compounds in CNSL is lower than the polar compounds; hence a lower TPC observed in the hexane extract [54]. Despite ethanol recording the highest percent yield (49.3 ± 3.2%), it had the second-lowest TPC. This could be because it was extracting some other polar but nonphenolic compounds, such as pigments, etc. [55]. In this work, the TPC varied widely between polar and nonpolar solvents; this indicates that phenolic compounds in CNSL have different polarities, and their extractability might be improved by mixing both polar and nonpolar solvents in known proportions. Nevertheless, the high TPC recorded for all the solvents in this work suggest that CNSL could have good antioxidant and sun protection abilities, as a lot of literature sources have reported a strong connection between TPC and SPF [57,58], as well as TPC and antioxidant activity [59].

3.3. Total Flavonoid Content (TFC)

The effect of solvents on the TFC of crude CNSL was determined by the aluminum chloride colorimetric method using quercetin as a standard. The quercetin standard curve was plotted and the TFC of the extracts was derived from the equation (\(Y = 0.0606X + 0.0012, \quad R^2 = 0.9945\)). The TFC was expressed as mg QE/g (the results are presented in Table 2). The TFC declined from hexane (33.3 ± 0.7 mg QE/g), chloroform (27.2 ± 2.2 mg QE/g), ethanol (26.1 ± 1.2 mg QE/g), methanol (23.2 ± 0.5 mg QE/g), and finally acetone (20.6 ± 2.5 mg QE/g). Flavonoids are phenolic compounds with a 15-carbon skeleton, which consists of two fused phenyl rings, and a heterocyclic ring containing embedded oxygen. They act in plants as photo stabilizers, antioxidants, antimicrobials, and feeding repellants. In this work, the nonpolar solvents hexane and chloroform, with polarities of...
0.009 and 0.259, respectively, recorded higher TFC than polar solvents such as methanol and acetone, with polarities of 0.762 and 0.355, respectively [48]. This suggests that the majority of flavonoids in CNS are nonpolar; hence their extractability was more favored in nonpolar solvents than polar ones. A statistically significant difference (p < 0.05) was found between methanol (the most polar) and hexane (the least polar) solvents. Our results agree with the other literature findings that flavonoid extraction from plant materials is sometimes more favored by nonpolar solvents than polar ones [60].

3.4. Sun Protection Factor (SPF)

The SPF of different extracts of crude CNSL was determined by an in vitro spectrophotometric method. This method is very handy during product development, as the in vivo method (involving the testing of human volunteers) is complex, expensive, and time-consuming [44]. The results for the SPF of different extracts of crude CNSL are presented in Table 2. The highest SPF was recorded in chloroform (22.1 ± 1.1), and acetone (21.5 ± 1.1), while the lowest was recorded in ethanol (17.4 ± 0.9), and hexane (16.4 ± 0.8), respectively. The high SPF of chloroform and acetone could be associated with the high TPC of these extracts (see the results in Table 2). The same holds for the lower SPF for the ethanol and hexane extracts. All the SPFs in this work were significantly different (p < 0.05) from each other, except for chloroform and acetone. These findings suggest that both acetone and chloroform could be the best solvents for extracting CNSL with a higher TPC and SPF. The higher the SPF of the extract, the greater the sun-protection effect. Overall, all the SPFs recorded in this work were higher than the standard threshold value of 15 in commercial SSPs. The high SPF observed in this work for crude CNSL could be attributed to the synergistic effect of the various phenolic compound in CNSL, as elsewhere, SPF values as low as 1.5 were reported from the derivatized individual components of CNSL [61]. Therefore, our results suggest that crude CNSL may have better sun protection abilities than its pure phenolic isolates. In fact, it is established that the pharmacological effect of plant extracts is a result of many compounds in the extract working together. Crude CNSL might have a lot of advantages over other natural oils currently being used in organic sun protection products, given that (1) it has a huge amount of cheap phenolic compounds, which are the main active ingredients in most sunscreen products [30], (2) it is readily available, (3) it is very versatile, (4) it is soluble in a number solvents, (5) it exhibits biological and antioxidant activities, (6) it is non-edible, (7) it is environmentally friendly and less toxic to humans, and (8) it has antimitagenic and anticarcinogenic effects [14,17,33,62].

4. Conclusions

Cashew nutshell is a cheap source of natural phenolic compounds that have numerous applications. In industries and research institutions, a lot of time and money can be served if informed decisions are made in choosing the proper methods for preparing materials. Thus, in order to guide future works on the best solvents for extracting CNSL with a good SPF, this study investigated the impact of solvents on the yield (%), TPC, TFC, and SPF of crude CNSL. The highest percent yield was recorded in ethanol (49.3 ± 3.2%), and methanol (47.8 ± 0.9%), while hexane (30.8 ± 0.7%), recorded the lowest. Acetone (101.2 ± 2.5 mg GAE/g), methanol (99.5 ± 0.1 mg GAE/g), and chloroform (95.4 ± 3.7 mg GAE/g), recorded the highest TPC. Whereas hexane (33.3 ± 0.7 mg QE/g), recorded the highest TFC. Chloroform (22.1 ± 1.1), and acetone (21.5 ± 1.1), recorded the highest SPF values, while hexane (16.4 ± 0.8), recorded the lowest. Among all the solvents, acetone, chloroform, and methanol seemed to be the best solvents for extracting CNSL with a good TPC and SPF. However, all the solvents investigated in this work presented an SPF above the recommended threshold value of 15, which is recommended by the Food and Drugs Administration for commercial sunscreen products. Thus, future studies should now focus on first determining the minimum concentration of CNSL that is less irritating to the skin and the cheapest way to formulate a CNSL-based sunscreen product, or they could look
at nano-emulsification of synthetic chemical UV filters with CNSL to improve the efficacy and residual effect on the skin.

**Author Contributions:** K.Z., A.L. and H.P. carried out the experiments. J.N. supervised the work. K.Z. analyzed the data and wrote the manuscript. J.N., A.L. and H.P. edited the manuscript. All authors have read and agreed to the published version of the manuscript.

**Funding:** This research received no external funding.

**Data Availability Statement:** Not applicable.

**Acknowledgments:** We would like to thank the members of the Department of Chemistry, the University of Zambia, for both provision of laboratory space and the kind donation of various reagents. The authors are grateful to the Ministry of Education for providing indirect support for the partial funding for school fees to K.D. and the International Science Programme (ISP), Uppsala University, for their direct support to A.L. and H.P., for the payment of the full school fees, and the payment of the bench space. The authors are also grateful to Mutibo Chijikwa (Senior Officer, National Biosafety Authority) for proofreading the manuscript.

**Conflicts of Interest:** The authors declare no conflict of interest.

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