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REVIEW - INVITED ARTICLE

Designer foods and their benefits: A review

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Abstract Designer foods are normal foods fortified with health promoting ingredients. These foods are similar in appearance to normal foods and are consumed regularly as a part of diet. In this article we have reviewed the global regulatory status and benefits of available designer foods such as designer egg, designer milk, designer grains, probiotics, designer foods enriched with micro and macronutrients and designer proteins. Designer foods are produced by the process of fortification or nutrification. With the advances in the biotechnology, biofortification of foods using technologies such as recombinant DNA technology and fermentation procedures are gaining advantage in the industry. The ultimate acceptability and extensive use of designer foods depend on proper regulation in the market by the regulatory authorities of the country and by creating consumer awareness about their health benefits through various nationwide programs.

Keywords Designer food · Fortification · Nutrification · Micronutrients · Probiotics · Designer egg · Designer milk · Designer proteins

Introduction

Designer food refers to the food that is designed to have some health benefits other than its traditional nutritional value. 'Designer food', 'functional food' and 'fortified food' are synonym, which refers to the food fortified or enriched with nutrient content already present in them or other complementary nutrient. The term was introduced in Japan in 1980s for referring processed food containing nutrient conferring of some additional health benefits apart from its own nutritional value (Arai 1996), whereas in China, designer food (referred to as health foods) is used in their traditional medicine. About 3000 varieties of health foods are available in China and widely accepted among the consumers due to their long history. Health Canada, department of the government of Canada with responsibility for national public health defines functional food as "A functional food is similar in appearance to, or may be, a conventional food that is consumed as part of a usual diet, and is demonstrated to have physiological benefits and/or reduce the risk of chronic disease beyond basic nutritional functions, i.e. they may contain bioactive compounds" (Health Canada 1998). The Institute of Medicine's Food and Nutrition Board (IOM/NAS 1994) defined functional foods as "any food or food ingredient that may provide a health benefit beyond the traditional nutrients it contains".

Functional foods included a wide variety of foods and food components believed to improve overall health and well-being, reduce the risk of specific diseases, or minimize the effects of other health concerns (IFIC 2011). It can be produced by fortification or nutrification of conventional food. Genetically engineered foods containing higher than normal amounts of health promoting nutrients and fermented foods with live cultures are considered functional foods. Infant formula may be the first designer food as it contains nutrients for the development of brain and immune system. The addition of docosahexaenoic acid (DHA) to health drinks for improving brain and visual development, the alteration or reduction of allergenic components in food, the use of probiotics and nucleotides to enhance immune response and

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sports nutrition are important examples of designer foods. Table 1 summarizes the health benefits of various designer foods. Fermentation is also a form of food modification. Folk medicine in various countries like China, Japan and India has the tradition of using fermented food for its health benefits, which includes red wine, yogurt, tempeh, red yeast rice etc.

Global regulatory status on designer foods

Most of the countries have most stringent regulations for food manufactured and imported for its sale, which include United States Food and Drug Administration (USFDA) in the USA (Anon 2010), Health Canada for Canada (Health Canada 1998), European Food Safety Authority for European Union (EFSA 2002), The State Food and Drug Administration for China (SFDA), Food Safety and Standards Authority of India (FSSAI) and Ministry of Food Processing Industry (MOFPI) (FSSAI 2006) for India and Ministry of Health, Labour and Welfare for Japan (MHLW). Only Japan is having specific regulatory approval process for designer foods i.e. Foods for Specified Health Use (FOSHU) approved from the Japanese Ministry of Health, Labour and Welfare (Arai 1996). Currently, 100 products are licensed as FOSHU foods in Japan. FOSHU approved products should be in the form of ordinary food not pills or sachets and are for regular consumption as a part of the diet.

