Valorization of cashew nut processing residues for industrial applications

Poonam Sharma, Vivek Kumar Gaur, Ranjna Sirohi, Christian Larroche, Sang Hyoun Kim, Ashok Pandey

Industrial Crops & Products 152 (2020) 112550

Contents lists available at ScienceDirect

Industrial Crops & Products

journal homepage: www.elsevier.com/locate/indcrop

Valorization of cashew nut processing residues for industrial applications

Poonam Sharma[a], Vivek Kumar Gaur[b,c], Ranjna Sirohi[d], Christian Larroche[e], Sang Hyoun Kim[f], Ashok Pandey[g,h,*]

[a] Department of Bioengineering, Integral University, Lucknow, Uttar Pradesh, India
[b] Environmental Biotechnology Division, Environmental Toxicology Group, CSIR-Indian Institute of Toxicology Research, Lucknow, India
[c] Amity Institute of Biotechnology, Amity University Uttar Pradesh, Lucknow Campus, Lucknow, India
[d] Department of Postharvest Process and Food Engineering, GB Pant University of Agriculture and Technology, Pantnagar, India
[e] Polytech Clermont Ferrand, Institut Pascal, University Auvergne Clermont, Clermont Ferrand, France
[f] Department of Chemical and Environmental Engineering, Yonsei University, Seoul, South Korea
[g] Centre for Innovation and Translational Research, CSIR-Indian Institute of Toxicology Research, Lucknow, India
[h] Frontier Research Lab, Yonsei University, Seoul, South Korea

ARTICLE INFO

Keywords:
Cashew nut
by-products/residues
Industrial processes
Biofuels
Chemicals
Paints
Pesticides
Adhesive

ABSTRACT

Considering global scenario of international market for cashew nut, its industrial processing has great economic consideration. Availability of all essential amino acids in cashew nuts rewards it as nutrition dense crop, providing cashew nuts in the form of dry fruits. Industrial processing of cashew nut generates various by-products/residues, which also cause environmental concerns. These include cashew nut shell liquid (CNSL), testa, cashew apple, and cashew apple bagasse. These by-products are industrially significant as they can be processed to form several bioactive compounds, polymers and other products, thus making the process and products economic and environmental friendly and sustainable. Cashew apple bagasse is rich in organic nature and could be a potent source of lignocellulosic material for the production of bioethanol and other microbial products through biological processes. CNSL is enriched with numerous phenolic compounds and has potential benefits for usage in preparation of coatings and laminates. Therefore, proper management of cashew crop residues could not only lead to high revenue generation, but it also offers environmental sustainability.

1. Introduction

Foods with nutritional properties attract consumers seeking to improve dietary quality. During industrial processing these foods are exposed to several factors influencing their nutritional and structural composition leading to degradation or biotransformation in biologically active compounds (Mattison et al., 2018; Sharma et al., 2020). Cashew nut is among the most important agro-industrial crop in India, Brazil, Vietnam, and African countries. Cashew (Anacardium occidentale) tree is native to Brazil and it is in the sixteenth century when it was introduced to other regions of the world primarily for soil conservation. Later on in majority of countries it became a considerable foreign exchange earner, it is mainly grown for its nuts although the fruit (cashew apple) is utilized and processed locally (Mubofu and Mgaya, 2018). The global production of cashew nut in 2005 is 3.21 million tonnes which increases to 4.44 million tonnes in 2013 and it contains kernels (35–45 %) and shells (55–65 %). The honey comb structure of cashew nut shell comprises dark reddish brown liquid (15–30 %) termed as cashew nut shell liquid (CNSL) (Mubofu and Mgaya, 2018). Cashew nut as a whole contains beneficial fatty acids, biologically active amino acids selenium phytosterols, tocopherols, high starchy content, alkyl-phenols and a polysaccharide profile which is industrially and nutritionally important (Melo et al., 1998; Mattison et al., 2018).

Raw nut free from shells are edible nuts called as cashew kernels. The kernels was obtained through roasting process undergoing hot oil bath for 90 s at 192 °C, this leads to the breaking of shell and releasing CNSL from shells to bath (Mubofu and Mgaya, 2018). Cashew nut processing industries generates CNSL as a by-product which contains unsaturated phenolic compounds viz. anacardic acid, 2-methyl cardol, cardanol, and cardol. Anacardic acid was reported to exhibit several pharmacological properties such as anti-inflammatory, histone acetyltransferase inhibition, anti-microbial, and anti-cancer (Kubo et al., 2006; Correia et al., 2006; Stasiuk and Kozubek, 2010).

By-products from cashew nut processing was reported to be used in various applications viz. bio-ethanol production, biodiesel production, surface coating agent, dye stuff, pesticide, larvicide, anti-termite,

* Corresponding author at: Centre for Innovation and Translational Research, CSIR-Indian Institute of Toxicology Research, Lucknow, India.
E-mail addresses: ashok.pandey1@iitr.res.in, ashokpandey1956@gmail.com (A. Pandey).

https://doi.org/10.1016/j.indcrop.2020.112550
Received 27 January 2020; Received in revised form 1 May 2020; Accepted 3 May 2020
Available online 14 May 2020
0926-6690/

Table 1
Valorisation of cashew nut by-products.

S.No.	Cashew by-product	Transformation or extraction method	Product obtained	References
	Cashew apple bagasse	Dark Fermentation (*Clostridium roseum*)	Biohydrogen	Silva et al., 2018
	Cashew apple bagasse	Alkaline hydrogen peroxide (AHP)	Biohydrogen	Da et al., 2013
	Cashew apple bagasse	Enzyme hydrolysis (Novozyme) and fermentation (*Hanseniaspora* sp.)	Second generation Bioethanol	Barros et al., 2014
	Cashew apple juice	Fermentation (Hanseniaspora sp.)	First generation bioethanol	Barros et al., 2014
	Cashew apple bagasse	Microwave-assisted alkali pretreatment and fermentation (*Saccharomyces cerevesiae*)	Ethanol	Rodrigues et al., 2011
	Cashew apple bagasse	Fermentation (*Kluyveromyces marxianus* CE025)	Ethanol	Rocha et al., 2011
	Distilled technical cashew nut shell liquid	Thermal processing	Biodiesel	Sanjeeva et al., 2014
	Cashew nut shell liquid	Deoxygenation, hydrogenation and cracking	Green diesel	Scaldaferri and Pasa, 2019
	Cashew nut shells	Supercrtical CO2 extraction at 120–300 bar and 30–60 °C	Phenolic rich oil (86 %) cardanol and (5%) phenols	Kim, 2015
	Cashew apple	Absorption and purification	Glucose and fructose	Luz et al., 2008
	Cashew apple juice	Enzyme dextransucrase	Prebiotic oligosaccharides	Da Silva et al., 2014
	Cashew apple juice	Fermentation (leuconostocmesenteroides nrrl b512f)	Enzyme dextransucrase	Da Silva et al., 2014
	Cashew nut shell liquid	Extraction	Surface coating agents (paints, lacquer)	Lubi and Thachil, 2000
	Cashew nut shell liquid resins	Blending polychloroprene rubber and CNSL resin	Metal-metal adhesive	Lubi and Thachil, 2006
	Cashew testa	Solid state fermentation (*Aspergillus niger CEPC 11*)	Tannase	Viswanath et al., 2015
	Cashew testa	Taguchi technique	Dye	Patil et al., 2015
	Cashew apple	Distilled water	Anthraquinone, indigoid, and naphthaquinone dyes	Muhammadu et al., 2017
	Cashew nut shell liquid	Cardanol based	Colorants and dyes	Balgude and Sabnis, 2014
	Cashew nut shell liquid	Cardanol coupling with diamines and aromatic amines	Bis (azo) dye	Paebumrung et al., 2012
	Cashew nut shell liquid	Condensation of CNSL, HCHO, CNSL, and phenol	Water-based coating material	Lubi and Thachil, 2000

adhesive resins and rubber (Table 1) (Hu et al., 2018; Sanjeeva et al., 2014; Pacheco et al., 2010; Candau and Ottewill, 1990; Lubi and Thachil, 2000; Balgude and Sabnis, 2014; Adetogun and Adegeye, 2003; Asogwa et al., 2007). While there are a large number of studies on the utilization of various agro-industrial residues through biotechnological interventions (Fan et al., 2006; Sabu et al., 2002; Mitchell et al., 1999; Benjamin and Pandey, 1997; Pandey and Soccol, 2000), there is a scarcity of coalesced data relevant to cashew nut waste generation and its diverse applications. Thus, the aim of this review article is to provide state- of-art information and knowledge on the by-products generated by cashew nut processing and their utilization for the production of various products and chemicals for various industrial applications in paint and coating, pharmaceutical and agricultural industry and as biofuel.

2. By-products generated during cashew nut processing

2.1. Cashew apple

Cashew is found in two parts: the nut and the peduncle. The nut is of greater economic interest. Cashew nut is a dry fruit with higher economic value and is enjoyed as a culinary item for decades. The peduncle region i.e. cashew apple, is a pseudo-fruit, with a short shelf life so it is generally consumed in local area as fresh fruit (Araújo et al., 2011). Cashew apple is widely accepted by people, due to its mild astringent flavour (De Abreu et al., 2013). Approximately 85 % of annual production of cashew apple was wasted which is around 1 million tons. Cashew apples were used for the preparation of an array of products including cashew apple juice (CAJ), jam, jellies, ice creams, and other products prepared in laboratory like burger, pastries, cakes, cereal bars, etc.

CAJ is a repository of reducing sugars, principal compounds like methyl-3-methyl pentanoate, trans- 2-hexenal, ethyl-2-methyl-2-butenoate, and 2-methyl-2- pentenal, vitamins (vit. C especially), amino acids, dietary fibres, minerals, phytonutrients and carotenoids such as a- carotene, cis-β- carotene, trans-carotene, auroxanthin and traces of β-cryptoxanthin (De Abreu et al., 2013; Araújo et al., 2011). CAJ is rich in sucrose and fructose therefore can act as a substrate for microbial assisted conversion into valorized products like ethanol and wine (Araújo et al., 2011). CAJ can also act as a substrate for the synthesis of enzymes and prebiotic oligosaccharide, simultaneously reduces the wastage of cashew apples. Dextransucrase was synthesized by *Leuconostoc citreum* B-742 along with the production of oligosaccharides (Rabelo et al., 2009). CAJ is a potent source for retrieval of components of pectin viz. highly branched arabinogalactan (AG II) and small amounts of a rhamnogalacturonan type I, due to presence of soluble dietary fibres in apple proportionate (Nobre et al., 2015).

