

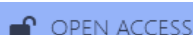


Original Article

Zesty Pomegranate Bon-Bon Candies: A Tasty Boost For Your Brain And Gut Health

Dr. Sharadendu Bali

MBBS, MS, PhD, Professor General Surgery, TMU, Moradabad



Corresponding Author:

Dr. Sharadendu Bali

MBBS, MS, PhD, Professor General
Surgery, TMU, Moradabad.

ORCID no : 0000-0002-5928-623X

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ABSTRACT

Pomegranate (Anardana) herbal balls are a traditional South-Asian nutraceutical made from dried pomegranate seeds (*Punica granatum*) mixed with cumin, fennel, black pepper, dried ginger, dried unripe mango powder (amchur), rock salt, black salt, and lemon juice. Pomegranate seed is the main ingredient, which contains polyphenols and punicalic acid that have been found to enhance mitophagy, limit NF- κ B-mediated neuro-inflammation, and improve cognition in 5XFAD mice models and in prion models. In clinical trials, some of the ingredients of the bon-bons were observed to reduce levels of fasting glucose and inflammatory markers in diabetic patients. Additionally, bioactives in *Zingiber officinale* (gingerols, shogaols, essential-oil terpenes) activate AMPK, inhibit the NLRP3 inflammasome, and relieve dysmenorrhoea, nausea, osteoarthritic pain, and insulin resistance in humans. Also, fennel compounds (anethole, rosmarinic acid) have been demonstrated to scavenge reactive oxygen species, modulate GABAergic signaling, ease infantile colic and hirsutism, and protect the myocardium and liver in animal studies. Besides, the cuminaldehyde from cumin down-regulates α -glucosidase activity and blood-pressure genes, whereas piperine from black pepper increases drug bioavailability, improves metabolic-syndrome markers, and reduces α -synuclein aggregation. Moreover, the mangiferin-rich amchur, triphala-fortified black salt (a dietary source of H₂S), and polyphenol-rich lemon juice add further antioxidant and antimicrobial actions. This review assesses the potential neuroprotective properties, favourable effects on the gut microbiome and other broader physiological benefits of Anardana-based herbal balls by connecting traditional herbal knowledge with modern medical science.

Keywords: Anardana Bon-bons; *Punica granatum* seeds; neuroprotection; herbal candies; food-based nutraceutical, gut microbiome.

INTRODUCTION

Herbal preparations have been utilized as preventive and therapeutic measures across South Asia for centuries. Some herbal formulations have evolved culturally into delectables and desserts, forming a part of life of children and adults. One such example is the ubiquitous availability of tasty sweet-sour herbal candy balls formulated from dried *Punica granatum* seeds, alongwith other condiments, used mainly as digestive stimulants [1,2]. These tangy, spice-enriched bon-bons (small candy balls) have been commonly savored as fun candies by children [Figure 1]. The composition comprises a synergistic mixture of botanical and mineral ingredients, including anardana (pomegranate seeds), cumin, fennel, black pepper, dried ginger powder, amchur (dried mango powder), rock salt, black salt, and lemon juice. Each one of these ingredients exerts specific pharmacological effects that have beneficial effects on multiple tissues sites.

Though commonly these spicy balls are considered to be mainly stomachic aids, a profusion of pre-clinical and clinical studies show that the individual ingredients also provide antioxidant, anti-inflammatory, metabolic, cardioprotective, and neuroprotective benefits. The wide range of bioactive constituents contained in the traditional ingredients are the underlying determinants for the health-promoting effects of Anardana-based herbal balls. Whether derived from fruits, spices, or mineral sources, each component offers potential physiological benefits that enhance the overall health and wellness. Recent scientific studies have confirmed that the bio-active compounds present in each ingredient exhibit a wide range of therapeutic effects. The combined action of these constituents supports the potential of Anardana herbal

balls as a broad-spectrum nutraceutical. This article presents a structured analysis of the current evidence regarding biological activity, underlying mechanisms, and possible contributions to neurological, and digestive, metabolic, cardiovascular, renal, immune, and musculoskeletal functions of each ingredient.

Traditional Uses and Bioactive Compounds contained in the ingredients

Pomegranate (*Punica granatum* L.), a deciduous shrub native to the Middle East and South Asia, has been used in traditional medicine systems including Chinese, Uyghur, and Tibetan, for managing gastrointestinal ailments such as diarrhea, dyspepsia, and inflammatory intestinal diseases. The **seeds**, known as *anardana* when dried, are recognized for their astringent properties and have been utilized in traditional Tibetan remedies to support digestive health. Current evidence suggests that *anardana* may influence metabolic regulation, neurological function, and inflammatory processes, highlighting its potential as a multifunctional health-supportive agent. Pomegranate seeds are rich in a variety of bioactive constituents. The dominant lipid component is punicic acid, a fatty acid which is a unique isomer of conjugated linolenic acid, and accounts for up to 76% of total seed oil. Other notable compounds include polyunsaturated fatty acids (linoleic, oleic), tocopherols (α -, γ -), and phytosterols such as β -sitosterol and campesterol. The seeds also contain significant levels of polyphenols (ellagic acid, gallic acid, ferulic acid), flavonoids (catechin, quercetin, kaempferol), anthocyanins (cyanidin-3-O-glucoside, delphinidin), and hydrolysable tannins. Proteins such as globulins and albumins along with essential amino acids (glutamine, leucine, lysine) also contribute to the nutritional and therapeutic potential of pomegranate seeds [3].



