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Review Article

Phytochemistry of sugarcane: An updated review

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ABSTRACT

Sugarcane, commonly known as noble cane, due to its high sucrose content and low fiber content is one of the important industrial crops of the world. Along with its industrial importance, sugarcane is also widely known for its medicinal purpose. The present review incorporates the exhaustive compilation of phytochemical nature of the different parts of the sugarcane plant (leaves, stalks, and roots). The phytochemical profile of sugarcane and its various products has revealed the presence of various fatty acid, alcohol, phytosterols, higher terpenoids, flavonoids, -O- and -C-glycosides, and phenolic acids. In addition to the Phytochemistry, this review also includes the medicinal benefits of the sugarcane plant parts.

Keywords: Sugarcane, *Saccharum officinarum*, sugar, stalk, juice, roots

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INTRODUCTION

Sugarcane (*Saccharum officinarum Linn*.) is a common and ancient crop known to man. The Saccharum is derived from the Greek word 'Sakcharon,' which means sugar principally sucrose [1]. Besides sugar production, large number of population in the tropics and subtropics enjoy its juice, and consume raw cane [2].

It is the primary raw material for the sugar industry as 70% of the world's sugar is obtained from sugarcane [3,4]. Sugarcane also becomes a major source of raw materials for other allied group of by-product industries. Acknowledgement of sugarcane as an important energy crop was recently intensified with the introduction of significant sugarcane-based ethanol production from molasses and cellulose [5]. The important by-products of this industry are acetic acid, butanol, paper, plywood, and industrial enzymes [4].

Sugarcane plays an important role in the economy of sugarcane growing areas [6]. In India, many sugar divisions have transformed themselves into Sugar-Agro industrial multiplexes which produce a variety of chemicals and utility products from sugarcane [7]. Sugarcane has been discovered as an alternative bio-fuel source to conventional petroleum fuels that further leads to global warming [8]. The high efficiency of sugarcane in fixing CO_2 into carbohydrate for conversion into biofuel has awakened the world's interest in the crop [9].

Sugarcane has been used in different parts of the world for the treatment of various diseases [1]. Some native and traditional naturopaths of the world have suggested sugarcane juice for its diuretic property. It is believed that consistent consumption of sugarcane juice will keep the urinary flow clear and fast [1,10,11]. Sometimes sugarcane juice is given with lime juice and ginger juice for better results [1]. It is also used as aphrodisiac, laxative, cooling, demulcent, antiseptic, and tonic [12]. It is considered advantageous for the liver and is recommended that jaundice patients should take sugarcane juice in a considerable amount for immediate relief [11]. The assumptions of the traditional Indian medicinal systems have been backed by modern pharmacological studies, which have shown that sugarcane has various biological activities like anti-inflammatory, analgesic, antihyperglycemic, diuretic, anti-stress, anti-cancer, and hepatoprotective effects [1].

Taking into consideration, the huge amount of crop is generated every year, it is necessary to make maximum use of the crop. Therefore, in the present study, we have tried to summarize the phytochemical profile and pharmacological characteristics of sugarcane and its products.

TAXONOMICAL CLASSIFICATION [1,13]:

Kingdom: Plantae – Plants
Subkingdom: Tracheobionta – Vascular plants
Superdivision: Spermatophyta – Seed plants
Division: Magnoliophyta – Flowering plants
Class: Liliopsida – Monocotyledons
Subclass: Commelinidaess
Order: Cyperales
Family: Poaceae – Grass family
Subfamily: Panicoideae
Tribe: Andropogoneae
Genus: *Saccharum* L. – sugarcane
Species: *Saccharum officinarum* L. – sugarcane

BOTANICAL DESCRIPTION OF SUGARCANE PLANT:

Sugarcane is a tropical and perennial grass. It forms lateral shoots at the base to produce multiple stems typically 3 to 4 m (10 – 13 Ft.) high and about 5 cm in diameter [14]. The stems grow into cane stalks, which when mature constitute around 75% of the entire plant. A mature stalk is typically composed of 11- 16% fiber, 12-16% soluble sugar, 2-3% non-sugar, and 63-73% water [15].