After extraction of juice, cashew apple bagasse (CAB) was obtained as a by-product of CAJ processing. This CAB is chiefly composed of residual fiber that was used as animal feed supplement (De Abreu et al., 2013). CAB is a lignocellulosic waste that appears as promising raw material for numerous applications (Reis et al., 2017). CAB has potential for the production of biosurfactant, enzymes, ethanol and xylitol, and synthesis of biohydrogen using *Clostridium roseum* via. dark fermentation process. Biohydrogen was produced by Pre-treatment of CAB with alkaline hydrogen peroxide to produce CAB-AHP, the acid and enzymatic hydrolysis of CAB-AHP yields hydrogen (Silva et al., 2018)

2.2. Deoiled cashew nut meal

About 30 % of total cashew kernels are reported to be not suitable for sale and discarded due to bruises, damages, oiliness or scorching during drying. Cashew nut has all the essential amino acids so it is termed as complete protein and furnishes 6000 calories/kg weight (Akande et al., 2015). It shows a protein value of 22.1 % and a lipid content of 35.0 % (Fernandes et al., 2016). Cashew nut meal (CNM) is prepared by milling whole and broken cashew nuts which are not suitable for human consumption due to processing and/or storage. There are two types of meal obtained as a by-product from cashew processing industries viz. full fat and defatted cashew meal (Akande et al., 2015).The rejected CNM kernel is utilized as animal feed and as a substitute of soybean, cotton seed flour, and groundnut flour. The nutritive profile of rejected cashew meal is found superior to soybean, in terms of protein, lipid, and calorific content (Fernandes et al., 2016). It was reported by researchers that feeding growing rats with reject CNM

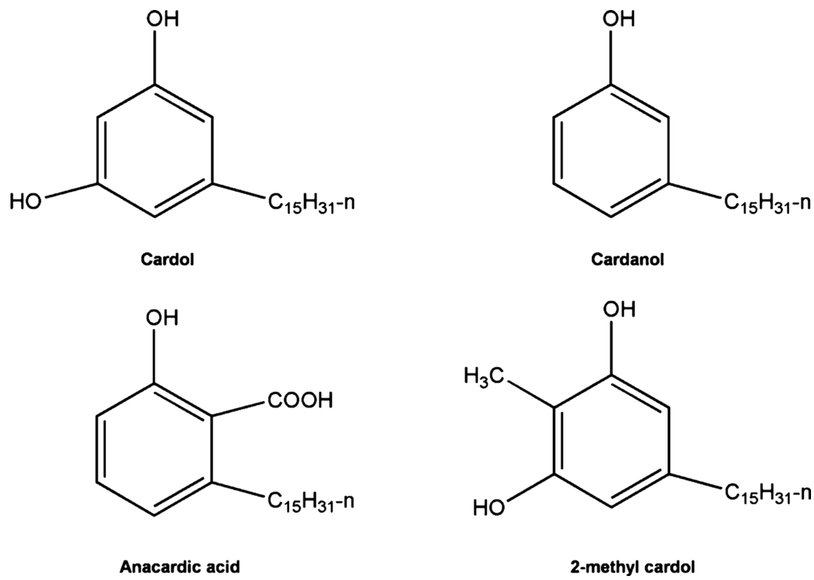

Fig. 1. Chemical structure of bioactive components present in CNSL.

leads to increment in protein efficiency ratio as compared to soybean meal feeding rats, and grants superior weight gain in growing pigs (Akande et al., 2015). Inclusion of reject CNM in meat quails diet leads to improvement of performance, nutrient digestibility, and carcasses characteristics (Fernandes et al., 2016). As sheep fed rations it was suggested that the intake of up to 30 % of CNM improves the apparent digestibility of nutrients and ingestive behaviour in sheep as feed alternative (Pimentel et al., 2011). Besides use as animal feed, it is nutritious for human beings as well, incorporation of full fat CNM in soft wheat flour for biscuit preparation is found to enhance its nutritive value. The nutrient fraction like fat, protein, digestible carbohydrate crude fiber, and ash increases with increasing CNM content (Aroyeun, 2009).

2.3. Testa shell

The cashew nut is covered with a thin antioxidant rich layer of reddish-brown colour, known as testa. Testa constitutes about 1–3 % of total cashew nut weight (Viswanath et al., 2016), it is an excellent source of hydrolysable tannins such as catechin, epicatechin and epigallocatechin, and polymeric proanthocyanidins. It comprises of phenolic acids like syringic acid, gallic acid and p-coumaric acids as the major constituents. The concentration of catechin and epicatechin were found as 5.70 and 4.46 g per kg dry matter, respectively (Edison et al., 2016; Trox et al., 2011; Viswanath et al., 2016). Approximately 25 % tannin is present in outer skin of cashew nut possessing similar properties as wattle bark used in leather industry (Viswanath et al., 2016).

The dried cashew nut testa consists of 190.0 g/kg dry matter (DM) crude protein, 103.0 g/kg DM crude fiber, 20.1 g/kg DM fat and 20.2 g/kg DM ash content with a metabolizable energy of 7.12 MJ kg DM (Donkoh et al., 2012). In a comparative study on composition of catechin and bioactive compounds in testa-free and testa-containing kernels of cashew nuts, it was found that testa-containing kernels exhibited significantly higher levels of β-carotene (218 vs. 89.6 mg/kg DM), a-tocopherol (10.1 vs. 2.4 mg/kg DM), lutein (525 vs. 292 lg/kg DM), merely similar amounts of zeaxanthin (7.0 vs. 7.1 lg/kg DM), stearic acid (41 vs. 43 g/kg DM), c-tocopherol (10.6 vs. 10.1 mg/kg DM), linoleic acid (69 vs. 62 g/kg DM), and oleic acid (214 vs. 219 g/kg DM) and a lower concentration of thiamine (3.0 vs. 10.7 mg/kg DM) (Trox et al., 2011). Antioxidant activities and content of phenolic extract increased with increase in roasting temperature. The obtained results suggested that short time roasting at high temperature of 130 °C for 33 min had effectively enhanced the antioxidant activity of testa. The exposure has increased the total phenolic content, proanthocyanidins and enhances extract yield. Increasing temperature leads to increase in the content of flavonoids, namely, catechin, epicatechin, and epigallo catechin (Chandrasekara and Shahidi, 2011).

Testa is a waste but the tannin content grants it a reward of high value product, in ancient time tannin was used as a tanning agent. Incorporation of testa tannins in coating discourages corrosion. It has potential for development of thermostable eco-friendly compounds. Gallic acid obtained as an intermediate by-product, is useful for cancer studies (Viswanath et al., 2016). Testa was utilized as a better carbon source for efficient and economic tannase production via *Aspergillus niger* CEPC 11 in solid state fermentation (Pacheco et al., 2017; Viswanath et al., 2015). Cashew testa was successfully used as capping agent of silver nanoparticle which inhibits aggregation of silver nanoparticles. It provides yellow colour to colourless silver ions and confirms formation of silver nanoparticles. Intensity of yellow colour increases with reaction time thereby indicating the formation of nanoparticles (Edison et al., 2016). Testa was added as a feed alternative to wheat bran in gestating sow diet, where 6% testa showed no negative effects on performance of gestating sow but increasing levels of testa in diet decreases piglet and litter birth weight (Fang et al., 2018). Efficacy of testa tannins as a coagulant was assessed for suspended solids removal from a fibre-cement industry effluent. A series of flocculation experiments showed that cashew tannins have significant flocculation properties specifically at lower doses and alkaline conditions. Testa tannin has an optimum efficiency of 84 % for TSS removal (Nnaji et al., 2014).

2.4. Cashew nut shell liquid

Cashew nut shell liquid (CNSL) is a viscous greenish yellow to reddish brown colour liquid found in the soft honeycomb of cashew nut shell, a pericarp fluid of cashew nut (Gandhi et al., 2012). It is a renewable product produced as a by-product of the cashew nut processing in industry. CNSL constitutes about one third of total nut weight or 30–35 % of nut shell weight depending upon the extraction method. CNSL contains cardanol (3-pentadecenyl phenol), cardol (5-pentadecenyl resorcinol), anacardic acid (6-pentadecenyl salicylic acid) and 2-methyl cardol (2-methyl, 5-pentadecenyl resorcinol) as its major components (Fig. 1) (Mishra et al., 2018; Maia et al., 2015; Lubi et al., 2000; Lubi et al., 2006). Components of CNSL commonly bears hydrophobic side chains, which differ in the degree of unsaturation due to the presence of 5–8 % saturated, 48–49 % monoene, 16–17 % diene, and 29–30 % triene (Kim, 2010; Hamad et al., 2015).

For extraction of CNSL various methods viz. hot oil roasting, open pan roasting, drum roasting, solvent extraction, vacuum pyrolysis, cold extrusion, supercritical carbon dioxide-based extraction were employed and it was recorded that method of extraction strongly affects quality (in terms of composition) and quantity of CNSL. By employing cold extrusion method about 70 % anacardic acid, 18 % cardol, 5% cardanol, phenols and polar substances can be obtained (Patel et al., 2006; Smith et al., 2003). On the basis of chemical composition and employment of different methods of extraction, CNSL was classified into two types viz natural CNSL and technical CNSL. For extraction of natural CNSL mild treatments were applied utilizing solvent extraction techniques like supercritical carbon dioxide or subcritical water, commonly termed as Soxhlet extraction so the original composition of CNSL can be obtained undisturbedly. Natural CNSL comprises of anacardic acids 60–70 %, cardols 10–20 %, cardanols 3–10 %, 2-methylcardols 2–5 %, and other minor constituents. Technical CNSL is an economically feasible source of phenolic compounds for synthesizing phenol/formaldehyde polymers. Technical CNSL is chemically different from natural CNSL and mainly composed of cardanol 60–70 %, cardol 10–20 %, 2-methylcardol 2–5 %, polymeric materials 5–10 %, along with other minor constituents. For recovery of technical CNSL cashew nut shells are processed automatically by immersing cashew nutshells in CNSL and heating at $180-190\,^{\circ}C$, where anacardic acid undergoes decarboxylation reaction to produce cardanol (Lomonaco et al., 2017). CNSL has a huge potential of applicability in various fields including pharmaceuticals, like resins, coating and lining materials, laminates, adhesives, biofuel derivative, insecticide, and it can substitute fully for partially in new product development (Kim, 2010; Lubi et al., 2006). The detailed usage and applications of CNSL are discussed in further sections of this paper.

3. Cashew nut wastes-based biorefinery for value-addition and sustainable management

As discussed in the above sections, processing of cashew nuts produces a substantial amount of underutilized by-products consisting of cashew nut apple, cashew nutshell, cashew nut shell liquid, de-oiled cashew meal, rejected cashew nuts, testa, effluents, and residues. In view of their richness in organic nature and also due to presence of other nutrients, these could be effectively employed as substrate for the production of value-added products on the principles of biorefinery. This would also offer environmental sustainability and provide eventually social and economic gains for the industry. A scheme for the valorization of these by-products using biorefineries or stand-alone process could result in the production of several natural products such as bioethanol, methane (biogas), wine, vinegar, oligosaccharides, lactic acid, biosurfactants, etc. (Fig. 2). The leftover or waste generated through such biorefineries is again utilized in the recycling process to significantly reduce economic and environmental concerns with resource recovery strategies.

