



## A Review of the Phytochemistry and Pharmacology of *Eleusine coracana* Linn (Poaceae): A Popular Nigerian Edible Grain

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### ABSTRACT

Since ancient times, plants have been used in the management of various disease conditions worldwide. They are known to be rich in secondary metabolites which are responsible for the therapeutic effects they exhibit. Scientists worldwide have long discovered the possibility of discovering newer, effective and affordable drugs with minimal side effects from plants and have already started isolating promising compounds (from plants) some of which are now being investigated for the management of various diseases. *Eleusine coracana* is an annual plant which belongs to the poaceae family. It contains different secondary metabolites with a wide range of uses and promise in the management of several disease conditions. This review is aimed at highlighting the various ethnomedicinal and pharmacological uses of the plant collated over the years using extensive literature search with a view to exploring the possibility of harnessing the potential of the plant and investigating if it could be a source of novel compounds in the management of various disease conditions.

**Keywords:** Medicinal plants, *Eleusine coracana*, Phytochemistry, Pharmacological activity.

### Introduction

From time immemorial, plants have been used in the prevention, management and treatment of various disease conditions such as malaria, diabetes, arthritis, ulcer, tumours, hypertension and so many other ailments. Lead compounds used in the synthesis of novel drugs with high efficacy and minimal side effects have been obtained from medicinal plants.<sup>1</sup> Apart from the fact that plants are rich in vitamins and minerals essential for normal body metabolism, they are also known to contain secondary metabolites such as alkaloids, tannins, flavonoids, phenols, saponins, cardiac glycosides, steroids and many other phytochemicals which have been found to have medicinal properties when used adequately.<sup>2</sup> Some plants that have been used in the management of various disease conditions are; *Acacia nilotica* used for the treatment of pile, *Allium sativum* for treating colds, *Cadaba farinose* for the management of cancer, *Ficus congensis* for treating arthritis, *Leptadenia hastata* as remedy against ulcer, *Mangifera indica* for the management of jaundice and malaria,<sup>3</sup> *Ipomea batatas* for the treatment of diabetes.<sup>4</sup> *Eleusine coracana* also known as finger millet is an important millet in the poaceae family. The poaceae family, a known family of grasses is said to be the fourth largest family of flowering plants having up to 800 genera and up to 13,000 species.<sup>5</sup> Members of the Poaceae family have been observed over the years to be useful in the management of different diseases. Some of them currently in use are; *Cymbopogon citratus* (lemon grass) used in the treatment of malaria,<sup>6,7</sup> *Vetiveria nigritana* (black vetiver grass) used in the management of HIV/AIDS,<sup>8</sup> *Cynodon*

*dactylon* (Bahama grass) used to stop vomiting, *Cyperus rotundus* (cocograss) for the management of malaria and stomach ache, *Saccharum officinarum* (sugar cane) for the management of scanty urination,<sup>9</sup> *Oryza sativa* (rice) used in the treatment of herpes labialis<sup>10</sup> and *Sorghum bicolor* (guinea corn) used in the management of infertility.<sup>11</sup> Other members of the Poaceae family claimed to possess pharmacological activity are the leaves of *Bambusa vulgaris* (Bamboo), *Sorghum caudatum* (sorghum),<sup>12</sup> the fruit of *Zea mays* (maize), the rhizome of *Imperata cylindrical* (spear grass).<sup>13</sup> Millets generally, are annual plants which are tiny grained members of the Poaceae family that thrives in warm weather conditions and can survive a long period of drought. Millets are mainly grown for the purpose of feeding animals or to be consumed by man. They are believed to have the capability of slowing down digestion because of the phytochemicals present. This causes sugars to be released more slowly into the bloodstream after consumption.<sup>5</sup> There are however some millets which are used for medicinal purposes such as *Sorghum bicolor* used in the management of retained placenta,<sup>14</sup> *Setaria italica* (foxtail millet) used for treating dyspepsia, *Pennisetum typhoides* (pearl millet) used as a purgative for children, *Paspalum scrobiculatum* (kodo millet) used for treating typhoid fever, *Panicum sumatrense* (little millet) used for the management of small pox and scalp infection and *Echinochloa crus-gali* (barnyard millet) combined with powdered turmeric is used for the management of internal hemorrhage.<sup>15</sup> Finger millet or *Eleusine coracana* which is said to be ranked as the fourth most important millet in the world<sup>16</sup> apart from being from the poaceae family, also belongs to the sub family chlorodoideae<sup>17</sup> and the Eragrostidae tribe. There are about nine species in the genus *Eleusine*, mainly found in the tropical and subtropical regions of Asia, Africa and South America. Some of the species known are *Eleusine africana*, *Eleusine indica*, *Eleusine coracana*, *Eleusine multiflora*, *Eleusine jaegeri*, *Eleusine floccifolia*, *Eleusine kigeziensis*, *Eleusine intermedia* and *Eleusine tristachya*. They are either annual or perennial and most of them are wild.<sup>18</sup> *Eleusine coracana* is an annual plant which is erect, stout and cultivated mainly for its dark brown grain. It is mostly grown in Asia and Africa and serves as a major meal in Southern India and Ethiopia. India is believed to be the largest producer of finger millet worldwide. Finger millets are said to be highly nutritious and are popular in different tribes where they are called different names such as; Tamba in

