CHAPTER 1

INTRODUCTION

Fruits are the fleshy parts of a plant (along with their seeds), which are either sweet or sour in taste. In strict botanical sense, these are the ripened ovaries of a plant. However, in a culinary role, these are the structures of a plant that are usually eaten as such or are served as a dessert. Fruits usually contain high amounts of organic acids (such as citric and malic acid), sugars, dietary fibers and water. On the other hand, vegetables are the edible portions (apart from mature fruits or seeds) of a plant that are eaten as (or with) the main course. These are usually cooked or eaten fresh as salads or processed into vegetable starches (usually in soups) or are frozen, dried or pickled. These have lower amounts of sugar than fruits and impart their own characteristic texture, color and flavor to diets (undergoing changes during cooking and storage). In addition, both fruits and vegetables have historically held a place in the dietary guidance owing to their high concentrations of antioxidants, vitamins and minerals (especially electrolytes).

India is the largest fresh fruit producing country in the world, while in terms of vegetables it ranks the second (FAOSTAT, 2012). A great variety of fruits and vegetables are commonly grown as well as consumed in India. Banana (Musa sp.), mango (Mangifera indica), sapodilla (Manilkara zapota), jambolan (Syzygium cumini), kinnow (Kinnow mandarin), grapes (Vitis vinifera) and pomegranate (Punica granatum) are some of the important fruits, while carrot (Daucus carota), beetroot (Beta vulgaris), bitter gourd (Momordica charantia), brinjal (Solanum melongena), spinach (Spinacia oleracea) and mentha (Mentha arvensis) are some of the important vegetables grown in India. These fruits and vegetables are available seasonally or throughout the year in almost all parts of India.

In recent years, the incidences of some chronic diseases (including cancer and cardiovascular disease) are increasing (especially in the developed nations), leading to a raised awareness about the importance of a balanced diet. The regular intake of fruits and vegetables in the diet has been associated with notable health benefiting factors against many diseases (such as cancer, coronary heart disease and neurodegenerative
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pathologies) that are caused by oxidative stress (Percival et al., 2006; Hervert-Hernández et al., 2011; Rodrigues et al., 2012). Moreover, fruits and vegetables also might function as anti-inflammatory and antimicrobial sources in the diet (Kang et al., 2011; Fujita et al., 2013). The present research has shown mounting evidences that people avoiding (or consuming very little) fruit and vegetables completely are at an increased risk of diet related diseases (Liu, 2013). In addition, an interest in understanding the types and modes of action of the different beneficial components present in fruits and vegetables is also increasing. Therefore, the World Health Organization (WHO) has recommended a daily intake of more than 400 g of fruits and vegetables per person worldwide. Liu (2013) recommended around 9 to 13 daily servings (in the form of fresh, dried, cooked, whole juice, canned or frozen) of fruits and vegetables.

Phytochemicals are the bioactive non-nutrient compounds present in plants which have been associated with providing many desirable health benefits (mainly reducing the risk of many chronic diseases) beyond basic nutrition (Liu, 2004). These compounds are structurally diverse and include the polyphenolic compounds, terpenoids (mainly carotenoids), sulfur-containing compounds and nitrogen-containing alkaloids. These function as secondary metabolites providing the plant itself with many unique adaptive or survival strategies for cell-to-cell signaling, protection and defense. In humans, as dietary components these compounds are responsible for medicinal actions. Fruits and vegetables contain plethora of bioactive phytochemicals such as polyphenolic compounds, carotenoids and ascorbic acid (Percival et al., 2006). The total effect of phytochemicals on human health appears to be more than the sum of their parts as many individual components act synergistically.

