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BIOACTIVE COMPOUNDS, TYPES, STABILITY AND HEALTH BENEFITS

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ABSTRACT

Bioactive compounds are secondary metabolites synthesized by plant cells and perform some function beyond the initial primary requirements of cell and contribute to the survival of the whole plant. These compounds vary widely in chemical composition and function and are categorized accordingly. Examples of bioactive compounds are phenols, terpenoids, thiols, and dietary fibre. However, bioactive compound stability is affected by many variables, including pH, temperature, light, water activity (a_w), storage conditions, the type of processing that suggests that these molecules are unstable and highly at risk of degradation and decay. Consumption of variety of food rich in bioactive compounds associates with reduced risk of cancer, heart disease, stroke, Alzheimer's disease, cataract, and other problems in ageing. Prevention is a more effective strategy than the treatment of chronic diseases. Functional foods that contain significant amounts of organic matter can provide desirable health benefits in addition to basic diets and play an important role in preventing chronic diseases. Bioactive compounds being a source of natural colour attract great attention in food industry.

Keywords**:** Bioactive compounds, dietary fibres, stability, applications and antioxidants.

Introduction

Bioactive compounds are secondary metabolites produced by plants which provide food that can alter metabolic processes by various pathways and lead to better health. They show beneficial effects such as antioxidant activity, anti-microbial effect, natural colourant etc. (Galanakis, *et al*., 2016). In recent times some evidence of the role of certain bioactive compounds in delaying the onset of diseases such as cancer and heart disease has been identified. Many researchers in this field believe that in most cases more evidence is required to substantiate the case for the ability of bioactive compounds to delay the onset of these diseases.

1. Types and structures

1.1 Phenols

Phenols are chemical compounds having one or more hydroxyl groups attached to carbon atom of an aromatic ring. Phenols are subcategorised as flavonoids, phenolic acids and other non-flavonoid compounds (Yaqoob *et al*., 2020).

1.1.1 Flavonoids

Flavonoids are the most consumed polyphenols in human eating routine. Flavonoids are a significant class of nutrient especially which have a place with a class of plant metabolites having a polyphenolic structure, broadly found in organic products and vegetables. They have numerous biochemical and antioxidant effects associated with different diseases, such as malignancy, Alzheimer's disease (AD), atherosclerosis (Lee *et al*., 2008). The chemical structure (Fig.1) is a skeleton of diphenylpropane. Two benzene rings (ring A and B, figure 1) connected by a three carbon chain that shapes a shut pyran ring (heterocyclic ring containing oxygen, the C ring) with benzene A ring.

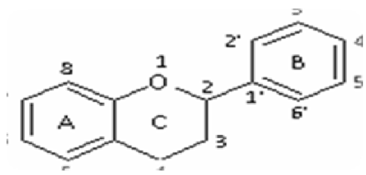

Fig.1: Skeleton of Diphenylpropane

1.1.2 Phenolic acids

Phenolic acids represent the phenolic compounds having one carboxylic acid group. Phenolic or phenol carboxylic acids (a kind of bioactive compound called a polyphenol) are one of the primary classes of plant phenolic compounds. They are found in the seeds, skins of products of the soil of vegetables etc. (Pereira *et al*., 2009). Phenolic acids are principally isolated into two sub-gatherings: hydroxybenzoic and hydroxycinnamic acid.

1.1.3 Non-flavonoids polyphenlos

Tannins are polyphenols in some cases called plant polyphenols, although initially the name tannin was given to the plant separates showing astringency. (Okuda, 2005). Some examples of non-flavonoid polyphenols are Curcuminoids, Stilbenes, Cinnamic acid and Lignans (found in flaxseed, berries and nuts).

1.2 Terpenoids

The fundamental structure of terpenes follows an overall standard: 2-Methylbutane structures. These are compounds which are built of isoprene subunits and are mostly of plant origin, figured by Ruzicka (1953).

1.2.1 Carotenoids

Carotenoids is a conventional term used in animal and plants to assign most typically found pigment. These are the fat-soluble pigments, there are over 700 compounds responsible for the red, orange and yellow tones. Carotenoids are commonly hydrocarbons containing 40 carbon particles and two terminal rings.

