1. Introduction

One of the biggest challenges that confront economic development in today’s world is malnourishment. According to a report, over 2 billion people are depleted of essential micro nutrients throughout the world due to consumption of starchy staples (Initiative M, 2009). Agricultural systems of the world fall short in meeting the complete nutritional needs and providing balanced diets to a majority of the population, particularly in developing countries. A larger proportion of the population rely on staple plant based diets that deny both quantity and quality food. Limited access to foods of animal origin, lack of variety and economic status in developing countries lead to high rates of prevalence of micronutrient deficiencies. Vitamin A, iron and iodine deficiency are the three commonly prevalent deficiencies. Although their daily requirement is less, they have a huge impact on human health and thus impose a significant stress over public health and economy. Other deficiencies of increasing concern include that of selenium, boron, tocopherol, ascorbate, cobalamin, folate and calcium. Iron deficiency, in particular is a global phenomenon and is equally prevalent in developed countries as in developing countries and is considered to be highest contributor to global disease burden (World Health Organization- WHO, 2002). The form of iron in frequently consumed foods is poorly bioavailable, resulting in higher prevalence of iron deficiency, particularly in women and children (Sandstead, 2000). The very recent worldwide database on prevalence of anemia as published by De Benoist et al., 2008 for the years of 1993 to 2005 shows the following statistics. Globally 1.62 billion people are affected by anemia (i.e., 24.80% of the population), 47.40% of pre-school age children, 25.40% of school age children, 41.80% of pregnant women, 30.20% of non-pregnant women, 12.70% of men and 23.9% of the elderly are anemic.
The global impact and significance of iron deficiency anemia has been assessed by Hambraeus (1999). Owing to the global existence of the nutrient deficiency, it is important that realistic and efficient methods to overcome it must be found. Despite the reason for micronutrient deficiency being social and cultural practices, economy and environment, food scientist and technologists have come up with several ways to overcome the problem in different target groups. Among the many ways that are employed, advocacy in terms of efficiency is given for two: fortification and supplementation. Fortification is a food based approach and is advantageous over supplementation due to reasonable cost of implementation, rapid improvements in micronutrient status and no requirement for changes in existing food pattern. According to the Codex Alimentarius Commission, 1991, fortification is defined as “the addition of one or more essential nutrients to a food whether or not it is normally contained in the food for the purpose of preventing or correcting a demonstrated deficiency of one or more nutrients in the population or specific population groups.”

In spite of massive progress in India’s life expectancy, child mortality, economic status and political scenario in the past five decades, it still has the highest number of malnourishment percentage in whole population and children in particular according to a report released by The United Nations Children's Emergency Fund (UNICEF) report in 2010. Studies have reported that the daily nutritional intake of Indians is far from satisfactory and that nearly 70% of the population consumes less than 50% of the Recommended Daily Allowance (RDA) for micronutrients. Iron deficiency, in particular is a major health problem and the figures reported are 12-63% in school children, 75-80% in preschool children and 56-62% in women of reproductive age (NNMB and ICMR, 2003, 2006; IIPS and NFHS, 2005-2006). The main reason for the extensive prevalence of iron deficiency in India is that the majority of the
populations depend on plant based food which has iron of less bioavailability. According to a study published by Prabhavathi and Rao, 1981 only 2-10% of iron from a typical cereal based Indian diet is bioavailable.

Many countries such as Canada, Sweden, Venezuela, Denmark and USA have successfully implemented fortification programs like addition of iron to wheat, maize and pasta; vitamin D addition to margarine; vitamin A addition to milk; niacin addition to wheat flour; and, vitamin A addition to sugar. Also, some countries have combined mandatory fortification programs with consumption of foods that improve absorption of the nutrient. This approach is considered to be effective in developed countries (Hurrell et al., 1996). Fortification programs already in place in India include vitamin A fortification of vanaspati, milk and margarine; iron fortification of wheat flour and rice, and; iodization of salt.

A successful fortification program will require consistent demand, supply, delivery and utilization of the fortified food vehicle. Also the food vehicle and the type/form of fortificant added determines how effective, safe and acceptable the fortified food is. It must also be designed in such a way that it matches the taste preferences and consumption pattern of the target population at the same time achieving shelf life of product and stability of fortificant. Criteria that should be considered when conceiving a fortification program include: target population, consumption preferences of the group, proportion of RDA to be met by the fortified food, interactions with the food itself and the whole diet, bioavailability of the compound, presence of inhibitors (anti-nutrients) and enhancers, possibility for incorporation in a already existing production line, point of incorporation, compensation for loss during production, transport and storage., etc. Some key gaps that make any fortification program achieve less are due to the lack of knowledge on: (a) upper tolerable limit for
different age groups (b) percentage RDA for addition per serving, leading to overestimation or underestimation of (c) research on the interaction of different compounds with food components (d) difference between nutrient requirements of healthy and malnourished people (e) sufficient data on costs and value of fortification of specific foods.