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Hausa, kpana in Biram and in Fulfude, it is called chargari.<sup>19</sup> It is called ragi in India, Kelvaragu in Tamil and Madua in Hindi.<sup>5</sup> Finger millet comes in different varieties such as; red, yellow, brown, white violet and tan.<sup>20</sup> The colour variation may be as a result of the difference in calcium and protein content in the seed.<sup>21</sup> They are very small grains not having a true caryopsis and has a pericarp that is not fused to the seed coat which makes the pericarp to be easily removed.<sup>22</sup> They can be prepared as roti, porridge, dosa, cakes and many other forms for consumption.<sup>5</sup> Constant consumption of the millet is said to aid in the reduction of blood glucose level.<sup>23</sup> Consumption of the seeds of finger millet is also said to be beneficial in the management of diabetes, obesity, prevention of osteoporosis, reduction of cholesterol levels and useful in the treatment of anaemia, depression and migraine.<sup>5</sup> It is also given for conditions of asthma, high blood pressure, liver disorders and given to breastfeeding mothers to enhance milk flow.<sup>5</sup> It is said to be useful in the management of ulcer.<sup>20</sup> Phytochemical screening of the seeds has revealed that it contains some important phytochemicals which may be responsible for the activities observed in the seed extracts.

## Methodology

The review was systematically conducted by searching the databases of PUBMED, MEDLINE, SCOPUS and GOOGLE scholar libraries for original research articles and books using relevant search terms or their combinations: “*Eleusine coracana*,” “phytochemistry,” “pharmacology,” “medicinal uses,” “extracts,” “products and formulations,” “nutraceuticals, herbal and orthodox medicines.” Our search was not limited by date but to all relevant publications available in the English language.

## Ethnomedicinal uses

The seed grain of the *Eleusine coracana* Linn is the part of the plant used for the management of certain ailments in different communities where they are found. It is said to be used in the management of diabetes, prevention of osteoporosis and anaemia. It is also said to be useful in improving milk flow in breastfeeding mothers who have problems lactating. Finger millet when taken is believed to cause relaxation and useful in the management of anxiety, depression and insomnia. The grains are also used to enhance weight reduction, reduce cholesterol levels, repair worn out tissues and also as anti-aging agent.<sup>5</sup> In some cases, it is used in the management of ulcer.<sup>24</sup>

## Phytochemical constituents

*Eleusine coracana* is believed to be rich in dietary fibres, micronutrients, proteins, carbohydrates, minerals, fats and polyphenols. It is also said to have a high content of calcium.<sup>11</sup> Investigations carried out by Ravindran,<sup>25</sup> revealed that the amino acids present in finger millet are; isoleucine, leucine, lysine, methionine, cysteine, phenylalanine, tyrosine, threonine, valine, arginine and histidine, and tryptophan.<sup>31</sup> Finger millet also contains vitamins such as; thiamin, riboflavin, niacin, ascorbic acid, tocopherols and B-vitamins.<sup>22</sup> Polyphenols believed to be present in the seed are; gallic acid, tannic acid, vanillic acid, ferulic acid, caffeic acid, and chlorogenic acid. High Performance Liquid Chromatography (HPLC) was used to fractionate crude polyphenols of *Eleusine coracana* extracted by HCl-methanol to obtain ferulic acid (32.8%), vanillic acid (3.8%), trans-cinnamic acid (3.6%), p-coumaric acid (4.4%), syringic acid (4.0%), gallic acid (12.6%), proto-cathechuic acid (15.3%), P-hydroxyl benzoic acid (17.9%) and quercetin (5.6%).<sup>26</sup> Shobana *et al.*,<sup>27</sup> were able to identify more polyphenols present in the seed coat of finger millets. The polyphenols previously identified by Shobana and co-workers include 4-O-Methyl gallic acid, kaempferol, Naringenin, Phloroglucinol, Apigenin, (+)-catechin, epicatechin, luteolin glycoside (orientin), trans feruloyl-malic acid, dimer of prodelphinidin, diadzein, catechin gallates, trimmers of catechin and tetramers of catechin. Banerjee *et al.*,<sup>28</sup> also used reverse phase HPLC to identify some other phenolics present in finger millets. They identified the presence of gentisic acid, sinapic acid and salicylic acid. Singh *et al.*,<sup>29</sup> used GC-MS to identify the presence of 1,2-benzenedicarboxylic acid which was contained in the ethyl acetate fraction of the millet. The polyphenols present in finger millet are said to be highly concentrated in the seed coat which is also edible.<sup>26</sup> Polyphenols are said to be responsible for the antioxidant activities and free radical scavenging activities observed in the plant extracts. According to Poonia *et al.*,<sup>30</sup> finger millet contains 0.74% of oil of which 47.17% is oleic acid, 24.78% is linoleic acid and 23.06% is palmitic acid. They are said to contain alkaloids, terpenoids and tannins.<sup>32</sup> Bwai *et al.*,<sup>33</sup> revealed the presence of terpenoids, saponins, alkaloids, cardiac glycosides, phenols, basalms,