1.2.2 Non-carotenoids

Limonene is a colourless fluid rich in the essential oils of pine and citrus trees and utilized as a lemon like odorant in industries and family household items. Saponins, Limonene and Phytosterols (found in vegetable oils) are some of the examples describing non-carotenoid terpenoids.

1.3 Thiols

Thiols can be characterized as a sulphur compound. It is an organic compound having a sulphur particle. It comprises of sulfhydryl groups, i.e. Thiol = R-SH. Thiols incorporates Glucosinolates, Allylic sulphides and non-sulphur containingindoles.

1.3.1 Glucosinolates

Glucosinolates are a class of organic compounds containing (Figure 2) nitrogen, Glucose, amino acid group and sulphur in its structure (Anastas and Warner, 1998). They are also known as group of thioglucosides found among vegetables such as vegetables like cauliflower, broccoli, turnip, kale, and cabbage (red and white) and radish (Yaqoob *et al*., 2020).

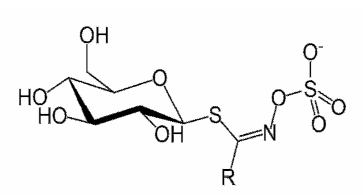

Fig. 2: Structure of glucosinolate

1.4 Chlorophyll (Green leafy vegetables)

Chlorophyll is a chlorin pigment which is found in green parts of the plant like stems and leaves. A magnesium ion is present at the centre of the chlorin ring, four nitrogen atoms from chlorin ring surrounds (it is a heterocyclic compound derived from pyrrole) and binds the magnesium atom. (Woodward *et al.,* 1960). It has a tadpole like appearance i.e. a porphyrin head and phytol (long chain alcohol) tail. Chlorin rings are linked by methane bridges, they contain 5 atoms of Carbon and 1 Nitrogen. Chlorophyll b and Chlorophyll a differ in their structures in having formyl group (-CHO). Instead of a methyl(-CH_3) group (figure 3).

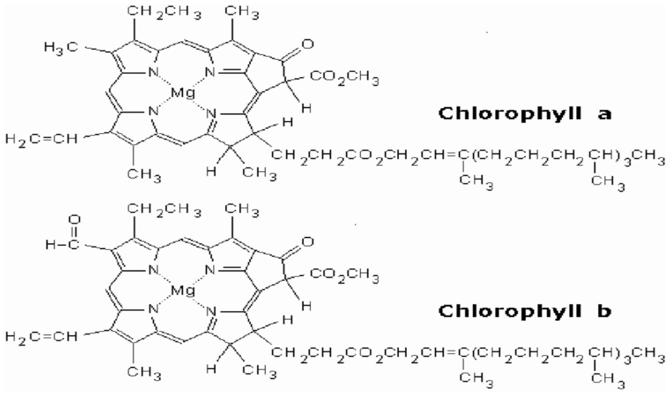

Fig. 3: Structure of Chlorophyll a and Chlorophyll b

1.5 Dietary fibres (Non-starch polysaccharides)

Polysaccharides are widespread biopolymers, which represent the most required group of nutrients in botanical feed. Carbohydrates constitute a wide nutrient category ranging from sugars easily digested by monogastric animals present in the small intestine to dietary fiber fermented by microbes present in the large intestine. The structure of the plant cell wall impacts the physical and chemical properties of the individual molecular weights of the same polymer (Choct, 1997). The factor that differentiates the physical properties among polysaccharides is the way the monomeric units of polysaccharides are linked together (Moms, 1992).

2. Stability under different conditions

2.1 pH

Generally bioactive compounds are sensitive to pH. A study by Oancea *et al*., 2013 shows that pH rigorous studies performed during the 10-day retention period of anthocyanin release at four different pH showed a significant decrease in TA content at pH> 4.5. The reduction of anthocyanins during the last period is reported to follow the first order of kinetics. Sims *et al*. (1993) found that acidification of chopped carrots at pH 4 or 5 with citric acid can improve the color of the juice (β. Carotene content). The effect of pH value on glucoraphanin (4-methylsulfinyl-Bu glucosinolate) was reported.The degradation of glucoraphanin was accelerated when stored under acid conditions. Therefore, glucoraphanin should be retained in a neutral pH state (Wang *et al*., 2000).

