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Review Article

FUNCTIONAL AND PHYTOCHEMICAL PROPERTIES OF FINGER MILLET (*ELEUSINE CORACANA* L.) FOR HEALTH

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ABSTRACT

Finger millet is native of Ethiopia, but spread out to Asia few thousand years ago. The growing public awareness of nutrition and health care research substantiates the potential of phytochemicals such as polyphenols and dietary fiber on their health beneficial properties. Hence, there is in need to identify newer sources of neutraceuticals and other natural and nutritional materials with the desirable functional characteristics. Finger millet (*Eleusine coracana*), one of the minor cereals, is known for several health benefits and some of the health benefits are attributed to its polyphenol and dietary fiber contents. It is an important staple food in India for people of low income groups. Nutritionally, its importance is well recognised because of its high content of calcium (0.38%), dietary fiber (18%) and phenolic compounds (0.3–3%). They are also recognized for their health beneficial effects, such as anti-diabetic, anti-tumerogenic, atherosclerogenic effects, and antioxidant and antimicrobial properties.

Keywords: Finger millet, Millet, health Benefit, Nutraceutical properties.

INTRODUCTION

Finger millet (Eleusine coracana L.) is important millet grown extensively in various regions of India and Africa, constitutes as a staple food for a large segment of the population in these countries. It ranks sixth in production after wheat, rice, maize, sorghum and bajra in India. The acidic methanol extracts from the seed coat showed high antibacterial and antifungal activity.

Nutrient composition of *Finger millet*

The nutrient composition of *finger millet* is shown in the Table 1. *Finger millet* carbohydrates comprise of free sugars (1 - 2%), starch (75 - 80%) and non-starchy polysaccharides consisting of cellulose and hemicellulose. It is a very good source of dietary fibre, micronutrients and polyphenols. The lower fat contents could be one of the contributing factors for the extremely good shelf life of *finger millet*.

Nutraceutical and functional properties

Oxidation of microbial membranes and cell components by the free radicals forms irreversible complexes with nucleophilic amino acids leading to:

- Inactivation of enzymes are major biochemical benefits of polyphenols towards the antifungal activity.
- Tannins with biopolymers such as proteins and polysaccharides and complexing with metal ions making nutrients unavailable to micro-organisms.

Seed coat phenolic extract—active against *Bacillus cereus, Aspergillus niger*[1]. Fermented finger millet extract—suppress growth of *Salmonella sp., Escherichia coli*[2]. Germinated and non-germinated millet phenol extract—against *Bacillus cereus,* *Staphylococcus aureus, Yersinia enterocolitica, Escherichia coli, Listeria monocytogenes, Streptococcus pyogenes, Pseudomonas aeruginosa, Serrtia marcescens, Klebsiella pneumonia*

Antimicrobial properties

Plant phenolics have been implicated for minimising the intensity of several diseases and also to inhibit the in vitro growth of an assortment of fungal genera. It was also indicated that finger millet grain phenolics including tannins may be involved in resistance of the grain to fungal attack[3]. Phenolic compounds, particularly tannins in the outer layers of the grain serve as a physical barrier to the fungal invasion. The acidic methanol extracts from the seed coat showed high antibacterial and antifungal activity compared to whole flour extract due to high polyphenols content in seed coat. It was reported that the fungal load (total fungal load and infection levels) of the unmalted millet grain and its malt, were negatively correlated ($p<0.05$) with total phenolics and phenolic type (condensed tannins, anthocyanins and flavan-4-ols) [4]. Oxidation of microbial membranes and cell components by the free radicals formed, irreversible complexation with nucleophilic amino acids leading to inactivation of enzymes are major biochemical benefits of polyphenols towards the antifungal activity. Besides, loss of their functionality and also the interaction of phenolic compounds, especially tannins with biopolymers such as proteins and polysaccharides and complexing with metal ions making them unavailable to micro-organisms are some of the mechanisms involved in the inhibitory effect of phenolic compounds on microorganisms. The extremely good storage property of finger millet and its processed foods could be attributed to its polyphenol content.