tannins and steroids in the millet. The percentage composition of tannins present in finger millet has been reported by Alwala *et al.*<sup>34</sup> to be  $8.11 \pm 0.2\%$ . Carbon 13 and proton NMR used in the study of the extracts of *Eleusine coracana* has also revealed the presence of arabinoxylan<sup>35</sup> and three  $\alpha$ -amylases have been purified from the seeds of *Eleusine coracana*.<sup>36</sup> Saxena *et al.*<sup>37</sup> also purified a bifunctional amylase/protease inhibitor from finger millet. Plant oxidative enzymes such as lipoxygenase, polyphenol oxidases, ascorbate oxidases and peroxidases have also been found in finger millet.<sup>38</sup> The lipoxygenase enzymes are said to be responsible for the high level of defense against the pest that the millet exhibits.<sup>38</sup> Although finger millet is said to contain so many beneficial phytochemical constituents and nutrients, it is also said to contain the antinutrient called phytates which are known for its ability to bind to important minerals like; iron, zinc and calcium, therefore reducing the availability of these ions in the millet.<sup>39</sup> They are also able to bind to protein and starch and this alters their absorption, functionality, digestion and solubility.<sup>40</sup> Tripathi and Platel<sup>39</sup> in their studies revealed that the amount of phytate contained in the finger millet they analyzed was  $765.5 \pm 35.6$  mg/100 g of finger millet flour.

Similarly, recent studies carried out on the root of the finger millet plant have led to the isolation of four antifungal compounds, isolated from the endophytic fungus called Endophyte WF4. They were characterized to be: viridicatol, alternariol, alternariol monomethyl ether and tenuazonic acid. Extracts from the WF4 was observed to have inhibited the growth of several fungus such as *Fusarium graminearum* ( $6.5 \pm 0.2$  mm), *Alternaria alternata* ( $3.0 \pm 0.2$  mm), *Aspergillus flavus* ( $4.0 \pm 0.2$  mm), *Fusarium lateritium* ( $6.0 \pm 0.5$  mm), *Fusarium sporotrichioides* ( $4.0 \pm 0.2$  mm), *Fusarium avenaceum* ( $4.5 \pm 0.3$  mm), and *Trichoderma longibrachiatum* ( $8.5 \pm 0.3$  mm).<sup>62</sup>

## Pharmacological activities

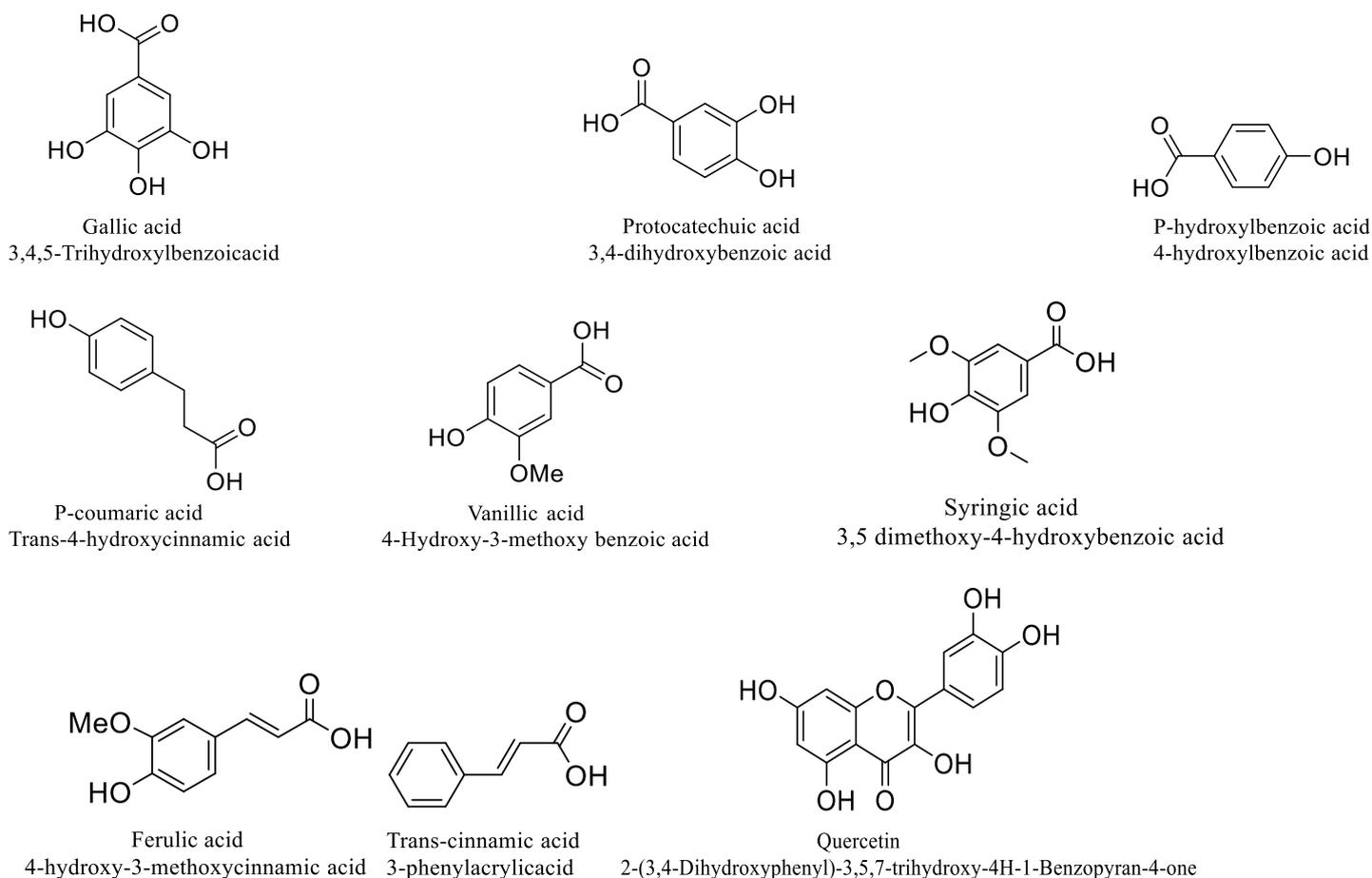
The different ethnomedicinal uses of the plant have stimulated research interest in its pharmacological activities. Various pharmacological studies have been carried out on the millet in order to validate the ethnomedicinal claims and set forth detailed pharmacological activities.