Polyphenolic compounds are the secondary metabolites ubiquitously distributed in all higher plants functioning as bioactive phytochemicals. These compounds are the products of secondary metabolism in plants and are mainly synthesized through the shikimic acid pathway. This pathway converts the intermediates from glycolysis (erythrose 4-phosphate and phosphoenolpyruvate) to chorismate, which is a precursor of most polyphenolic compounds and aromatic amino acids (Herrmann and Weaver, 1999). Polyphenolic compounds contain an aromatic ring having one or more hydroxyl groups and their structure might vary from a simple phenolic molecule to complex polymers.
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(Haminiuk et al., 2012). In plants, these compounds play important roles such as contributing to the color of plants, acting as defense mechanisms against UV irradiation and some pathogens, parasites and predators (Naczk and Shahidi, 2004). In humans, polyphenolic compounds function as antioxidants, antimicrobial, anti-inflammatory, anticancer and anti-allergic agents (Daglia, 2012). These are categorized into four major classes that include the phenolic acids, flavonoids, stilbenes and lignans (Spencer et al., 2008). The amount of polyphenolic compounds in fruits and vegetables is mainly dependent on many factors that include the storage conditions, variety, soil composition, climate and geographic location (Belitz et al., 2009). Additionally, polyphenolic compounds are mainly accumulated in the peel portions of fruits and vegetables (Pande and Akoh, 2009).

Mostly organic solvents are used for the extraction of polyphenolic compounds, while reverse-phase high-performance liquid chromatography (RP-HPLC) is commonly used method for their separation and quantification. Other ways of quantifying polyphenolic compounds include spectrophotometric analysis. Further, their antioxidant activity is determined by various in vitro and in vivo assays. Antioxidant activity of these compounds can be accounted to their redox properties that play important roles in adsorbing as well as scavenging free radicals, decomposing peroxides and quenching oxygen (Kaisoon et al., 2011). Moreover, the antimicrobial activity of these compounds may be helpful in eliminating some pathogenic microorganisms which have acquired the ability of survival against existing antibiotics at concentrations that are clinically relevant (Daglia, 2012). These microorganisms include multidrug-resistant *Escherichia coli* and methicillin-resistant *Staphylococcus aureus* (MRSA) which have become a worldwide problem in the food sector (Xu et al., 2014). Furthermore, some studies have reported that polyphenolic compounds may be used in combination with the commercial antibiotics for lowering their dose and potentiating their efficacy (Coutinho et al., 2009; Eumkeb et al., 2010).

Dietary fiber is the remnant of plant cells (mainly carbohydrate) that is resistant to digestion (hydrolysis) by the human enzymes present in the alimentary canal. This component of the diet is neither degraded nor absorbed when passed through the gastrointestinal tract (upper part), while in the large intestine, it gets degraded by the gut
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bacterial enzymes and then is partially or completely fermented to produce short chain fatty acids, water and gases. The consumption of these fibers is related to reduction in constipation in humans and occasionally several other diseases including cancer.

In the recent years, fruits and vegetables have emerged as the non-conventional sources of dietary fiber. Fruit and vegetable by-products (skins, peels, stems, pips and cores) from the juice processing industries have grown in popularity as dietary fiber sources owing to their abundance and low cost. It is nowadays well accepted that diets having high amounts of dietary fibers (such as those rich in fruits, vegetables and cereals) is essential for good human health.

Fruits and vegetables are usually commercialized in frozen form for making them accessible throughout the year (even during off season). However, these are perishable food items having high water content, which lowers their shelf life as well as limits distribution to far off places. The possible solution to this problem is the production of dehydrated fruits and vegetables. Dehydrated food products have a low water content which prevents the development of microorganisms responsible for deterioration. On the flip side, these drying processes might have a negative influence on the nutrients present in the food products.

Hot air drying methods usually employ cabinet or bed dryers. Fruit or vegetable is placed in a heated enclosed chamber, where hot air is passed over it continuously. Many factors such as the air velocity, temperature, humidity, thickness of the sample and air exchange affect the drying rate. Generally, the drying rate is directly proportional to the hotness of the air and inversely to the humidity. However, hot air drying affects the contents of the fruits and vegetables that are heat labile (Mcsweeney and Seetharaman, 2015).