Antioxidant properties

Antioxidant compounds are gaining importance due to their main roles as lipid stabilizers and as suppressors of excessive oxidation that causes cancer and ageing. Their stable radical intermediates prevent the oxidation of various food ingredients, particularly fatty acids and oils. henolic acids and their derivatives, flavonoids and tannins present in millet seed coat are of multifunctional and can act as reducing agents (free radical terminators), metal chelators, and singlet oxygen quenchers[5]. The potency of phenolic compounds to act as antioxidants arise from their ability to donate hydrogen atoms via hydroxyl groups on benzene rings to electron- deficient free radicals and in turn form a resonance-stabilized and less reactive phenoxyl radical. Studies were carried out on the natural antioxidants in edible flours of small millets.

Total antioxidant capacity of finger, little, foxtail and proso millets were found to be higher and their total carotenoids content varied from 78–366 mg/100 g in the millet varieties.

Total tocopherol content in finger and proso millet varieties were higher (3.6–4.0 mg/100 g) than in foxtail and little millet varieties (~1.3 mg/100 g). HPLC analysis of carotenoids for the presence of β-carotene showed its absence in the millets, and vitamin E indicated a higher proportion of γ-and α-tocopherols; however, it showed lower levels of tocotrienols in the millets. Edible flours of small millets are good source of endogenous antioxidants[6].

The antioxidant activity of millet phenols and their health benefits have also been reported. For instance, in Japanese barnyard millet, the antioxidant activity of luteolin was nearly equal to that of quercetin; however, the activity of tricin was lower than luteolin. Finger millet is a potent source of antioxidants and has potent radical-scavenging activity that is higher than that of wheat, rice, and other millets; these results corresponded to their phenolic content.

The brown or red variety of finger millet, which is commonly available, had higher activity (94%) than the white variety (4%) using the DPPH method[5]. Kodo millet quenched DPPH by nearly 70% higher than other millets (15–53%); white millet varieties had lower activity[7].

Glycemic response

Recent reports indicate that hyperglycemia could induce non-enzymatic glycosylation of various proteins, results in the development of chronic complications in diabetes. Therefore, control of postprandial blood glucose surge is critical for treatment of diabetes and for reducing chronic vascular complications which can be controlled by intake of high complex carbohydrate and high fiber diet.

Research has shown that the carbohydrates present in finger millet are slowly digested and assimilated than those present in other cereals. Regular consumption of finger millet is known to reduce the risk of diabetes mellitus and gastrointestinal tract disorders and these properties were attributed to its high polyphenols and dietary fiber contents[8]. The beneficial effect of phenolics is due to partial inhibition of amylase and α-glucosidase during enzymatic hydrolysis of complex carbohydrates and delay the absorption of glucose, which ultimately controls the postprandial blood glucose levels[9]. Beneficial effect of dietary fiber is usually attributed either to slower gastric emptying or formation of un-absorbable complexes with available carbohydrates in the gut lumen and these two properties might result in delayed absorption of carbohydrates and in the reduction of absolute quantity absorbed.

Another study provided evidence for hypoglycaemic, hypocholesterolaemic, nephroprotective and anti-cataractogenic properties of finger millet, the 'health-grain'. Feeding a diet containing 20% millet seed coat matter (SCM) to streptozotocin induced diabetic rats for 6 weeks exhibited lesser degree of fasting hyperglycemia and partial reversal of abnormalities in serum albumin, urea and creatinine compared to diabetic control. Hypercholesterolaemia, hypertriacylglycerolaemia, nephropathy and neuropathy associated with diabetes were notably reversed in diabetic group fed with the diet containing millet seed coat matter[9].

Inhibition of collagen glycation and cross-linking

The chemical reaction between the aldehyde group of reducing sugars and the amino group of proteins termed non enzymatic glycosylation is a major factor responsible for the complications of diabetes and aging. Increased oxidative stress and hyperglycemia contribute significantly to the accelerated accumulation of advanced glycation end products and the cross-linking of collagen in diabetes mellitus. Free radicals play major role in non- enzymatic glycosylation of collagen and crosslinking whereas antioxidative conditions and free radical scavengers inhibit these reactions. The effects of methanolic extracts of finger millet and kodo millet on glycation and crosslinking of collagen were studied[7]. The collagen incubated with glucose (50 mM) and 3 mg methanolic extracts of finger millet inhibited glycation. This may be due to natural antioxidants primarily of polyphenolic nature and other phytochemicals extracted from the seed coats of the millet grains. Finger millets could have a potent therapeutic role as dietary supplements for the prevention of glycation induced complications, as in diabetes or aging.