### Antioxidant activity

*Eleusine coracana* has been screened by different researchers for its antioxidant properties. Sreeramalu *et al.*<sup>41</sup> carried out an investigative study on the antioxidant activity of finger millet and other millets, cereals, legumes and pulses using 2,2-diphenyl-1-picrylhydrazyl (DPPH) radical scavenging method, Ferric Reducing Antioxidant Power (FRAP) method and also tested the reducing power of the extracts. They found out that, out of all the millets analyzed (pearl millet, finger millet, sorghum, maize, milled rice, parboiled rice, puffed rice, wheat and semolina), finger millet had the highest antioxidant activity in all three methods used. With the mean DPPH inhibitory activity of finger millet  $1.73 \pm 0.03$  mg Trolox eqv/g, FRAP showed mean of  $471.71 \pm 33.48$   $\mu$ mol/g and mean reducing power activity of  $4.54 \pm 0.81$  mg/g. Finger millets have been shown to have free radical scavenging activity.<sup>29</sup> Mathanghi and Sudha,<sup>24</sup> showed that finger millet is a potent source of antioxidants and has free radical scavenging activity. Ademosun and Oboh,<sup>42</sup> carried out an investigation on the antioxidant properties of *Eleusine coracana* and other edible seeds. Their findings revealed that the aqueous extract of *Eleusine coracana* had the highest phenolic content compared to the other seeds tested and also had the ability to scavenge DPPH in a dose-dependent manner with EC<sub>50</sub> of  $8.19 \pm 0.80$   $\mu$ g/mL. Viswanath and Urooj,<sup>43</sup> evaluated the antioxidant properties of finger millet polyphenols using  $\beta$ -carotene-linoleic acid assay method. In the study, 50  $\mu$ g/mL of the seed coat extract showed higher (86%) antioxidant activity when compared to whole flour (27%) at the same concentration. Subba Rao and Muralikrishna,<sup>44</sup> also investigated the antioxidant activity of free and bound phenolic acids in native and malted finger millet extracts. Results of the study showed that free phenolic acids in the malted extract exhibited higher antioxidant activity coefficient ( $770.00 \pm 7.8$ ) compared to the bound phenolic acids ( $570.0 \pm 6.0$ ). These results showed that the malting process significantly increases the antioxidant potential of the plant extracts.

### Anticancer activity

The seed extract has also been shown to possess anticancer activity which was attributed to the high level of polyphenols in the millet and the free radical scavenging activity of the extracts. According to Singh *et al.*,<sup>29</sup> the ethyl acetate fraction of finger millet extract showed a dose-dependent activity against HepG2 liver cancer cell line. Also, studies have been carried out on the effect of finger millet on chronic myeloid leukaemia.



**Figure 1:** Compounds isolated from *Eleusine coracana* Linn.

The result of the investigation carried out by Sen *et al.*<sup>45</sup> revealed that finger millet proteins could inhibit the proliferation of K562 cancer cell lines and also induce apoptosis in a dose-dependent manner with an  $IC_{50}$  value of 2 mg/mL. They observed that the finger millet protein did not exhibit its anti-proliferative effect on normal mononuclear human cells. This enabled them to conclude that it can selectively inhibit K562 cancer cell line.<sup>45</sup> Sen and Dutta,<sup>46</sup> isolated Ragi Bifunctional Inhibitors (RBI) from finger millet and carried out an evaluation of the RBI on human chorionic myeloid leukemia cells. It was reported that the RBI was also cytotoxic against K562 chronic myeloid leukaemia cells with  $IC_{50}$  value of 20  $\mu$ g/mL. It also showed no toxicity to normal human peripheral blood mononuclear cells.

#### Antimicrobial activity

Mathanghi and Sudha,<sup>24</sup> showed that the methanol-HCl fraction of the seed coat matter of *Eleusine coracana* had significant antimicrobial activity. They attributed this activity to the presence of phenolic compounds in the seed coat matter of the millet. They went further to explain that the good storage property of the millet may be attributed to the high level of polyphenols in the seed coat. They suggested that the mechanism of its antibacterial effect was due to the polyphenols causing oxidation of the cell membrane and cell components of the microorganisms and also formed an irreversible complex with nucleophilic amino acids in the organism hence causing inactivation of enzymes essential for the survival of the microorganisms. They also suggested that the polyphenols especially tannins react with the polysaccharides, proteins and even metal ions in the microorganism hence, depriving them of important nutrients. The antimicrobial activity of finger millet was also reported by Shukla *et al.*<sup>32</sup> and Singh *et al.*<sup>29</sup> According to Singh *et al.*, the ethyl acetate fraction was active against *Enterococcus sp* (17 mm), *Pseudomonas aeruginosa* (22 mm), *Staphylococcus aureus* (14 mm), *Proteus mirabilis* (15 mm), *Shigella dysenteriae* (14 mm), *Salmonella sp.* (16 mm), *Klebsiella pneumonia* (17 mm) and *Serratia marcescens* (13 mm) but it was not effective against *Escherichia coli*.

