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REVIEW

Health effects, sources, utilization and safety of tannins: a critical review

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ABSTRACT

Tannins are complex, astringent and water soluble phenolic compounds known to reduce the bioavailability of nutrients in gut. Furthermore, tannins pose some health consequences *viz.* anti-nutritional effect, reduced digestibility, mutagenic and carcinogenic effects and inducer, hepato-toxic activity and co-promoters of several diseases. However, recent studies have explored and confirmed numerous health benefits like anti-oxidant, anti-cancerous, anti-allergic, anti-inflammatory, anti-helminthic and anti-microbial activities). Owing to their astringency, the food applications are very limited; whereas, they have wide applications in pharmaceutical industries. The present review has been aimed to highlight the classification, sources, occurrence, health effects, industrial applications and the safe limits of consumption of tannins.

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1. Introduction

Seguin coined the term ''Tannin''($C_{76}H_{52}O_{46}$), (commonly known as tannic acid) for substances present in the extracts of vegetables and responsible for the animal skin conversion into leather (Chung *et al.* 1998, Ghosh, 2015). The tannins are majorly categorized into two groups, namely, condensed tannins (non-hydrolyzable) and hydrolyzable tannins. They are naturally present in leaves, seeds, bark, roots, fruits, vegetables, legumes, cereals, shrubs and in more than 40 herbs (Hassanpour *et al.* 2011, Ghosh, 2015). Tannins are consumed by more than 80% of the world population in one or another form. Its consumption is more frequent among children and adults through beverages such as tea, coffee and wine, beer as it elevates the mood and lessens the fatigue (Morton, 1992). It is present in high amount in kola nut which is commonly chewed by people in West African countries, as well as in Guarana seeds; which is added in soft drinks in American countries and Brazil (Kumar *et al.* 2018).

Tannin, a polyphenol possesses various medicinal, therapeutic properties as well as acts as an antioxidant; and therefore exhibits various pharmacological properties such as anti-toxic, anticancerous, antiallergic and anti-inflammatory, anthelmintic, antimicrobial, antiviral, healing of wounds, curing of dysentery etc. (Ghosh, 2015). Besides, tannins have various adverse effects i.e. antinutritional effect, enhanced indigestibility, mutagenic and carcinogenic, inducer and co-promoters of many diseases, severity of the migraine, hepatotoxic activity, inhibitory actions. The present review focuses on various sources, health benefits and simultaneously the adverse effects of tannins to provide a brief overview of its importance to the readers.

2. Types of tannins

Tannins are plant based polyphenols which are astringent in nature and are found in different parts of the herbs, plants are consumed as food and feed. These are majorly categorized into two groups, namely, condensed tannins (non hydrolyzable) and hydrolyzable tannins. Hydrolyzable tannins are further sub categorized into gallotannins and ellagitannins, where former are the simplest type among the hydrolyzable tannins (Khanbabaee and van Ree, 2001). A brief explanation of the different types of tannins is given in Figure 1. Condensed tannins, also known as proanthocyanidins, are more complex and therefore not yet determined completely. These are present in amounts greater than condensed tannins which occur only in trace amounts

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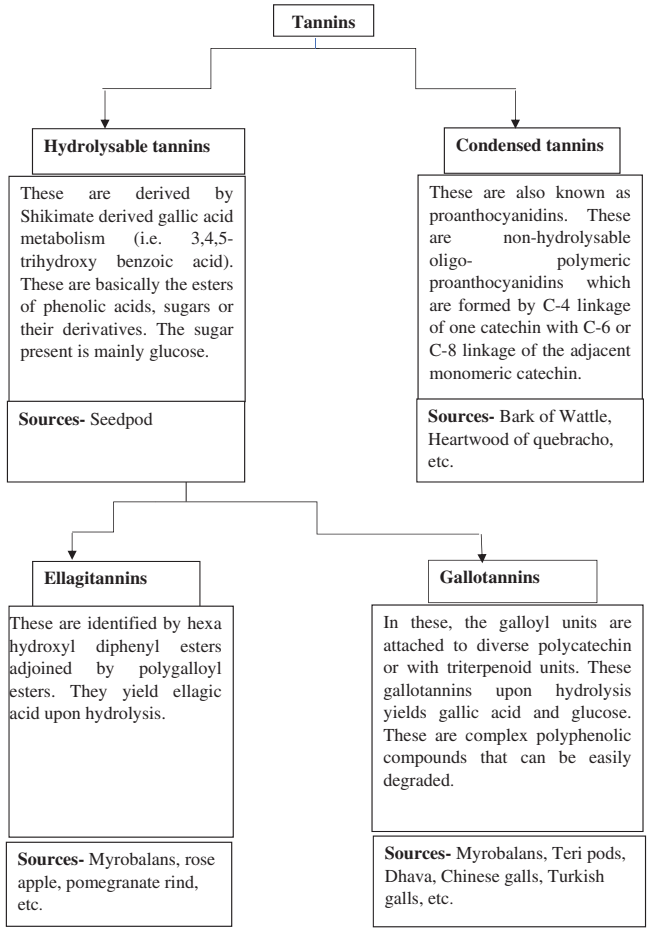

Figure 1. A brief explanation of different types of tannins. **Source-** Ramakrishnan and Krishnan (1994); Bravo (1998); Khanbabaee and van Ree (2001); Ghosh (2015).

in certain foods (Chung *et al.* 1998). Condensed tannins are the most commonly existing ones that are generally found in stems, legumes, trees, forages, etc. (Hassanpour *et al.* 2011), whereas hydrolyzable tannins are found in seedpod, bark, wood, leaves, fruits, etc.