Table 1 Summary of designer foods and their health benefits

S No	Micro/Macro nutrient	Designer foods	Health benefits
1	Omega 3 fatty acid	Omega 3 fatty acid enriched egg, oil and milk	Management of Cardiovascular disease, hypertension, autoimmune, allergic, neurological disorders, maternal health (Hargis and Van Elswyk 1993), osteoarthritis (Roush et al. 2010) and rheumatoid arthritis (Kjeldsen-Kragh et al. 1992)
2	Conjugated linoleic acid (CLA)	CLA enriched egg and milk	Antiadipogenic, anti-carcinogenic, anti-atherogenic and anti-inflammatory (Magdalena et al. 2008)
3	Selenium (Se)	Se enriched egg, broccoli and milk	Prevents cardiac muscle degeneration, muscular dystrophy (Beale et al. 1990), reduce the risk and prevalence of prostate and colon cancer and antioxidant activity (Navarro-Alarcon and Cabrera-Vique 2008)
4	Glucoraphanin	Glucoraphanin enriched broccoli sprouts	Reduce the risk of cancer (Latté et al. 2011)
5	Probiotics	Probiotic yoghurt	Produces pro-inflammatory cytokines (Meyer et al. 2007), eliminates enterotoxigenic *Bacteroides fragilis*, *H. Pylori,* prevents gastrointestinal (Odamaki et al. 2012) and lower respiratory tract infections (Jayakanthan et al. 2011), improves defecation frequency and abdominal pain due to constipation in pediatric patients (Guerra et al. 2011), improves antioxidant status in type 2 diabetic patients (Ejtahed et al. 2011)
6	Vitamin D and calcium	Vitamin D and calcium fortified milk	Lowers PTH levels, reduce bone turnover, prevents the occurrence of overweight and obesity among postmenopausal women (Bonjour et al. 2009; Kruger et al. 2010)
7	Micronutrients	Micronutrient fortified milk, salt fortified with iodine, iron and vitamin A	Improves anemic status and reduces anemia in children and pregnant women (De-Regil et al. 2011; Sunawang et al. 2009)
8	Docosahexaenoic acid (DHA)	DHA enriched milk	Reduces the level of blood lipids, improves composition of red blood cell membranes (Atalah et al. 2009) and intelligence in infants when consumed by pregnant and lactating mother (Gale et al. 2010)
9	Monacolin, Gamma amino butyric acid (GABA)	MFR (Expand)	Anti-diabetic and anti-cholesterol property (Rajasekaran and kalaivani 2009; 2011), promotes bone formation and immunomodulation (Tseng et al. 2012)
10	Phytosterols	Phytosterols enriched oil	Reduces total cholesterol, very low density lipoproteins and RLP cholesterol (Lugasi 2009)
11	Folic acid	Folic acid fortified grains	Reduces the risk of neural tube defects in newborns (Hertrampf et al. 2003)
12	Vitamins	Golden rice	Management of vitamin deficiencies (Potrykus 2003)

Designer food or functional foods are gaining greater importance in USA due to their role in disease prevention and health promotion. USFDAs Dietary Supplement Health and Education Act of 1994 (DSHEA) regulates only the dietary supplement or dietary ingredient but not designer food but health claims may be made for foods and dietary supplements in accordance with the 1990 *Nutrition Labelling and Education Act* (NLEA) and the 1994 DSHEA, an amendment to the *Food, Drug and Cosmetic Act*. The legitimate basis for health claims were expanded in 1997 with the passage of the *Food and Drug Administration Modernization Act*. Under this act health claims may be approved on the basis of recommendation from certain federal agencies in the Department of Health and Human Services and the Department of Agriculture, and from the National Academy of Sciences or any of its subdivisions (USFDA). According to NLEA health claim represents the relationship between a nutrient and a disease or medical condition that is related to the diet.

In Canada there is no specific regulation for neutraceuticals, but the *Food and Drugs Act* and *Regulations* regulates the quality and safety of all foods and drugs. Under the *Act*, the "food" includes "any article manufactured, sold or represented for use as food or drink by man, chewing gum and any ingredient that may be mixed with food for any purpose whatever." As per this regulation currently permit only 'food as part of healthy eating and claiming that a nutrient or nutritive substance is generally recognized as an aid or factor in maintaining the functions of the body, or necessary for the maintenance of good health and normal growth and development (also known as "biological role claims" and nutrient function claims)'. Because of the dichotomy of designer food between foods and drugs, manufacturers of nutraceuticals and functional foods are left with two choices, either they can market their product without health claims or they have to follow more stringent regulatory requirements necessary for drugs (*Food and Drug Regulations)*.

The European regulatory has broad category as nutraceuticals and the definition of a nutraceutical is, "any food or food ingredient which is considered to have a beneficial effect on health". Nutraceuticals are required to comply with food law but are not under the provision of s130(2) Medicines Act 1968 due to its health claim not medicinal claim. The Food Safety Act 1990 (FSA), subsequent primary and secondary legislation and codes of practice ensure that food placed on the market is safe and that any information provided about the product is not misleading. European regulatory includes food for specific health benefit rather than to enhance physiologic function, may include infant formula, processed baby foods (weaning foods), low-calorie foods for weight reduction, high-calorie foods for weight gain, ergogenic foods for athletes, and foods for special medical purposes like the treatment of diabetes or hypertension.

