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Antioxidant dietary fiber: A healthy functional ingredient

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Abstract
Due to several beneficial effects of dietary fiber, the number of dietary fiber enriched food products are introduced into the food market, mainly due to high beneficial effect on the digestive system. Dietary fiber produced by by-products of foods are rich in antioxidants include healthy and important antioxidants such as carotenoids and polyphenols. This brings concept of antioxidant dietary fibre (ADF), which combines beneficial effects of both dietary fibres and antioxidants. This review focuses on the present knowledge in the literature about the sources and potential applications of ADFs as functional ingredients in the Food industry. Also it is aimed to attract the attention of producers to the economic importance of converting those food processing by-products into healthy value-added products.

Keywords: Antioxidant, dietary fibre, plant waste, polyphenols, bioavailability

Introduction
European Food Safety Authority (EFSA) described dietary fibre as non-digestible carbohydrates along with lignin, including all carbohydrate components occurring in foods are not digestible in the small intestine and pass into the large intestine (Jones 2014) [5]. They are believed to play a significant role in maintaining the functional integrity of the gastrointestinal tract. High dietary fibre intake, depending on the dietary fibre consumed, is related with the body weight control with reduced risk of diseases such as colon cancer and atherosclerosis. An intake of 25–30 g dietary fibre per day is recommended by the American Heart Association (Pérez-Jiménez *et al.*, 2008) [12].
Nowadays, there is a trend to find new sources of dietary fibre that can be used as ingredients in the food industry. The most frequently consumed dietary fibre products are those derived from cereals. In general, fruit dietary fibre concentrates have better nutritional quality than those found in cereals, because of their significant contents of associated bioactive compounds i.e., flavonoids, carotenoids, etc. Antioxidants are compounds that inhibit or delay the oxidation of other molecules by inhibiting the initiation of oxidizing chain reactions (Velioglu *et al.*, 1998) [19].
Foodstuffs rich in dietary fibre and dietary fibre ingredients are popular in the food market, but their antioxidant capacities are negligible (Zhu *et al.*, 2010) [21]. Recently, the concept of antioxidant dietary fibre (ADF) has been introduced (Saura-Calixto, 1998) [14]. The main characteristic of these natural products is that they combine the physiological effects of both dietary fibre and antioxidants in a single material. One gram of ADF should have DPPH (2, 2-diphenyl-1-picrylhydrazyl) free radical scavenging capacity equivalent to at least 50 mg vitamin E and dietary fibre content higher than 50% dry matter (Dm) from the natural constituents of the material (Saura-Calixto 1998) [14].

Antioxidant Dietary Fiber Sources
Fruit and vegetable wastes from industrial food processing are usually discarded or used as animal feed and fertilizers. The studies indicated that these so-called wastes of nutritive plant originated processed foods are rich in ADF. However, since the antioxidant capacity and dietary fibre content of the studied material are high, they can be referred to as "good sources of ADF", therefore, they were included in this review.

Apple: Apple contains antioxidant activity mainly due to phenolics acids and flavonols. The peel of apple has a higher antioxidant capacity than the pulp of apple. A study on proximate composition analysis of three apple varieties showed that 83.28–89.92% of apple consists of

water while the amount of dietary fibre is only 0.86–1.81% (Lim and rabeta., 2007). However, the apple pomace which was separated during processing is reported to have 51.10 g/100 g Dm of total dietary fibre, of which 14.60 g/100 g Dm is soluble and 36.50 g/100 g Dm is insoluble dietary fibre besides the total phenol content of 10.16 mg/g (Sudha *et al*., 2007) [15]. However, these contents depend on pressing, use of enzymes and additional extraction with water etc.

Cabbage: Species of cabbage (*Brassica oleracea*) are widely used in traditional medicine due to their antibacterial properties and anti-inflammatory. There are studies on the production of ADF powder from cabbage (*B. oleracea* L. var. *capitata*) from outer leaves, which are usually separated as processing waste and are used only as fertilisers. In one of the study it has been reported that (Nilnakara *et al.,* 2009) [11] the crude fibre content of cabbage leaves was found to be 19.92–47.47 g/100 g Dm, which was similar to the study results (total dietary fibre 40.89 g/100 g Dm) obtained by Tanongkankit *et al*. (2010) [16]. In addition, the total antioxidant capacity was reported to be 89.57–96.00% with the total phenolic content up to 571.50 mg GAE/100 g Dm. The authors also investigated that the effects of heat treatments and slicing steps during powder production on dietary fibre content and antioxidant capacity of cabbage outer leaves at different steps, which indicated that these by-products are good sources of ADF.