3. Sources of tannins

In nature, there are two major sources of tannins i.e. natural and synthetic, which play a significant role in affecting the plants as well as human health in both positive and negative terms.

3.1. Natural sources

The chief sources of tannins are kola nuts (*Cola vera*), guarana (*Paulliniacupana*), tea *(Camellia sinensis),* coffee (*Coffea spp.*), cocoa (*Theobroma cacao*). Various fruits, vegetables, cereals, legumes, herbs, forages, condiments and spices are also known to be good sources of tannins (Hassanpour *et al.* 2011). It is widely distributed all over the kingdom Plantae, majorly among trees (higher plants), herbs, shrubs, legumes, etc. whereas, lower plants such as mosses, fungi and algae do possess tannin but in trace amounts (Ashok and Upadhyaya 2012). Tannins are reported to be present in plants adapted to warm climates and possess broader leaves, such as sorghum (*Sorghum bicolor*), Sericea lespedeza (*Lespedeza cuneata*), etc. Few parts of some plants are also reported to have a significant amount of the tannins such as leaves (White clover i.e. *Trifolium repens*) and seed coat (Alfalfa i.e. *Medicago sativa*) (MacAdam *et al.* 2013). The location of tannin varies from crop to crop, and can be found in leaves or roots or stem or fruits or peel or seeds or shell or bark, etc. (Table 1).

Among the different natural sources of tannins, tea is cultivated worldwide and the major tea producing countries are India, Java, Sri Lanka, Sumatra, Kenya and Japan (Willson and Clifford 2012). It is one of the most widely consumed beverages after water (Kumar *et al.* 2016, Kumar and Joshi 2016, Joshi and Kumar 2017) and is used as a source of refreshment. Coffee is cultivated all over the world and the major coffee

Table 1. Occurrence of tannins in different parts of plant and their beneficial effects.

Sr. No.	Plant part	Specific location	Function
1.	Non woody parts	Secondary xylem and phloem	Supports and regulates the growth of tissues.
2.	Heartwood	Heartwood of conifers	Possess antimicrobial activity and thereby increasing the durability of wood naturally.
3.	Bud	Outer parts of buds	Provides protection against freezing.
4.	Leaf	Epidermis	Provides protection against predators by reducing its palatability.
5.	Root	Hypodermis	• Inhibits the colonial formation of pathogens. • Tannins along with other polyphenols influences growth as well as development of the plant. • It also plays important role in reproduction of plants by its interaction with Gibberlic acid and auxin.
6.	Seed	Layer between aleurone and outer integument	Helps in maintenance of dormancy stage of plant. It also possesses bactericidal and allopathic properties.
7.	Stem	Region of active growth	Plays important role in growth and regulation of such tissues.

Source: Green and Corcoran (1975); Jacobson and Corcoran (1977); Ashok and Upadhyaya (2012).

producing countries are Ethiopia, Brazil, Indonesia, Vietnam, Columbia (Kumar *et al.* 2018). Most of the coffee species that are used for commercial purposes originate from Africa (Pohlan and Janssens 2010). Cocoa is the primary ingredient used in the manufacturing of chocolates (Ghosh 2015). Ghana is the second largest producer of cocoa beans as well as famous for top most production of cocoa beans of premium quality (Kumar *et al.* 2018). Guarana, which is obtained from (*Paullinia cupana*) is a climbing shrub native to Venezuela, Peru, Brazil, Uruguay and Bolivia. Guarana and kola nuts have a stimulating effect (Morton 1992).

Fruits such as berries (strawberries, raspberries, blackberry, blueberries, etc.) contain significant amount of tannins, however, other fruits such as majuphal (*Quercus infectoria*), babul (*Acacia arabica*), amla (*Emblica officinalis*), red supari (*Areca catechu*), munakka (*Vitis vinifera*), dates (*Phoenix sylvestris*), raisins (*Vitis vinifera*), pomegranate, peach, plum, grapes, apple juice, apricots, peaches, bananas, persimmons, etc. also contain tannins in ample amount (Kumari and Jain 2015). Moreover, tannin is the major component after cellulose, lignin and hemicellulose in most of the vegetables (Samanta *et al.* 2004).

Sorghum, which is one of the staple food in Asian and African countries contains high amount of tannins. Although cereals contain less amount of tannins, whereas, millets, barley as well as legumes like chick peas, fava beans, pinto beans, common beans, cowpeas, kidney beans are few of the typical tannin containing foods (Bennick 2002, Kumari and Jain 2012). Various herbs such as curry leaves (*Murraya koenigii), Prunella spica, Polygonum multiflorum, Agrimoniapilosa, Ephedeasinica, Rheum palmatum* and forages like lespedeza, sainfoin, trefoil, lotus, crown vetch, etc. also contain good amount of tannins (Ghosh 2015). Condiments and spices such as coriander, tamarind, turmeric, chilies, etc. which are commonly used as flavoring agents in various dishes contain tannins in appreciable amount. Tannin is not limited to food items such as vegetables and fruits but is also present in bark, seeds, roots, leaves and grains of various plants. The detailed description of the various sources of tannins along with their concentration is presented in Table 2.