#### Anti-aging activity

The methanol fraction of *Eleusine coracana* has been shown to have enough antioxidant activity to inhibit the glycosylation and cross-linking action that occurs with the aging process. Tail tendons obtained from rats were incubated with 50 mM glucose solution and also incubated in 3 mg of extract of finger millet in methanol and it was observed that the finger millet extract had the ability to inhibit glycosylation process and this was attributed to the presence of high level of antioxidants in the extract and other phytochemical constituents present in the seed coat.<sup>47</sup>

#### Wound healing activity

Investigations have been carried out to show the effect of finger millet on wound healing process in diabetic rats.<sup>48</sup> In the experiment, incisions were made on some alloxan-induced diabetic rats 15 days after diabetes was induced. Finger millet was fed to one group of the diabetic rat and another group of diabetic rats were fed with normal diet. The control group which had no diabetes was also fed with normal feed. It was observed that the healing process was faster in rats fed with finger millet than the group that received normal diet. The wound healing activity of finger millet was also reported by Mathanghi and Sudha.<sup>24</sup>

#### Antilithiatic effect

Research carried out on the aqueous and ethanol fractions of finger millet revealed that finger millet was able to inhibit the formation of crystal growth and improve the function of the kidney.<sup>24</sup> Finger millet has also been shown to have the capability of ameliorating pathology associated with the kidney.<sup>49</sup> Bahuguna *et al.*<sup>50</sup> found out that 300 mg/kg body weight of the aqueous and alcoholic extract of finger millet was sufficient to inhibit crystal growth and improve kidney function in their experiment carried out on male albino rats to determine the effect of the extracts on calcium oxalate nephrolithiasis.

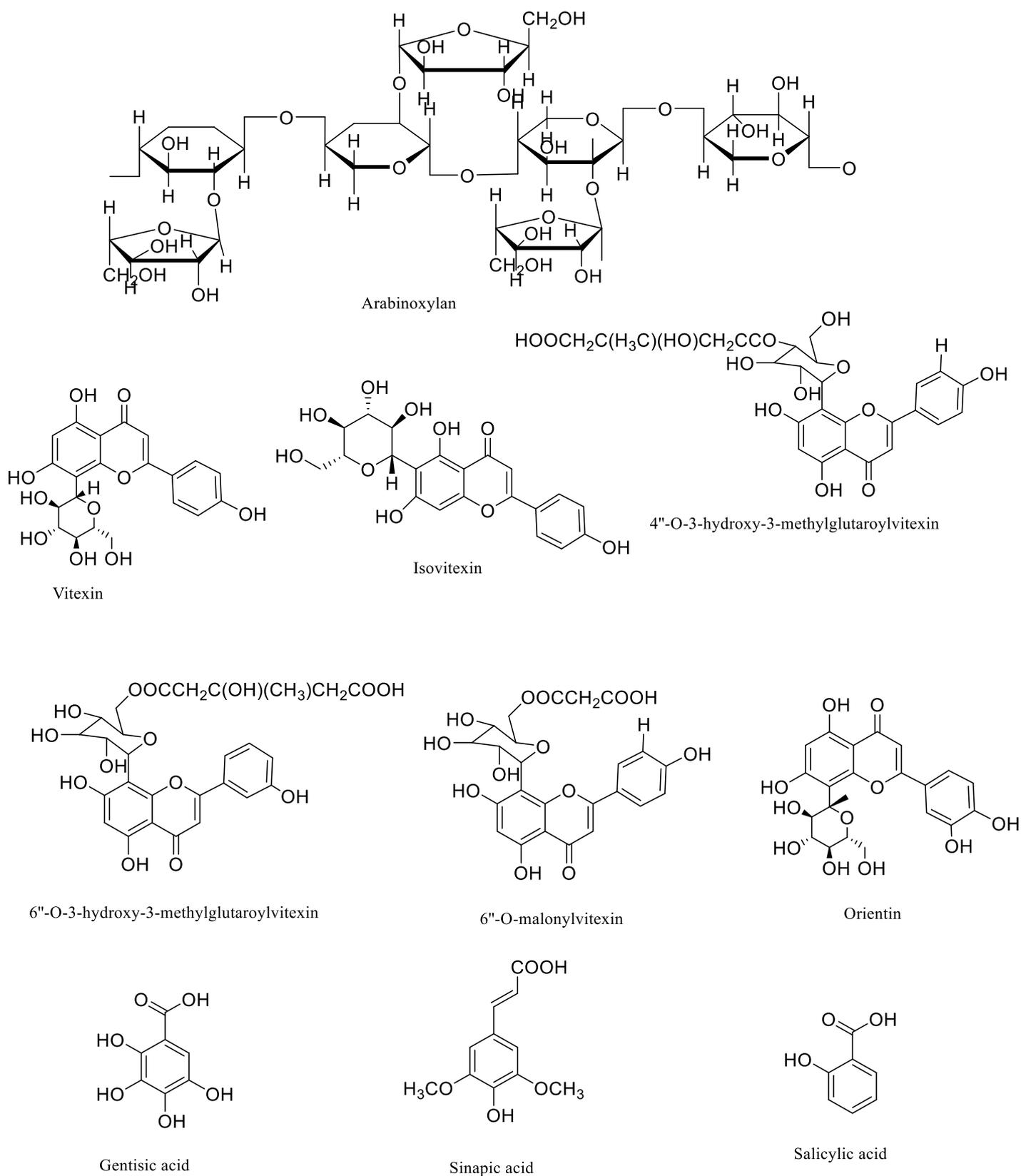


Figure 2: Phenolics from *Eluesine coracana* Linn.