Figure 1. Children enjoying Pomegranate Bon-bons

Ginger (*Zingiber officinale*), a flowering plant belonging to the Zingiberaceae family, has a long-standing history of use in traditional medical systems across Asia, including Ayurveda, Unani and Chinese. The rhizome of ginger is the primary medicinal part, traditionally used to address digestive disorders, gut inflammation, and nausea. Modern pharmacological research has confirmed many of these uses, with ginger now recognized for its broad therapeutic actions, including gastrointestinal, antiemetic, analgesic, anti-inflammatory, antioxidant, metabolic, neuroprotective, and cardioprotective functions. Its active constituents have been isolated and evaluated extensively in both preclinical and clinical settings, leading to the identification of multiple bioactive molecules responsible for its health benefits. Among the biologically active compounds that contribute to its therapeutic efficacy, phenolic compounds and volatile oils are of primary importance. The main phenolic components include gingerols, particularly 6-gingerol (6-GN), 8-gingerol, and 10-gingerol, as well as their dehydrated products, shogaols (primarily 6-shogaol or 6-SG), which are formed during drying or heat processing [4]. Zingerone and paradols are other important phenolics formed during storage or metabolism. Among volatile oils, zingiberene, β -sesquiphellandrene, camphene, and curcumen dominate the essential oil fraction, contributing to the aromatic and therapeutic properties.

Fennel (*Foeniculum vulgare*), a perennial herb from the Apiaceae family, is native to the Mediterranean region and widely cultivated for culinary and medicinal purposes. It has been used in traditional medical systems for treating gastrointestinal discomfort, infections, and hormonal imbalances. The pharmacological activities of fennel are attributed to its diverse phytochemical constituents, including essential oils, phenolic acids, and flavonoids. Major bioactive compounds include volatile oils such as anethole, estragole, fenchone, limonene, and p-anisaldehyde. It also contains fatty acids including linoleic acid, oleic acid, and coumarins such as scopoletin and dillapional. Moreover, the flavonoids and phenolic constituents include quercetin, kaempferol, rosmarinic acid, and caffeoylquinic acid [5].

Cumin (*Cuminum cyminum*), an aromatic member of the Apiaceae family, is traditionally known for its digestive and carminative properties. It has shown potential benefits in managing metabolic syndrome, inflammatory states, cardiovascular diseases, infections, and cancer. These effects are largely due to its essential oil components, particularly cuminaldehyde, which constitutes approximately 48.8% of the oil [6]. Additional constituents like terpenes, flavonoids, and phenolic acids further support the pharmacological potential of cumin.

Black pepper (*Piper nigrum*) is a widely used culinary spice and traditional medicinal plant known for its wide range of pharmacological properties. It has long been used in various traditional healing systems, including Ayurveda and traditional Chinese medicine, for treating digestive disorders, respiratory ailments, and pain. The biological effects of black pepper are attributed largely to its unique chemical composition, particularly its alkaloid and phenolic constituents, which modulate molecular targets and signaling pathways. The major bioactive constituent of black pepper is piperine, a nitrogen-containing alkaloid that exhibits a broad spectrum of therapeutic effects, including antioxidant, anti-inflammatory, neuroprotective, anticancer, and bioenhancing activities. Other notable compounds include piperic acid and essential oil constituents such as β -caryophyllene, sabinene, limonene, and pinene. Additionally, black pepper contains phenolic compounds such as 3,4-dihydroxyphenyl ethanol glucosides [7].

Dried unripe mango powder (*Amchur*) is a traditional culinary spice derived from unripe green mangoes (*Mangifera indica*), commonly used in South Asian cuisine. Beyond its flavoring properties, *amchur* is used in traditional medicine systems for its digestive, antidiabetic, and antioxidant effects. Its health-promoting potential is linked to the presence of a range of bioactive phytochemicals present in the fresh fruit, particularly in the unripe pulp and peel. *Amchur* retains this concentrated profile of phytochemicals found in unripe mangoes, including mangiferin (a C-glucosyl xanthone), phenolic acids (gallic acid, ellagic acid, and ferulic acid), flavonoids (quercetin, catechins and epicatechins), and carotenoids (β -carotene) [8,9].

Black salt, also known as *Kala Namak*, is a traditional herbal salt widely used in Ayurvedic medicine and Indian snacks. Unlike regular table salt, black salt is rich in sulfur-containing compounds, contributing to its characteristic pungent aroma and potential health benefits. The three myrobalans (*Triphala*), namely *Phyllanthus emblica* (*Amla*), *Terminalia chebula* (*Harad*), and *Terminalia bellerica* (*Baheda*), are incorporated into the salt by firing in brick kilns, and each contributes additional bioactive functions. The therapeutic properties of black salt are attributed to both its inorganic sulfur compounds and the plant-derived phytochemicals present in *Triphala*. The sulphur compounds include hydrogen sulfide (H_2S) precursors such as Na_2S , FeS and sodium bisulfate ($NaHSO_4$), polyphenols such as gallic acid, ellagic acid, quercetin, and catechins from *Amla* and *Baheda* [10]. Also, it contains tannins (present in *Harad* and *Baheda*) and mangiferin (a potent antioxidant from *Amla*). Moreover, other nutrients like high potassium content are also present in black salt [11].

Lemon juice (*Citrus limon*) is rich in a wide range of bioactive compounds that contribute to its multiple pharmacological activities. Phytochemical analysis of indigenous varieties such as Lisbon, Eureka, Mayre, and Bush has revealed significant amounts of phenolic contents, flavonoids, and vitamin C, along with low but detectable carotenoids [12]. Furthermore, detailed profiling showed that *C. limon* juice contains flavonoids such as hesperidin, naringin, apigenin, diosmetin, luteolin, quercetin, and isorhamnetin; phenolic acids like ferulic and synapic acids; vitamins A, B1, B2, and B3; and coumarins, carboxylic acids, carbohydrates, and amino acids. Eriocitrin is particularly abundant in lemon compared to other *Citrus* species. Additional studies have also confirmed the presence of alkaloids, steroids, terpenoids, saponins, cardiac glycosides, and reducing sugars in lemon juice. Traditionally, lemon juice has been widely used across Ayurvedic, Unani, and Western herbal traditions to treat scurvy, fevers, sore throats, high blood pressure, digestive problems, and rheumatism. In Indian, Caribbean, and Mediterranean folk medicine, it was also used to promote menstruation, relieve coughs, treat kidney stones, and support wound healing. Mixtures of lemon juice with oils or alcohol were commonly applied for infections, while its ingestion was valued for detoxification and overall vitality [13].