Another way of dehydrating fruits and vegetables is the freeze drying method, where the samples are first frozen and then sublimation of ice occurs, producing products that are dry (Marques et al., 2006). A little or almost no shrinkage of the food sample takes place during freeze drying and it is able to retain its size and shape on rehydration. Moreover, this method has several advantages over hot air drying. Firstly, freeze drying allows food samples to rehydrate quickly as their structure becomes very porous after this process. Secondly, the food retains its odor as well as taste as volatiles are entrapped.
Lastly, freeze drying helps foods to maintain their nutritional quality, which is a great advantage over hot air drying (Marques et al., 2006). Besides this, the extraction of phytochemicals (such as polyphenolic compounds) can be enhanced (mainly when powdered) in freeze dried foods, especially in fruits and vegetables (Kim et al., 2002). On the contrary, freeze drying has some disadvantages such as foods that have a structure which is susceptible to damage during freezing will rehydrate poorly. In addition, the proteins present in foods might be denatured owing to the high concentration of solutes during the freezing stage. Furthermore, as foods become very brittle after freeze drying expensive packaging might be required. Last but not the least; it is an expensive process as compared to other modes of drying.

The consumer demand for foods that not only have balanced calorific content, but also have additional health-promoting functions has increased in the recent years (Bech-Larsen and Scholderer, 2007). This increase is as a result of extensive media coverage of diet-related diseases and their influence on human health. A recent trend in food and pharmaceutical industry has been the increased utilization of bioactive phytochemicals present in fruits and vegetables (either in extracted or form). The processing of fruits into pulp leaves behind a considerable amount of residues (mainly in form of peels). As these residues become a bulk of organic waste, they are often disposed in municipal bins or open spaces which lead to environmental pollution. However, peels and other fruit as well as vegetable residues contain a significant amount of essential minerals and bioactive constituents. These can be utilized for the production of nutraceuticals, which will not only be a value addition but also might help in the reduction of environmental pollution. Antioxidants present in fruit wastes have been suggested for their application in the food, pharmaceutical and cosmetic industries as substitutes of synthetic antioxidants, providing protection against oxidative stress (Makris et al., 2007; Babbar et al., 2011).

Functional foods are termed as foods that provide health benefits beyond basic nutrition (Day et al., 2009). Foods such as fruits and vegetables constitute the simplest form of functional foods as these are rich in bioactive phytochemicals. These can be consumed as whole and also can be added to food products that are nutritionally deficient. The paradigm of food industry is currently in incorporating functional
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ingredients (such as whole fruits and vegetables or bioactive enriched concentrates from them) into foods. This can provide novel functional product categories and new commercial opportunities.

Highly nutritious ready-to-eat products can be developed by incorporating fruits and vegetables into cereal-based raw materials using extrusion technology. The consumption of these products has grown by leaps and bounds, owing to their texture, attractive appearance and convenience (Bisharat et al., 2013). Extrusion technology is an energy efficient, inexpensive, versatile high-temperature short-time (HTST) processing technique, where starchy or proteinaceous raw food materials are moistened, expanded, cooked as well as plasticized in a screw barrel assembly (along with the combination of temperature, pressure and mechanical shear), which leads to chemical as well as structural transformations (Altan et al., 2008). Various factors such as the process parameters (such as barrel temperature, feed moisture and screw speed) and composition of raw materials affect the quality of extruded products (Shevkani et al., 2014).

Cereals are commonly used raw materials for producing extruded products, which contain high amounts of starch. The starch present in raw materials gets gelatinized at a high extrusion temperature that leads to an increase in the amount of easily digestible carbohydrates along with the enhancement of puffing in the final products (Ding et al., 2006). Most of the commercially available extruded products are produced from corn grit that is obtained after corn dry milling. Moreover, refined flours are also preferred for extrusion as these are easy to process when compared to whole grain ones (Brennan et al., 2013). However, the nutritional value of traditionally used raw materials for extrusion is low. In regard to this issue the paradigm of food industry has shifted towards the increase in the nutritional value of conventional extruded products by incorporating bioactive ingredients in order to meet the needs of health conscious consumers and sell more products. These products have the future potential of replacing commonly available ones (that have low amounts of nutrients) in the market, as well as help in reducing childhood obesity (Bisharat et al., 2013).