India has Food Safety and Standards Act, 2006, Food Safety and Standards Rules, 2011, Food Safety and Standards Regulations, 2011 and the Food Safety and Standards Authority of India (FSSAI), established under the Food Safety and Standards Act, 2006 as a statutory body for laying down science based standards for articles of food and regulating manufacturing, processing, distribution, sale and import of food so as to ensure safe and wholesome food for human consumption. In India, normal food, nutraceuticals, designer food/functional food etc. are not categorized separately (FSSAI 2006).

A brief account of selected designer foods is given below.

Designer eggs

Regular intake of well balanced diet plays an important role in maintaining good health. Among various foods, egg is an important and easily available food delivering balanced essential nutrients to the body and egg is the best medium for incorporating health components in it. The designer food approach has been explored widely using egg in providing various essential nutrients to the human body, which are not usually present in required quantity (Sim 1998). Designer egg approach was started in 1934 by Cruickshank, who reported the modification of fatty acid composition in egg yolk by making feed interventions. Omega-3 fatty acids are proved to be beneficial in various disorders such as cardiovascular disease, hypertension, autoimmune, allergic, and neurological disorders and it is also essential for normal functioning of the human physiology not only in normal adult and also in pregnant and lactating women. A diet balanced in omega-3 and omega-6 fatty acids is important during human evolution (Hargis and Van Elswyk 1993; Simopoulos 2000). Dennehy (2011) stated in his review on omega-3 fatty acid that there are sufficient data from randomized controlled trials on omega-3 fatty acids and ginger that their pharmacologic properties, efficacy, and safety data for specific indications in maternal health. Omega-3 fatty acids benefit gestation, infant vision, and neurodevelopment and ginger is efficacious for nausea in pregnancy but is limited in its safety data. It is also recommended to take omega-3 fatty acid supplement daily during pregnancy (Abdel-Nour and Ngadi 2011). Gheita et al. (2012) in their study stated that add on supplementation with omega-3 fatty acid along with non steroidal anti-inflammatory drugs (NSAIDs) in juvenile idiopathic arthritis was proved to be effective as it reduces the daily requirements of NSAIDs and the risk of related side effects.

Sim and Sunwoo (2002) developed designer egg rich in omega-3 fatty acids and antioxidants by feeding hen with flax seed and patented as Professor Sim's Designer Egg, in which saturated fatty acid in yolk was replaced with 3-poly unsaturated fatty acid (PUFA) i.e. the yolk triglyceride is replaced by linolenic acid and yolk phospholipids are replaced by longer chain omega-3 fatty acids, such as eicosapentaenoic (EPA), dososapentaenoic and docosahexaenoic (DHA) acids (Jiang et al. 1991). To overcome the instability due to 3-PUFA the authors incorporated natural antioxidants like vitamin E, selenium and carotenoid pigments. Caston and Leeson (1990) also reported that the increase in the concentration of omega-3 fatty acid in hens egg by adding flax seed or fish oil in hens diet. Bourre and Galea (2006) produced designer egg fortified with omega-3 fatty acid by feeding hens with linseed, minerals, vitamins and lutein. The nutritional value of 100 g of these eggs contains 6 times more of the omega-3 fatty acid alpha-linolenic acid (ALA), 3 times more DHA, 3 times more vitamin D, 4 times more folic acid, 6 times more vitamin E, 6 times more lutein and zeaxanthine, 2.5 times more iodine and 4 times more selenium. These eggs also contain a little amount of cholesterol and, like standard eggs, are rich in B—complex vitamins and vitamin A, phosphorus and proteins. The consumption of these eggs improved the blood concentration of omega-3 fatty acids, high density lipoprotein (HDL)—cholesterol, low density lipoproteins (LDL)—cholesterol and triglycerides. These omega-3 fatty acids enriched designer eggs showed better stability of PUFA during egg storage and cooking, high availability of such nutrients as vitamin E and carotenoids, which improves antioxidant and omega-3 status of people consuming these eggs (Surai and Sparks 2001).