It has a thick longitudinal stalk, which is generally three to five meters in height, approximately 5 cm in diameter, and is characterized by its sweet taste due to its high sucrose content [16]. The sugarcane crop grows well in tropical and subtropical regions [17]. It will require well-drained soil of pH 7.5 - 8.5 and high organic matter, along with a hot and humid environment [16].

A sugar cane crop is sensitive to the climate, soil type, irrigation, fertilizers, insect's disease control varieties, and harvest period [18]. The average yield of cane stalk varies between 30 and 180 tons/ hectare/year, depending on crop management and knowledge used in sugarcane cultivation [19]. Sugarcane is a cash crop, but is also used as life stalk fodder [6].

PLANT PARTS OF SUGARCANE:

1. *The Stalk:* The sugarcane crop is reproduced by vegetative propagation. It is propagated by stem cuttings, containing one or more buds [20]. It is composed of a series of nodes and internodes. During a certain periods, each node has a leaf and a bud is usually found in its axil [21]. The basic chemical constituents present in the stalk of the sugarcane are cellulose, hemicellulose, and lignin [22].

2. *The Leaf:* The leaves are usually attached to parts of sugarcane node [23, 24]. Parts of sugarcane stalk are attached alternately to the nodes, thus forming two ranks on opposite sides [24]. The leaves constitutes of the large vascular bundles which are typically surrounded by two bundle sheaths, an outer chlorenchymatous bundle sheath and an inner mestome sheath [25].Sugarcane leaves consists approximately 30.79% hemicellulose, 40.84% cellulose and 25.80% lignin on dry solid basis. It has the potential to serve as a low cost feedstock for production of value added products like ethanol, xylitol, organic acids, etc. [26].

3. ***The Roots*****:** Sugarcane root systems are usuallycharacterized as the ones comprising highly branched superficial roots, and intenselyprobing agglomerations of vertical roots which arealso known as rope roots. There is little information available on the root system of sugarcane, but it has been reported that the root system is not completely replaced when ratooning occurs [27].

PHYTOCHEMICAL PROFILE OF SUGARCANE PLANT PARTS:

Physically, sugarcane constitutes four major fractions, whose quantity depends on the sugar agro industrial process: fiber, nonsoluble solids, soluble solids, and water [28]. The fibres are extracted from the sugarcane bagasse obtained from the stalk [29]. The nonsoluble solids, or the fraction that cannot be dissolved in water, which includes mainly inorganic substances such as rocks, soil, and extraneous materials, and they are greatly influenced by the conditions of the agricultural cane processing, types of cutting, and harvesting [30]. Soluble solid fractions that can be dissolved in water are composed primarily of sucrose as well as other chemical components such as waxes, in a smaller proportion [31]. Lignocellulosic components are chemically constituted by cellulose, hemicelluloses, and lignin. Cellulose is a linear polymer of glucose units linked with β (1 → 4)-glycosidic bonds, forming cellobiose that is repeated several times in its chain. This cellulosic fraction can be converted into glucose by enzymatic hydrolysis with the help of cellulases, or by performing chemical reactions, using acids like sulfuric acid, that can subsequently be fermented to ethanol [32,33]. Hemicellulose is a heteropolysaccharide composed by hexoses, pentoses, acetic acid, D-glucuronic acid and 4- O-methyl-D-glucuronic acid units. The hemicelluloses are classified basically according to the sugars that are present in the main chain of the polymer: xylan, glucomannan, and galactan [34]. The hemicellulose differs substantially of cellulose to be amorphous, which make it easier to be hydrolysed than cellulose [35]. The hemicellulosic fraction can be removed from lignocellulosic materials by methods like acid or hydrothermal hydrolysis [36,37].