4. Value-added products from cashew nut by-products

4.1. Biofuel production and stabilization

4.1.1. Biodiesel preparation

CNSL is an economically viable natural substrate, over other contemporary resources for consideration as an alternate source of biofuel production (Vedharaj et al., 2016). Although there are some crops exclusively cultivated for biodiesel production like *Jatropha*. These crops faces severe criticism as leaves and seed husk posses hydrogen cyanide thus cannot be used as cattle feed and can be harmful to people associated with processing of seeds and in seed collection. These sources need high amount of energy for preparation of transesterified biodiesel and high processing cost, distillation step consumes more energy than obtained from product (Sanjeeva et al., 2014). CNSL being a richest source of phenolic content and a by-product from cashew industrial processing, can appropriately replace many of the crops (Lomonaco et al., 2017; Sanjeeva et al., 2014). As an ideal substrate CNSL is a renewable source that produces high cost food, blending of CNSL in commercial fuel improves fuel efficiency and reduces the toxic effects of fuel combustion on environment (Sanjeeva et al., 2014).

Pyrolysis of technical CNSL produces components with characteristics similar to diesel. Mannish base of cardanol formed by a reaction between amine of cardanol with formaldehyde and a carbon acid is responsible for fuel like properties of CNSL derivatives (Sanjeeva et al., 2014). The biodiesel obtained from CNSL does not require transesterification or any other further processing. Many investigators had examined the emissions and engine performance of diesel engines fuelled with biodiesels. Hence, Cashew nut oil can also be used as fuel in diesel engines (Nallusamy, 2015).

Pushparaj and Ramabalan (2013) studied the effect of blending ethanol as additive to CNSL biodiesel to check the feasibility of using fuel containing higher proportion of biodiesel in an unmodified diesel engine. Emission tests revealed about the influence of blends on composite emissions of carbon mono-oxide (CO), carbon dioxide (CO_2), oxides of nitrogen (NOX), hydrocarbon (HC), and smoke concentration. Exhaust gas emission test for 10 % ethanol blend shows reduction of 27 % CO_2 emission, 8 % HC emission and 57 % NOX emission.

Blending of up to 20 % unprocessed CNSL or distilled technical CNSL as a biofuel in diesel is advantageous over other biofuels, due to several reasons like elimination of transesterification, low cost of production, and low cost of substrate. When 20 % CNSL was used in a single cylinder diesel engine to test its efficacy at different fuel injection pressure such as 200 bar, 235 bar, 270 bar, and 300 bar, better performance than diesel engine was observed. The HC, CO, NOX, O_2, CO_2, and smoke were computed on the basis of ISO 8178 D2 standard test cycle, the results revealed CNSL blends to be a better fuel than diesel incompliance with the legislative norms. It was reported to furnish better cetane number, calorific value, sulphur content, and flash point than those of diesel fuel (Nallusamy, 2015). It mitigates the emission of greenhouse gases and other toxic gases in atmosphere thereby reducing environment pollution (Nallusamy, 2015; Vedharaj et al., 2015, 2016). DT-CNSL is a nonionic detergent which stabilizes triglycerides in diesel by increasing their solubility (Sanjeeva et al., 2014).

A blend of 20 % cardanol, 10 % methanol, and 70 % diesel (B20M10) was used as biofuel in a four-stroke single cylinder direct injection diesel engine and the effect of injection pressure (IP) on the performance, combustion, and emission characteristics were investigated against baseline diesel operating under standard conditions. The test result exhibited that at optimum biofuel injection pressure of 220 bar, there was a significant reduction in concentration of HC, CO, smoke emissions while concentration of NOX and brake thermal efficiency increases (Dinesha and Mohanan, 2015).

Mallikappa et al. (2012) compared the performance and emission characteristics of cardanol biofuel on three stationary diesel engines operated with 20 % cardanol bio fuel volumetric blends containing base fuel (Petro diesel). The cardanol biofuel volumetric blends has higher density, viscosity, flash and fire points of the blended fuel and lower calorific value in a range of 94–96 % to that of diesel. It was observed that malfunctioning of biofuel mixture can cause slight variations in NOX emissions from all 3 engines at 0% and 100 % load. It was noted that blending of ethanol with biofuel may reduce NOX emission, due to the cooling effect of ethanol. High temperatures and high NOX formation were resultant of the higher oxygen content of ethanol and higher fuel burning while premixed burning phase.

CNSL was subjected to thermal cracking process at different temperatures to produce thermal cracked cashew nut shell liquid (TC-CNSL) as biofuel. TC-CNSL was used as biofuel (B100) in a four stroke,

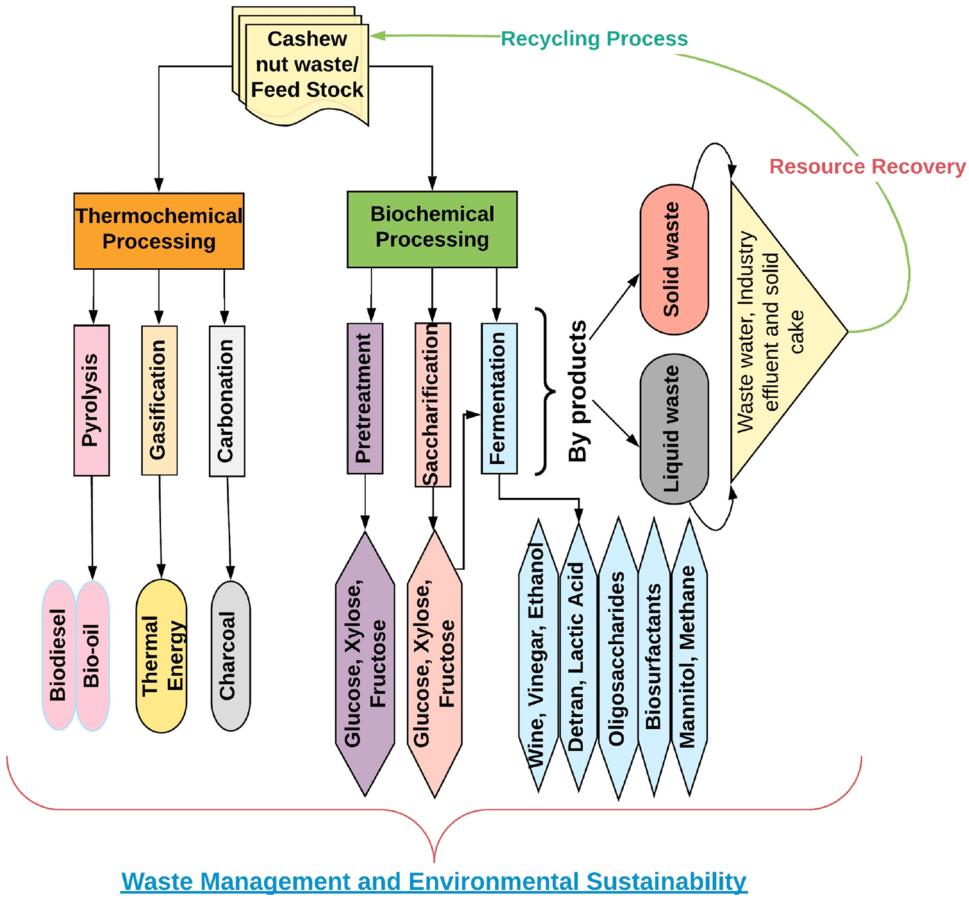

Fig. 2. Biorefinery scheme for the valorization of cashew nut processing wastes.

single cylinder, water cooled, DI, Kirloskar AV-1, type diesel engine at a speed of 1500 rpm. It was found that the HC, CO emissions, and brake thermal efficiency of B100 was lesser than neat diesel operation. B100 has higher specific fuel consumption, rates of pressure rise, heat release and NOX emission as compared to neat diesel (Velmurugan et al., 2014).

4.1.2. Bioethanol production

Cashew apples have drawn much attention of researchers due to its capability to synthesize both first and second generation fuel ethanol, which offers an alternative to fossil fuel (Candido et al., 2019). Cashew apple peduncle was processed in juice processing industry to produce cashew apple juice (CAJ) while around 20 % w/w of the total peduncle weight is wasted as cashew apple bagasse (CAB) (Rodrigues et al., 2011). CAJ has a hub of organic nutrients and minerals required for the growth of microorganisms such as sugar, iron, calcium, vitamin C, phosphorous, potassium, sodium etc. (Maruthai et al., 2012). CAB chiefly composed of cellulose, hemicellulose and lignin, which is usually discarded by local industries, and has essentially no commercial value. Only a small proportion of it is utilized by rural inhabitants in the production of homemade alcoholic beverages (Maruthai et al., 2012). CAB has emerged as a paradigmatic substrate for ethanol production, due to various factors like low cost, abundance in nature, lack of competence with food or feed applications and its ready availability in cashew apple facilities (Da Costa Correia et al., 2013; Rodrigues et al., 2011).

CAJ is fermented by strains of *Saccharomyces cerevisiae* in an immobilized system by utilizing CAB as a cheap matrix for immobilization of *S. cerevisiae* cells to produce ethanol. Immobilized cell system has several benefits for improving ethanol fermentation, with increase in process productivity and minimum production cost. It enhances efficiency and suitability of immobilized yeast cells for ethanol production due to higher cell densities which consequently increases reaction rates and productivity of ethanol. Due to shorter residence time in process a smaller size reactor can be employed. This process yields ethanol concentrations (about 19.82–37.83 g/L in average value) and ethanol productivities (about 3.30–6.31 g/L/h) with around 85.30–98.52 % efficiency (Pacheco et al., 2010). Fermentation of CAJ by yeast belonging to the genus *Hanseniaspora* at a pH range of 3.0–5.5 yielded a maximum ethanol production of 42 g/L and 0.44 g/g of product with approximate 96 % efficiency at 32 °C. CAJ as a medium produces higher yield, concentration, efficiency, and productivity of ethanol as compared to synthetic medium (Barros et al., 2014)

Cashew apple bagasse is a lignocellulosic material that appears to be a promising alternative raw material for bioethanol production. It can be converted into bioethanol by performing the following operations: pretreatment, hydrolysis, fermentation, and distillation (Da Costa et al., 2015). Microorganisms cannot readily act upon complex sugars like xylose present in CAB so conversion of complex sugar to simpler sugar is necessary. A number of treatments have been employed to rupture the recalcitrant structures of CAB. Microwave-assisted alkali pretreatment was employed with a treatment of microwave power at 600–900 W for 15–30 min pre-treatment time exhibited no significant effect on hydrolysis. Enzymatic hydrolysis of CAB with enzyme load of 30 FPU gCAB-M^{-1} shows improvement on solid percentage (16 % w/v) and increased glucose concentration to 15 g/L. Upon fermentation of the hydrolyzate by *Saccharomyces cerevesiae* a productivity of 1.41 g/L/h was obtained with a concentration of 5.6 g/L (Rodrigues et al., 2011).