Wound healing process

The process of wound healing is determined by inflammation, a vital and protective response offered by the injured cells at the wound site that actually starts the process of tissue repair. The perfect wound healing process is interrupted in diseased conditions like diabetes and age associated biochemical phenomenon due to increased level of reactive oxygen species (ROS). The diabetic conditions had a deleterious influence on the wound healing process through abnormal physiological response. Free oxygen radicals damage the cells in the zone of stasis, which lead to necrosis and conversion of superficial wound into a deeper wound. Antioxidants significantly prevent tissue damage and stimulate the wound healing process.

Antioxidant effects of finger millet on the dermal wound healing process in diabetes induced rats with oxidative stress-mediated modulation of inflammation were studied[10]. They reported that the role of finger millet feeding on skin antioxidant status, nerve growth factor (NGF) production and wound healing parameters in healing the impaired early diabetic rats. Hyperglycemic rats received food containing 50 g/100 g finger millet (FM) and the non-diabetic controls and diabetic controls received balanced nutritive diet. Full- thickness excision skin wounds were made after 2 weeks prior to feeding of finger millet diet. They studied the intensity of wound, levels of collagen, hexosamine and uronic acid in the granulation tissue, skin antioxidant status and lipid peroxide concentration.

The healing process was hastened with an increased rate of wound contraction in hyperglycemic rats fed with finger millet diet and skin antioxidant levels of glutathione (GSH), ascorbic acid and α-tocopherol in alloxan-induced diabetic rat was lower as compared to non-diabetics. Altered activities of superoxide dismutase (SOD) and catalase (CAT) were also recorded in diabetic rats. The thiobarbituric acid reactive substances (TBARS) levels of both normal and wounded skin tissues were significantly elevated ($P<0.001$) when compared with control (nondiabetic) and diabetics fed with FM[10].

Increased expressions of NGF determined by ELISA and immunocytochemical evaluation were observed in hyperglycemic rats supplemented with FM diet. Histological and electron microscopic examinations revealed the epithelialization, increased synthesis of collagen, activation of fibroblasts and mast cells in FM-fed animals. Increased levels of oxidative stress markers accompanied by decreased levels of antioxidants, causes delaying in wound healing of diabetic rats.

Feeding the diabetic animals with finger millet for 4 weeks, regulated the glucose levels and improved the antioxidant status, this hastened the dermal wound healing process and could be due to the structure, anti-oxidative mechanism and the synergistic effects of different phenolic compounds. It is attributed that the phenolic antioxidants present in FM partially protected the insulin-producing cells from alloxan-mediated cell damage, and hence promoted the healing process[10].

Anti-lithiatic Effect

The effect of aqueous and alcohol extracts of *Eleusine coracana* on calcium oxalate nephrolithiasis has been studied in male albino rats were studied[11]. Ethylene glycol feeding resulted in hyperoxaluria as well as increased renal excretion of calcium and phosphate. Supplementation with aqueous and alcohol extracts of grains significantly reduced the elevated urinary oxalate, showing a regulatory action on endogenous oxalate synthesis.

The increased deposition of stone forming constituents in the kidneys of calculogenic rats was significantly lowered using extracts. Prophylactic and therapeutic treatment with extracts of grains of *finger millet* had an inhibitory effect on crystal growth, with improved kidney function & cytoprotective effect.

Inhibition of aldose reductase:

Mode of inhibition of aldose reductase from cataracted eye lenses by finger millet polyphenols was studied[8]. Diabetes induced cataract is characterized by an accumulation of sorbitol, which is mediated by the action of a key enzyme aldose reductase (AR). The non-enzymatic glycation (binding of glucose to protein molecule) induced during diabetes appear to be the key factor for AR mediated sugar-induced cataract. AR enzyme is crucial in cataracto- genesis via a polyol pathway (Fig. 2).