2.2 Light

Light may cause oxidation of carotenoids, proteins, lipids, and vitamins commonly present in our food. Palamidis and Markakis (1975) studied the role of light in the formation of anthocyanin in grape juice and showed that exposure to color in light accelerates their destruction. Their experiments showed that after placing anthocyanin-containing juice samples in the dark for 135 days at 20oC, about 30% of the other pigments were destroyed, but the same samples were placed at the same temperature and the same time in light, more than 50% of whole pigments was destroyed. Light can make carotenoids unstable. Carotenoids are known to exist in a variety of geometric ways (cis- and trans-isomers). These forms can be modified by light (Rock *et al*., 1997). Lin and Chen (2005), that light has a greater influence on the isomerization and fight of--carotene cis-isomers than heat. The photocatalyzed oxidation of β-carotene is also more sensitive to ultraviolet light than to visible light (Bonnie and Coo, 1999). It was reported that the glucoraphanin content was 0.0548 mg / mL when the discharge was lighted for nine days. When kept in the dark for nine days, it remained at 0.0775 mg/mL. Glucoraphanin should therefore be kept away from light and mixed (Wang *et al*., 2000).

2.3 Temperature

Generally bioactive compounds are liable to temperature change. Ferreres *et al.* (1996) reported the stability of the anthocyanin pigment of Spanish red onions. It was noted that there was a significant difference in the status of individual anthocyanins. With increasing temperature, we see more destruction of anthocyanin. High temperatures can cause a decrease in carotenoids in the diet (Richardson and Finley, 1985). It was found that canning led to higher destruction of carotenoids, followed by high temperature (HTST) heat and acidification (Chen *et al*., 1996). Refrigeration at 4 °C and cold temperature may be the best saving practices to maintain high levels of glucosinolates in broccoli (Rodrigues and Rosa, 1999).

2.4 Conventional heat processing

Thermal processing techniques have been shown to produce a variety of responses to the chemical content in a plant food. It is therefore wrong to generalize and recommendations about methods suitable for the storage of Bioactive compounds. But depending on the effect of method on the chemical structure of the bioactive compound and the matrix in it, method can be chosen. By roasting (120^o – 160^o C for 20 - 30 min), total flavonoid content was decreased by 12–16% (Zhang *et al*., 2010). By blanching (90^0 C for 30 sec), loss in vitamin C was there by 20% (Ewald *et al*.,1999). The sterilization has shown to increase the availability of carotenoids by reducing isomerisation. Simple processes such as cooking often alter the composition and availability of nutrients for Dietary fibres.

2.5 Mechanical food processing

Typical mechanical processes include cutting, peeling, crushing, and compression. These processes have different effects on the content, discovery, and function of bioactive compounds (Nicoli *et al.* 1999). Cutting has resulted in an increase in phenolic content and antioxidant activity of anthocyanin (Reyes *et al*., 2007). Removal of the outer layer by about 5% reduces β-carotene and lutein levels above 50 and 20% respectively in whole wheat (Adom *et al*., 2005). Any processing step that involved cutting or disrupting cell integrity has resulted in the loss of complete glucosinolates, as this has led to a combination of glucosinolates and the enzyme myrosinase (Jones *et al*., 2006). Mechanical strength can have adverse effects on polysaccharides (Poutanen *et al.* 1998). Grinding can affect hydration properties, in particular, the kinetics of water absorption (Yaqoob *et al*., 2020).

2.6 Non-thermal food processing

The growing consumer demand for nutritious food, i.e., lightly processed and highly nutritious has led to a grow interest in non-thermal technology. Irradiation (10 kGy) increases phenolic acid in cloves and cinnamon but not in nutmeg. Because Irradiation may have facilitated the breakdown of heavy chemicals into active components, in Anthocyanin.Weak ultrasonic radiation is reported to promote an increase in thenumber of phenolic compounds found in red wine (Masuzawa, Ohdaira and Ide, 2000). HPP (High Pressure Processing) in 300 MPa in three cycles caused the highest degradation of carotenoids (41%) and the lowest decrease (26%) reached at 600 MPa. (Stinco, Carla M., *et al.* 2019). For glucosinolates, UVBH radiation and harvesting after 24 h, led to a very high increase in whole and individual glucosinolates; followed by UVAL rays and harvesting after 24 hours (Moreira-Rodríguez *et al.*2017). Thed and Phillips (1995) reported that microwave heat and deep fat frying reduce the amount of in vitro starch and significantly increases its resistance to starchy (RS) and water-free food fibre.