Lignin is a complex aromatic macromolecule which is formed by radical polymerization of three phenyl-propane alcohols, namely p-coumarilic, coniferilic, and synapilic. In the plant cell wall, lignin and hemicelluloses involve the cellulose elementary fibrils, providing protection against chemical and/or biological degradation [38]. The content of lignin and its distribution are the responsible factors for catalysing lignocellulosic materials to enzymatic hydrolysis, limiting the accessibility of enzyme, and the process of delignification can improve the conversion rates of enzymatic hydrolysis [39]. The lignin is primarily used as a fuel, but it can be chemically modified to be used as chelating agent [40], for removal of heavy metals from wastewater [41], or as precursor material for production of add-value products as activated carbon [42].

CHEMISTRY OF SUGARCANE STALK:

The two main components obtained from sugarcane stalk are sugarcane wax and sugarcane juice.

Sugarcane wax is an important component of the stalk. Sugarcane wax appears as a cuticle layer of whitish to yellow powdery deposit on the surface of stalks and leaves of sugarcane [43-45]. It is necessary to study sugarcane wax when reviewing the phytochemical profile of sugarcane because of its widespread industrial application, and cosmetic and pharmaceutical interest [46]. Sugarcane wax is a potential substitute for the expensive carnauba wax. The amount of wax in sugarcane varies, generally between 0.1 and 0.3% [47,48].

It has been reported that methanol extracted fraction accounts for the 10% of crude wax. It is made up of fatty acid esters, pentacyclic triterpenoids, sterols, free fatty acids, triterpenes, and methyl and ethyl fatty acid esters. The presence of palmitic acid isopentyl ester (1.5%) was also detected. Odd and even carbon numbered n-alkanes in the C20–C29 ranges were found, with a large amount of heptacosane. In addition, minor amounts of branched alkanes were detected. Phytosterols such as b-sitosterol, stigmasterol, and campesterol were also found. Odd carbon-numbered n-alkanes ranging from C25 to C35 were found in isooctane extracted fraction. A large predominance of Octacosanol (C28) was also observed [49].

Sugarcane wax is used as a commercial source of long chain fatty alcohols, acids, esters, aldehydes, and ketones. Policosanols and D-003 along with some steroids and terpenoids have also been identified and isolated from sugarcane wax [50]. Policosanol is widely known to have beneficial effects on human health [51]. Policosanols are a mixture of long chain primary aliphatic alcohols such as Octacosanol, tetracosanol, hexacosanol, heptacosanol, nonacosanol, triacontanol, dotriacontanol, tetratriacontanol ranging from 2.5 – 80%. Octacosanol constitutes 50 – 80% of the total policosanols [50]. Other major pharmacologically active components of sugarcane wax are long chain aliphatic fatty acids are hexacosanoic acid, heptacosanoic acid, octacosanoic acid, nonacosanoic acid, triacontanoic acid, hentriacontanoic acid, dotriacontanoic acid, tritriacontanoic acid, pentatriacontanoic acid, hexacotriacontanoic acid. (9 – 18) present at lower concentrations. The mixture of these acids is known as D-003 [52]. Although fatty acid and fatty alcohols such as Hexacotracontanoic acid, stigmasterol, tetracosanol, hexacosanoic acid, heptacosanoic acid are reported as major constituents [53-57], various phytosterols such as stigmasterol, betasitosterol, campesterol, brassicasterol, steroids such as 24-methylcholest-3,6-dione, 24-ethylcholest-3,6-dione, 24-ethylcholest-22-en-3,6-dione, 6-hydroxycampest-4-en-3-one, 6-hydroxystigmast-4-en-3-one, 6-hydroxystigmast-4,22-dien-3-one and higher terpenoids such as arundoin and saw amilletin have also been reported in sugarcane wax [58,59].