Crude phenolic extracts from finger millet exhibited the strong inhibitory effects on AR activity and showed an IC50 of 60.12 μg/ml. Mode of inhibition of polyphenols on aldose reductase could be by preventing either the enzymatic conversion of glyceraldehyde to glycerol and glucose to sorbitol, thereby replenishing the depletion of NADPH levels.

Phenolic constituents in finger millet phenolics such as gallic, protocatechuic, p-hydroxy benzoic, p-coumaric, vanillic, syringic, ferulic, trans-cinnamic acids and the quercetin was found to inhibit cataract effectively. Structure and function analysis revealed that phenolics with hydroxy group at 4th position is important for aldose reductase inhibitory property.

Furthermore, the presence of neighboring O-methyl group in phenolics denatured the AR activity. Quercetin is the most potent AR inhibitory component among the finger millet polyphenolic constituents with IC50 at 25.23±2.2 μg/ml. The activity was correlated with antioxidant potency with the correlation coefficient (r=0.99, $p \leq 0.1$) between antioxidant and AR inhibitory effect of phenolic constituents suggesting that the proton abstracting ability is responsible for AR inhibitory effect.

Quercetin exhibits non competitive inhibition on AR enzyme and it may render reversible inhibition by successfully blocking the polyol pathway leading to cataracto- genesis.

The strong hydrogen abstracting ability of quercetin may replace the proton donation from AR-Histidine-110/ Tyrosine-48, which is a key step in the NADPH regenerating potential substantiating the effective AR blockade activity. AR inhibitions potentially resulted in no or only trace accumulation of sorbitol, which is beneficial to overcome the osmotic pressure that may also affect eye lens.

Dietary fibre

The NSP includes arabinoxylans, 1-3/1-4 β-D-glucans, pectins and arabinogalactans. Yield of water-soluble NSP, hemicellulose-B and cellulose polysaccharides increase upon malting of the millet causing a substantial decrease in the yield of hemicellulose-A. Arabinoxylans, along with some amount of β-D-glucans, are the major components of soluble dietary fiber.

The main water soluble NSP exhibit a wide range of functional properties and health benefits. They are known to have many beneficial roles in human nutrition and health such as lowering cholesterol and fat contents, reducing the disease symptoms of constipation and the risk of diabetes, atherosclerosis and colorectal cancer. Arabinoxylans are also proposed to have wound dressing potential. Structural elucidation of purified arabinoxylans isolated from finger millet and its malt by methylation followed by fractionation in GLC–MS, periodate oxidation, Smith degradation, NMR, IR, optical rotation, and oligosaccharide analysis indicated that the backbone of the molecule was a 1,4-β-D-xylan, with the majority of the residues substituted at C-3. The structural analysis of oligosaccharide generated by endo xylanase treatment showed that it contained eight xylose and six arabinose residues, substituted at C-3 (monosubstituted) and at both C-2 and C-3 carbons (disubstituted)[12].

Feraxans are shown to be low molecular weight poly-saccharides with high amounts of arabinose, galactose, uronic acid and ferulic acid. Ferulic acid, a major bound phenolic acid, is known to exist as ester linked mainly to arabinoxylans and influence their physicochemical properties. Ferulic acid is supposed to have a number of health benefits. It is known to decrease total cholesterol and increase bioavailability of vitamin-E, vitality of sperms and offers a good protective action against UV radiation–induced skin damage. It is known to have anti-tumor and anti-cancer effects. Apart from dietary fiber, several reports have proven that ferulic acid is a potential chemo-preventive agent for colorectal cancer. Feruloyl arabinoxylans were shown to be highly antioxidant, and this property is correlated with their molecular architecture.

DF has gained importance during the last two decades due to its role in decreasing the risk diseases such as diabetes,cardiovascular diseases, colon cancer, constipation and diverticulosis. Physical attributes of the fiber causes change in morphology of the intestine and these changes could be associated with functional changes in the gastrointestinal tract through different mechanisms. Consumption of dietary fiber that are viscous lowers blood glucose levels and helps to maintain it and also helps to treat cardiovascular and type II diabetes.