3. Health benefits

In food science the term "bioactive compounds" includes a variety of plant ingredients that are capable of health-promoting effects. They occur only in lesser concentrations and usually have a pharmacological effect. Depending on the dosage, these bioactive compounds may have adverse health effects or health benefits (Leitzmann, 2016). In the past, these effects were studied in cell and tissue cultures as well as in animal models. But in the current scenario there are numerous epidemiological data that point to the extensive health potential of bioactive compounds in humans such as anti-carcinogenic, promotes eye health, anti-oxidative, lowers the cardiovascular disease, manage blood pressure, etc.

3.1 Anti-carcinogenic

The health promoting effects of bioactive compounds have been revealed by a number of epidemiological studies, which initially found a consistent relationship between an abundant consumption of fruits and vegetables and a reduction in the risk of developing several diseases, including various types of cancer (Key *et al*., 2009). Research shows that certain flavonoids (Maheep K Chahar *et al*., 2011) and polyphenols (Yue Zhou *et al*., 2016) may block the growth and development of various cancer cells.

3.2 Cardiovascular disease

Epidemiological studies suggests that bioactive compounds of plants such as anthocyanins, polyphenols, flavonoids, etc may be important in lowering risk of cardiovascular disease (Howard *et al*., 1997). The consumption of foods containing high anthocyanins (Daneshzad *et al*., 2019) and flavonoids (Ponzo*et al*., 2015) as part of their diet lower the risk of cardiovascular disease.

3.3 Eye health

Bioactive compounds present in plants/foods may help to prevent or delay the progression of eye diseases. Recent studies show that there can be can decrease in risk of developing macular degenerative by 43 % with incorporating at least six milligrams of lutein (carotenoids) diet a day. Also increasing the amount of lutein and zeaxanthin in diet can help to slow or halt current eye damage, and prevent current condition from progressing.

3.4 Anti-oxidative

Bioactive compounds such as polyphenols and carotenoids contribute the most to the antioxidant properties of foods/plants. The pigment of carotenoids has the ability to act as antioxidants and thus protect cells against photooxidation. Also the ability of carotenoids to quench singlet oxygen is well known and reactions with radical species have also been studied (Edge *et al*., 1997).

3.5 Anti-diabetics

Bioactive compounds found in fruits and vegetables can have anti-diabetics and can be protective against various diseases and metabolic disorders. Food diets that are rich in flavonoids may decrease the risk of type 2 diabetics. Result of meta-analysis study Min Li *et al*., 2018 suggest that a high intake of dietary flavonoids correlates with a lower risk of type 2 diabetes. Furthermore, an increase in intake of 500mg of flavonoids each day was associated with a significant risk reduction of 5%.

3.6 Anti-inflammatory

A biological process in response to infection, injury or irritation is inflammation. Chronic inflammation seems to be connected with different types of diseases, such as arthritis, allergy, atherosclerosis, and even cancer (Devi *et al*., 2015). One of the major inflammatory mediators is Nitric oxide (NO). The bioactive components such as narirutin, polyphenols, bioactive peptides, etc inhibits the over productions of NO (F. Zhu *et al*., 2017). And thus bioactive compounds can prevent from inflammation.

3.7 Manage blood pressure

Epidemiological studies suggest that bioactive compounds present in various fruit, vegetables, tea and mineral water may protect against high blood pressure (AkramKooshki *et al*., 2014). Different foods rich in flavonoids in diet may be an effective way to help manage high blood pressure.

3.8 Anti-thrombotic

Bioactive compounds have biological effect on human health such as anti-thrombotic which is useful in preventing excess bleeding. When platelets circulating in the bloodstream begin to clump together then blood clots are formed which is known as platelet aggregation. According to test-tube and animal studies (Michal Bijak *et al*., 2016), polyphenols may help reduce the platelet aggregation process, thereby preventing the formation of blood clots.