Health Benefits of Constituents of *Anardana*-based spicy herbal Balls

The health benefits of *anardana*-based herbal balls are attributable to their traditional composition of dried pomegranate seeds blended with botanicals such as cumin, black pepper, fennel, dry ginger, *amchur*, and herbal salt [Figure 2]. The therapeutic properties of this preparation arise from the rich phytochemical profile, including polyphenols, essential oils, flavonoids, organic acids, and minerals present in each ingredient, as described below.

A. Pomegranate seed

Preclinical investigations have consistently demonstrated that pomegranate seed (PS) and pomegranate seed oil (PSO) exert protective effects across a spectrum of metabolic, neurological, oncological, and inflammatory conditions. In Alzheimer's and prion disease models, nano-encapsulated PSO enhanced mitochondrial function, reduced p25 and A β accumulation, and improved cognitive performance in 5XFAD mice [14]. PS Polyphenols such as punicalagin and ellagic acid attenuated neuroinflammation via NF- κ B inhibition and reduced tau and β -amyloid pathology, while enhancing autophagy and mitochondrial integrity. Urolithin A, a microbial metabolite, is specifically produced by the gut microbiota from the breakdown of ellagic acid and ellagitannins contained in PS. Urolithin A has been shown to penetrate the blood-

brain barrier and improve mitophagy and synaptic plasticity, and also reduce neuroinflammation in Alzheimer's and Parkinson's models [15].



Figure 2. The ingredients used for preparing Pomegranate seed bon-bons

Additional studies on PSO and pomegranate juice have demonstrated infarct size reduction and neuroprotection in ischemic brain models through elevated antioxidant defenses. In **cancer models**, PSO suppressed proliferation of breast cancer cells via G0/G1 arrest, modulated apoptosis-related genes (Bax $\uparrow$, Bcl-2 $\downarrow$, p53 $\uparrow$), and reduced VEGF levels [16]. Punicic acid targeted PI3K/Akt/mTOR signaling in glioblastoma, while PS extracts promoted apoptosis and oxidative stress in HepG2 liver cancer cells. Notably, PSO nanoemulsions improved targeted delivery of cytotoxic agents in glioma and inhibited nitrosamine formation. Anti-inflammatory and antioxidant properties were evident in PSO-treated skin and liver inflammation models, where COX-1/2, VEGF, IL-6, TNF- α , and IL-2 levels were reduced, and in aged mice, where PSO elevated SOD, CAT, and GSH-Px activity [17].

Further studies have revealed PSO's role in regulating glycaemia and metabolism. In high-fat diet models, PSO enhanced GLUT-4 expression, **insulin sensitivity**, and reduced fasting blood glucose, with mechanisms involving AMPK activation and antioxidant modulation [18]. **Osteoprotective** effects were evidenced through improved bone mineral density, MMP-1 suppression, and enhanced Col-II expression in osteoarthritic and ovariectomized rodents [19]. **Cardioprotective** activities included ROS inhibition, improved lipid ratios, and inflammation attenuation in methotrexate-exposed and H₂O₂-challenged models [20]. In anti-obesity research, PSO reduced visceral fat and upregulated UCP1 expression, promoting beige adipogenesis and reducing neuroinflammation [21]. Finally, antimicrobial effects were demonstrated in some Gram-positive and Gram-negative strains, where PSO accelerated healing in wounds infected by these microbes, and decreased inflammation in topical models [22].

Clinical trials have begun validating these outcomes. Khajebishak et al. (2019) reported that 3 g/day of PSO significantly lowered fasting glucose and pro-inflammatory cytokines (TNF- α , IL-6) in obese T2DM (Type 2 Diabetes mellitus) patients over 8 weeks [23]. Hashemi et al. (2021) found that daily supplementation with 10 g of pomegranate seed powder improved fasting glucose and HbA1c in 60 T2DM patients. In neurocognitive studies, pomegranate juice enhanced memory, retention and learning in older adults [24], while supplementation post-cardiac surgery improved recovery. Mechanistically, the therapeutic effects of PS and PSO are attributed to multiple molecular targets. Punicic acid, the major bioactive fatty acid in PSO, reduces ROS and enhances endogenous antioxidant systems (SOD, CAT, GSH-Px). PSO activates AMPK, promoting insulin sensitivity and glucose regulation, while urolithin A mediates neuroprotection by restoring mitochondrial integrity and downregulating α -synuclein and β -amyloid [15]. Anti-inflammatory actions involve suppression of NF- κ B signaling and COX enzymes, along with reduced cytokine and VEGF expression [18].

B. Ginger (*Zingiber officinale*)

Ginger is medically used in its dried, powdered form, called *Saunth* in the vernacular. Several preclinical models have confirmed the health potential of consuming ginger. Under oxidative stress conditions, ginger **increased antioxidant**

enzyme activities and reduced malondialdehyde (MDA) levels in diabetic rats and the nematode *Caenorhabditis elegans* [25]. In models of Alzheimer's and Parkinson's disease, ginger **improved cognitive performance**, inhibited acetylcholinesterase, decreased β -amyloid and tau pathology, and protected dopaminergic neurons, in part by preserving the integrity of the gut-brain axis, and modulating neuroinflammatory responses [26]. Also, **anticancer** activity was observed across breast, colon, cervical, and renal cancer lines, where ginger induced apoptosis via mitochondrial pathways, inhibited NF- κ B and STAT3 signaling, and modulated apoptosis-related genes such as BAX, BCL2, p53, and caspase-3 [27].