3.2. Synthetic sources of tannins

Tannins can be synthesized artificially by using naphthalenes, cresols and other higher hydrocarbons as primary ingredients. Vegetable tannins such as digallic acid, ellagic acid, metellagic acid, flavellagic acid, luteic acid, etc. are synthesized artificially, whereas, Neradol D, Neradol N, Ordoval G and tannic acids (contained in galls) are the synthetic tannins used for various industrial applications majorly in food and leather industry. Digallic acid is soluble in methyl alcohols as well as in ethyl alcohols while partially soluble in hot or cold water. Upon hydrolysis, it yields gallic acid, whereas oxidation of it yields ellagic acid and luteic acid. Ellagic acid is completely soluble in caustic potash while slightly soluble in ether, water and alcohol. Neradol D is water soluble, used along with natural tannins in leather industry; possesses commercially advantageous because of its low cost. Ordoval G is a product of formaldehyde condensation of higher hydrocarbons. It is far more effective than natural tannins as 40 Kg of Ordoval G amounts to 100 Kg of vegetable tannins (Grasser 2005).

4. Health effects

4.1. Beneficial effect of tannins

The beverages containing tannins like tea, wines, beer, etc. are more popular among adults and the products with tannins such as chocolates, ice creams are

Table 2. Various sources of tannins along with concentration.

Sr. No.	Particulars	Name of Plant	Tannin (%)	References
1.	Fruits	Majuphal (*Quercus infectoria*)	10.62	Arogba (1997), Del Bubba *et al.* (2009), Kumari and Jain (2015)
		Babul (*Acacia arabica*)	7.27	
		Amla (*Emblica officinalis*)	4.15	
		Ripened banana	0.025–0.48	
		Red Supari (*Areca catechu*)	1.52	
		Munakka (*Vitis vinifera*)	0.23	
		Dates (*Phoenix sylvestris*)	0.23	
		Raisins (*Vitis vinifera*)	0.11	
		Badillayachi (*Amomum xanthiodes*)	0.14	
		Persimmon (*Rojo Brillante*)	9–27	
		Persimmon (*Kaki Tipo*)	17–32	
		Mango kernel (*Ikanekpo variety*)	4.48	
		Sangiri (*Prosopis cineraria*)	0.14	
2.	Leafy vegetables	Canola (whole)	2.71	Gupta et al. (2005), Goel *et al.* (2008), Lipsa *et al.* (2012), Gupta *et al.* (2013), Sriwichai *et al.* (2016)
		Canola (dehulled)	3.91	
		Drumstick (*moringa oleifera*)	0.08	
		Bathua (*Chenopodium album*)	0.116	
		Gotu kola (*Centella asiatica*)	0.123	
		Joseph's coat (*Amaranthus gangeticus L.*)	0.171	
		Edible Amaranth (*Amaranthus tricolor*)	0.305	
		Fenugreek (*Trigonella foenum graecum*)	0.163	
		Desert horsepurslane (*Trianthema portulacastrum*)	0.061	
		Plumed cockscomb (*Celosia argentea*)	0.113	
		Snakeroots (*Polygala eriopter*)	0.098	
		Punarnava (*Boerhaavia diffusa*)	0.094	
		Mexican mint (*Coleus aromaticus*)	0.015	
		False amaranth (*Digera arvensis*)	0.079	
		(*Cocculus hirsutus*)	0.205	
		Benghal dayflower (*Commelina benghalensis*)	0.105	
		Shona cabbage (*Gynandropsis pentaphylla*)	0.136	
		Buttercup (*Cucurbita maxima*)	0.157	
		White Gulmohur (*Delonix elata*)	1.330	
		Musk thistle (Carduus leaves)	0.36	
3.	Cereals and millets	Rice (*Oryza sativa*)	0	Rao and Prabhavathi (1982), Bennick 2002), Medugu *et al.* (2012), Devi *et al.* (2014), Balasubramanian *et al.* 2014)
		Wheat (*Triticum aestivum*)	0.041	
		Sorghum grain (red)	1.54–7.44	
		Sorghum grain (white)	0.55	
		Sorghum grain (yellow)	0.2–2.0	
		Bajra (*Pennisetum typhoideum*)	0	
		Ragi (*Eleusine coracana*)	0.36	
		Finger millets (Brown)	0.12–3.47	
		Finger millets (White)	0.04–0.06	
		Pearl millet	0.152	
4.	Seeds/ Nutseeds	Cumin seeds (*Cuminum cyminum*)	0.23	Bennick (2002), Venkatachalam and Sathe (2006), Murthy and Manonmani (2009), Kumari and Jain (2015), Kirubakaran *et al.* (2016)
		Mango seeds (*Mangifera indica*)	0.35	
		Fenugreek (on dry basis)	0.01	
		Coffee (Monsooned malabar)	0.08	
		Coffee (Monsooned robusta)	0.15	
		Castor seeds	0.6–3.68	
		Faba beans	0.7–3.8	
		Tamarind seeds	20	
		Almond	0.07–0.29	
		Brazil nut	0.01	
		Cashew nut	0.03–0.04	
		Virginia peanut	0.16–0.29	
		Walnut	0.18–0.34	
		Pistachio	0.02–0.22	
		Pecan	0.84–0.88	
		Pine nut	0.01	
		Hazelnut	0.04–0.23	
		Macadamia nut	0.01	
5.	Legumes	Pigeon pea	4.3–11.4	Rao and Prabhavathi (1982), Medugu *et al.* (2012)
		Chickpea	1.9–6.1	
		Green gram (*Phaseolus aureus*)	0.437	
		Bengal gram	0.33	
		Red gram (*Cajanumcajan*)	0.607	
		Soya bean (*Glycine max merr.*)	0.045	
		Kidney bean (*Dolichos lablab*)	1.024	
		Cowpea (*Vigna catjang*)	0.175	