Sugarcane juice is the first raw material which is used for the manufacturing of sugar and other various products like brown sugar, jaggery, and molasses [60]. Even though these products are prepared from the same raw material, their methods of manufacturing are various. The reports show the presence of some phenolic compounds, which enhance the nutritional and medicinal value of the by-products obtained from sugarcane juice[61]. Sugarcane juice is relished as a refreshing drink as it is nutritious and rich in vitamins, carbohydrates, and amino acids[62]. Sugarcane juice basically comprises 70 – 75% water, 13 – 15% sucrose, and 10 – 15% fiber. Several coloured components were identified in 1971, namely chlorogenic acid, cinnamic acid, and flavones being some of them [61]. Following that, all the coloured components from sugarcane juice were classified into four major classes: Plant pigments, polyphenolic compounds, caramels, and degradation products of sugars condensed with amino derivatives [63]. Sugarcane juice was then extensively studied for their flavonoid content. Thereafter, a large number flavonoids, some of them being, 6-hydroxycampest-4-en-3-one, 6-hydroxystigmast-4-en-3-one, 6-hydroxystigmast-4, 22-dien-3-one were isolated and identified [64-66]. High-Performance Liquid Chromatography with Diode-Array Detection (HPLC-DAD) analysis of phenolic compounds from sugarcane juice showed the presence of phenolic acids such as hydroxycinnamic acid, sinapic acid, and caffeic acid, and flavones, namely, apigenin, luteolin, and tricin. Among all the flavones present in the sugarcane juice, tricin derivative named arundoin is found in highest concentration [67]. Four new minor flavones namely swertisin, tricin-7-O-neohesperoside-4'-O-rhamnoside, tricin-7-O-methylglucuronate-4'-O-rhamnoside, and tricin-7-O-methylglucuronide were also isolated and identified from sugarcane juice [68]. Some novel acylated flavone glycosides, namely, tricin-7-O-β- (6'-methoxycinnamic) -glucoside, luteolin-8-C-rhamnosyl glucoside, and tricin-4'-O-(erthroguaicylglyceryl) -ether and orientin were isolated from sugarcane juice [69].

CHEMISTRY OF SUGARCANE LEAVES:

The percentages of potassium, nitrogen, silicon, and phosphorus in sugarcane leaf decrease quite noticeably during the first one to four months of cane growth, all nutrients, except potassium and silicon, decrease only slightly as the plant ages. The chemical composition of a leaf changes as it grows older. The concentration of potassium and nitrogen decreases, apparently due to migration of these elements into the stalk as the leaf grows older. On the other hand, a prominent accumulation of silicon takes place and calcium and magnesium also accumulate in the aging leaves. The behaviour of phosphorus appears indeterminate. A further important point, made by various workers, quoted by van Dillewijn, is that the composition of trash and green leaves differs significantly. Green leaves contain a much higher percentage of nitrogen and potassium and sometimes phosphorus than trash. This suggests that a considerable proportion of nitrogen and potassium in the leaves translocate to the stem, before the leaves die [70].

Sugarcane leaves are also a significant source of various policosanols and D-003, due to the presence of a thick coating of sugarcane wax on their surface. Besides policosanols and D-003 fatty acids, sugarcane leaves are also reported to have some phenolic compounds like flavonoids. Various flavones such as O and C glycosides, diosmetin-8-C-glucoside, tricin-7-O-neohesperoside, vitexin, orientin, luteolin-8-C-rhamnosyl glucoside, tricin-4'-O-(erthroguaicylglyceryl) ether were identified by performing HPLC micro fractionation of Methanolic extract of sugarcane leaves [1].

The calorific value of dry sugarcane leaves is 3500-4196 Kcal/kg. Dry sugarcane leaves contain 27.64% cellulose, 11.95% lignin and 19.15% hemicellulose [71].

CHEMISTRY OF ROOTS:

The literature survey revealed that roots are mostly unexplored with respect to quantitative determination of phytoconstituents. The few reposts suggested the presence of phenolic acids, and anthocyanins in roots [72].