In order to recover bioethanol CAB had undergone a series of teatment. CAB was slurried in diluted sulphuric acid (H_2SO_4) (0.8 mol/L) for hydrolysis, followed by washing with 100 mM citrate buffer until pH 4.5 to form CAB-H. Alkali treatment of CAB-H removes lignin content of CAB by mixing 4% NaOH (w/v) which produces CAB – OH. Saccharification of pretreated CAB-H and CAB – OH with 1.5 L of commercial enzyme celluclast (30 FPU/g bagasse) enhanced the availability of sugar and other nutrients in fermentable form. The fermentation of hydrolysate with *S. cerevisiae* produces ethanol yield of 0.38 and 0.47 g/g glucose with ethanol concentration of 20 g/L in 6 h of fermentation (Rocha et al., 2009).

CAB was treated with alkaline hydrogen peroxide to generate fermentable sugars by breaking the polymeric structures of lignin and carbohydrates, this further enhances the accessibility of enzymes to the solid substrate thus aiding in enzymatic hydrolysis. A combination and ratio of different enzymes including cellulase complex (NS22074), xylanase (NS22036), hemicellulase (NS22002) and β-glucosidase (NS50010) were assessed for the optimal conditions for hydrolysis of CAB. The simultaneous saccharification and fermentation (SSF) of the pure hydrolysate by *Kluyveromyces marxianus* ATCC 36,907 leads to production of 18 g/L ethanol concentration corresponding to 80 % yield and 74.2 kg/tonn CAB ethanol yield in a SSF process (Da Costa et al., 2015).

Genetically modified *S. cerevisiae* strains were exploited to produce bioethanol from CAB along with several other yeasts including several *Pichia* and *Candida* species as well as some strains of *Kluyveromyces marxianus*. *K. marxianus* CE025 was reported to consume both glucose and xylose therefore can emerge as a potent microorganism for ethanol production from liognocellulosic content carrying waste like CAB (Rocha et al., 2011). Fermentation of CAB by *Saccharomyces diasticus* yields maximum ethanol concentration of 15.3 g/L at 30 °C at 6.8 pH in 72 h (Maruthai et al., 2012). Second generation of bioethanol is produced by yeast *Hanseniaspora* sp. GPBIO03, isolated from CAJ, upon fermentation of CAB. This resulted in ethanol concentration of 24.37 g/L with a productivity of 4.87 g/L/h and 80.23 % efficiency in 5 h, at an optimum conditions of temperature from 28 to 36 °C and pH 3.0–5.5 (Barros et al., 2014).

4.2. Industrial applications

4.2.1. Coating and laminates

4.2.1.1. Surface coatings. Paint is a mixture of binders, solvent, and pigments which forms a protective or decorative film. Coating refers to the specialized or advance paint with a specific function which is more towards protection rather than its aesthetics. It comprises of lacquers, varnishes, powder, and enamels (Lubi and Thachil, 2000). On applying a liquid paint to surface, the vehicles (combination of volatile liquid and binder) volatile portion evaporates which leaves behind the combination of pigment and non-volatile binder (Candau and Ottewill, 1990). Although oil paints were superior to emulsions yet their increased use causes global warming as they generate volatile organic compounds (VOC). This warranted the need to explore alternate binders that exhibit better water solubility and good oil paint properties. People who were working with or come in contact with oil paints were reported to exhibit 20 % - 40 % increase in susceptibility for many cancer types especially lung cancer. There are very few reports indicating the application of cashew nut waste for their use in paints.

Onoja et al. (2019) collected polystyrene from Bauchi metropolis refused dump sites and purchase cashew nutshell from Tudu market Bauchi. They blended this polystyrene with different concentrations of cashew nutshell liquid leading to the formation of CNSL-PS that works as binder. They showed that in all the different concentrations of CNSL viz. 5, 10, 15, 20, 30 and 35 % the paint exhibited levelness and deeper colour. Among all the concentrations, 10 % CNSL was reported to be the optimum for furnishing best properties of the produced paint sample. This group showed that CNSL-PS binder used in emulsion paints exhibited better application performance viz. opacity, viscosity, adhesion, blistering, settling resistance, and flexibility than that of PS. Thus, suggesting CNSL-PS as economic and better alternative for preparing renewable binder used in emulsion paint production. 5% cardanol containing phenolic resins was used for coating of cans engaged in food packaging.

Combinations of Lac–CNSL were reported to exhibit properties that can be employed in surface coatings that offer weather resistance. This combination was also reported for application as metal primer which offers anticorrosive, solvent and water resistance properties (Lubi and Thachil, 2000). Water based coating material was prepared by treating the condensation product of HCHO phenol, and CNSL with bromoacetic or chloroacetic acid in alkaline environment followed by neutralization with an amine or ammonium hydroxide (Lubi and Thachil, 2000). Water-based paint can also be prepared by treating HCHO with CNSL, this was cross-linked by using maleic anhydride followed by neutralization by ammonia. CNSL – HCHO resins were used to formulate paints as oil-in-water type stable emulsions that are water based. Condensation products of CNSL – HCHO condensation products on reacting with chloroacetic or bromoacetic acid gives rise to water-based coating with chemical and hot water resistance (Lubi and Thachil, 2000).Nitric acid was used to oxidize CNSL in order to produce coatings of different colours which can air-dry very quickly. This was reported to be used in formulating varnishes, paints, woven fabrics, impregnating paper, electrical insulation, etc. (Jain and Shah, 1960). CNSL cured for 10 min at 150 °C produced most satisfactory coating. Addition of cobalt naphthenates, lead, and silico-chromates was found to enhance the corrosion resistance these materials act as fillers (Selvaraj, 1987; Lubi and Thachil, 2000).

4.2.1.2. Dye stuff. Since ancient times natural dyes have been used for different purposes including painting, food, coloration of clothing, leather tanning etc. These dyes were reported to be obtained from animal sources (cochineal and shellfish) or from vegetative plant parts (leaf, bark, root, flower and fruit). Synthetic substitute of dyes were first produced in mid 1800 and currently the market is dominated by these synthetic dyes owing to their easy, varied, and vast, production (Mahanta and Tiwari, 2005). Although the existence of synthetic dyes is very less than those of natural dyes yet they have been reported to cause serious concerns to both environment and human health. This led the path to follow green chemistry principle by preferentially utilizing natural dyes instead of synthetic ones (Patil et al., 2015).

Several researchers have reported the extraction of colorant or dyes from cashew plant parts viz. cashew testa, cashew fruits and CSNL (Balgude and Sabnis, 2014; Patil et al., 2015; Muhammadu et al., 2017). CSNL and its derivatives were reported to be an excellent raw material for colorant and dye preparation. Various cardanol based azo compound modified dyes were reported for use as colorant in plastic/polymer coating (Achary et al., 2012; Balgude and Sabnis, 2014). Cardanol in combination diamines and diazotized aromatic amines leads to synthesis of a novel bis (azo) dye. Because of the cardanol unit the dye was found to be effectively soluble in gasoline and many common organic solvents (83). Active dye constituents were also reported from cashew apple. Muhammadu et al. (2017) showed that distilled water was the most suitable solvent for extracting dyes from cashew apple. They reported three types of dyes from the fruit namely naphthaquinone, anthraqinone, and indigoid. The m-toluidine and aniline were used to prepare heterolepetic phenols viz. CBDFT and CBDFA dyes by utilizing cardanol as a scaffold. Interestingly, these dyes were reported to be good monomers when they acid-catalyzed with formaldehyde in azo group presence. The resulting resins further exhibit high temperature tolerance upto 400 °C (Mubofu, 2016).

4.2.2. Agriculture industry

4.2.2.1. Pesticides. Excessive use of synthetic pesticides is associated with serious health problems and environmental threats, so employment of biological pesticides like CNSL is an effective solution. Pesticides derived from CNSL can control pest and plant diseases. The active constituent of CNSL was reported to inhibit the growth of infestation causing insect and pest, thus present themselves as biological pesticides. Raja (2008) evaluated the effect of CNSL on pulse beetle (*Callosobruchus chinensis* L.) or bruchids on its ovipoisition discouragement and toxicity in blackgram (*Vigna mungo*) seeds and cowpea (*Vigna unguiculate*). It was found that CNSL exhibited both oviposition deterrence and toxic effect at a lower dosage of 4 mL/kg of pulse beetle seed by reducing adult emergence, egg laying potency and percentage of seed infestation, without affecting the germination capacity and seedling vigour seed during storage. CNSL produces comparable results to plant oils and chemicals. It was observed that CNSL treatment exhibits 92 % germination, which is similar to the effect of monocrotophs treatment on seeds (Raja, 2015).

Researchers investigated effect of pesticides on inhibition of increase in the growth of *Gliocladium* sp. and *Trichoderma* sp. mycelium using invitro method. The findings concluded that concentration of 2.5 % botanical pesticides from cashew shell could minimize mycelium of *Gliocladium* sp. and *Trichoderma* sp. by 21.04 % and 22.73 % respectively, along with an increase of cashew shells extract. Furthermore it was reported that natural pesticide at a concentration of 10.0 % exhibit inhibition of *Gliocladium* sp. and *Trichoderma* sp. mycelium become 49.35 % and 54.98 % respectively (Bande et al., 2018). Cashew shells extract at a concentration of 2.5 % was reported to control fruit rot diseases, 3.5 % concentration of this botanical pesticide controls growth of *Phytophthora palmivora* and reduces pot rot disease in cocoa plant by 87.67 %. An extract of 2.5 % cashew shell liquid was also reported to reduce pod rot diseases in cocoa plant by 64.16–71.02 %.

The crude extract of cashew nut shell exhibits fungi toxicity against *Coriolopsis polyzona, Pycnoporus sanguineus, Ganoderma lucidum* and *Lenzites palisoti* which are causative agents of wood decaying. When tested at different concentration, most of the levels of CNSL exhibited strong antifungal activity. As the concentration of CNSL increases, the rate of inhibition also increases and the best fungicidal effect was observed at a concentration of 1600 ppm. While at 800 ppm and 1200 ppm concentration a reduced radial growth was noticed (Adetogun and Adegeye, 2003). A mixture of CNSL crude extract with n-hexane was prepared and tested against Trametes cingulata and *Lentinus lepideus* and as a preservative for *Triplochiton scleroxylon* sapwood. It was reported that 16 % concentration of CSNL crude extract permit minimum fungal growth and this concentration was termed as killing point concentration. At the similar concentration, significant improvements in quality of wood on various parameters like radial compression and modulus of elasticity were observed. CSNL Crude extract can be used as wood preservative by controlling wood decaying pathogen basidiomycetes (Adeguton et al., 2010).