Fortification of omega-3 fatty acid not only increases the health benefits of designer egg but also reduces the cholesterol content of the egg by replacing saturated fatty acid in egg yolk. The dietary cholesterol and fatty acids plays an important role in various cardiovascular diseases. The scientific attempt to reduce cholesterol content in diet is the promising approach for the management of cholesterol (Hargis 1988). Designer eggs were also developed by replacing yolk cholesterol with conjugated linoleic acid (CLA). CLA is studied for its various health related properties such as anti-adipogenic, anti-carcinogenic, anti-atherogenic and anti-inflammatory (Magdalena et al. 2008). Raes et al. (2002) produced designer egg enriched with CLA by feeding hens with CLA rich diet and found that adding CLA to layers diets rich in omega-3 fatty acids produces CLA enriched eggs. Cook et al. (2000) had patented a method of production of CLA enriched designer eggs by feeding poultry a diet enriched in CLA. Dietary addition of CLA to hens diet decreased lipid content and concentrations of monounsaturated fatty acids in egg yolk, but increased CLA and saturated FA. CLA supplementation of egg also increased yolk moisture content, firmness and impaired the sensory quality of eggs.

Magdalena et al. (2008) studied the anti-cholesterol and anti-inflammatory effect of CLA-enriched eggs in animal models. The authors found that CLA-enriched eggs significantly reduce total plasma cholesterol as compared with CLA-supplemented eggs and it also reduces the size of atherosclerotic plaque, number of atherogenic macrophages and increases the area occupied by smooth muscle cells in atherosclerotic. Cholesterol content of the egg yolk can also be reduced by supplementing hen's feed with chromium at 200–800 ppb concentration (13.9 to 33.7 % reduction) (Anderson et al. 1989; Lien et al. 1996). The pharmacological approach was also studied for reducing cholesterol level in egg by administering egg laying hens with cholesterol lowering drugs. US patent was issued to Meier and Wilson (1997) for the method of reducing the cholesterol content of egg by supplementing hen with L-dihydroxyphenylalanine (L-DOPA).

Selenium (Se), a micronutrient is essential for preventing cardiac muscle degeneration. Supplementation of Se will enhance Se-specific antioxidant status and improve the development of embryos in gilts (Fortier et al. 2012). Se has an essential role in thyroid hormone metabolism and iodine (I) deficiency (Kandhro et al. 2011). Se supplementation is used globally for preventing and treating muscular dystrophy and other Se deficiency syndromes (Beale et al. 1990). Se deficiency is a global problem, to treat this deficiency regular intake of Se rich food is important. Organic source of Se is better absorbed than inorganic source (Fortier et al. 2012). Compared to plant source, egg and meat are the good source of Se. Recommended daily requirement of Se is 55 μg for human adults (Bennett and Cheng 2010). Regular dietary intake at recommended level may reduce the risk and prevalence of prostate and colon cancer and it also proved to have a role in prevention of cardiovascular diseases through antioxidant property (Navarro-Alarcon and Cabrera-Vique 2008; Bennett and Cheng 2010). Among the food sources of selenium egg is the most important and it is easy to fortify the egg with increasing amount of Se. Se concentration in egg had increased from 0.044 to 0.243 μg/g for eggs from hens fed with organic Se (Se yeast product) (Cantor and Scott 1974). Se enriched eggs are marketed in various countries like UK, Ireland, Mexico, Columbia, Malaysia, Thailand, Australia, Turkey, Russia and the Ukraine (Fisinin et al. 2009). Bennett and Cheng (2010) in their study on the production of Se enriched egg concluded that feeding hen up to 5.1 μg/g of Se will increase the concentration of Se in egg without affecting egg production. Se-enriched chicken, pork and beef can also be produced by feeding organic Se in the diet of poultry and farm animals (Fisinin et al. 2009). Increased levels of Se are excreted in liver, kidney and eggs (Beale et al. 1990).

Apart from Se, other nutritional quality of the egg was also improved by enhancing levels of antioxidants such as vitamin E, omega-3 fatty acids such as DHA, carotenoids and Se (Surai and Sparks 2001). In a double-blind, placebo-controlled trial by Surai et al. (2000) to evaluate the ability of designer eggs enriched in vitamin E, lutein, Se and DHA in delivering micronutrients to the human found that consumption of designer eggs enriched in vitamin E, lutein, Se and DHA significantly increased the levels of α-tocopherol, lutein and DHA in plasma as compared to the normal table eggs, whereas it did not change Se concentration in plasma, blood pressure and plasma lipid profile. From the results the authors concluded that dietary intake of designer eggs enriched in vitamin E, lutein, Se and DHA will be a beneficial approach in supplying those nutrients. Designer egg with enhanced vitamin A and β—carotene concentration was also developed (Jiang et al. 1994). Sookwong et al. (2008) developed Tocotrienol (T3)-fortified eggs (0.62 mg of T3/egg) by adding rice bran scum oil to the feed, whereas normal egg contains 0.11 mg of T3/egg.