Celiac disease is an autoimmune disorder resulting from consuming gluten that causes inflammation of the small-intestinal mucosa and further leads to nutrient malabsorption (Murray, 1999). This disease affects one in a hundred people worldwide.
and until now, the only known treatment is the strict avoidance of foods having gluten (Mustalahti et al., 2010). Gluten-free products (containing less than 20 ppm of gluten protein) are designed at present not only for people suffering from celiac disease, but also for those interested in wheat-free food materials (Nachay, 2010). However, most commercially available gluten-free products have an inferior quality when compared with their gluten containing counterparts, as gluten protein is responsible for the elasticity and extensibility of the dough (Sae-Eaw et al., 2007; Matos et al., 2014). Rice is one of the suitable cereals for developing gluten-free products as it possesses some desirable properties such as having a bland taste, is hypoallergenic as well as colorless and contains low prolamine levels (Sakač et al., 2011).

Most gluten-free foods are usually made from purified starches or flours that are deficient in dietary fiber. In past, dietary fibers from cereal sources were commonly used in designing of gluten-free bakery products, but nowadays economic and novel sources of fibers such as juice industry by-products are gaining attention among consumers that are health conscious (Ayala-Zavala et al., 2011). Fruits as well as vegetables have a better nutritional quality than cereals, mainly due to more balanced compositions and high amounts of bioactive phytochemicals (Nanditha and Prabhasankar 2008). Gluten-free products having incorporated dietary fiber have to meet many quality requirements that include easy handling while processing, nutritionally added value, safety, texture-taste, palatability and convenience (Ronda et al., 2015).

Muffins are commonly consumed breakfast or evening snack foods that are highly appreciated among consumers and are usually prepared from wheat flour, milk, sugar, oil/fat and eggs. Gluten-free muffins are type of muffins which do not contain wheat flour or any gluten containing raw ingredients. These can be consumed by celiac disease patients, but the absence of gluten protein in the formulation leads to the failure in the entrapment of carbon dioxide which reduces their quality (Sae-Eaw et al., 2007). Consequently, the incorporation of hydrocolloids (such as gums and proteins) from gluten-free sources is suggested to improve the muffin quality. Among these, xanthan gum (XNG) is commonly used hydrocolloid, which is a polysaccharide that is secreted by Xanthomonas campestris. It has been commonly employed as a food thickening agent. In regard of gluten-free products, XNG functions as a polymeric substance that mimics the
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Gluten viscoelastic properties (Gomez et al., 2007). Ashwini et al. (2009) reported that addition of XNG to the eggless cake batters increases their viscosity and this was a desirable trait in the designing of gluten-free muffins. Moreover, XNG has been reported to improve the quality of gluten-free cakes/muffins owing to its high water binding capacity that increases the values of batter moduli (Preichardt et al., 2011). Additionally, eggless muffins are also in demand nowadays due to the egg allergies in some people. In India (where a significant proportion of the population is vegetarian), the preparation of eggless muffins will allow their consumption by lacto-vegetarians.

The available information on the evaluation and utilization of polyphenolic compounds and dietary fibers from various commonly consumed fruits and vegetables in India is limited. Therefore, the present study was undertaken with the following Objectives:

(i) To compare the physicochemical characteristics of selected fruits (peels and pulps) and vegetables.

(ii) To characterize the polyphenolic compounds and determine the dietary fiber contents present in selected fruits (peels and pulps) and vegetables.

(iii) To evaluate the in vitro antioxidant and potential antimicrobial activities of selected fruits (peels and pulps) and vegetables.

(iv) To explore the possible application of selected fruits and vegetables in extruded products and gluten-free muffins.