(*continued*)

Table 2. Continued.

Sr. No.	Particulars	Name of Plant	Tannin (%)	References
6.	Condiments, spices and herbs	Tamarind (*Tamarindus indica*)	0.6	Rao and Prabhavathi (1982),
		Tamarind powder	1.240	Tur and Brenner (1998),
		Mixed condiment powder	0.611	Mansoori *et al.* (2006), Kumari
		Coriander (*Coriandrum sativum*)	0.311–0.82	and Jain (2015), Sriwichai
		Turmeric (*Curcuma domestica*)	3.350	*et al.* (2016), Hoffmann *et al.*
		Turmeric (*Curcuma longa*)	0.11	(2016), Mamatha and Prakash
		Kathaa (*Acacia catechu*)	10.86	(2016), Kirubakaran
		Chilli powder (*Capsucum annuum*)	0.98	*et al.* (2016)
		Ajowan (*Carum copticum*)	1.26	
		Cumin seeds	0.90	
		Black pepper (*Piper nigrum*)	0.94	
		Puliogare powder (formulated)	0.206	
		Rasam powder (formulated)	0.233	
		Sambhar powder (formulated)	0.204	
		Bisibele-bhat powder (formulated)	0.216	
		Perilla leaves	0.556	
		Potentilla officinalis	15–25	
		Cinnamon (*Cinnamomum zeylanicum*)	0.35	
		Garlic (*Allium sativum*)	0.12	
		Dry ginger (*Zingiber officinale*)	0.54	
7.	Beverages	Apple juice	0.005	Rao and Prabhavathi (1982),
		Red wine	0.075	Bennick (2002), Mousavinejad
		Tea (per cup)	0.195	*et al.* (2009), Khasnabis
		Black tea	13.36	*et al.* (2015)
		Green tea	2.65	
		Oolong tea	8.66	
		Cranberry juice	0.025	
		Dry red wines	0.236	
		Sweet white wines	0.036	
		Sweet red wines	0.096	
		Sparkling wines	0.035	
		Pomegranate juice	0.015–0.054	
		Dry white wines	0.039	
		White	0.025–0.031	
		Red	0.14–0.32	
		Bordeaux	0.15–0.49	
		Madeira	0.08	
8.	Masticatories/ Stimulants	Betelnuts (*Areca catechu L*)	8–15	Tur and Brenner (1998)
		Betel leaf (*Piper betle*)	1.0–1.3	
		Coffee beans	0.7	
		Roasted coffee beans	1.7	
		Guarana	12	
		Dry tea leaves	3.7	
		Kola nuts (*Cola acuminata, Cola nitida*)	3.9–4.4	
		Katha (from catechu)	11.7–14.2	
		Cassava leaves	0.15–3.0	
9.	Gel	*Aloe vera*	0.14	Kumari and Jain (2015)

preferred by the kids. Tannins in these products are beneficial in one or the other form and provide us relief from various types of ailments such as reducing the risk of diabetes by enhancing glucose uptake and thus lowering blood sugar level (Kumari and Jain 2015). Diluted tannin solution is applied over an open wound as it precipitates the protein of the wound, thereby making a protective covering and prevents bleeding to aid faster healing (Ramakrishnan and Krishnan 1994). Condensed tannins are also effective against various types of allergies such as asthma, hypersensitive pneumonitis, allergic rhinitis, mite allergens from carpet dust and many more (Chung *et al.* 1998). Tannins possess some of the biological properties such as anti-inflammatory, anticancerous, anti-allergic (Ghosh 2015), anthelmintic (Athanasiadou *et al.* 2000, 2001, Ketzis *et al.* 2006), antimicrobial (Muthukumar and Mahadevan 1981), and antiviral against enteric virus, herpes simplex virus, poliovirus, etc. (Ashok and Upadhyaya 2012). Medicinally, these are employed as antihemorrhoidal, antidiarrheal and for treatment of hemostatic. Tannin's ability to form a protective covering (as discussed earlier) and helps the tissue from getting infected, and is thus used to get immediate relief during skin ulcers, dysentery, soaring of throats, diarrhea, hemorrhaging and fatigue (Ashok and Upadhyaya 2012). Besides, tannin also acts as a precipitating agent (especially in liquor industries) and has good effects on vascular health (Ashok and Upadhyaya 2012). A complete detail regarding the health benefits of tannins is presented in Table 3a along with specific remarks of the researchers.