Helicobacter pylori are one of important cause of gastritis and gastric ulcer and leads to gastric cancers in most of the developed and developing countries (Satoh et al. 1996; Malekshahi et al. 2011). *H. pylori* has been classified as a category 1 carcinogen by WHO (Ruggiero et al. 2002; Prinz et al. 2003). Development of resistance to antibiotic leads to failure of antibiotic therapy (Malekshahi et al. 2011). Roe et al. (2002) developed a egg-yolk immunoglobulin (IgY) against *H. pylori* whole-cell lysate, which reduces gastric inflammation due to *H. pylori*-infection in Mongolian gerbils. Later various researchers found that administration of anti-urease specific IgY was effective passive immunization against *H. pylori* infection and its related gastrointestinal disorders (Shin et al. 2003, 2004; Nomura et al. 2005). Malekshahi et al. (2011) in their study developed recombinant IgY from by using hens immunized with recombinant UreC and found that UreC-induced IgY is specifically successful in inhibition of *H. pylori* infection. Genetic immunization of ducks with a plasmid expressing *H. pylori* UreB produced UreB induced IgY polyclonal and monospecific antibodies against recombinant *H. pylori* urease (Kazimierczuk et al. 2005). Consumer acceptance of these designer eggs are similar to that of normal eggs (Scheideler et al. 1997).

Designer oil with omega 3 fatty acid

Omega 3 fatty acids are unsaturated fatty acids found in green leafy vegetables, vegetable oils, nuts and fish and fish oil. The most common omega-3 fatty acids found in the diet include long-chain PUFA, EPA and DHA. Dietary consumption of omega 3 fatty acid reduces the incidence of cardiovascular disease (CVD), osteoarthritis (Roush et al. 2010), and rheumatoid arthritis (Kjeldsen-Kragh et al. 1992). Designer diet based approach will be effective for increasing omega-3 fatty acid (Penny et al. 2002). Riediger et al. (2008) studied the impact of the source of n-3 fatty acid on cardiovascular benefits using C57BL/6 mice. From the study the authors suggested that the health benefits may be achieved by lowering dietary omega-6: omega-3 fatty acid even in a high fat diet medium. Riediger et al. (2009) studied cardiovascular and metabolic benefits of 'designer oils' containing a lower ratio of omega-6: omega-3 fatty acids. Three groups of C57BL/6 mice were fed for 6 weeks with an atherogenic diet supplemented with either a fish oil- or flaxseed oil-based 'designer oil' with an approximate omega-6: omega-3 fatty acid ratio of 2:1 or with a safflower oil-based formulation with omega-6: omega-3 fatty acids ratio of 25:1. From the observation of food intake, body weight, and blood lipid levels it was concluded that lowering dietary ratio of omega-6: omega-3 fatty acids may significantly reduce cardiovascular and metabolic risks in mice. Napier and Graham (2010) have reported the promising approach of transgenic metabolic engineering in developing transgenic plant producing designer oil enriched with omega-3 long chain PUFA equivalent to the level found in marine organisms.

Designer oil based approach for rapeseed oil enriched with micronutrients such as polyphenols, tocopherols and phytosterols may be effective in the prevention of atherogenesis (Xu et al. 2011). Phenol enrichment of olive oils (Suárez et al. 2010) and palmitic acid-fortified vegetable oil produced synergistic effects on calcium absorption and it is beneficial for baby foods including infant formula, with regard to increasing absorption of calcium by higher soluble calcium in the small intestinal content (Lee et al. 2008). Eshigina et al. (2007) investigated the influence of dietary therapy containing sunflower oil with phospholipids (PL) on the lipid profile of plasma and composition of fatty acids of red blood cells in patients with hypertension and obesity and observed the reduction in serum total cholesterol, low density lipoprotein (LDL), apolipoprotein A 1, apoB and fibrinogen.

Designer broccoli

Broccoli is a highly valued vegetable due to its chemopreventive property. Latté et al. (2011) reported that the benefit from consumption of broccoli in modest quantities and in processed form outweighs potential risks. Sulforaphane is a chemopreventive isothiocyanate (ITC) derived from glucoraphanin (GRP) hydrolysis by myrosinase, a thioglucoside present in broccoli. Due to lack of myrosinase in commercially available glucoraphanin supplement bioavailability of sulforaphane is not achieved. Cramer et al. (2011) showed that combining broccoli sprouts with the glucoraphanin powder synergistically enhanced the early bioavailability of sulforaphane, proved that regular intake of designer broccoli sprouts enriched with glucoraphanin powder reduces the risk of cancer compared the GRP powder or sprouts alone. Designer broccoli fortified with Se is effective in cancer prevention, due to its high glucosinolate (GSL) content and Se accumulation, which can be developed by fertilizing broccoli with Se (Hsu et al. 2011). Abdulah et al. (2009) achieved Se enrichment by using a sodium selenite solution, which showed potential anticancer properties in human prostate cancer cell lines, as compared with those of a control broccoli sprout extract.