Carrot: Carrot is known for its high beta-carotene content. However, its antioxidant properties are not only limited to carotenoids. Carrot is extensively used in the food industry, but its peels or pomace of carrot are discarded or used as an animal feed. The byproducts have 45.45 g/100 g Dm of dietary fibre with a high antioxidant capacity (94.67%), which is appropriate for the production of ADF powder. Their conclusion indicated that blanching improves the total dietary fibre (TDF) yield and the insoluble dietary fibre (IDF) to soluble dietary fibre (SDF) ratio while having no significant consequence on total phenolics content (Chantaro *et al.,* 2008) [3].

Guava: Guava (*Psidium guajava* L.) is a tropical fruit, commonly consumed fresh and also in processed forms like beverages, syrup, ice cream, and jam (Jimenez-Escrig *et al*., 2001) [4]. Helpful health effects of guava fruit and its by-products are reported due to their high antioxidant capacity. The guava concentrate and by-products exhibited high dietary fibre content (up to 69.1 g/100 g Dm), antioxidant activity (up to 462 µmol Trolox eq./g Dm) and associated polyphenols (26.2–77.9 g GAE/kg Dm), which indicated that guava is rich in ADF (Martínez *et al.,* 2012) [10].

Grapes: Grapes are cultivated mainly as *Vitis vinifera* for wine production. It is estimated that around 13% of the total weight of grapes used for wine making results in grape pomace, which is a by-product in this process. Grape pomace consists of seeds, skins and stems, and in some cases this by-product is used to extract grape seed oil (Torres *et al.,* 2002) [17]. Grape pomace has 64.6% Dm of dietary fibre with 400 mg dl-a-tocopherol/g lipid oxidation inhibition and 100 mg dl-a-tocopherol/g free radical scavenging capacity. A similar findings reported that white grape pomace and stem with total dietary fibre content of 715.6–790.5 g/kg Dm and total extractable polyphenols content of 34.9–87.3 g GAE/kg Dm could also be considered as ADF (Llobera and Canellas., 2008) [9].

Mango: mango (*Mangifera indica* L.) is a popular fruit that can be cultivated in various regions, mainly in the tropics (Sultana *et al.,* 2012). Mango is generally rich in ß-carotene, L-ascorbic acid, total phenols and individual phenolic compounds (Liu *et al.,* 2013) [8]. Its peels, leaves, stem bark and kernels were also found promising as functional food ingredients due to their high levels of antioxidants (Pitchaon 2011) [13]. Mango fibre concentrate (Martinez *et al*., 2012) and powder from mango peels (Ajila *et al*., 2010) [1] also possessed high dietary fibre content (total dietary fibre 28.05–70.0 g/100 g Dm) and polyphenols (16.14–283 mg GAE/100 g), which makes mango a good source of ADF.

Melon: Watermelon rinds and Sharlyn melon peels, which are usually discarded as wastes, are good sources of ADF with a crude fibre content of 17.28–29.59% (Al-Sayed and Ahmed., 2013) [2]. The authors worked on fortification of cakes with powder produced from these by-products and found out that it is possible to evaluate water melon rinds and Sharlyn melon peels for enriching foods with functional components while providing better freshness to the product.

Orange: Orange is well known for its high vitamin C and phenolic content. Orange juice is also rich in these bioactive compounds contributing effectively to its antioxidant activity (Stella *et al.,* 2011). Some studies confirmed their results of high phenolics (40.67 mg GAE/g Dm) and they also indicated that the orange peel has high dietary fibre content (71.62 g/100 g Dm).

Pineaplle: Pineapple (*Ananas cosmosus*), a member of the family Bromeliaceae, is a widely consumed tropical fruit which can be consumed as fresh fruit, juice, jam, jelly and dried product. The pineapple stem, which is separated as waste, has moderate antioxidant and antimicrobial effects, while antifungal effect was considerable probably due to high benzoic acid content (Upadhyay *et al.,* 2012) [18]. Pineapple fibre concentrate, obtained as waste from industrial productions and showed that pineapple fibre concentrate is rich in total dietary fibre (75.8 g/100 g Dm) and shows high antioxidant activity (1.7–7.7 µmol Trolox eq /g).

Tomato: Tomato (*Solanum lycopersicum*) is a good source of the carotenoids lycopene and ß-carotene, phenols, flavonoids, and ascorbic acid which is widely used in the food industry as well as its domestic use is important (Kavitha *et al.,* 2014) [6]. Processes that tomato goes through during preparation have an effect on antioxidant capacity. Peeling was shown to cause serious losses in lycopene, ß-carotene, ascorbic acid, and phenolics contents. While seed removal resulted in a loss of carotenoids and phenolics which consequently cause a decrease in antioxidant capacity (Vinha *et al.,* 2014) [20]. The tomato peel is rich in phenolics (158.10 GAE/100 g) with high dietary fibre content as high as 86.15% (Navarro-Gonzalez *et al.,* 2011).