Metabolically, ginger **promotes insulin sensitivity** by activating AMP-activated protein kinase (AMPK) and enhancing GLUT-4 translocation. It also increases GLP-1 secretion and reduces protein glycation via methylglyoxal scavenging [28]. In hyperglycemic models, 6-SG (6-Shogaol is a key bioactive compound found in ginger) modulated the NLRP3/caspase-1/IL-1 β inflammasome and reduced arterial calcification. Ginger's **anti-obesity** effects were demonstrated by reduced visceral fat, upregulation of PPAR- δ , and favorable shifts in gut microbiota [29]. Additional benefits were seen in models of sarcopenia, where ginger prevented myoblast senescence and **enhanced muscle regeneration** [30], and in dermatology, where it inhibited elastase activity and protected against UV-induced skin damage [31].

Human clinical trials have demonstrated that ginger shows efficacy in controlling **nausea and vomiting** across multiple contexts: pregnancy, chemotherapy, postoperative recovery, and antiretroviral therapy [32,33]. Ginger improves gastric motility, reduces dysrhythmias, and modulates apoptosis markers in colorectal cancer risk patients [34]. **Pain-relief** trials showed significant efficacy in cases suffering from dysmenorrhea, migraines, and osteoarthritis, with results often comparable to standard drugs like ibuprofen and mefenamic acid [35,36,37]. Clinical data on metabolic health are also encouraging. Ginger supplementation reduced fasting glucose, HbA1c, insulin resistance (HOMA-IR), and inflammatory markers such as CRP in patients with T2DM, while modest improvements in body weight and QUICKI index were reported in obesity trials [38]. Additionally, ginger improved blood pressure and lipid profiles and showed antiplatelet effects in **coronary artery disease** patients [39]. Other studies have highlighted its ability to reduce heavy menstrual bleeding and enhance lactation volume in postpartum period [40,41].

Mechanistically, the presence of bioactive constituents in ginger, particularly 6-gingerol (6-GN) and 6-shogaol (6-SG), exert **antioxidant** effects by neutralizing reactive oxygen species (ROS) such as hydroxyl radicals, superoxide, and nitric oxide. They also enhance production of endogenous antioxidant enzymes like superoxide dismutase (SOD), catalase (CAT), and glutathione peroxidase [42]. Ginger modulates inflammation through downregulation of key mediators including TNF- α , IL-1 β , IL-6, and inducible nitric oxide synthase (iNOS), primarily via inhibition of the NF- κ B, PI3K/Akt, and MAPK signaling pathways [43]. It also inhibits COX-2 expression and reduces prostaglandin E2 (PGE2) production [44]. These **anti-inflammatory** effects extend to gastrointestinal, neurological, and cardiovascular benefits [Figure 3].



Figure 3. Beneficial effects of the motley of ingredients contained in Pomegranate Bon-bons.

C. Fennel (*Foeniculum vulgare*)

The diverse pharmacological actions of Fennel, called *Saunf* in Hindi, have been confirmed by extensive preclinical studies, which have demonstrated myriad beneficial effects, including antimicrobial, antioxidant, anti-inflammatory, neuroprotective, gastroprotective, cardiometabolic, antidiabetic, anticancer, hepatoprotective, and cytoprotective actions. In **antioxidant** models, fennel extracts demonstrated exceptional free radical scavenging capacity, surpassing even α -tocopherol in reducing hydrogen peroxide and metal-induced oxidative stress. These effects are associated with observations of increased activity of endogenous antioxidants like superoxide dismutase (SOD) and catalase, along with significant reductions in lipid peroxidation markers such as malondialdehyde (MDA) in animal models [45]. Antioxidant effects are driven by the contained polyphenolic compounds, including rosmarinic acid, caffeoylquinic acid, kaempferol, and quercetin derivatives, which neutralize reactive oxygen species (ROS) and simultaneously upregulate endogenous antioxidant enzymes like SOD and catalase, reducing oxidative markers such as MDA. The **anti-inflammatory** properties of fennel seeds have been confirmed in both acute and chronic inflammation models, where methanol extracts markedly decreased edema and cytokine production [46]. The anti-inflammatory actions of fennel involve downregulation of inflammatory mediators including cytokines, nitric oxide (NO), and prostaglandin E2 (PGE2), potentially via inhibition of COX and iNOS enzymes.

Neuroprotective effects of fennel have been demonstrated in animal studies, which showed that fennel extract mitigated anxiety-like behavior, reduced corticosterone levels, and improved memory performance under oxidative and behavioral stress conditions, likely via modulation of GABAergic neurotransmission and antioxidant defense pathways [47]. Neuroprotective and anxiolytic actions likely occur through fennel's flavonoids and phytoestrogens, which facilitate improvements in mood, cognition, and stress responses [48]. **Gastrointestinal benefits** have been shown in models of gastric ulceration, with fennel extract protecting mucosal integrity and suppressing inflammation. In diabetic animal models, fennel extracts significantly lowered blood glucose and oxidative stress biomarkers, supporting its antidiabetic potential [49]. **Hepatoprotective** efficacy has also been demonstrated in chemically induced liver injury models, with reduction in inflammatory cytokines and oxidative damage, and improvements in hepatic architecture [50].