CHEMISTRY OF SUGARCANE PRODUCTS:

Chemistry of various sugarcane products like mill syrups, brown sugar, molasses, and non-centrifugal sugar was also extensively studied [73]. In addition to some known compounds of sugarcane juice, three new flavonoid glycosides, and tricin7-(2’ -rhamnosyl) -α-galacturonide, orienstin-7, 3’ -dimethyl ether, and iso-orientin-7, 3’ -O-dimethyl ether, were isolated and identified from mill syrups [74]. Molasses have also been studied for their anti-oxidant activity of polyphenolic content [75]. One novel O-glycoside namely, dehydroconiferylalcohol-9’-O-β-D-glucopyranoside along with the already reported isoorientin-7, 3’-O-dimethyl ether was isolated as antibacterial compounds from sugarcane molasses [76]. Liquid chromatography-mass spectrometry (LC-MS) analysis of aqueous and dichloromethane extracts of brown sugars confirmed the presence of various phenolic acids such as p-hydroxy benzoic acid, ferulic acid, syringic acid, vanillic acid, p-coumaric acid. In addition to phenolic acids, eight major volatile constituents such as 1-methyl-2-pyrolidinone, 2, 3-butanediol, 4-hydroxybenzaldehyde, benzyl alcohol, syringaldehyde, dimethylsulphoxide, benzophenone were also reported to be present in brown sugars. A comparative study of polyphenolic compounds in various sugarcane products indicated that molasses were the richest source of phenolic acids as compared to clear juices and syrup [77].

PHARMACOLOGICAL ACTIVITY:

Sugarcane contains various phytoconstituents such as phenolic compounds, plant sterols, and policosanols. Phenols help in the natural defence of plants against pests and diseases. Plant sterols and policosanols are the components of wax and plant oils. The phytochemicals have gained increased interest due to their antioxidant activity, cholesterol-lowering properties, and other potential health benefits.

Analgesic and Anti-inflammatory activity: A mixture of fatty acids, isolated and purified from sugarcane wax was studied. The main constituents of the mixture were 9-octadecanoic, hexadecanoic, 9, 12-octadecanoic. The results suggested that the mixture of fatty acids exerts anti-inflammatory and anti-nociceptive effects on all the models tested [78]. Ethanol extracts (95%) of both fresh leaves and stalks of sugarcane were studied. The extract of sugar cane leaves was found to be active against benzoyl peroxide-induced writhing and tail-flick response, whereas, an ethanol extract of stalks was found to be active only against the tail-flick method [79].

Anti-hepatotoxic activity: Sugarcane juice was found to be efficient for partial reduction of isoniazid induced liver damage, when administered to mice. Several researchers have reported the relation of liver damage by isoniazid to the reactive oxidative effects of its metabolites such as acetylhydrazine. Extracts from sugarcane have been reported to possess antioxidants and exhibit potent effects against hepatotoxicity induced by oxidative stress [80,81]. Bioactivity of tricin along with apigenin and luteolin has been proposed to be synergistic or additive in sugarcane juice [81]. It has been reported that sugarcane juice significantly lowers the raise in aminotransferases and alkaline phosphatase levels, which show the functional status of the liver [80]. The aqueous extract of dried stems was found to be active against chloroform-induced hepatotoxicity [1].

Anti-hyperglycaemic activity: The ethanol extract of both dried leaves and stems when administered to rabbits, it is reported that the extract of leaves produced weak activity against alloxan-induced hyperglycaemia, while the juice of dried stems also exhibited hypoglycaemic activity [82]. The α-amylase and α-glucosidase inhibitory activities of sugarcane and molasses were measured to assess their antihyperglycaemic potential. In contrast, molasses exhibited a higher α-glucosidase inhibitory activity than sugarcane likely because of its considerably higher total phenolic content. Another major compound found in molasses, which acts synergistically with luteolin is gentisic acid, which exhibits α-amylase and α-glucosidase inhibitory activities [63].

Anti-fibrotic activity: The protective effect of the sugarcane polyphenol extract (SPE) on carbon tetrachloride-induced liver fibrosis in rats was studied. The results suggested that SPE improves the serum GOT (glutamic oxaloacetic transferase) and GPT (glutamic pyruvate transaminase) levels whereas decreases the expression of α-smooth muscle actin (α-SMA) in liver tissues [83].