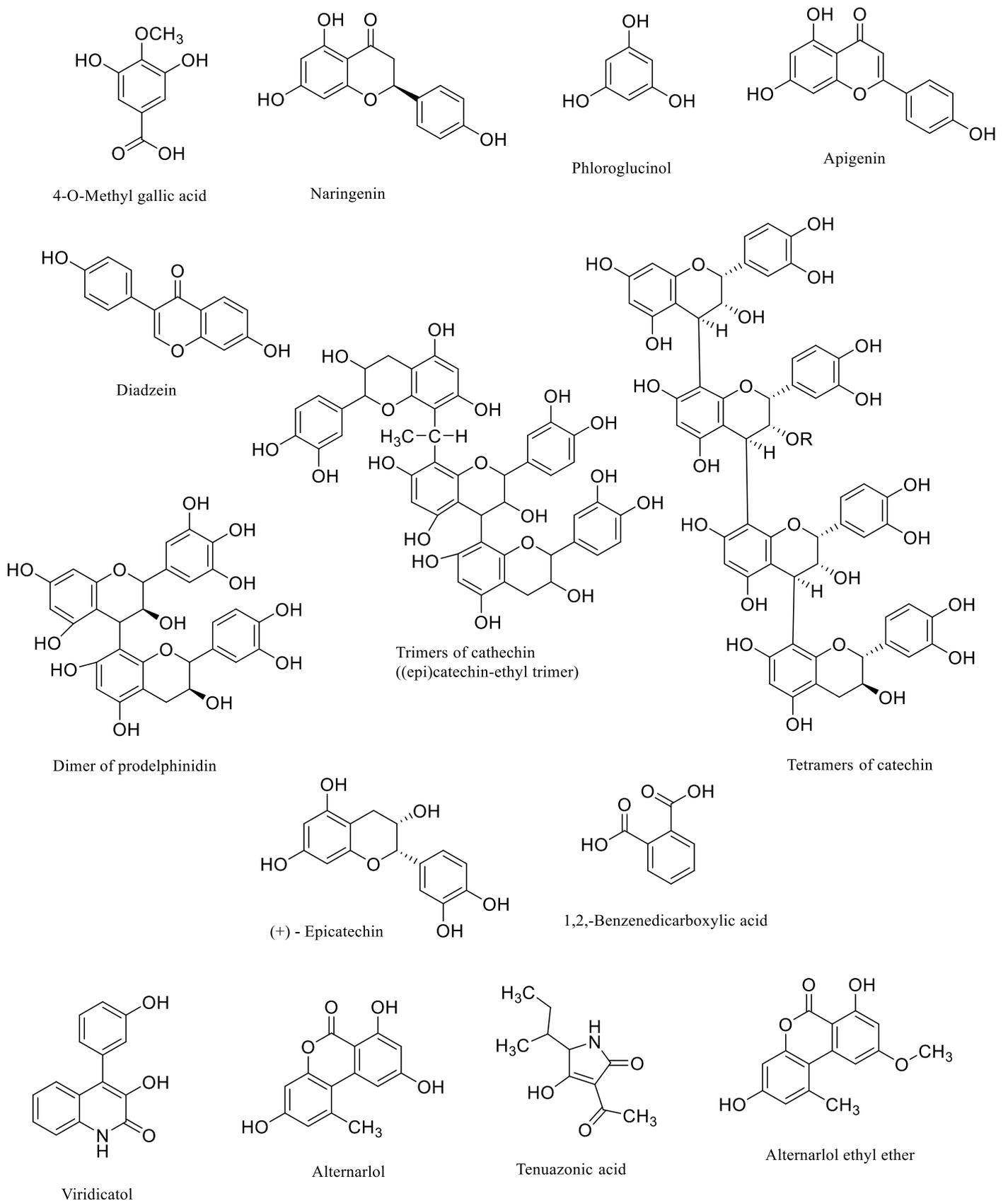


Figure 2 Cont'd.

**Aldose reductase inhibitory effect**

Experiments carried out by Chethan *et al.*<sup>26</sup> on the seed coat matter of *Eleusine coracana* revealed that the polyphenols extracted from the seed coat matter, were able to effectively inhibit the activities of aldose reductase which is an enzyme implicated in the complications of diabetes.