Moreover, **anticancer** effects of fennel have been observed in vitro, where its major constituent compound anethole induced apoptosis in leukemia and hepatocellular carcinoma cells and attenuated tumor-associated oxidative stress [51]. Mechanistically, Anethole has been shown to suppress NF- κ B activation triggered by TNF- α , thereby inhibiting inflammation and promoting apoptosis in cancer cells, a key mechanism behind the anticancer potential of fennel [52]. Fennel has shown **improved coronary perfusion** and reduced lipid accumulation in vascular tissues in cardiovascular models, contributing to blood pressure reduction [53]. Besides, gastrointestinal benefits have been clinically demonstrated in infants, where fennel extract significantly reduced symptoms of colic, such as abdominal pain and flatulence, most likely due to its spasmolytic and antioxidant effects. Fennel essential oil also demonstrates spasmolytic action on smooth muscles, contributing to anti-colic and uterine regulatory effects [54].

Antimicrobial investigations carried out in vitro, have shown that aqueous and alcoholic extracts of fennel exhibit broad-spectrum bactericidal activity against both Gram-positive and Gram-negative bacteria, including resistant strains like *Acinetobacter baumannii* [55]. Further, the essential oil and extracts display antifungal effects against *Candida albicans*, *Aspergillus* spp. and dermatophytes [56]. Additionally, its essential oil constituents such as fenchone, estragole, and thymol exhibit potent acaricidal and insect-repelling properties [57]. Mechanistically, the antimicrobial effects arise from lipophilic constituents of fennel, such as anethole, dillapional, scopoletin, oleic acid, and linoleic acid, which disrupt microbial membranes and interfere with enzyme systems, resulting in pathogen death.

Clinical studies have further backed the traditional and experimental findings on the therapeutic potential of fennel. In a notable double-blind, placebo-controlled trial, fennel extract creams at 1% and 2% concentrations were shown to significantly **reduce facial hirsutism**, with greater efficacy at the higher dose, suggesting a dose-dependent response [58]. In the domain of female reproductive health, fennel's phytoestrogenic constituents, especially anethole, have been linked to alleviation of menstrual discomfort, supporting its use in those with **dysmenorrhea**. Estrogenic effects of anethole and dianethole, mediated via estrogen receptor binding, support menstrual regulation, hormone modulation, and **lactation enhancement** [59].

D. Cumin (*Cuminum cyminum*).

Various preclinical studies have confirmed the therapeutic actions of cumin (*jeera*). In digestion-related models, continuous dietary intake of 1.25% cumin improved pancreatic and intestinal enzyme activity in rats, including increased amylase and chymotrypsin secretion. This led to enhanced nutrient absorption and faster gastrointestinal transit [60]. In bile secretion studies, cumin **stimulated bile flow** by nearly 70%, supporting its traditional use in managing sluggish digestion [61]. In antidiabetic research, cumin consistently showed **hypoglycemic** effects. In streptozotocin and alloxan-induced diabetic rats, cumin extract reduced fasting glucose and improved lipid profiles [62]. Cuminaldehyde, a key active compound, inhibited α -glucosidase and aldose reductase, both of which are involved in diabetic complications [63]. Cumin also **attenuated oxidative damage** by reducing advanced glycation end products and lipid peroxidation. Cardiovascular studies in hypertensive rats revealed that 200 mg/kg of cumin extract **lowered systolic blood pressure**. This was associated with increased nitric oxide (NO) levels and favorable gene expression changes, including eNOS

upregulation and suppression of inflammatory genes [64]. Cumin also raised paraoxonase and arylesterase activity in hyperlipidemic models, enzymes that protect against oxidized LDL [65].

The **chemopreventive** properties of cumin have also been demonstrated. In murine models, cumin extract reduced tumor incidence in the forestomach and uterine cervix by modulating cytochrome P450 enzymes and glutathione S-transferase (GST), which support detoxification [66]. In colon cancer models, cumin decreased DMH-induced tumor growth and altered bile acid metabolism, indicating gut-mediated protection [67]. Other functional benefits include **anti-diarrheal** activity. Aqueous cumin extract delayed castor oil-induced diarrhea onset and reduced intestinal secretion in rats, showing dose-dependent effects [68]. Additionally, cumin essential oil inhibited the fibrillation of α -synuclein in vitro, suggesting a role in **neuroprotection** relevant to Parkinson's disease [69]. Although limited, **clinical studies** offer encouraging support for the therapeutic use of cumin. In a trial on non-insulin-dependent **diabetic** patients, a polyherbal formulation including cumin significantly reduced both fasting and postprandial glucose over 24 weeks, suggesting **long-term glycemic control** benefits [70]. In hypercholesterolemic patients, cumin extract supplementation **improved cardiovascular markers** [71]. These included decreased oxidized LDL and increased paraoxonase-1 activity, which helps prevent lipid oxidation and atherosclerosis [65]. The above studies highlight the potential role of cumin in managing chronic metabolic disorders.