With increasing number of food processing industries, numerous possibilities and options are opening up for implementation of additional measures to ensure public health with the additional advantage of targeting specific age groups and communities. All the more so, consumers regard specific food components for health and well being. Over the years, the idea of a successful fortification program and its goals has undergone a paradigm shift. Formerly, all fortification programs were aimed at groups at high risk and would be a public sector initiative. However, the approach now aims at covering a larger proportion of the population with help of the private sector on the basis of market drive.

Some of the commonly fortified foods include cereals, beverages, energy bars, dairy products and children food. Beverages are commonly used as a food vehicle for iron fortification. Their consumption pattern offer advantage for achieving the necessary results. Thus, a potential approach would be development of an iron fortified beverage. Coffee has been studied to a lesser extent in this regard. This widely consumed beverage could be tested for its suitability as an iron fortification vehicle. It possesses benefit of covering a larger section of population with a regular consumption pattern. It has the added advantage of being consumed separately from meals, isolating the fortificant from common anti-nutrients present in daily diet. Even though tea possess the same advantages of being a potential food vehicle, its negative impact in terms of iron binding is much higher than that of coffee (Hurrell et al.,
1999; deAlarcon et al., 1979) and hence was not recommendable. Thus coffee possesses qualities of a potential food vehicle.

Certain compounds commonly referred to as anti-nutrients present in plants hinder the absorption of micronutrients by competitive binding mechanisms. These include polyphenols, phytates, certain proteins, minerals etc (Siddhuraju et al., 2000, 2002; Rehman and Shah, 2005). Fortification initiatives till date have targeted addition of iron to food vehicles to increase daily consumption amounts. However, they ignore the fact that wide prevalence of iron deficiency is mainly due to the high susceptibility of the mineral to interactions with major food components rather than low consumption (Zimmermann et al., 2005a; WHO/UNICEF/UNU, 2001; Institute of Medicine, 2001; Hurrell, 1997a). A fortification program must therefore pay attention to these factors and device ways to suppress their activity in the food vehicle. Two ways of addressing the negative effect of anti-nutrients are: (a) addition of absorption enhancers (b) employ methods to reduce anti nutrient levels in food vehicle (Gibson, 2006). Few methods with respect to these two strategies that have been investigated and found to be successful are: addition of ascorbic acid and folic acid for improved iron absorption; soaking, high pressure processing, irradiation and other processes for reduction of anti-nutrients levels. These have been tested at basic research level and have not been studied in a practical application for development of an iron fortified product. In this line, the work taken up was aimed at finding ways to overcome the effect of coffee anti-nutrients on iron uptake will pave way to better utilize its other obvious advantages of being a potential food vehicle for fortification. Traditional ways to remove anti-nutrients such as phytates by soaking in water cannot be applied for all foods. Hence product specific approach is a must in this regard. Irradiation as a means to remove anti-nutrients present in coffee was tested.
The work taken up in this thesis involves developing an iron fortified instant coffee powder mix with improved bioavailability of the added fortificant. The instant coffee powder mix contains both coffee extract and milk and prepared by drying a blend of the two. The product is a convenience product that can be dissolved in hot water with required sugar during consumption. Iron fortified instant coffee powder mix has not been developed so far and such a product offers advantage of lesser ingredients and preparation time. The target group would be middle aged women (30-55 years) whose iron status is as poor as that of adolescent girls in the country and completely ignored. According to a report issued by FAO-WHO in 2004, 52% of non pregnant women between the age groups of 15-50 had iron deficiency anemia. An improvement in the iron status of middle aged women would result in both greater domestic and national productivity owing to increased number of working women. Improved bioavailability was achieved by employing irradiation to degrade anti-nutrients in coffee beans. Spray drying and freeze drying operation technologies were optimized for the product manufacture. Ascorbic acid as an enhancer of iron absorption was tested in the developed product. Interaction effect of coffee extract and milk solids with iron fortificant was evaluated. Fortified product was tested for fortificant retention and shelf life of the product was established. Further, *in vitro* study to evaluate the iron bioavailability was carried out to establish the effectiveness of the product against iron deficiency.