**Antidiabetic effect**

Antidiabetic studies on *Eleusine coracana* have been carried out by researchers such as Shobana *et al.*<sup>27</sup> They investigated the hypoglycemic effect of finger millet on streptozotocin-induced diabetic rats. The result of their study showed that the mean fasting blood glucose of the rats fed with finger millet was reduced by 31%. Rajasekaran *et al.*<sup>48</sup> also reported the hypoglycaemic effect of finger millet in alloxan-induced diabetic rats. Similarly, Hegde *et al.*<sup>52</sup> reported the hypoglycemic effect of the whole grain of finger millet on alloxan-induced diabetic rats using a dose of 180 mg/kg body weight. The rats were fed with finger millet for 28 days. It was observed that the blood sugar level was significantly reduced from  $212 \pm 14$  mg/dL to  $137 \pm 6$  mg/dL in the diabetic rats fed with finger millet. Shukla and Srivastava,<sup>53</sup> incorporated finger millets into noodles by incorporating 0, 30, 40 and 50% of the finger millet flour into refined wheat flour. They found out that consumption of these noodles induced hypoglycemic effect which was attributed to the high fibre content of the millet. In a research conducted by Kumari and Sumathi,<sup>54</sup> on humans with non-insulin dependent (type 2) diabetes of average body weight 55-60 kg, it was shown that the experimental groups fed with finger millet products had significantly lower mean peak rise in fasting blood glucose (FBG), with whole finger millet roti ( $59.3 \pm 5.3$  mg/dL) and germinated finger millet roti ( $80.1 \pm 14.8$  mg/dL) producing the least mean peak rise in FBG compared to the control group ( $209 \pm 64.32$  mg/dL) on hypoglycaemic drugs only. This study revealed that the finger millets incorporated diets have the potential of significantly reducing blood glucose levels.<sup>54</sup>

**Anticataract effect**

Experiments conducted on cataracted human eye lenses by Chethan *et al.*<sup>26</sup> showed that finger millet has the ability to prevent and treat cataract. This was attributed to the high level of polyphenols present in the seed coat matter of the millet. Also, Shobana *et al.*<sup>27</sup> in their experiment, reported that rats fed with 20% seed coat matter diet for six weeks after induction of diabetes with 40 mg/kg body weight dose of streptozotocin showed lesser progression of cataract compared with the control group (not treated with the seed coat matter) which showed mature cataract after six weeks of diabetes induction under a slit lamp with an attached camera.<sup>27</sup>

**Weight loss activity and prevention of obesity**

An experiment was conducted to determine the ability of finger millet to cause weight loss and prevent obesity. Whole grain finger millet and Bran of finger millet were fed to high-fat fed mice as a dietary supplement. The results of the experiment revealed that finger millet bran effectively reduced the body weight of the high-fat fed mice compared to the whole grain finger millet. This gave credibility to the use of finger millet in weight reduction and amelioration of obesity.<sup>55</sup>

**Hepatoprotective activity**

Pingle *et al.*<sup>56</sup> conducted an experiment to determine the hepatoprotective activity of *E. coracana* in carbon tetrachloride-induced hepatotoxicity in rats. The results of the study showed that the hepatoprotective activity of the n-hexane, ethyl acetate, butanol and ethanol fractions at a dose of 500 mg/kg, was comparable to the standard silymarin at a dose of 100 mg/kg.

**Pharmaceutical uses****Reducing agent**

Paul *et al.*<sup>57</sup> was able to effectively use *Eleusine coracana* as a reducing agent in the synthesis of silver nanoparticles. In this study, approximately 167 mg/mL *Eleusine coracana* extract reacted with 3 mM silver nitrate (AgNO<sub>3</sub>) induces nanoparticles formation in the reaction pot. Transmission Electron Microscopy (TEM) and UV-Visible spectroscopic analysis revealed spherical shape of silver nanoparticles with an average size of 4-25 nm and a change from the pale yellowish colour of AgNO<sub>3</sub> to reddish brown colour ions, respectively. The plant extract demonstrated strong potential for the synthesis of silver nanoparticles. Paul *et al.* postulated a very simple, rapid, cost-effective and eco-friendly method for the synthesis of silver nanoparticles.

**Table 1:** Pharmacological activity of *Eleusine coracana* Linn.

| Pharmacological activity           | Plant part used | References            |
|------------------------------------|-----------------|-----------------------|
| Anticataract effect                | Seed            | 26, 27                |
| Antidiabetic activities            | Seed            | 52, 53, 54, 27, 48    |
| Reduction of hyperlipidemia        | Seed            | 55                    |
| Anticancer activity                | Seed            | 29, 45, 46            |
| Anti-inflammatory activity         | Seed            | 48, 24                |
| Antiaging effect                   | Seed            | 47                    |
| Antimicrobial activity             | Seed            | 24, 32, 29            |
| Antibacterial activity             | Seed            | 28, 29                |
| Antioxidant activity               | Seed            | 29, 24, 42, 43, 49,44 |
| Inflammatory inhibition            | Seed            | 55                    |
| Wound healing activity             | Seed            | 48, 11                |
| Hepatoprotective activity          | Seed            | 56                    |
| Aldose reductase inhibitory effect | Seed            | 26                    |
| Antilithiatic effect               | Seed            | 24, 49                |

**As a binding agent**

Shiishii *et al.*<sup>58</sup> performed an experiment comparing the use of starch derived from *Eleusine coracana* and maize starch BP as a binder in drug formulations. In the experiment conducted, starch obtained from finger millet was used to formulate paracetamol tablets at different concentrations of 2.5% w/w, 5% w/w, 7.5% w/w, 10% w/w and 12.5% w/w and compared with paracetamol formulated with maize starch BP at the same concentrations. It was observed that hardness of tablets formed from finger millet starch was a little lower than tablets formulated from maize starch with the exception of the 2.5% w/w and 7.5% w/w concentrations whose hardness was seen to be higher than that of maize starch BP. However, the friability values of tablets formulated with finger millet starch were higher. Also, tablets formulated with starch obtained from finger millet with concentrations above 2.5% w/w were seen to have passed the necessary friability tests with a very minimal deviation of less than 1% except for the 7.5% w/w concentration. The overall results obtained from the experiment revealed that the binding properties of starch obtained from finger millet are comparable to maize starch.