4.2.2.2. Larvicides. CNSL is a pool of biological and therapeutic properties, it was reported toxic or larvicidal against mosquitoes of the genus *Aedes*, thereby checks the transmission of epidemics like dengue fever, chikungunya fever, zika virus and diseases like lymphatic filariasis or elephantias (De Sousa Leite et al., 2019). CNSL is a natural larvicide so it can combat environment and human health associated threats caused due to excessive use of synthetic larvicides, namely organophosphates, organochlorines, diflubenzuron, and pyrethroids (cypermethrin and deltamethrin). Synthetic insecticides are endocrine-disrupting chemicals (EDCs) which showcase harmful effects on human and environmental health (Briou et al., 2019). These effects include disrupting reproductive and sexual development, male infertility, hormonal disorder, genetic/genomic instability leading to increased susceptibility to cancer, high prevalence of cryptorchidism and hypospadias (Vani et al., 2018).

LC50 value of technical CNSL was reported to be 51 ppm, while cardanol and cardol isolated from CNSL showed LC50 values of 32.9 and 14.2 ppm, respectively. Thus, Lomonaco et al. (2009) concluded that cardol is the primary constituent responsible for the larvicidal activity due to the presence of alkyl side chain that increases its passage through cell membrane via facilitating liposolubility. Cardol is a phenolic lipid, which is immisible in water. A number of formulations using cardol as active agent were designed which showed different toxicity. A formulation prepared by Farias et al. (2009) using sodium anacardate (obtained from natural CNSL) tested against *Ae. aegypti* larvae, showed an LC50 of 55.47 ppm. An emulsion of cardanol and liquid vegetable soap prepared and tested by Mukhopadhyay et al. (2010) against larvae of *Ae. aegypti* and larvae of the *Anopheles subpictus*, shows LC50 of 12 ppm and 38 ppm respectively, while an emulsion of natural CNSL and nut fruit soap (Sapindus rarak DC) extract prepared by Raraswati et al. (2014) to study larvicidal effect in the 3rd instar stage against *Ae. aegypti* presented LC50 of 14.12 ppm. It was reported that the mixture of CNSL and aqueous extract of Sapindus rarak DC exhibit larvicidal effect against Cx. Quinque-fasciatus where larva mortility, LC_{50} and LC_{90} value were 20 ppm,52 ppm and 5541 ppm respectively after 24 h of exposure (Fauziah et al., 2014; Farias et al., 2009; Vani et al., 2018).

Tensoativo do Liquido da Casca da Castanha do Caju (TaLCC-20) was prepared by blending CNSL: Castor oil in a ratio of 20:80, which was proven to be key alternative to commercial larvicides with most promising properties it was most effective at a concentration of 0.2 ppm which kills 97 % larvae in 24 h of exposure. It is found that 5 mg/mL of TaLCC-20 killed 100 % of larvae in 3 h, these results are comparable to gold standard of Ministry of Health. TaLCC-20 does not induce any genetic damage (Vani et al., 2018). Being a natural component, CNSL can minimize harms associated to population and the environment. CNSL is considered a viable alternative to commercially available synthetic larvicides that are toxigenic (Vani et al., 2018).

4.2.2.3. Anti-termite properties. CNSL was reported to exhibit anti-termite properties due to the presence of cardol and anacardic acid which causes high mortality in termites (Asogwa et al., 2007). CNSL successfully replaced hazardous chemicals thereby had reduced the burden of hazardous chemicals like cypermethrin, aldrin, permethrin, bifenthrin, fenvalerate, fenitrothion, chlorpyrifos, imidacloprid, copper naphthenate, heptachlor, boric acid and chlordane etc. These chemicals were reported to exhibit deleterious impact on non-targeted biotic and abiotic factors of environment. These harmful chemicals are banned in developed countries like US and other European countries, but developing countries are still using them (Kamble et al., 2017; Karak et al., 2014; Asogwa et al., 2007).

CNSL based termiticide along with chlorpyrifos has shown camparable results in termite control as copper naphthenate and boric acid (Kamble et al., 2017). Toxicity of CNSL had also been reported to be improved with AS2O3 or boric acid to enhance efficacy of termicide (Lubi et al., 2000). CNSL is nontoxic and is present in abundance in nature therefore substitution of CNSL in commercial termiticides can significantly reduce the cost of termiticide along with reduction in unregulated and indiscriminate usage of hazardous chemicals in termite control in various fields (Kamble et al., 2017).

4.3. Pharmaceuticals

By-products of cashew processing have proven them as a repository of functional compounds with medicinal properties and hold tremendous potential to cure a wide spectrum of diseases (Table 2). Although these by-products are inedible in nature yet they were reported to be used in traditional medicines in continents like South America, Africa, and Asia for decades. CNSL was reported to be used as an astringent, anti-inflammatory, anti-diarrheal, antibacterial, antioxidant, anti-asthmatic, depurative and tonic medication in folk medicines to cure a number of ailments including diabetes, skin infections, cracks on feet soles, cancer, dental hypersensitivity, wounds and warts (De Sousa Leite et al., 2019; M and Rathinasamy, 2017). CNSL exhibited immunoprotective and anti-inflammatory properties due to its phenolic lipids content thus exhibiting a rapid and effective activity for treatment of inflammation by suppressing the expression of the TNF-α, NF-

Table 2
Bioactive compounds obtained from cashew nut waste processing.

Substrate	Bioactive compound obtained	Biological application	Reference
Cashew nut shell liquid, Cardanol	3-Vinylphenol, Norfenefrine, Metaraminol, Etilefrine, Fenoprofene, Racemic phenylephrine	Neurotransmitter, anti-hypotensive sympathomimetic, vasoconstrictor, mydriatic, cardiotonic, cardiac stimulant, and nonsteroidal anti-inflammatory drug (NSAID)	Shi et al., 2019
Cashew nut shell liquid, unsaturated cardanol	Cardanol-methacrylate-epoxy (CNME)	Desensitizing agent	Moreira et al., 2018
Cashew nut shell liquid, anacardiaceae extract	Polyphenols (cardol/cardanol)	Crosslinking (biomodification) agents for dentine bond	Moreira et al., 2017
Purified cashew nut shell liquid	Anacardic acid, Cardol, Cardanol and Methyl cardol	Anti-cancer, anti-bacterial and wound healing activity viz. curing skin infections, heal and sole cracks of feet	M and Rathinasamy, 2017
Cashew nut shell liquid	Polyphenols like anacardic acids and their semi-synthetic derivatives (benzyl amines)	Anti-bacterial, anti-tumor, and antioxidant activities	Hamad and Mubofu, 2015
Cashew leaves	Dichloromethane extract of cashew leaves	Analgesic effect	De Sousa Leite et al., 2016
New leaves of cashew tree	Boiled extract of cashew leaves	Wound healing property	
Cashew leaves	Aqueous extract of cashew leaves (β-ocimene, α-copaene and δ-cadienol)	Hypoglycaemic activity	
Cashew stem bark	Sisterol, alkaloids, tannins and anacardic acids	Anti-inflammatory, anti-genotoxic activity and antinociceptive effects	
Cashew nut shell liquids, Cardanol	Phenolic compounds (Anacardic acid, Cardanol, Cardol, and 2-methyl Cardol)	Insecticidal, larvicidal, anti-acetylcholinesterase, anti-inflammatory, antioxidant, anxiolytic, antibacterial. Treatment of chronic and degenerative diseases like cancer, cardiovascular and neurodegenerative diseases.	De Sousa Leite et al., 2019

κB, COX-2, iNOS, IL-1β and IL-6 inflammatory genes (De Sousa Leite et al., 2019). Cardanol, anacardic acid, and methylcardol content of CNSL inhibits the proliferation of HeLa cells by causing mitotic bock, spindle abnormality and apoptosis, also accelerates wound closure in L929 cells (Ashraf and Rathinasamy, 2018). Benzyl amine derived from anacadic acid fraction of CNSL makes it a potent antibacterial agent against gram positive bacteria. It was reported 2048 times more effective against *Streptococcus mutans* strain ATCC 25,175 and 64 times more effective against *Staphylococcus aureus* strain ATCC 12,598 than activity of salicylic acid and has shown comparable activity with standard ciprofloxacin on *S. aureus* (Hamad and Mubofu, 2015). Purified CNSL was reported to produce clear zone of inhibition in concentration dependent manner against *Bacillus subtilis* (Ashraf and Rathinasamy, 2018).

Cardanol, a component of CNSL was reported to be modfied in high-value medicinal drugs like norfenefrine, rac-phenylephrine, etilefrine and fenoprofene by undergoing a series of catalytic reactions. Hydroxyamination of 3-vinylphenol, an intermediate compound with iron porphyrin catalyst produces norfenefrine. Norfenefrine is an adrenergic agent used as a sympathomimetic drug, acts as a minor neurotransmitter, and regulates blood pressure in acute hypotensive states. Methylation and ethylation of norfenefrine produces rac-phenylephrine and etilefrine respectively. Phenylephrine is a sympathomimetic, mydriatic, vasoconstrictor and cardiotonic agent, used as decongestant, pupil dilator, vasopressor in the treatment of hemorrhoids and priapism, to dilate the pupil or to increase the blood pressure. Etilefrine is a cardiac stimulant, used as an antihypotensive agent. Fenoprofene is a further synthesized drug as a result of C—O coupling, isomerising metathesis and selective methoxycarbonylation. Fenoprofen is a nonsteroidal antiinflammatory drug (NSAID) sold in USA market as Nalfon, effective for the treatment of fever, pain and swelling caused by inflammation (Shi et al., 2019).

CNSL have significant capabilities to aid in dentin biomodification by improving the dentin collagen, mechanical properties, stiffness of the adhesive interface, protection of collagen fibrils from biodegradation and by promoting collagen crosslinking. Industrial CNSL mainly composed by cardanol (70 %) and cardol. The long carbon-chain phenols obtained from the industrial extraction of cashew nut shell liquid (CNSL) with antioxidant, and enzyme inhibitory potential along with two hydroxyls groups in p-position in cardol aids in dentin biomodification (Moreira et al., 2017; Maia et al., 2012). Cardanol-methacrylate-epoxy (CNME) synthesized through epoxidation of CNSL followed by methacryloyl chloride esterification, significantly reduces dentine permeability and it uniforms occluded surface even after acid exposure, which makes it a suitable acid-resistant treatment option for dentin hypersensitivity (Moreira et al., 2018).

5. Production of Biocomposites from cashew nut by-products

5.1. Adhesives

CNSL because of its renewable nature, high polarity, inherent tackiness of phenolic materials and ease of liquid-to-solid conversions is an advantageous starting material for adhesive formulation (Lubi and Thachil, 2006). CNSL has emerged as a natural substrate for manufacturing of adhesives with superior water resistance and shear strength. A lot many of studies have been performed on elucidating the efficacy of CNSL as adhesive material and effect of bending other materials on the rheological properties of the adhesive formed. CNSL resin adhesive with formaldehyde (HCHO) reveals shear thickening properties by relaxation in a couette viscometer and penetrometry studies (Lubi et al., 2000). CNSL, Xylol and HCHO were condensed in the presence of catalysts and hardeners to produce adhesives. By incorporating colloidal polymers having considerable amount of hydroxyl groups, the hardness of CNSL-based adhesives can be increased noticeably. Adhesive made from CNSL–aldehyde resins mixed with tannin aldehyde resin and tamarind seed powder as a filler was reported to exhibit controlled flow properties. Phosphorylation of CNSL enhances its adhesive properties by five folds therefore contributing towards better adhesive properties as compared to CNSL – HCHO resin.