Fibers are incompletely or slowly fermented by microflora in the colon promotes normal laxation which prevents constipation, diverticulosis and diverticulitis. Daily intake of fiber is 20–35 g/day for healthy individuals and age plus 5 g/day for children is recommended.

Finger millet husk, a natural fiber composed of many types of indigestible fractions incorporated to 9%protein diet at a level of 10% promoted better growth in albino rats[13].

Addition of finger millet husk at 8% level to 9% protein diet increased the small bowel length; the villous height in the duodenum and ileum and elevated the activity of the chymotrypsin in both pancreas and intestine and no marked difference was seen in pH profile and activity of trypsin and these results indicated no deleterious effect on the gastrointestinal tract of the albino rats[13]. NDF has cholesterol lowering action and high hemicellulose content of the dietary fiber content is positively correlated with the effect on cholesterol metabolism. Hypo-cholesterolemic action of *finger millet* NDF fed in rats showed the lower concentration of cholesterol, triglycerides in serum and tissues and concentration of hepatic bile acids, faecal bile acids, faecal sterols are higher compared to isocaloric fiber free diet fed rats. In vitro binding of NDF with bile acids is found to be low[14]. Whole grains of foxtail millet and proso millet fed as diet for a period of 5 weeks to hyperlipidemic rats reduced the concentrations of serum triglycerides and concentrations of serum total, high density lipoprotein (HDL), and low-density lipoprotein (LDL)-cholesterol was found to be lower. Levels of C- reactive protein were significantly lower in the foxtail millet group than the white rice, sorghum, and proso millet groups and these millets may prevent cardiovascular disease by reducing plasma triglycerides[15].

CONCLUSION

Finger millet is reported to have antiulcerative properties and *finger millet* diets lowered blood glucose and cholesterol in diabetic rat models. *Finger millet* seed coat matter which is a rich source of dietary fibre and phenolic compounds were found to exhibit blood glucose and cholesterol lowering, nephroprotective and anti-cataractogenic properties in streptozotocin induced diabetic rat models. *Finger millet* extracts were also reported to possess free radical scavenging, anti-protein glycation, anti-cataractogenic and antimicrobial properties in 'in vitro'. Inhibition of snake venom phospholipases by *finger millet* phenolics in 'in vitro' were also reported elsewhere. Most of these studies are confined to in vitro model systems and animals studies. However, clinical trials are required to prove these health benefits in humans. Millets are water saving, drought tolerant crops. Therefore they must be viewed as climate change compliant crops. This quality makes them India's food and farming future. This is the perspective from which the millet cultivation and its promotion must be regarded. Every millet farmer of India must be given a climate change bonus, biodiversity bonus, water conservation bonus. The urgent and immediate need is to put millets into the Public Distribution System. Research institutions must give a new thrust on millet areas and issues. But such research initiatives must be led by farmers since they offer exciting perspectives for the research which has to be people-centered and people directed.

Table 1: Nutrient composition of Finger millet (*Eleusine coracana* L.))

Nutrient	Composition
Carbohydrates	65-75 %
Protein	5-8 %
Fat	1-2 %
Dietary fibre	15-20 %
Minerals	2.5-3.5 %