Contribution to Storage, Stability and Quality: Since there is an increased interest in using natural ingredients in food production, in vitro and in vivo studies on ADFs suggest the use of ADF as a food ingredient to improve shelf life due to its inhibitory effect on lipid oxidation in food products

besides increasing the nutritive value of the product.

The effect of grape antioxidant dietary fibre (GADF) addition to minced fish muscle (MFM) on lipid stability during frozen storage (6 months) was studied by I. Sanchez-Alonso *et al*. (2005). GADF was characterized in terms of dietary fibre, total polyphenols and antioxidant capacity, and multifunctional antioxidant assays were carried out on all the MFM samples. The addition of red grape fibre considerably delayed lipid oxidation in minced horse mackerel muscle during the first 3 months of frozen storage.

Wine grape pomace (WGP) as a source of antioxidant dietary fibre (ADF) was fortified in yogurt (Y), Italian (I) and Thousand Island (T) salad dressings. Dried whole pomace powder (WP) fortified products had dietary fibre content of 0.94–3.6% (w/w product), mainly insoluble fractions. Total phenolic content and DPPH radical scavenging activity were 958–1340 mg GAE/kg product and 710–936 mg AAE/kg product, respectively. The highest ADF was obtained in 3% WP-Y, 1% WP-I and 2% WP-T, while 1% WP-Y, 0.5% WP-I and 1% WP-T were mostly liked by consumers based on the sensory study. Study demonstrated that WGP may be used as a functional food ingredient for promoting human health and extending shelf-life of food products (A. Tseng and Y. Zhao., 2013).

H.M.A. Al-Sayed and A.R. Ahmed (2013) [2] studied some physical and chemical properties of watermelon rind and sharlyn melon peel powders and its utilization as partially, substituted of wheat flour at levels of 2.5%, 5.0% and 7.5% or fat at levels of 5.0%, 10% and 15% in cake making. The incorporation of Watermelon Rind and Sharyln melon peel powders in cakes batter at all the studied levels enhanced the volume and specific volume of the baked cakes to overcome, those of the control. These materials also retard staling of cakes and inhibition the lipids oxidation and free fatty acids formation during storage. It is revealed that, substitution of 5% flour and 10% fat with watermelon rinds and sharlyn melon peels produced acceptable cakes which were not significant different with the control.

Mango peel is a major by-product obtained during processing of mango products such as mango pulp and *amchur*. mango peel was incorporated into biscuits and improvement in the nutraceutical properties of the biscuits was studied. The studies indicated that mango peel contained 51.2% of total dietary fiber, 96 mg GAE/g of polyphenols and 3092 mg/g of carotenoids. Farinograph characteristics of the wheat flour incorporated with mango peel powder (MPP) showed an increase in water absorption from 60 to 68%. Soft dough biscuits were prepared using different levels (5.0, 7.5, 10.0, 15.0 and 20.0%) of MPP and objective, sensory and nutritional properties of the biscuits were evaluated. The total dietary fiber content increased from 6.5 to 20.7% with a high proportion of soluble dietary fiber with incorporation of 20% MPP. The content of polyphenols increased from 0.54 to 4.50 mg/g and carotenoid content increased from 17 to 247 mg/g of biscuit with 20% incorporation of MPP. The biscuits incorporated with mango peel exhibited improved antioxidant properties. Acceptable biscuits with mango flavor were obtained by incorporating 10% MPP. Thus, the results indicated that wheat flour incorporated with MPP yielded dietary fiber enriched biscuits with improved antioxidant properties (C.M. Ajila *et al.*, 2008).

Conclusion

As there arise negative concerns regarding the use of synthetic ingredients for food preservation, natural alternatives such as plant extracts rich in phenolics are gaining popularity among consumers. ADF is proposed as a new potential antioxidant ingredient that was proved to prevent or delay lipid oxidation in foods, which is a major problem of the food industry. Besides, ADF brings along several benefits together; it gives an opportunity to enrich food formulas with both dietary fibre and antioxidants –which are essential parts of a healthy diet –at the same time while soothing concerns of the consumers. By-products from the processing of plant-originated food materials are good sources of ADF. Using these wastes as ingredients may provide environmental and economic benefits. Sources of ADF are not limited to those reviewed in this article. Future studies must be carried out on finding new sources and better methodologies to make better use of plant originated antioxidant and dietary fibre rich food material; namely ADF.

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