Anti- oxidative activity: Sugarcane juice is a rich source of antioxidants and it efficiently protects plasmid DNA as well as enhanced the *E. coli* survival on irradiation. The total phenolic and flavonoid contents in sugarcane juice were found to be directly proportional to their antioxidant effects.
The antioxidant capacities of sugarcane juice and molasses were studied using 2,2-Diphenyl-1-picrylhydrazyl free radical-scavenging ability (DPPH) and Trolox equivalent antioxidant capacity (TEAC) radical scavenging assays. Reports suggested that sugarcane and molasses exhibited notable DPPH radical scavenging activities. Their antioxidant activities were attributed to the presence of flavonoid conjugates (i.e., apigenin, luteolin, and tricin derivatives) [84].

Another antioxidant model, the ferric reducing antioxidant power (FRAP) assay, is widely used to determine the antioxidant potentials of plant extracts. FRAP assay works on the basis of electron-donating abilities. Similar to their radical scavenging rates, sugarcane, and molasses showed appreciable antioxidant effects [63].

Effect of sugarcane juice on lipid profile, liver enzymes, and sex hormones: Sugarcane juice improved lipid profile, but had no substantial effect on liver enzymes, testosterone, and estradiol when studied in male rats [85].

Anti- stress activity: Oral intake of non-centrifuged sugarcanewas reported to produce potent anti-stress effects in humans. Phenolic compounds detected in the non-sugar component fractions contribute to the anti-stress property of Kokuto. [86].

Anti-cancer activity: Invitro antiproliferative activity of crude extract of sugarcane peel was performed by MTT assay. After treatment with extracts for 24 hours, the cells lost their surface morphology and died at a concentration of 50%. The study confirms the invitro antiproliferative activity of sugarcane peel extracts against the HT29 cell line. Sugarcane peel extracts inhibit HT-29 colon cancer cell growth even at lower concentration [87].

Anti-lithiatic activity: The ethanol extract of roots of sugarcane was found to possess anti-lithiatic activity [88].

Anti-hypercholesterolemic effect: The anti-hypercholesterolemic effect of policosanols was studied in New Zealand rabbits. Results showed that there was a significant decrease in the level of total cholesterol and low density lipoprotein cholesterol (LDL-C) in a dose-dependent manner. The serum triglyceride level was also reduced, but the reduction observed was not dose-dependent. The high-density lipoprotein level remained unchanged [89].

Anti-atherosclerotic activity: The activity of policosanols was examined for prevention of atherosclerosis in male New Zealand rabbits. Policosanol-treated rabbits did not develop marked hypercholesterolemia and the intima thickness was also significantly less compared to the control animals [90].

Antithrombotic activity: Policosanols and D-003 were examined for their platelet aggregation and antithrombotic activity in rats. The study showed a significant rise in the plasma level of 6 keto-PGF1-α (a stable metabolite of prostacyclin PGI (2) as compared to the control group. Furthermore, D-003 also significantly reduced the thromboxane, TxB (2), plasma levels and weight of venous thrombus in collagen-stimulated whole blood of rats [91]. The effect of D-003 was studied on platelet aggregation in hypercholesterolemic patients. D-003 inhibited AA- and collagen-induced platelet aggregation in hypercholesterolemic patients and was found to be well tolerated [92].

CONCLUSION

Sugarcane is an important crop in India and is cultivated due to the economical and medicinal value of its high yielding products. Sugarcane juice is well known as a raw material for the production of refined sugar and is globally consumed for its health benefits. Sugarcane wax is considered as a potential substitute for the expensive carnauba wax, which is of cosmetic and pharmaceutical interest. Refined sugar is the primary product of sugarcane juice, but during its processing, various other valuable products are also obtained in an unrefined form, such as, brown sugar, molasses, and jaggery. In this study, an attempt is made to review the potential of sugarcane and its by-products.The recent phytochemical and pharmacological reports on the sugarcane crop and its products suggested that the by-products obtained from sugarcane were equally important. The phytochemical profile of sugarcane revealed the presence of various fatty acids, alcohols, phytosterols, higher terpenoids, flavonoids, and phenolic acids.

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