E. Black pepper

Preclinical studies on black pepper provide significant evidence supporting the pharmacological activities of *Piper nigrum*, primarily through its active compound, the alkaloid piperine. In **antimicrobial** in-vitro research studies, piperine demonstrated inhibitory effects against *E. coli*, *S. aureus*, *S. typhi*, and drug-resistant strains, including inhibition of quorum sensing and biofilm formation [72,73]. Further, these anti-bacterial effects of piperine were observed to enhance the susceptibility of bacteria to standard antibiotics, thus establishing piperine as a **bioenhancer** [74]. In addition, piperine acts as a natural efflux pump inhibitor by blocking P-glycoprotein and other multidrug resistance (MDR) transporters. This action results in increased intracellular levels of co-administered drugs, improving their bioavailability and therapeutic efficacy. This bio-enhancing effect has been especially noted with antibiotics, antifungals, and chemotherapeutic agents. In **cancer biology**, piperine contributes to apoptosis, autophagy, and cell cycle arrest. It targets signaling pathways such as PI3K/Akt/mTOR, MAPK, and ERK1/2, while also downregulating HER2 expression. Simultaneously, it activates caspase-3, caspase-9, and pro-apoptotic proteins like BAX, disrupting tumor cell survival mechanisms [75]. These **anticancer effects** of piperine have been observed across several models. In vitro, piperine inhibited the growth of MCF-7, HT-29, and HL-60 cancer cells by promoting apoptosis, mitochondrial dysfunction, and DNA fragmentation. In vivo, piperine administration in mice reduced tumor volume, metastasis, and VEGF expression [76].

In metabolic disease models, piperine showed **antidiabetic** effects by reducing fasting glucose and HbA1c, and also improved lipid profiles. These effects were mediated through aldose reductase inhibition and enhanced insulin sensitivity [77]. **Antioxidant** properties of piperine have been confirmed through both in vitro assays and animal models, which showed that piperine scavenged free radical species, such as superoxide, hydroxyl radicals, hydrogen peroxide, nitric oxide, and peroxynitrite. This is complemented by its ability to boost endogenous antioxidant systems, including superoxide dismutase (SOD), catalase (CAT), glutathione peroxidase (GPx), and glutathione (GSH) in hepatic and neural tissues, thereby protecting these tissues from oxidative stress [78]. Concurrently, lipid peroxidation markers such as MDA were significantly reduced. Piperine also displayed strong **anti-inflammatory and analgesic effects**. It significantly reduced carrageenan-induced paw edema and pain behaviors in multiple animal models [79]. Piperine inhibits nuclear factor-kappa B (NF- κ B) and mitogen-activated protein kinase (MAPK) signaling, including ERK and JNK pathways. As a result, there is a downregulation of inflammatory mediators such as interleukin-1 β (IL-1 β), tumor necrosis factor- α (TNF- α), interleukin-6 (IL-6), cyclooxygenase-2 (COX-2), and inducible nitric oxide synthase (iNOS). In the nervous system, piperine influences neurotransmitter processes. It enhances levels of dopamine (DA), serotonin (5-HT), and gamma-aminobutyric acid (GABA), and supports neural communication and mood regulation. Furthermore, it protects neurons by suppressing acetylcholinesterase (AChE) activity and activating neurotrophic pathways such as BDNF/CREB and PI3K/Akt. These effects help reduce neuronal oxidative injury and inflammation [80]. The **neuroprotective** benefits have been confirmed in models of Alzheimer's, Parkinson's, Huntington's, and epilepsy, where Piperine reduced amyloid- β plaques and α -synuclein aggregation, while increasing BDNF, dopamine levels, and reducing neuroinflammation and oxidative damage. Additionally, its **anticonvulsant** potential was demonstrated in PTZ- and MES-induced seizure models, where it increased latency to seizures and enhanced GABAergic activity [81].

Clinical trials have confirmed the above preclinical studies, and demonstrated the therapeutic potential of piperine in metabolic, inflammatory, neurological, and gastrointestinal disorders. In **obesity and metabolic syndrome**, piperine-containing supplements significantly reduced body fat, insulin resistance, LDL, and inflammatory markers such as CRP and leptin/adiponectin ratio over 8–12 weeks [82]. Combined use of piperine with curcumin, resveratrol, or tocopherol further enhanced antioxidant enzyme activity and reduced oxidative markers [83]. In **osteoarthritis**, a combination of piperine, curcumin, and gingerol led to significant pain relief and improved joint function after four weeks of treatment [84]. Similarly, in elderly individuals with **dysphagia**, oral piperine improved swallowing reflexes and sensitivity, indicating its utility in geriatric care [85]. In healthy adults, piperine reduced mental fatigue and **improved cognitive**

alertness under stress conditions [86]. Liver and kidney support was observed in hemodialysis patients. When co-administered with turmeric, piperine reduced oxidative stress biomarkers, suggesting a role in mitigating inflammation-induced organ damage. In gastrointestinal applications, a 2-week herbal blend including 500 mg *P. nigrum* improved **bloating** and intestinal discomfort, likely through its enzyme-activating and prokinetic actions [87].

F. Unripe mango powder (*Amchur*)

Preclinical and clinical research studies attest that *amchur*, acting primarily through its bioactive compound mangiferin, exerts significant therapeutic effects by modulating oxidative, inflammatory, metabolic, and cellular stress pathways. In vitro and in vivo studies consistently demonstrate strong **antioxidant** activity, with mangiferin scavenging reactive oxygen species (ROS) such as superoxide, hydroxyl radicals, and hydrogen peroxide. Additionally, it also enhances endogenous defenses like catalase, superoxide dismutase (SOD), and glutathione peroxidase (GPx) [8,88]. In diabetic models, mangiferin reduced fasting glucose, HbA1c, and triglyceride levels, improved insulin sensitivity, and preserved pancreatic β -cell function, likely via activation of AMP-activated protein kinase (AMPK), suppression of advanced glycation end products (AGEs), and upregulation of GLUT-4 expression [89]. It also mitigated diabetic nephropathy and renal oxidative stress. **Anti-inflammatory** effects were validated in DSS- and LPS-induced inflammation models, where mangiferin suppressed NF- κ B and NLRP3 inflammasome activation, and upregulated Nrf2/HO-1 signaling, resulting in tissue protection in the liver, lung, kidney, and colon [90]. In gastrointestinal studies, *amchur* reduced mucosal damage, inflammatory cytokines, and oxidative stress while improving gut motility and barrier function [91]. **Cancer-preventive** effects were demonstrated in murine models, where mango juice and mangiferin reduced tumor incidence, enhanced apoptosis, and modulated cell cycle regulators such as Bax, Bcl-2, and caspase-3 [92,93]. In **cardiovascular** studies, mangiferin improved endothelial function, increased nitric oxide (NO) via eNOS upregulation, and lowered inflammatory markers such as CRP and ICAM-1 in hypertensive rats [94]. Additionally, it normalized ALT, AST, BUN, and creatinine in models of hepatotoxicity and renal injury [8, 95].