Table 3a. Beneficial effects of tannin.

Sr. No.	Effect	Key Points/ Findings	References
1.	Treatment of diabetes mellitus	• Tannin enhances the uptake of glucose and thereby lowering the level of blood sugar and reduces the chances of diabetes.	Kumari and Jain (2015)
2.	Usage as medicine	In Ayurveda- • Tannin is used as a strengthening agent for gums in *Siddha* and *Ayurveda* tooth powders. Manufacturing of *Triphla*churna- • During coughs, *triphla* churna is given along with honey to cure it. • Decoction is used to treat conjunctivitis. • Churna solution is diluted for washing and cleaning of ulcers and wounds.	Ramakrishnan and Krishnan (1994)
3.	Healing of wounds	• Diluted tannin solution when applied over an open wound, aids in precipitation of protein, thereby making a protective covering and prevents bleeding to aid faster healing.	Ramakrishnan and Krishnan (1994)
4.	Cures dysentery	• Decoction of the pomegranate rind in folk medicine claims to cure different types of dysentery.	Ramakrishnan and Krishnan (1994)
5.	Prevents cardiovascular diseases	• The antioxidant property of tannins prevents the cholesterol oxidation, which is a precursor of plaque formation in vessels, thus prevents the body from cardiovascular diseases.	Auger *et al.* (2002)
6.	Anticarcinogenic	• Green tea has inhibitory effect on cancer formation and is well documented. People who consume green tea frequently showed lower risk of gastric cancer. • Tannin blocks the carcinogens formation and also retards the formation of tumor, if taken in relevant amount.	Fujiki *et al.* (2002), Buzzini *et al.* (2008)
7.	Antimutagenic activity	• It was reported that tannin obtained from the seeds of grapes possess antimutagenic activity against various mutagens such as alfatoxinB, 2-aminofluorene, Benzo-(a)-pyrene, etc.	Yilmaz and Toledo (2004), Ghosh (2015)
8.	Anthelmintic effect	• Administration of condensed tannin resulted in reduction of parasites.	Athanasiadou *et al.* (2000, 2001), Ketzis *et al.* (2006)
9.	Antioxidant activity	• Tannins because of high molecular weight possess high degree of hydroxylation of aromatic rings, shows antioxidant activity.	Koleckar *et al.* (2008)
10.	Antimicrobial activity	• Presence of tannins causes inactivation of viruses. • It also causes inactivation of extracellular enzymes of various microorganisms. • It is effective against *Penicillium* spp., HIV virus, *S. aureus, C. botulinum,* etc. • Catechin, Epigallocatechin-3-gallate (EGCG) have stronger membrane disrupting capability than that of hydrolyzable tannins but lesser antibacterial activity. • Hydrolyzable tannins (TG-I) possess bactericidal activity against H. pylori by lowering their viability.	Muthukumar and Mahadevan (1981), Chung *et al.* (1998), Khanbabaee and van Ree (2001), Funatogawa *et al.* (2004)
11.	Antiviral activity	• P24 HIV-1 replication is significantly inhibited by tannins. • Upon incubation of tannins with red wines together with high condensed tannins, is useful in inactivation of viruses such as enteric virus, herpes simplex virus, polio virus, etc.	Lu *et al.* (2004) Buzzini *et al.* (2008), Ashok and Upadhyaya (2012)
12.	Effects on vascular health	• Tannins in proanthocyanidin form suppress the production of peptides which are responsible for hardening of arteries.	Ashok and Upadhyaya (2012)

4.2. Adverse effects of tannins

Although tannin is widely used due to its beneficial properties, it also possesses certain adverse effects. Tannin's property of imparting astringency which is used as an advantage in beverage industry is one the major disadvantage for other food industries as it leads to reduced palatability of food products (Price and Butler 1980). Tannin exhibits antinutritional properties by forming complexes with minor elements such as phosphorus, calcium, magnesium, etc., as well as with major elements such as carbohydrates, proteins and rendering them unavailable for the utilization by the body (Waghorn *et al.* 1994, Hagerman *et al.* 1998). It also forms complexes with enzymes that are involved

Table 3b. Adverse effect of tannin.

Sr. No.	Effect	Key points/ Findings	References
1.	Antinutritional effects	• Interaction with nutrients- Tannins form complexes with minerals such as phosphorus, calcium, magnesium and makes them unavailable to monogastric animals.	Waghorn *et al.* (1994), Hagerman *et al.* (1998)
		• Binding activity- Condensed tannins bind with the proteins in diet and interfere in nutrient digestion. Tannin posses much more affinity towards the protein than any other molecule.	Lacassagne *et al.* (1988), Longstaff and McNab (1991)
		• 1 mole of tannin can bind to 12 moles of protein.	Chung *et al.* (1998)
		• Reduces the bioavailability- Tannin reduces the bioavailability of various vitamins (vitamin B12 and vitamin A).	
2.	Enhance indigestibility	• Intake of condensed tannins results in reduced food intake as well as digestibility.	Reed (1995), Dawson *et al.* (1999), Acamovic and Brooker (2005), Ketzis *et al.* (2006)
3.	Mutagenic and Carcinogenic		Chung *et al.* (1998)
		• As per OSHA (Occupational Safety and Health Administration), tannins are enlisted in class 1 carcinogens.	
		• 11–26% of Betel nuts is responsible for causing esophageal and cheek cancer.	
		• Herbal tea in combination with staple diet causes stomach cancer due to mutagenesis.	
4.	Inducers or co-promoters	• Tannins can act as inducers and promotes cancer if present with other carcinogenic molecules.	Chung *et al.* (1998)
5.	Relation with Migraines	• Reduction in the levels of serotonin increases the severity of migraine. This is due to unavailability of starch, which is bounded by tannin and is a precursor of serotonin.	Mather (1997)
6.	Hepatotoxic activity	• Tannic acid causes hepatic cell necrosis in humans as well as grazing animals.	Chung *et al.* (1998)
7.	Inhibitory action	• Condensed tannins are responsible for inhibition of endogenous enzyme activities by forming indigestible complexes.	Medugu *et al.* (2012)
		• There is increase in toxicity and enzyme inhibition effect due to enzymatic oxidation of tannins.	Awad *et al.* (2001)