Probiotics

Probiotics are live microorganisms such as *Lactobacilli* Sp., *Bifidobacteria* Sp. and *Streptococcus thermophilus,* which provide various health benefits upon ingestion. These probiotics are commercially available as spores or in lyophilized forms or in the form of probiotic fortified fermented dairy products. Probiotics are potential in the treatment for eczema (Gore et al. 2011), pediatric antibiotic-associated diarrhea (Johnston et al. 2011), acute upper respiratory tract infections (Hao et al. 2011), chronic and acute enteric infections and their associated diarrheal complexes (Sleator 2010). Daily dietary intake of probiotics reduces the incidence and severity of acute and chronic infection, prevents and reduces the recurrence of cancer and incidence of several atopic conditions (Sleator and Hill 2008) and also increases the level of liver aminotransferases in patients with non - alcoholic fatty liver disease (NAFLD) (Aller et al. 2011). Manipulation of cellular system using recombinant technology in probiotic bacteria is easier, which can facilitate survival in stressful conditions, and can also lead to production of designer strains (Corcoran et al. 2008). 'Designer probiotics'—strains are specifically tailored to target certain pathogens and/or toxins in vivo (Sleator and Hill 2008), for controlling human immunodeficiency virus (HIV) and as novel mucosal vaccine delivery vehicles (Elson 2006; Sleator 2010) and which interacts ligand-receptor binding of toxins released by microbial pathogens causing enteric infections (Paton et al. 2006).

Designer drinking yogurt

Fresh yogurt is an example for naturally available probiotics; it contains live cultures of lactic acid-producing bacteria that can prevent traveler's diarrhea, antibiotic-induced diarrhea, rotavirus infection, and vaginal yeast infection (Fig. 1). Regular dietary intake of conventional and probiotic yogurt stimulated the production of pro-inflammatory cytokines in young healthy women (Meyer et al. 2007) and anti-inflammatory activity in parallel with the expansion of peripheral pool of putative T(reg) cells in inflammatory bowel disease patients (Lorea Baroja et al. 2007). Probiotic yogurts potentially eliminate enterotoxigenic *Bacteroides fragilis*, which causes acute and persistent diarrheal disease, inflammatory bowel disease and colorectal cancer (Odamaki et al. 2012). Designer yoghurt containing *Bifidobacterium lactis* Bb12(R) prevents gastrointestinal and lower respiratory tract infections (Jayakanthan et al. 2011) and also improves defecation frequency and abdominal pain due to constipation in pediatric patients (Guerra et al. 2011).

Regular consumption of probiotic yogurt improves fasting blood glucose and antioxidant status in type 2 diabetic patients (Ejtahed et al. 2011), apart from anti-diabetic activity vitamin D or vitamin D - calcium fortified yoghurt ameliorated compromised vitamin D status and improved lipid profile and endothelial biomarkers in type 2 diabetic patients (Nikooyeh et al. 2011; Shab-Bidar et al. 2011). Curcumin mixed into yoghurt exhibited anti-diabetic activity and improved physiological and biochemical markers of experimental diabetes (Gutierres et al. 2011). The gut-associated lymphoid tissue (GALT) is a major site of HIV activity and significantly influences disease prognosis. Reducing immune activation at this site helps slow disease progression. Studies also showed that probiotic microorganisms have considerable immunomodulatory effects at the level of the GALT. Irvine et al. (2011) in Mwanza, Tanzania evaluated the ability of probiotic yogurt in reducing the incidence and severity of opportunistic infections among people with HIV and concluded that yogurt supplemented with *L. rhamnosus* may effectively alleviate GI symptoms and improve productivity, nutritional intake and tolerance to antiretroviral treatment among people with HIV.