In a recent randomized control study, raw mango consumption improved **glycemic control** in a majority of diabetic patients. The outcomes were attributed to reduced insulin resistance and antioxidant activity [96]. In schoolchildren, mango juice byproducts **boosted immunity** and reduced infection rates, likely due to immunomodulatory polyphenols [97]. Further, clinical studies involving **metabolic disorder** patients reported consistent improvements in glucose and lipid profiles and reductions in oxidative and inflammatory markers. The therapeutic outcomes of *amchur* are mechanistically supported by the capability of mangiferin to activate the Nrf2 pathway, inhibit NF- κ B and MAPKs (ERK, JNK), suppress iNOS, COX-2, TNF- α , IL-1 β , and IL-6, and block the NLRP3 inflammasome. Its anticancer properties are linked to G2/M arrest, pro-apoptotic protein activation, and modulation of detoxification enzymes like GST [98]. Additionally, mangiferin enhances gastrointestinal integrity via cholinergic stimulation and promotes cardiovascular health through vascular relaxation and antioxidant activity [90].

G. Black salt

Black salt, also known as *Kala Namak*, demonstrates a wide range of pharmacological activities attributed to its unique composition, particularly its sulfur compounds and Ayurvedic constituents such as *Triphala* (three myrobalans). **Preclinical studies** have revealed that the sulfur compounds of black salt, specifically sodium sulfide (Na_2S), iron sulfide (FeS), and sodium bisulfate (NaHSO_4), are metabolized into hydrogen sulfide (H_2S), which functions as a gasotransmitter in mammalian systems. H_2S has been shown to regulate vascular tone, enhance endothelial nitric oxide production, and mitigate mitochondrial dysfunction by modulating K^+ -ATP channels and inhibiting ER-stress-related proteins such as phosphorylated eIF2 α and caspase-12, offering cardiovascular and neuroprotective benefits in ischemia-reperfusion and stroke models [99, 100,101]. Studies in rodent models have demonstrated that H_2S produced from black salt reduces oxidative neuronal damage and preserves mitochondrial integrity [99,102], while *Triphala* components such as Amla and Baheda further protect against oxidative renal and hepatic injury through inhibition of iNOS and COX-2, as well as suppression of systemic CRP levels [103].

Clinical trials investigating the individual components of black salt support its therapeutic actions. Amla (*Phyllanthus emblica*) supplementation in hyperlipidemic patients led to significant reductions in LDL, triglycerides, and markers of oxidative stress such as malondialdehyde (MDA), alongside improved endothelial function and glucose tolerance in diabetic subjects [104,105]. Similarly, *Terminalia chebula* (Harad) and *Terminalia bellirica* (Baheda), when administered in extract form, improved renal biomarkers and reduced gingival inflammation in patients, likely through antibacterial effects targeting *Streptococcus mutans* and enhancement of nitric oxide bioavailability [106,107]. Additional studies confirmed the role of Baheda in lowering uric acid and creatinine levels in CKD patients [107] and showed that its supplementation can mitigate oxidative stress and improve metabolic parameters in models of non-alcoholic fatty liver disease (NAFLD) and obesity [108]. Mechanistically, the anti-inflammatory activity of black salt is achieved through downregulation of NF- κ B and MAPK pathways, along with inhibition of NLRP3 inflammasome assembly by Chebulagic acid, Gallic acid and Ellagic acid, resulting in reduced IL-1 β , TNF- α , and COX-2 expression in models of sepsis, colitis, and arthritis [109,110].

H. Lemon juice

Several studies have been conducted to determine the anti-microbial and anti-mutagenic effects of Citrus limon juice. Lemon juice exhibits antibacterial activity against both Gram-positive and Gram-negative strains, notably inhibiting *Staphylococcus aureus* and *Pseudomonas aeruginosa*, [111, 112]. Lemon juice also inhibits the growth of the fungus *Candida albicans*. In other studies, lemon juice exhibited strong antibacterial effects against multidrug-resistant strains such as *Shigella flexneri* and *Staphylococcus epidermidis*. In cancer prevention studies, lemon juice significantly decreased viability of human astrocytoma cancer cells in vitro, and demonstrated anti-mutagenic activity by inhibiting sodium azide-induced back mutations in *Salmonella typhimurium* (TA100), with half-ripened lemon juice showing stronger effects than ripened juice in both the scenarios [113]. **Preclinical studies** have confirmed these activities. *C. limon* nanovesicles inhibited proliferation of cancer cells and suppressed chronic myeloid leukemia tumor growth in vivo [13].

Lemon juice also shows moderate antioxidant capacity by inhibiting DPPH [114]. Citrus flavonoids such as hesperidin and eriocitrin, along with vitamin C neutralize reactive oxygen species (ROS) and enhance antioxidant enzyme activity by upregulating the Nrf2 pathway. This antioxidant action reduces oxidative stress in tissues exposed to intense physical activity or inflammation. In **animal models**, lemon and lime extracts have demonstrated anti-inflammatory properties by suppressing NF- κ B activation and decreasing levels of pro-inflammatory cytokines (IL-1 β , IL-6, TNF- α), cyclooxygenase-2 (COX-2), and inducible nitric oxide synthase (iNOS), especially in models of colitis, arthritis, and metabolic syndrome [115]. Also, protection against formation of urinary calculi is achieved through the citric acid content in lemon and lime, which elevates urinary citrate levels and alkalizes the urine, thereby preventing calcium oxalate stone formation. Lime juice also shows digestive benefits, since it stimulates bile and gastric secretion, enhances gut motility, and soothes symptoms of reflux and colitis through cholinergic and vagal modulation.