in digestion of carbohydrates, proteins, pectins because of which they cannot act upon and this in turn is responsible for lowering the nutritional quality of the food. Consumption of too much of tannins in beverages such as tea, coffee without milk can often lead to diseases such as anemia, osteoporosis that can go worst upto cancer (Ricardo-da-Silva et al. 1991). A complete detail of adverse effect of tannin is given in Table 3b. Several adverse effects of tannins on plant growth and development reported by different researchers have been discussed in Table 4.

5. Industrial uses of tannins

Tannins are commonly employed in dye industry for cationic dyes in the manufacturing of inks (iron gallate inks). It is also employed in the clarification of beer, wine and other fruit juices in food industry. It's property of imparting bitterness is used as an advantage in beverage industries, especially in the manufacturing of beer and wines in order to make it more acceptable (Ashok and Upadhyaya 2012). In leather industries, tannin's property of converting animal skin into leather is used as an advantage in the manufacturing process of leather. It is also used in manufacturing of adhesives, plastic resins, gallic acid surface coatings, etc. (Ramakrishnan and Krishnan 1994). It is used as a coagulant in the manufacturing process of rubber. It also forms poison on reacting with heavy metals (Khanbabaee and van Ree 2001). Tannin (Ellagic acid) accelerates the clotting of blood and is therefore used as a hemorrhage, probably due to its antagonistic effect on liberators of histamine (Chung *et al.* 1998).

6. Tannin consumption and safe limits

Tannins (natural or synthetic) are consumed by people through different food sources. It has a great role in reforming the mood, increasing alertness as well as performance of an individual (Morton 1992). In India, the daily intake of tannin varies from 1500–2500 mg as per the diet analysis whereas in USA, it is 1 g per day (may vary from region to region). Much of the content of tannin in diet is contributed by spices. Daily intake of tannin below the range of 1.5–2.5 g is safe for consumption and do not cause any side effects but the consumption beyond this range is responsible for low absorption of iron from diet (Rao and Prabhavathi 1982). The estimated value of catechin and proanthocyanidins dimers, trimers intake is 18–50 mg/day and the major sources includes

Table 4. Inhibitory effects of tannins on plant.

Sr. No.	Effect	Key Points/ Findings	References
1.	Delay in germination	• Various tannins such as Myrobalan tannins and Wattle tannins caused delay in rice seed germination by 1 day.	Muthukumar and Mahadevan (1981)
2.	Suppression of radical development	• Due to tannin (Myrobalan), the radical development was suppressed by 3–4% concentration of tannins.	Muthukumar and Mahadevan (1981)
3.	Photosynthesis	• Stomatal aperture reduction was observed when tobacco plants were treated with tannic acid solution.	Einhellig and Kuan (1971)
4.	Effect on Nitrogen	• Application of tannin decreased the total nitrogen content of plants. • Inhibition of nodulation results in low nitrogen fixation • Tannin treated plants showed low nitrogen uptake, may be due to reduced root system. • Inhibition of nitrate formation results in inhibition of nitrification process.	Hesse 1957, Basaraba (1964), Alexander (1965)
5.	Iron chloresis	• Tannin interferes with iron bioavailability. • Soil treated with tannin showed reduction in the available iron content.	Radhakrishnan and Sivaprasad (1980)
6.	Oxidation capacity	• Oxidation capacity of old roots of rice and groundnut was inhibited by tannins.	Muthukumar and Mahadevan (1981)
7.	Seedling growth	• Gallotannic acid showed inhibitory effect towards the seedling growth of *Helianthus annuus, Digitariasanguinalis* and *Lycopersiconesculentum*. • Significant inhibition of *Tobacco* seedlings by tannic acid was observed. • Growth- 0.5% of Gallotannin shows inhibitory effect towards the growth of bean plants. • Nodulation in groundnut seedlings were inhibited by tannins.	Floyd and Rice (1967), Einhellig and Kuan (1971), Lewis and Papavizas (1968), Muthukumar and Mahadevan (1981)

chocolates, red wine, pears, grapes, etc. (Kumari and Jain 2012). A single cup of tea contains approximately 195 mg/100 g of tannins. The intake level of tannins among children is comparatively lesser than that of adults. For the therapeutic purposes, tannins are to be used in permissible and safe limits as per the guidelines of the regulatory bodies. The natural sources of the tannins such as tea, fruits, wines, chocolates and herbs can be consumed for healthy and disease free life without worries because of their low or negligible risk factor and more beneficial effect (Ghosh 2015).