**Other investigations**

Apart from the fact that the millet is rich in phytochemicals, and several pharmacological investigations have been conducted on the plant, other studies of interest have been carried out on this plant, such studies include:

**Gene advances of finger millet**

Investigation on the gene of finger millet is ongoing. This is because this plant shows special adaptive features in harsh weather conditions, contains numerous phytochemicals and minerals and can also be stored for a long period of time. It is believed that it could be a store house for genomic resources that could be explored for plant improvement.<sup>59</sup>

**Finger millet as a potential bio-insecticide**

$\alpha$ -amylases have been reported to be useful in the breakdown of carbohydrates in insects and this is essential for the survival of the insects.  $\alpha$ -amylase inhibitors are said to be capable of antagonizing this effect. In the work carried out by Sivakumar *et al.*,<sup>60</sup>  $\alpha$ -amylase inhibitors (50  $\mu$ g) was extracted from finger millet (FMCO3 variety) and was found to be able to inhibit the activity of  $\alpha$ -amylases (10  $\mu$ g) extracted from different insects such as pulse beetle *Callosobruchus chinensis* (37.51% inhibition), castor semilooper *Acaea janata* (34.85% inhibition), rice moth *Caryca cephalonica* (39.35% inhibition).

**Finger millet as a potential source of anticholesterolic metabolites**

Venkateswaran and Vijayalakshmi<sup>61</sup> compared the production of statins by *Monascus purpureus* cultured in finger millet and other cultures like rice. It was observed that the statins produced by the fungus cultured in germinated finger millet (5.2 g/kg dry weight) were higher than those obtained from other cultures which ranged from 1.04–4.41 g/kg.

**Immunomodulatory activity**

Arabinoxylans isolated from finger millet have been shown to have immunomodulatory activity. Prashanth and Shruthi,<sup>63</sup> in their work discovered that arabinoxylans extracted from finger millet was able to activate macrophages and improve mitogenic activities significantly and they attributed the effect to the presence of ferulic acid in the millet.

**Patented products of finger millet**

Finger millet is a rich source of minerals and nutrients. Flour obtained from the millet can be used to prepare food such as unleavened pancakes and porridge. The flour could also be used in combination with other types of flour in the preparation of products such as noodles, biscuits, cakes, muffins, and so many other products.<sup>64</sup> Some of the products of finger millet have actually been patented. Examples are; finger millet biscuit (US 20040191386 A1),<sup>65</sup> finger millet bread (WO 2005063026 A1),<sup>66</sup> decorticated finger millet (US20030185951 A1),<sup>67</sup> and so many others.

**Nutraceutical importance of finger millet**

Finger millet is known to be rich in minerals, vitamins and other phytochemical constituents. This has made it a valuable source of nutraceuticals although it is currently underexplored. It was proposed that the high content of phytochemicals present in finger millet was beneficial for managing cardiovascular diseases, diabetes, cataract, hypercholesterolemia, cognition and neurodegenerative diseases, cancer and kidney diseases, the presence of protein in the millet is said to be essential in the management of protein-energy malnutrition and as a natural relaxant. The vitamin and mineral content of the plant is said to be beneficial in the management of anaemia and osteoporosis. Glycoproteins and lower fat contents of the millet are said to be beneficial in slowing down the ageing process. Finger millet has high fibre content and this enables them to be useful in the management of diabetes, stomach disorders, cardiovascular diseases, gallstones and cancer.<sup>68</sup> The polyphenols present in finger millet are known for their antioxidant activity as well as their anticancer activity.<sup>69</sup> P-hydroxybenzoic acid<sup>70</sup> is said to be known for its' antifungal, antisickling, estrogenic, antimicrobial and antimutagenic activities. Gentisic acid found in the millet has cytostatic, analgesic, anti-inflammatory, antiarthritic and antirheumatic properties. Salicylic acid which is also found in finger millet has antiseptic, antipyretic, keratolytic, analgesic, antifungal and anti-inflammatory properties while Protocatechuic acid has antifungal, anti-inflammatory, antioxidant and antihepatotoxic activities. It also has cytotoxic and platelet aggregation inhibitory activities. It is said to be neuroprotective and also have the ability to inhibit low-density lipoprotein oxidation. Other phenols contained in finger millet that have been shown to have biological activity are; Vanillic acid which has antisickling properties, Gallic acid, antineoplastic and bacteriostatic activities and syringic acid, antibacterial and hepatoprotective activities.<sup>69</sup>

**Conclusion**

*Eleusine coracana* commonly found in the tropical regions of the world, Asia, Africa and South America has been used not only as edible grain in these cultures but also in traditional medicine practice. Different parts of the plant have been used in various forms in the treatment and management of different health conditions (diabetes, cancer, gall stones, degenerative diseases) and for weight reduction in the obese. This study highlighted the pharmacology, phytochemistry, pharmaceutical and nutraceutical uses and also the economic potentials of the plant. The phytochemicals isolated from different solvents extracts of this plant have shown promising pharmacological activities in different disease conditions, requiring further study for possible isolation and development of cost-effective product(s) for use in diabetes, cancer and as an eco-friendly agent in the synthesis of pharmaceutical nanoparticles.

**Conflict of interest**

The authors declare no conflict of interest.

**Authors' Declaration**

The authors hereby declare that the work presented in this article is original and that any liability for claims relating to the content of this article will be borne by them.

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