Human clinical and observational studies on lemon juice have also unveiled interesting outcomes. In overweight Korean women, a "lemon detox diet" involving 2 liters of lemon juice per day significantly reduced body fat, insulin resistance, and serum hs-CRP levels without adverse hematological changes [116]. In middle-aged Japanese women, daily lemon juice intake combined with walking resulted in significant reductions in systolic blood pressure, highlighting lemon juice's cardiovascular benefits [117]. Cardiovascular protection is also achieved by improving thrombin time and anticoagulant profiles, and enhancing protein C levels. Lemon juice also exhibits neuroprotective effects by significantly improving short- and long-term memory in passive avoidance tests in mice [118]. Also, a systematic review concluded that lemon polyphenols significantly reduce oxidative damage and inflammatory markers following exercise, promoting faster recovery and reduced muscle soreness. In patients with GERD or functional dyspepsia, lemon and lime, particularly when combined with honey or herbs, were associated with symptomatic relief. Furthermore, warm lemon water has been associated with weight loss benefits due to its pectin content and citric acid-induced metabolic stimulation. In tropical regions, lime juice remains a vital dietary source of vitamin C, supporting immune function and preventing scurvy, particularly in nutritionally vulnerable populations. These collective findings support lemon juice's broad systemic benefits, including antioxidant, anti-inflammatory, anticancer, antimicrobial, cardiovascular, and neuroprotective actions.

Mechanistically, the bioactive constituents of lemon juice exert antioxidant effects by scavenging reactive oxygen species (ROS) like superoxide and hydroxyl radicals, reducing lipid peroxidation, and strengthening endogenous antioxidant defenses, such as SOD, CAT, GPx [118]. Anti-inflammatory actions are mediated via suppression of NF- κ B signaling and downregulation of inflammatory cytokines (TNF- α , IL-1 β). Lemon-derived nanovesicles activate TRAIL-mediated apoptosis in cancer cells, while lemon juice modulates metabolic markers such as hs-CRP during calorie-restricted diets.

DISCUSSION

Pomegranate bon-bons are sold everywhere in India, and children love to snack on these spicy, sweet and sour candies. Research studies on herbs and spices conducted in the last few decades have unraveled the health benefits of spices, and it turns out that these delectables are not simply tasty candies, but also rather useful for the functioning of body systems. The human and animal evidences from studies reviewed above demonstrate that each ingredient in the Anardana herbal bon-bons, taps into key molecular pathways, and together these actions offer neuro and cardio-protective effects, alongwith whole-body benefits.

The key bioactives in the formulation such as punicalagin and ellagic acid (pomegranate), gingerols/shogaols (ginger), anethole (fennel), cuminaldehyde (cumin), piperine (black pepper), mangiferin (amchur), Triphala-derived tannins (black salt), and the flavonoid–vitamin C complex of lemon juice uniformly activate the Nrf2 pathway, thereby up-regulating endogenous antioxidant enzymes. Concomitantly, they suppress the NF- κ B, MAPK, and NLRP3 signalling axes, limiting downstream inflammatory cytokine production. Several constituents (e.g., punicic acid, urolithin A, piperine) additionally restore mitophagy and mitochondrial integrity, effects linked in preclinical models to improved metabolic control, vascular function, neurocognitive performance, and attenuation of tumor growth.

Moreover, **pre-clinical studies** demonstrate that the combined phytochemical profile of the ingredients lowers cerebral β -amyloid and α -synuclein burdens, enhances insulin sensitivity, improves lipid ratios, reduces arterial pressure,

preserves hepato-renal architecture, and exerts broad-spectrum antimicrobial activity. Early-phase trials with the individual botanicals have confirmed these findings, reporting better glycemic control, loss of body fat, attenuation of osteoarthritic pain, higher cognitive performance, and decrease in systemic inflammatory markers. The coherence of mechanisms across ingredients, including redox balance, inflammation resolution, metabolic re-programming, and microbiota modulation suggests true pharmaco-dynamic synergy when the spices, salts and fruit acids are co-formulated in traditional proportions.

CONCLUSION

Anardana Goli exemplifies how traditional formulations can offer more than nostalgic flavor—they serve as biofunctional agents deeply intertwined with gut microbiology. Through the generation of metabolites like Urolithin A, modulation of microbial diversity by polyphenols and spices, and the antimicrobial properties of essential oils, this age-old remedy demonstrates a diverse potential for supporting gastrointestinal and neuroimmune health. Bridging traditional remedies and modern pharmacology, Anardana Goli highlights the importance of exploring cultural dietary practices through a scientific lens, showing how they can play a valuable role in today's approach to health.

This review aimed to systematically gather, evaluate, and synthesize pre-clinical and clinical evidence on the systemic benefits of individual ingredients of Anardana-based herbal balls, in order to clarify their shared and complementary biological mechanisms for amelioration of several bodily disorders. While classical texts primarily depict these spicy balls as remedies for digestive issues, numerous pre-clinical and clinical studies have demonstrated that their individual components also offer antioxidant, anti-inflammatory, metabolic, cardioprotective, and neuroprotective effects. The delectably tangy, sweet-sour taste is an added advantage that no doubt proves helpful in compliance and regular use after meals, and also in-between meals.

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