There is not much documentation done on the safe limits of tannins for humans, however, there are few food products for which the safe limit for tannin is given. According to Joint FAO/WHO Food Standards Program (1995), the tannin content for whole sorghum grains should not exceed 0.5% on dry weight basis, whereas, for decorticated sorghum grains it must be below 0.3% on dry weight basis. According to Food Safety and Standards Regulation (2009), the tannin content for Carob powder (i.e. powder of roasted carobs of *Ceratonia Siliqua*) should be in range 0.1 to 0.15%. Predicted amount of tannic acid given by the Food and Drug Administration in the USA must not exceed 100 mg/kg in foods however there is no such estimation given for European population. As a feed additive, the use of tannic acid upto 15 mg/kg for all animal species is safe. Tannic acid has attained a GRAS status (Generally Recognized as Safe) by FDA (Food and Drug Administration) to be used directly as a food additive, although for various foods, the FDA has limited its use upto certain level (Table 5).

Various studies suggest that tannins if used in permissible amount (such as upto 15 000 mg/kg feed for adult ruminants, 10 000 mg/kg for rabbits and laying hens, 1500 mg/kg for pigs, 1000 mg/kg for chickens) do not result in any ill effects on infants, children, adults, pregnant women (Jamroz et al., 2009; Anonymous 2006; Aquilina et al., 2014). As per FEEDAP panel (The *Panel* on Additives and Products or Substances used in Animal Feed), tannic acid can be used as a feed additive but under the proposed conditions, which will not cause any safety risk to the consumers (Anonymous 2006). Tannin, being a polymer gets poorly absorbed in digestive tract (Nakamura *et al.* 2003) but gets degraded by enzymes (tannases or tannin acyl hydrolases) and bacteria in the gut where its end products are absorbed. As per *in vitro* studies in ruminal fluid from cattle showed that the tannic acid gets converted into resorcinol, pyrogallol

Table 5. Maximum level of use of tannic acid in various foods.

Sr. No.	Food	Maximum level of use (%)
1.	Baked goods and baking mixes	0.01
2.	Meat products	0.001
3.	Alcoholic beverages	0.015
4.	Non-alcoholic beverages and beverage bases	0.005
5.	Hard candy and cough drops	0.013
6.	Frozen dairy desserts and mixes, soft candy	0.04
7.	Gelatins, Puddings and fillings	0.005

Source: Anonymous (1988).

and gallic acid but after incubation of 48 to 72 h neither gallic acid nor tannic acid was detected (Singh *et al.* 2001) which might be due to degradation of these compounds by microbiota in ruminants (Goel *et al.* 2005).

7. Impact of tannin on environment and animals

Tannins are the phenolic compounds that are present in almost every food and feed material in one form or the other. Since it is consumed more frequently via natural sources and somehow by synthetic sources due to their astringent effect, their demand is increasing day by day leading to more production of tannins by industries. Since tannin is majorly obtained from the natural sources and degrades in the environment itself, it is unlikely to possess any adverse effect on the environment (Anonymous 2006). Tannins ultimately reaches either ground water or surface of drinking water or will bio accumulate in the environment, where it undergoes aerobic degradation which lasts for weeks (Anonymous 2006; Kraus et al., 2003). Tannin's exposure to humans from its use in pesticides is extremely small as compared to its exposure via natural sources. Its rapid atmospheric oxidation, low toxicity, biodegradation along with rapid metabolism and excretion decreases the risk of concerns via dietary exposure if used in permissible amount (Anonymous 2006).

Researchers have conducted numerous animal studies, which states that excess use of tannins beyond permissible limits may cause impairment and malfunctioning in the body (Table 6). However, many studies reported no effect of tannins on the animal body as the metabolism of body and diet plays a major role in the effect of tannin. As per the study of Marzo *et al.* (1990) the feed containing 30 000 mg tannic acid/kg can impair the immune system of chicken within 35 days. Incorporation of tannic acid (from chestnut wood) up to 5000 mg/kg for 21 days trial had no adverse effect on feed intake and growth rate of the rabbits and were comparatively better than the control group which were given the normal diet without the incorporation of tannic acid (Liu *et al.* 2011). Similar results were obtained in another study when the concentration of tannic acid (from chestnut wood) was increased up to 10 000 mg/kg of feed (Liu *et al.* 2012). A study on rats where the concentration of tannic acid (green tea polyphenols) 100 g/litre was given to rats for eight weeks resulted in reduction of hemoglobin and hepatic iron by 10% and 25% respectively, however significant reduction in the feed intake was also observed (Marouani *et al.* 2007). Besides this, many researchers have not reported any significant differences in the iron status after consumption of tannin rich diets. In a 4 weeks study rat containing diet 20 mg of condensed tannins per kg of body weight + - phytoferritin, significant reduction in weight gain, serum iron and hemoglobin level was observed. Despite the reduction in iron, rats were not iron deficient and the ferritin was not reduced. However, in the same study, the anemic rats died at the end due to toxicity at daily dose of 20 mg/kg (Delimont *et al.* 2017). Similarly, in developmental studies no effect on implantation, fetal or maternal survival, abnormalities in skeletal tissue or soft tissues were observed when mice were administered with dosage up to 135 mg/kg/bw/day for 10 days during pregnancy. However, reproductive activity was found to be suppressed in mice consuming 8% tannic acid diet continuously prior to and throughout the breeding cycle (Anonymous 2006).