Various in vitro studies indicated that yoghurt bacteria generates water-soluble vitamins such as vitamin B1 and B2 and daily intake of 200 g of probiotic or conventional

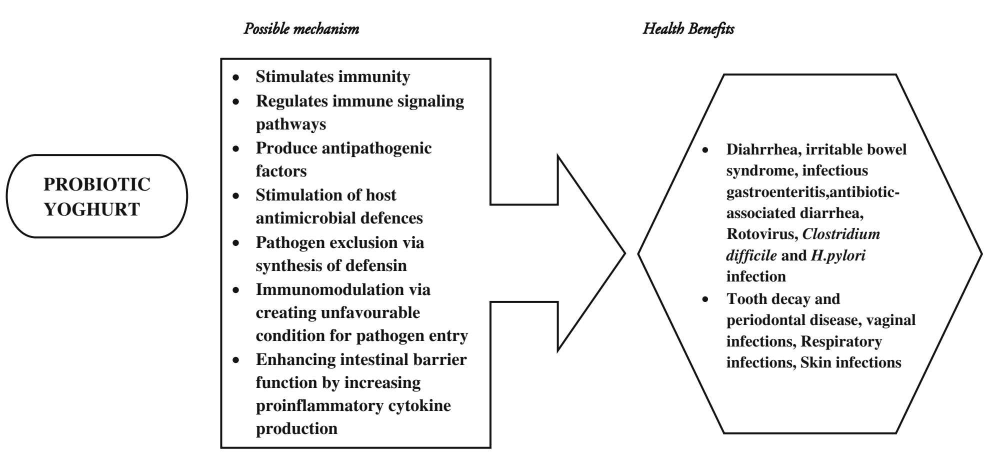

Fig. 1 Possible mechanism of action and health benefits of probiotic yoghurt

yoghurt will be a good source of these micronutrients (Fabian et al. 2008), when compared to the specific intake of probiotic bacteria. Horie et al. (2004) designed drinking yogurt containing *Lactobacillus acidophilus* and *Bifidobacterium* sp. and fortified with 1 % egg yolk IgY-urease, consumption of which may lead to suppression of *H. pylori* infection in humans. Estrada et al. (2011) developed a fortified strawberry yogurt containing microencapsulated salmon oil, which help to increase intake of long-chain n-3 fatty acids. McCowen et al. (2010) studied that ω-3 fatty acid fortified yoghurt increases ω-3 fatty acid content of plasma lipids, and reduces arachidonic acid concentrations on plasma lipids. Increase in storage of fat during pregnancy leads to elevated lipid levels. Consumption of probiotic yogurt among pregnant women could not affect normal serum lipid profile as compared to the conventional yogurt (Asemi et al. 2011). Apart from health benefits designer yoghurts are useful in maintaining healthy skin. Antioxidant potential of yoghurt face pack using natural ingredients (F-YOP) improved the moisture, brightness and elasticity of treated skin (Yeom et al. 2011).

Designer milk

Designer milk may have modification in the primary structure of casein, alteration in the lipid profile to include more healthy fatty acids such as conjugated linoleic acid (CLA) and omega-fats, improved amino acid profiles, more protein, less lactose and absence of beta-lactoglobulin (beta-LG) and increased protein recovery. Other milk containing nutraceuticals are the important aspects in designer milk achieved through transgenic technology. Cow milk allergy in children could also be reduced by eliminating the beta-LG gene from bovines (Sabikhi 2007). The genetic manipulation of dairy cattle is also a feasible and has significant impacts on milk quality, attributes of novel dairy products and human health (Karatzas and Turner 1997).

Hernández et al. (2007) studied the effect of 11.2 % sunflower seed supplemented diet for cows on the chemical composition of milk and dairy products. The results of the study showed that the contents of CLA and transvaccenic acid (TVA) were increased from 0.54 to 1.6 g/100 g total fatty acid, respectively in control products to 2 and 6.4 g/100 g total fatty acid, respectively in diet supplemented group without affecting lactose content in milk, total fat, protein and ash contents in the dairy products, which is approximately 4 fold higher. Moreover, CLA-rich products showed considerably low atherogenicity index and thrombogenicity index i.e. 38.4 and 25 % less than those from control products. The study also demonstrated that fatty acid profiles were unaffected during processing. From these studies Hernández et al. (2007) concluded that designer milk produced by supplementing cow with 11.2 % sunflower seed diet may contribute to the reduction of the risk of CVDs in humans.