CNSL was also used for synthesis of heat and pressure sensitive adhesive which is now used for sticking reflectors as well as for bonding rubbers to fibres (Lubi et al., 2000). CNSL based adhesive can do wonders in timber industry, CNSL–xylene – HCHO based adhesive was used for manufacturing of particle board as a wood substrate from agriculture waste like coconut fibres. Fireproof particle boards were prepared with addition of borax in CNSL adhesive. Fireproof plywood adhesive was prepared by incorporating ammonium phosphate, and ammonium dihydrogen phosphate or diammonium hydrogen phosphate in CNSL – HCHO. High quality plywood adhesive was prepared by oxidation of CNSL with KMnO4 or MnO2 at 100 °C, reacting with HCHO and compounding with $CuCl_2$ (Lubi et al., 2000).

CNSL-phenol formaldehyde resin based cold settling wood adhesive containing 10–12 para-toluenesulfonic acid as a hardener was proposed to be an excellent choice over synthetic adhesive. By impregnating low-grade wood species in CNSL resin quality of wood species was upgraded. Not only plywood or particle boards adhesive but exterior-grade plywood adhesives have also been developed from CNSL. Water proof adhesive has also been developed using red onion skin extract and HCHO resins modified with CNSL which yielded wood adhesives with better water resistance and shear strength that can easily replace PhOH – HCHO adhesives as a moisture-proof adhesive (Lubi et al., 2000).

In the USA, the California Air Resources Board (CARB) enacted regulations that regulate formaldehyde emissions from wood-based panels of flooring, plywood and fancy veneers. The CNSL-formaldehyde (CNSLF) resin was used to replace urea-formaldehyde resin in the formaldehyde-based resin system in order to reduce formaldehyde and volatile organic compound emissions from the adhesives used between the plywood and fancy veneers. It has better bonding strength and wood penetration than commercial natural tannin adhesive. The CNSLF resin coating satisfied the E1 and E0 grades of the Korean Standard therefore, this environmental friendly adhesive of surface bonding is a suitable material for manufacturing engineered flooring (Kim, 2010).

CNSL based adhesives are capable to bind other object like metals. Phenolic resin based on CNSL can be employed in formulation of adhesives CNSL-based resin is an effective adhesive for strongly bonding aluminium to aluminium. 3-aminopropyl triethoxysilane was added to improves the shear and peel strength of adhesives used for bonding metal-to-metal. CNSL is cheap and renewable therefore, can partially be used for adhesive manufacturing (Lubi and Thachil, 2006). Adhesive developed from polymerized CNSL–furfural–furfural alcohol mixtures was reported to be used as binders for heat exchangers made from carbon plates. It has been proposed that casein or gelatinous materials like animal glue, blood and egg, albumin, etc based adhesives can also be prepared by using CNSL (Lubi et al., 2000).

5.2. Resins and rubbers

CNSL is an excellent alternative to diminishing petrochemical reserves for synthetic resins manufacturing due to the presence of different phenolic components. Derivatives of CNSL have immense potential to be used widely in rubber compounding. CNSL is a biomonomer with outstanding application in thermosetting polymer formulation (Srivastava et al., 2018). CNSL and CNSLF resin were also reported to impose modification of tensile strength and elongation at break of natural rubber vulcanizate. This modification can lead to improvement of physico-mechanical properties and plasticization effect of rubber (Menon et al., 2002). Phosphorylated cashew nut shell liquid (PCNSL) is a prepolymer that aids in improvement of processability and physico-mechanical properties of natural rubber as a multifunctional additive. PCNSL can function as multifunctional additive due to hydrophilic phosphate group and hydrophobic aliphatic side chain (Menon et al., 2002).

Cardanol, an alkyl phenol component derived from CNSL, reacts with formaldehyde by condensation polymerization to form cardanol–formaldehyde (CF) resins. CF resins have special qualities like high-temperature resistance, high surface hardness, resistance to chemicals and detergents, modulus retention at elevated temperatures, and low cost. This made CF a desirable material for preparing thermosetting or thermoplastic resins with reactants. Cardanol forms soft resin at higher temperature because it possess long aliphatic side chains which imparts flexibility by diminishing the polar effect of phenolic resin while CF resins are hard in nature (Chuayjuljit et al., 2007). Acid-catalyzed reaction of 1 mol of formaldehyde with 1 mol of cardanol yields novolak, a two-step thermoplastic resin, while base-catalyzed reaction of less than 1 mol of formaldehyde/mol of cardanol reveals resole type resin (Hu et al., 2013; Chuayjuljit et al., 2007; Srivastava et al., 2018). Substitution of phenol–formaldehyde novolak resins in natural rubber (NR) vulcanizates as reinforcing fillers in place of carbon black and silica, improves mechanical properties of rubber products. CF-resin filled rubbers showed higher compression set and hardness, with increasing reinforcing filler load the hardness values of rubber increases and the resilience of the natural rubber reduces due to interaction between the rubber and filler molecules. Rubber produced by filling CF-novolak resin possesses higher hardness than the CF-resole resin filled rubbers because novolak forms stiffer crosslinks (Chuayjuljit et al., 2007). Novolac resins were further modified by epoxidation with epichlorohydrin to duplicate the performance of epoxy resins. These epoxy resins are brittle in nature therefore in order to overcome this problem liquid rubbers such as carboxyl- and amine terminated butadiene acrylonitrile rubber (CTBN and ATBN) were blended to epoxy resin. Further substitution of these resins to natural rubber greatly improves toughness of the rubber formulation (Srivastava et al., 2018). With these capabilities CNSL can emerge as a potent renewable raw material for biopolymer production and can be a solution to the deterioration of environment due to accumulation of non-biodegradable solid waste. It is a cheaper biomaterial which could be used as a fine substitute for existing thermosetting materials (Srivastava et al., 2018).

6. Conclusion

Primary product of cashew crop processing yield cashew nuts which is a highly nutritive profile providing all essential amino acid. Residues of cashew nut processing is although a waste material yet holds immense potential to produce a number of high-end products like adhesives, ethanol, pharmaceuticals, diesel etc. They can easily replace synthetic components with natural substitutes thereby reduces health and environment related issues. Cashew nut shell liquid, cashew apple bagasse, and testa can emerge as a natural source for obtaining high end products. The multiverse application of cashew nut by-products warrants more detailed investigations into their applicability in diverse fields.

Declaration of Competing Interest

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

CRediT authorship contribution statement

Poonam Sharma: Literature survey, Data curation and Writing - original draft. **Vivek K Gaur:** Literature survey, Data curation, Formal analysis, and Writing - original draft. **Ranjna Sirohi:** Literature survey, Data curation and Writing - review & editing. **Christian Larroche:** Methodology, and Writing - review & editing. **Sang Hyoun Kim:** Methodology, Validation, and Writing - review & editing. **Ashok Pandey:** Conceptualization, Supervision, Writing - review & editing and Validation.

Acknowledgements

The authors do not receive any financial support for the publication of this article. This manuscript bears CSIR-IITR communication number 3636.

References

Achary, P.G.R., Namita, M., Guru, B.N., Pal, N.C., 2012. Synthesis and thermal degradation study of polymer blends from polyurethanes of linseed oil and cardanol based dyes with aminophenols. J. Chem. Pharm. Res. 4 (3), 1475–1485.

Adetogun, A.C., Adegeye, O.A., 2003. In vitro evaluation of cashew nut shell liquid (CNSL) as a fungicide against wood rotting basidiomycetes. Moor J. Agric. Res. 4 (1), 131–134.

Akande, T.O., Akinwumi, A.O., Abegunde, T.O., 2015. Cashew reject meal in diets of laying chickens: nutritional and economic suitability. J. Anim. Sci. Technol. 57 (1), 17.

Araújo, S.M., Silva, C.F., Moreira, J.J.S., Narain, N., Souza, R.R., 2011. Biotechnological process for obtaining new fermented products from cashew apple fruit by *Saccharomyces cerevisiae* strains. J. Ind. Microbiol. Biotechnol. 38 (9), 1161–1169.

Aroyeun, S.O., 2009. Utilization of cashew kernel meals in the nutritional enrichment of biscuit. Afr. J. Food Sci. 3 (10), 316–319.

Ashraf, M.S., Rathinasamy, K., 2018. Antibacterial and anticancer activity of the purified cashew nut shell liquid: implications in cancer chemotherapy and wound healing. Nat. Prod. Res. 32 (23), 2856–2860.

Asogwa, E.U., Mokwunye, I.U., Yahaya, L.E., Ajao, A.A., 2007. Evaluation of cashew nut shell liquid (CNSL) as a potential natural insecticide against termites (soldiers and workers castes). Res. J. Appl. Sci. 2 (9), 939–942.

Balgude, D., Sabnis, A.S., 2014. CNSL: an environment friendly alternative for the modern coating industry. J. Coat. Technol. Res. 11 (2), 169–183.

Bande, L.O.S., Gusnawaty, H.S., Trisulpa, L., 2018. Botanical pesticides effect from shells of bean's cashew nut on biological agents of *Trichoderma* sp. And gliocladium sp. In IOP Conference Series. February. Earth Environ. Sci. Trans. R. Soc. Edinb. 122 (1), 012047 IOP Publishing.

Barros, E.M., Rodrigues, T.H.S., Pinheiro, A.D.T., Angelim, A.L., Melo, V.M.M., Rocha, M.V.P., Gonçalves, L.R., 2014. A yeast isolated from cashew apple juice and its ability to produce first-and second-generation ethanol. Appl. Biochem. Biotechnol. 174 (8), 2762–2776.

Benjamin, S., Pandey, A., 1997. Coconut cake–a potent substrate for the production of lipase by *Candida rugosa* in solid-state fermentation. Acta Biotechnol. 17 (3), 241–251.

Briou, B., Caillol, S., Robin, J.J., Lapinte, V., 2019. Non-endocrine disruptor effect for cardanol based plasticizer. Ind. Crops Prod. 130, 1–8.

Candau, F., Ottewill, R.H., 1990. Scientific Methods for the Study of Polymer Colloids and Their Applications. Kluwer Academic, pp. 303.

Candido, R.G., Mori, N.R., Gonçalves, A.R., 2019. Sugarcane straw as feedstock for 2G ethanol: evaluation of pretreatments and enzymatic hydrolysis. Ind. Crops Prod. 142, 111845.

Chandrasekara, N., Shahidi, F., 2011. Antioxidative potential of cashew phenolics in food and biological model systems as affected by roasting. Food Chem. 129 (4), 1388–1396.

Chuayjuljit, S., Rattanametangkool, P., Potiyaraj, P., 2007. Preparation of cardanol–formaldehyde resins from cashew nut shell liquid for the reinforcement of natural rubber. J. Appl. Polym. Sci. 104 (3), 1997–2002.