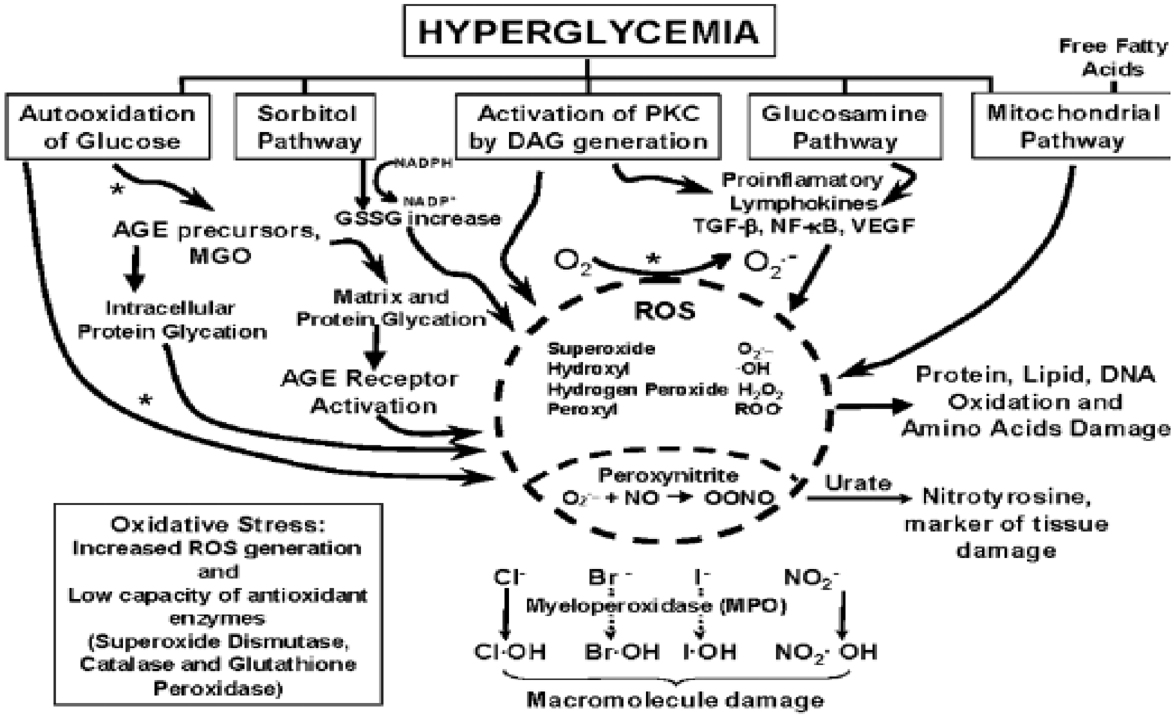

Fig. 1: Pathways for the generation of reactive oxygen species (ROS) and oxidative stress

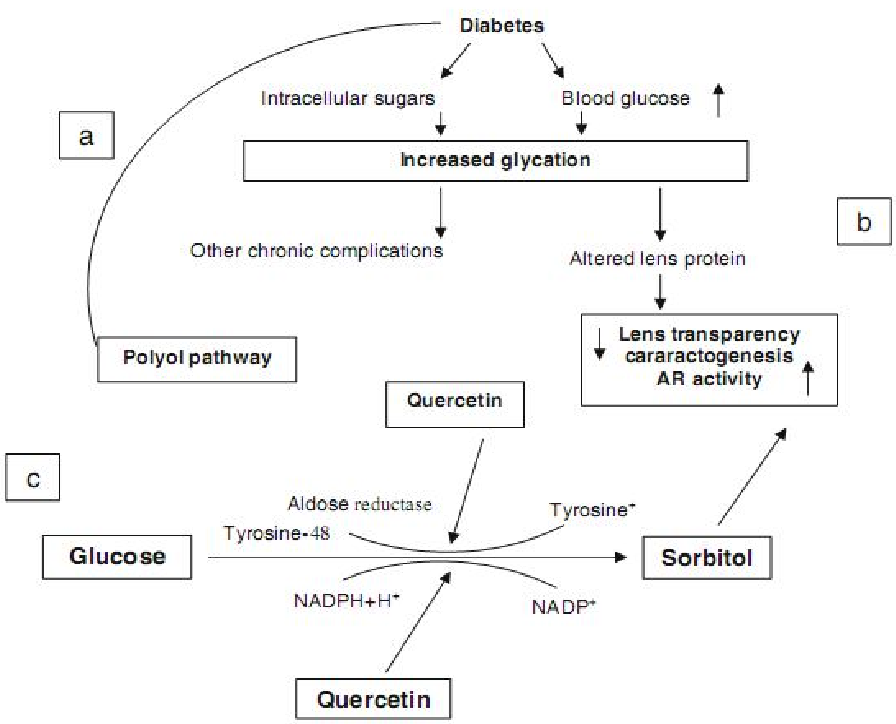

Fig. 2: Etiology of complications of diabetes (Chethan *et al*,. 2008)

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