8. Author's opinion

Tannin, a water-soluble polyphenol can be called as a *sword of double edges*. However, if used in permissible limits, its advantages can be reaped upon for the benefit of mankind. Moreover, the dose of tannins required to cause a particular disease or disorder is far beyond the permissible limits. Additionally, as per the studies, the amount of tannin responsible for causing a particular disorder in one animal, does not cause any disorder in another animal of same species. In such cases the type of food taken with tannins is of major concern. In addition, the metabolism of body is responsible for its readily degradation, which varies from animal to animal and species to species. It does not pose any serious environment concern as it undergoes aerobic degradation and is degraded within a span of few weeks only. As tannic acid is present naturally in feed materials, it is improbable that its use in feed or as feed additive would result in its increased

Table 6. Animal models showing the adverse effects of tannin.

Place of study	Duration of study	Animal model	Experiment	Finding	References
Northern California	7 days	Calves	Calves were given dosage of 4.4 - 5.5 g/kg of tannic acid	Calves developed methemoglobinemia.	Plumlee *et al.* (1998)
University of Queensland, Australia	40 days	Mice	Mice were orally administered with 2 - 4.6 g of tannic acid per kg of body weight	Periacinar coagulative and hemorrhagic necrosis developed in liver.	Zhu *et al.* (1992)
University of Queensland, Australia	40 days	Sheep	Sheep were administered with 8 g tannic acid per kg of body weight	Hepatocellular necrosis, steatosis and acicular crystal cleft formation was observed through electron microscopy. However, liver necrosis was not observed.	Zhu *et al.* (1992)
Kangwon National University, Republic of Korea	9 days	Pig	Pigs were administered with diet containing 125, 250, 500 and 1000 mg tannic acid per kg.	Increase in concentration of tannic acid in feed results in reduction of feed efficiency, feed intake. The concentration of iron in excretion was also on higher side. It also reduced the fecal coliform count at day 14, thus imparting negative impact on performance, plasma iron status of pig.	Lee *et al.* (2010)
Hokkaido University, Japan	21 days	Rats	Rats were administered with diet containing 5 g and 10 g tannic acid per kg.	No effect was seen during the diet period of 5 g per of tannic acid. However feeding the diet containing more than 10 g per kg of tannic acid reduced the hemoglobin concentration, serum iron concentration due to decrease in iron absorption.	Afsana *et al.* (2004)
University of Georgia, Georgia	7 days	Rats	Rats were administered with diet containing 0.1 % tannic acid (low concentration) and 0.5 - 2 % tannic acid (high concentration).	Low concentration of tannic acid (0.1 %) didn't appear to be toxic, however at higher levels (0.5 - 2 %), the feeding consumption was reduced and thereby reduction in growth was also observed.	Chang and Fuller (1964)
University of California, California	53 days	Rats	Rats were given dosage of 2 % and 10 % tannic acid	Significant increase in concentration of fecal nitrogen was observed when given 2 % tannic acid; however, the fecal nitrogen content remained same even at 10 % tannic acid concentration.	Glick and Joslyn (1970a)
University of California, California	14 days	Weanling rats	10 weanling rats were fed with 4 % and 8 % tannic acid diet.	Weanling rats that fed diet containing 8 % tannic acid died within 4 to 6 days due to severe depression in food intake. However, rats that fed diet containing 4 % tannic acid survived the experiment. Also, the adult rats when fed with diet containing 8 % tannic acid did not die.	Glick and Joslyn (1970b)
Chemin des Capelles, France	35 days	Goat	Infected goats with 10.000 third stage of larva of *Haemonchus contortus* were given 150 ml of an aqueous suspension of quebracho (source of tannin).	Reduction in fecal egg count (64 %) was observed and was persisted even after the quebracho administration was stopped. Fecundity per capita was also reduced by 57 % as compared to the control.	Paolini *et al.* (2003)
Tunisia	8 days	Rats	Rats were given decoction of green tea or black tea with bean ragout meal.	Significant reduction in hemoglobin and iron bioavailability was observed.	Hamdaoui *et al.* (2003)

concentration in the environment, thus contributing no risk and harm to the environment.

9. Conclusion

A wide range of plant-based food products contain a significant amount of the tannins, which may impart adverse as well as positive health effects on human body depending upon its concentration. However, tannins, when consumed through foods, reduce the digestibility of the nutrient, but they can be reduced to a significant level by several domestic processing treatments such as soaking, germination, cooking etc. Contrarily, tannins can be isolated and purified to develop such pharmaceutical preparations, which can further be used for the treatment of several allergic reactions, inflammatory diseases, infections, cancers, etc. In nutshell, it is concluded that the tannins possess both health and adverse effect (depending upon dose). However, the negative effects of tannins can be discounted over the numerous health benefits it offers; and thus, tannins can be considered as a boon rather than a bane.

Disclosure statement

The authors declare that they have no conflict of interest in the publication.

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