Correia, S.D.J., David, J.P., David, J.M., 2006. Secondary metabolites from species of *Anacardiaceae*. Quã¯â¿â½mica Nova 29 (6), 1287–1300.

Da Costa, J.A., Marques Jr., J.E., Gonçalves, L.R.B., Rocha, M.V.P., 2015. Enhanced enzymatic hydrolysis and ethanol production from cashew apple bagasse pretreated with alkaline hydrogen peroxide. Bioresour. Technol. 179, 249–259.

Da Costa Correia, J.A., Júnior, J.E.M., Gonçalves, L.R.B., Rocha, M.V.P., 2013. Alkaline hydrogen peroxide pretreatment of cashew apple bagasse for ethanol production: study of parameters. Bioresour. Technol. 139, 249–256.

Da Silva, I.M., Rabelo, M.C., Rodrigues, S., 2014. Cashew juice containing prebiotic oligosaccharides. J. Food Sci. Technol. 51 (9), 2078–2084.

De Abreu, F.P., Dornier, M., Dionisio, A.P., Carail, M., Caris-Veyrat, C., Dhuique-Mayer, C., 2013. Cashew apple (*Anacardium occidentale* L.) extract from by-product of juice processing: a focus on carotenoids. Food Chem. 138 (1), 25–31.

De Sousa Leite, A., Islam, M.T., Júnior, A.L.G., e Sousa, J.M.D.C., de Alencar, M.V.O.B., Paz, M.F.C.J., Rolim, H.M.L., de Medeiros, M.D.G.F., de Carvalho Melo-Cavalcante, A.A., Lopes, J.A.D., 2016. Pharmacological properties of cashew (*Anacardium occidentale*). Afr. J. Biotechnol. 15 (35), 1855–1863.

De Sousa Leite, A., Islam, M.T., Paz, M.F.C.J., Júnior, A.L.G., da Silva Oliveira, G.L., Cito, A.M.D.G.L., de Carvalho Melo, A.A.A., Lopes, J.A.D., 2019. Cytogenotoxic and mutagenic profiling of cashew nut shell liquids and cardanol. Clin. Phytoscience 5 (1), 37.

Dinesha, P., Mohanan, P., 2015. A study of the effect of injection pressure on the combustion, performance, and emission characteristics of cardanol biofuel blend fuelled compression ignition engine. Asia-pacific J. Chem. Eng. 10 (1), 56–64.

Donkoh, A., Attoh-Kotoku, V., Osei Kwame, R., Gascar, R., 2012. Evaluation of nutritional quality of dried cashew nut testa using laboratory rat as a model for pigs. The Scientific World Journal 2012.

Edison, T.N.J.I., Atchudan, R., Sethuraman, M.G., Lee, Y.R., 2016. Reductive-degradation of carcinogenic azo dyes using *Anacardium occidentale* testa derived silver nanoparticles. J. Photochem. Photobiol. B, Biol. 162, 604–610.

Fan, L., Pan, H., Soccol, A.T., Pandey, A., Soccol, C.R., 2006. Advances in mushroom research in the last decade. Food Technol. Biotechnol. 44 (3).

Fang, L.H., Hong, Y.G., Hong, J.S., Jeong, J.H., Han, Y.G., Kwon, I.H., Kim, Y.Y., 2018. Effects of cashew nut testa levels as an alternative to wheat bran in gestating sow diets. Asian-australas. J. Anim. Sci. 31 (6), 881.

Farias, D.F., Cavalheiro, M.G., Viana, S.M., De Lima, G.P., Da Rocha-Bezerra, L.C.B., Ricardo, N.M., Carvalho, A.F., 2009. Insecticidal action of sodium anacardate from Brazilian cashew nut shell liquid against *Aedes aegypti*. J. Am. Mosq. Control Assoc. 25 (3), 386–389.

Fauziah, R.S., Sudarsono, S., Mulyaningsih, B., 2014. Larvicidal activity of the mixture of cashew nut shell liquid (CNSL) and aqueous extract of *Sapindus rarak* DC against larvae of *Culex quinquefasciatus*. Biol. Med. Nat. Prod. Chem. 3 (1), 21–23.

Fernandes, D.R., Freitas, E.R., Watanabe, P.H., Filgueira, T.M.B., Cruz, C.E.B., do Nascimento, G.A.J., Aguiar, G.C., Nascimento, E.R.M., 2016. Cashew nut meal in the feeding of meat quails. Trop. Anim. Health Prod. 48 (4), 711–717.

Gandhi, T., Patel, M., Dholakiya, B.K., 2012. Studies on effect of various solvents on extraction of cashew nut shell liquid (CNSL) and isolation of major phenolic constituents from extracted CNSL. Nat. Prod. Plant Resour 2, 135–142.

Hamad, F.B., Mubofu, E.B., 2015. Potential biological applications of bio-based anacardic acids and their derivatives. Int. J. Mol. Sci. 16 (4), 8569–8590.

Hu, L., Zhou, Y., Liu, R., Zhang, M., Yang, X., 2013. Synthesis of foaming resol resin modified with oxidatively degraded lignosulfonate. Ind. Crops Prod. 44, 364–366.

Hu, Y., Shang, Q., Tang, J., Wang, C., Zhang, F., Jia, P., Feng, G., Wu, Q., Liu, C., Hu, L., Lei, W., 2018. Use of cardanol-based acrylate as reactive diluent in UV-curable castor oil-based polyurethane acrylate resins. Ind. Crops Prod. 117, 295–302.

Jain, N.C., Shah, R.S., 1960. Research and Ind. 5 (4), 94–95.

Kamble, K.J., Thakor, N.J., Sonawane, S.P., Sawant, A.A., 2017. Development of cashewnut shell liquid based termiticides by using chemicals. International Journal of Engineering Technology Science and Research 4 (10), 2394–3386.

Karak, T., Sonar, I., Paul, R.K., Das, S., Boruah, R.K., Dutta, A.K., Das, D.K., 2014. Composting of cow dung and crop residues using termite mounds as bulking agent. Bioresour. Technol. 169, 731–741.

Kim, S., 2010. The reduction of formaldehyde and VOCs emission from wood-based flooring by green adhesive using cashew nut shell liquid (CNSL). J. Hazard. Mater. 182 (1-3), 919–922.

Kim, J.S., 2015. Production, separation and applications of phenolic-rich bio-oil–a review. Bioresour. Technol. 178, 90–98.

Kubo, I., Masuoka, N., Ha, T.J., Tsujimoto, K., 2006. Antioxidant activity of anacardic acids. Food Chem. 99 (3), 555–562.

Lomonaco, D., Santiago, G.M.P., Ferreira, Y.S., Arriaga, Â.M.C., Mazzetto, S.E., Mele, G., Vasapollo, G., 2009. Study of technical CNSL and its main components as new green larvicides. Green Chem. 11 (1), 31–33.

Lomonaco, D., Mele, G., Mazzetto, S.E., 2017. . Cashew nutshell liquid (CNSL): from an agro-industrial waste to a sustainable alternative to petrochemical resources. Cashew Nut Shell Liquid. Springer, pp. 19–38.

Lubi, M.C., Thachil, E.T., 2000. Cashew nut shell liquid (CNSL)-a versatile monomer for polymer synthesis. Des. Monomers Polym. 3 (2), 123–153.

Lubi, C.M., Thachil, E.T., 2006. Studies on metal-to-metal adhesives based on CNSL resins. Polym. Technol. Eng. 45 (1), 43–48.

Luz, D.A., Rodrigues, A.K.O., Silva, F.R.C., Torres, A.E.B., Cavalcante Jr, C.L., Brito, E.S., Azevedo, D.C.S., 2008. Adsorptive separation of fructose and glucose from an agroindustrial waste of cashew industry. Bioresour. Technol. 99 (7), 2455–2465.

Mahanta, D., Tiwari, S.C., 2005. Natural dye-yielding plants and indigenous knowledge on dye preparation in Arunachal Pradesh, northeast India. Curr. Sci. 1474–1480.

Maia, F.J.N., Ribeiro, V.G.P., Lomonaco, D., Luna, F.M.T., Mazzetto, S.E., 2012. Synthesis of a new thiophosphorylated compound derived from cashew nut shell liquid and study of its antioxidant activity. Ind. Crops Prod. 36 (1), 271–275.

Maia, F.J.N., Ribeiro, F.W.P., Rangel, J.H.G., Lomonaco, D., Luna, F.M.T., de Lima-Neto, P., Correia, A.N., Mazzetto, S.E., 2015. Evaluation of antioxidant action by electrochemical and accelerated oxidation experiments of phenolic compounds derived from cashew nut shell liquid. Ind. Crops Prod. 67, 281–286.

Mallikappa, D.N., Reddy, R., Murthy, C.S., 2012. Performance and emission characteristics studies on stationary diesel engines operated with cardanol biofuel blends. International Journal of Renewable Energy Research (IJRER) 2 (2), 295–299.

Maruthai, K., Thangavelu, V., Kanagasabai, M., 2012. Statistical screening of medium components on ethanol production from cashew apple juice using *Saccharomyces diasticus*. International Journal of Chemical and Biological Engineering 6, 108–111.

Mattison, C.P., Cavalcante, J.M., Gallão, M.I., de Brito, E.S., 2018. Effects of industrial cashew nut processing on anacardic acid content and allergen recognition by IgE. Food Chem. 240, 370–376.

Melo, M.L.P., Maia, G.A., Silva, A.P.V., Oliveira, G.S.F., Figueiredo, R.W., 1998. Chemical composition of the raw and toasted cashew nut (*Anacardium occidentale* L.). Ciencia e Tecnologia de Alimentos 18 (2), 184–187.

Menon, A.R.R., Aigbodion, A.I., Pillai, C.K.S., Mathew, N.M., Bhagawan, S.S., 2002. Processability characteristics and physico-mechanical properties of natural rubber modified with cashewnut shell liquid and cashewnut shell liquid–formaldehyde resin. Eur. Polym. J. 38 (1), 163–168.

Mishra, V., Desai, J., Patel, K.I., 2018. (UV/Oxidative) dual curing polyurethane dispersion from cardanol based polyol: synthesis and characterization. Ind. Crops Prod. 111, 165–178.

Mitchell, D.A., Pandey, A., Sangsurasak, P., Krieger, N., 1999. Scale-up strategies for packed-bed bioreactors for solid-state fermentation. Process. Biochem. 35 (1-2), 167–178.

Moreira, M.A., Souza, N.O., Sousa, R.S., Freitas, D.Q., Lemos, M.V., De Paula, D.M., Maia, F.J.N., Lomonaco, D., Mazzetto, S.E., Feitosa, V.P., 2017. Efficacy of new natural biomodification agents from *Anacardiaceae* extracts on dentin collagen cross-linking. Dent. Mater. 33 (10), 1103–1109.