4. Food applications

4.1 Bioactive compounds in fruits and vegetables

The most important sources of bioactive compounds are fruits and vegetables. Bioactive compounds used for both natural antimicrobial agents and human diets in food preservation such as flavonoids, polyphenols, anthocyanins and carotenoids. They are also used to preserve and control microbial spoilage in foods. Biologically active compounds are found in fruits and vegetables as phenolics. Fruits and vegetables have special bioactive compound group which protect plants from their environment stress such as pollution, pathogens, or various abiotic stresses (Kafkas, 2017).

4.2 Cereal based foods

Cereal grains like wheat, rye, oat, and barley offer great opportunities for the development of functional foods such as bread, pasta, breakfast cereals, snack bars, and others reported by Sidhu*et al*. (2007).Whole grain breakfast cereals have been found to be important dietary sources of antioxidants along with fruits and vegetables(Miller *et al*., 2000). High lutein wholegrain bakery products including bread, cookie, and muffin have been developed as staple foods to enhance lutein daily intake (Abdel-Aal *et al*., 2010). Lutein is the main carotenoid in wheat and accounts for 77–83% of the total carotenoids in relatively high-lutein wheat species such as einkorn, durum, Kamut, and Khorasan (Abdel-Aal *et al*., 2007). Dietary fiber is one of the important health-enhancing components in cereals, located mostly in the outer layers (testa, pericarp, and aleurone) (Selvendran, 1984). The pericarp contain insoluble fiber along with some other antioxidants bound to the cell walls. The aleurone layer has soluble and insoluble fiber, antioxidants, vitamins, and minerals, and the testa layers are composed of soluble and insoluble fiber, phenolic compounds, and other bioactive compounds (Raninenet *et al*., 2010). Barley and oat are especially rich in β-glucan (Brennan, 2005; Wood, 2007, 2010), while the major dietary fiber constituent in wheat and rye is arabinoxylan (Ragaee *et al*., 2001; Kamal-Eldin *et al*., 2009). They have been shown to have lot of health benefits.

4.3 Meat products

The impact of protein oxidation on the quality of meat and meat products is demostrated by the presence of a free radical chain similar to those described for lipids. The discolouration of raw burger patties is generally attributed to the oxidation of ferrous hemi–iron (Fe^{2+}) intoits ferric form (Fe^{3+}) in proteins induced by lipid products an intense loss of redness and increase in rigidness was found to take place throughout the refrigerated storage. The effect of several fruit extracts and quercetin in these trends showed that most phenolic rich wild Mediterranean fruit extracts as well as quercetin reduced the formation of proteincarbonyls and inhibited the colour and texture deterioration during refrigerated storage (Yin and Faustman, 1993).

4.4 Dairy products

There are different types of dairy product like curd, cheese, ice cream, skim milk etc. Yoghurt is a long time known appreciated dairy food product available in various textures (i.e., liquid, set, smooth), fat contents (luxury, low-fat, virtually fat-free) and flavours (natural, fruit, cereal) (Shah, 2003; McKinley, 2005).Owing to consumers' preferences and demands for functional foods, bioactive compounds from various sources are progressively being applied as the ingredients to improve quality traits, nutritional and therapeutic properties. Bioactive compound can be introduced in yogurt in the form of essential oil or plant extract. Adding like zataria, basil, or peppermint essential oil into probiotic yogurt formulation can improve the potential functionality of the product and provide an inhibitory effect against Listeria monocytogenes and Escherichia coli. Moreover, the addition of lemongrass leaves and stem into yogurt have been seen to improve the physicochemical properties as well as sensory characteristics of yogurt Apart from that, they are also play a role in the decontamination from mycotoxigenic fungi and mycotoxins formation in yogurt.(Fazilah *et al*., 2018).

4.5 Bakery

Worldwide bread is the major product among baked foods and consumed relatively in large amounts. Among different types of food systems, baked products provide an excellent opportunity to incorporate bioactive compounds. With appropriate formula or process optimization, breads with acceptable quality can be produced with the addition of bioactive compound-based ingredients. As the number of available bioactive compounds increases, the incorporation of these functional ingredients into bakery foods will become easier (Hayta *et al*., 2011). Many bioactive compounds exist for bakery applications, and producers have started formulating breads with soy isoflavones, β-glucans, conjugated linoleic acid, and n-3 fatty acids.

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