Moreira, M.M., da Silva, L.R.R., Mendes, T.A.D., Santiago, S.L., Mazzetto, S.E., Lomonaco, D., Feitosa, V.P., 2018. Synthesis and characterization of a new methacrylate monomer derived from the cashew nut shell liquid (CNSL) and its effect on dentinal tubular occlusion. Dent. Mater. 34 (8), 1144–1153.

Mubofu, E.B., 2016. From cashew nut shell wastes to high value chemicals. Pure Appl. Chem. 88 (1-2), 17–27.

Mubofu, E.B., Mgaya, J.E., 2018. Chemical valorization of cashew nut shell waste. Top. Curr. Chem. 376 (2), 8.

Muhammadu, A.B., Muhammadu, H.B., Okoro, E.S., 2017. Characterisation of colourant extracted from riped cashew fruits. Niger. J. Chem. Res. 22 (2), 20–30.

Mukhopadhyay, A.K., Hati, A.K., Tamizharasu, W., Babu, P.S., 2010. Larvicidal properties of cashew nut shell liquid (*Anacardium occidentale* L) on immature stages of two mosquito species. J. Vector Borne Dis. 47 (4), 257.

Nallusamy, S., 2015. Experimental analysis of emission characteristics using CNSL biodiesel in dual fuel mode. Pollution Research 34 (4), 721–726.

Nnaji, N.J.N., Ani, J.U., Aneke, L.E., Onukwuli, O.D., Okoro, U.C., Ume, J.I., 2014. Modelling the coag-flocculation kinetics of cashew nut testa tannins in an industrial effluent. J. Ind. Eng. Chem. 20 (4), 1930–1935.
Nobre, A.C.D.O., De Almeida, Á.S.S.D., Lemos, A.P.D., Magalhães, H.C.R., Garruti, D.D.S., 2015. Volatile profile of cashew apple juice fibers from different production steps. Molecules 20 (6), 9803–9815.
Onoja, A., Adamu, H.M., Jauro, A., 2019. Production of emulsion paint using polystyrene waste/cashew nutshell liquid copolymer as a binder compiled. International Journal of Research and Innovation in Applied Science 4 (5).
Pacheco, A.M., Gondim, D.R., Gonçalves, L.R.B., 2010. Ethanol production by fermentation using immobilized cells of *Saccharomyces cerevisiae* in cashew apple bagasse. Appl. Biochem. Biotechnol. 161 (1-8), 209–217.
Pacheco, G., Nogueira, C.R., Meneguin, A.B., Trovatti, E., Silva, M.C., Machado, R.T., Ribeiro, S.J., da Silva Filho, E.C., Barud, H.D.S., 2017. Development and characterization of bacterial cellulose produced by cashew tree residues as alternative carbon source. Ind. Crops Prod. 107, 13–19.
Paebumrung, P., Petsom, A., Thamyongkit, P., 2012. Cardanol-Based Bis (azo) dyes as a gasoline 91 colorant. J. Am. Oil Chem. Soc. 89 (2), 321–328.
Pandey, A., Soccol, C.R., 2000. Economic utilization of crop residues for value addition: a futuristic approach. J. Sci. Ind. Res. 59, 12–22.
Patel, R.N., Bandyopadhyay, S., Ganesh, A., 2006. Extraction of cashew (*Anacardium occidentale*) nut shell liquid using supercritical carbon dioxide. Bioresour. Technol. 97 (6), 847–853.
Patil, P.D., Rao, C.R., Wasif, A.I., Anekar, S.V., Nagla, J.R., 2015. Cashew-nut husk natural dye extraction using Taguchi optimization: green chemistry approach. J. Sci. Ind. Res. (India) 74, 512–517.
Pimentel, P.G., Pereira, E.S., Queiroz, A.C.D., Mizubuti, I.Y., Regadas Filho, J.G.L., Maia, I.S.G., 2011. Intake, apparent nutrient digestibility and ingestive behavior of sheep fed cashew nut meal. Rev. Bras. Zootec. 40 (5), 1128–1133.
Pushparaj, T., Ramabalan, S., 2013. Green fuel design for diesel engine, combustion, performance and emission analysis. Procedia Eng. 64, 701–709.
Rabelo, M.C., Fontes, C.P., Rodrigues, S., 2009. Enzyme synthesis of oligosaccharides using cashew apple juice as substrate. Bioresour. Technol. 100 (23), 5574–5580.
Raja, K., 2008. Toxicity and oviposition deterrency of cashew nut shell liquid (CNSL) on pulse beetle in blackgram seeds. Seed Sci. Technol. 36 (1), 210.
Raja, K., 2015. Comparative performance on insecticidal and oviposition deterrence of cashew nut shell liquid (CNSL) on bruchids (*Callosobruchus chinensis* L.) in cowpea (Vigna unguiculata (L.) Walp.) seed. Journal of Biopesticides 8 (2), 147.
Raraswati, G.R., Sudarsono, S., Mulyaningsih, B., 2014. Larvicidal activity of a mixture of cashew nut shell liquid and water-soluble extract of soap nut fruit (*Sapindus rarak* DC.) against 3rd instar larvae of *Aedes aegypti*. Biol. Med. Nat. Prod. Chem. 3 (2), 53–57.
Reis, C.L.B., e Silva, L.M.A., Rodrigues, T.H.S., Félix, A.K.N., de Santiago-Aguiar, R.S., Canuto, K.M., Rocha, M.V.P., 2017. Pretreatment of cashew apple bagasse using protic ionic liquids: enhanced enzymatic hydrolysis. Bioresour. Technol. 224, 694–701.
Rocha, M.V.P., Rodrigues, T.H.S., de Macedo, G.R., Gonçalves, L.R., 2009. Enzymatic hydrolysis and fermentation of pretreated cashew apple bagasse with alkali and diluted sulfuric acid for bioethanol production. Appl. Biochem. Biotechnol. 155 (1-3), 104–114.
Rocha, M.V.P., Rodrigues, T.H.S., Melo, V.M., Gonçalves, L.R., de Macedo, G.R., 2011. Cashew apple bagasse as a source of sugars for ethanol production by Kluyveromyces marxianus CE025. J. Ind. Microbiol. Biotechnol. 38 (8), 1099–1107.
Rodrigues, T.H.S., Rocha, M.V.P., de Macedo, G.R., Gonçalves, L.R., 2011. Ethanol production from cashew apple bagasse: improvement of enzymatic hydrolysis by microwave-assisted alkali pretreatment. Appl. Biochem. Biotechnol. 164 (6), 929–943.
Sabu, A., Sarita, S., Pandey, A., Bogar, B., Szakacs, G., Soccol, C.R., 2002. Solid-state fermentation for production of phytase by *Rhizopus oligosporus*. Appl. Biochem. Biotechnol. 102 (1-6), 251–260.
Sanjeeva, S.K., Pinto, M.P., Narayanan, M.M., Kini, G.M., Nair, C.B., SubbaRao, P.V., Pullela, P.K., Ramamoorthy, S., Barrow, C.J., 2014. Distilled technical cashew nut shell liquid (DT-CNSL) as an effective biofuel and additive to stabilize triglyceride biofuels in diesel. Renew. Energy 71, 81–88.
Scaldaferri, C.A., Pasa, V.M.D., 2019. Green diesel production from upgrading of cashew nut shell liquid. Renewable Sustainable Energy Rev. 111, 303–313.
Selvaraj, M., 1987. Paintindia 37 (7), 19–22.
Sharma, P., Gaur, V.K., Kim, S.H., Pandey, A., 2020. Microbial strategies for bio-transforming food waste into resources. Bioresour. Technol. 299, 122580.
Shi, Y., Kamer, P.C., Cole-Hamilton, D.J., 2019. Synthesis of pharmaceutical drugs from cardanol derived from cashew nut shell liquid. Green Chem. 21 (5), 1043–1053.
Silva, J.S., Mendes, J.S., Correia, J.A.C., Rocha, M.V.P., Micoli, L., 2018. Cashew apple bagasse as new feedstock for the hydrogen production using dark fermentation process. J. Biotechnol. 286, 71–78.
Smith Jr., R.L., Malaluan, R.M., Setianto, W.B., Inomata, H., Arai, K., 2003. Separation of cashew (*Anacardium occidentale* L.) nut shell liquid with supercritical carbon dioxide. Bioresour. Technol. 88 (1), 1–7.
Srivastava, K., Rathore, A.K., Srivastava, D., 2018. Studies on the structural changes during curing of epoxy and its blend with CTBN. Spectrochim. Acta A. Mol. Biomol. Spectrosc. 188, 99–105.
Stasiuk, M., Kozubek, A., 2010. Biological activity of phenolic lipids. Cell. Mol. Life Sci. 67 (6), 841–860.
Trox, J., Vadivel, V., Vetter, W., Stuetz, W., Kammerer, D.R., Carle, R., Scherbaum, V., Gola, U., Nohr, D., Biesalski, H.K., 2011. Catechin and epicatechin in testa and their association with bioactive compounds in kernels of cashew nut (*Anacardium occidentale* L.). Food Chem. 128 (4), 1094–1099.
Vani, J.M., Monreal, M.T.F.D., Auharek, S.A., Cunha-Laura, A.L., de Arruda, E.J., Lima, A.R., da Silva, C.M., Antoniolli-Silva, A.C.M.B., de Lima, D.P., Beatriz, A., Oliveira, R.J., 2018. The mixture of cashew nut shell liquid and castor oil results in an efficient larvicide against *Aedes aegypti* that does not alter embryo-fetal development, reproductive performance or DNA integrity. PLoS One 13 (3).
Vedharaj, S., Vallinayagam, R., Yang, W.M., Chou, S.K., Chua, K.J.E., Lee, P.S., 2015. Performance emission and economic analysis of preheated CNSL biodiesel as an alternate fuel for a diesel engine. Int. J. Green Energy 12 (4), 359–367.
Vedharaj, S., Vallinayagam, R., Yang, W.M., Saravanan, C.G., Roberts, W.L., 2016. Synthesis and utilization of catalytically cracked cashew nut shell liquid in a diesel engine. Exp. Therm. Fluid Sci. 70, 316–324.
Velmurugan, A., Loganathan, M., Gunasekaran, E.J., 2014. Experimental investigations on combustion, performance and emission characteristics of thermal cracked cashew nut shell liquid (TC-CNSL)–diesel blends in a diesel engine. Fuel 132, 236–245.
Viswanath, V., Leo, V.V., Prabha, S.S., Prabhakumari, C., Potty, V.P., Jisha, M.S., 2015. Biosynthesis of tannase from cashew testa using *Aspergillus niger* MTCC5889 by solid state fermentation. J. Food Sci. Technol. 52 (11), 7433–7440.
Viswanath, V., Leo, V.V., Sabna Prabha, S., Prabhakumari, C., Potty, V.P., Jisha, M.S., 2016. Thermal properties of tannin extracted from *Anacardium occidentale* L. Using TGA and FT-IR spectroscopy. Nat. Prod. Res. 30 (2), 223–227.