Various forms of designer milks and milk products were evaluated by researchers for the health benefits of human, which include milk-based beverages fortified with added apple or grape seed polyphenols (Axten et al. 2008), lutein-fortified fermented milk (Granado-Lorencio et al. 2010), milk fortified with phenolic compounds from olive vegetable water and fermented with γ-amino butyric acid (GABA)-producing (*Lactobacillus plantarum* C48) and autochthonous human gastro-intestinal (*Lactobacillus paracasei* 15 N) lactic acid bacteria (Servili et al. 2011), prebiotic and probiotic fortified milk (Sazawal et al. 2010), lactoferrin-enriched fermented milk, which ameliorates acne vulgaris (Kim et al. 2010), folic acid fortified milks for better absorption of folic acid (Achón et al. 2011), milk fortified with EPA (Martin-Bautista et al. 2010). Fermented milk was produced by fermenting Ching-shey purple sweet potato (CPSP) substrate/media milk with lactic acid bacteria strains possessing high GABA concentrations, organic acid contents, anthocyanin contents, and antioxidant activity (Wu et al. 2011), among which calcium and vitamin D fortified milk and cheese are important for bone health of children and women. Calcium and vitamin D fortified milk along with magnesium and zinc improves vitamin D status, lower parathyroid hormone levels and reduce bone turnover (Bonjour et al. 2009; Kruger et al. 2010) Regular consumption of vitamin D-fortified milk provides a mean intake of nearly 4 μg/d in children (Green et al. 2010; Houghton et al. 2011; Rich-Edwards et al. 2011) and study also showed that high-calcium enriched milk prevents the occurrence of overweight and obesity among postmenopausal women (Angeles-Agdeppa et al. 2010). Good bone health can be achieved through appropriate diet and lifestyle, which protects from osteoporesis and bone fracture in later stage of life. Optimal intake of calcium and vitamin D in early adulthood is essential and should be achieved through diet. Van der Hee et al. (2009) developed designer icecream fortified with calcium. Calcium bioavailability in the two calcium-fortified ice cream formulations as high as milk indicates that ice cream will be a good vehicle for delivery of calcium.

Anemia during infancy impairs neurodevelopment; iron-fortified milk improves anemic status (Rivera et al. 2010; Semba et al. 2010). Multiple micronutrient deficiencies are highly prevalent among preschool children and often lead to anemia and growth faltering. Milk provides an acceptable and effective vehicle for delivery of specific micronutrients, especially zinc and iron. Micronutrient fortified milk providing micronutrient bundle, improved growth and iron status and reduced anemia in children 1–4 years old (Sazawal et al. 2010). Designer milk produced by enriching milk with fish oil, oleic acid, minerals and vitamins reduces indices of endothelial cell activation in children (Romeo et al. 2011). EPA and DHA enriched milk reduces the level of blood lipids, mainly cholesterol, LDL-cholesterol and triglycerides (Lopez-Huertas 2010). Consumption of DHA fortified milk during pregnancy and lactation improved composition of red blood cell membranes as well as in human milk (Atalah et al. 2009) and showed improved intelligence in infants (Gale et al. 2010). Selenium enriched milk may improve Se status and reduce the risk of cancer (Hu et al. 2010).

Human milk is the best food for neonates; however, in very low birth weight pre-term infants it may not provide sufficient protein and energy. Various studies reported the use of fortified human milk in preterm infants, which produces adequate growth and satisfies the specific nutritional requirements (Arslanoglu et al. 2009; Maggio et al. 2009; Martins and Krebs 2009; Reali et al. 2010; Di Natale et al. 2011; Zachariassen et al. 2011). α-Lactalbumin-enriched infant formula containing 12.8 μg/l protein was found to be safe and supported age-appropriate growth; weight gain (Trabulsi et al. 2011). Due to unawareness among consumers and other issues, demand for fortified human milk is less as compared to that of infant formulas (Arslanoglu et al. 2010). Early neonatal intake of cow's milk protein may sensitize immune system and lead to allergic conditions for cow's milk (Høst 1991).

Monascus fermented rice

Monascus fermented products have featured in Chinese cuisine for thousands of years and are widely used as food colourants and dietary materials in many Asian countries. It is produced by fermenting rice with fungi *Monascus* sp, which leads to fortification of rice with active constituents such as monacolins and γ - amino butyric acid (GABA). Tseng et al. (2012) reported in vitro antioxidant and immunomodulatory activity in RAW 264.7 cells. Various studies also proved its health benefits for human with regard to diabetes, cholesterol, cancer, alcohol induced liver disease and inflammation (Kalaivani et al. 2010). It is also proved to have potential for promoting bone formation and immunomodulation. In our laboratory, we have developed Monascus fermented rice using Indian variety of rice and reported its anti-diabetic (Rajasekaran and Kalaivani 2009) and anti-cholesterol (Rajasekaran and Kalaivani 2011) activity in animal models. The benefits of the Monascus fermented rice may be due to the presence of monacolins (Fig. 2).

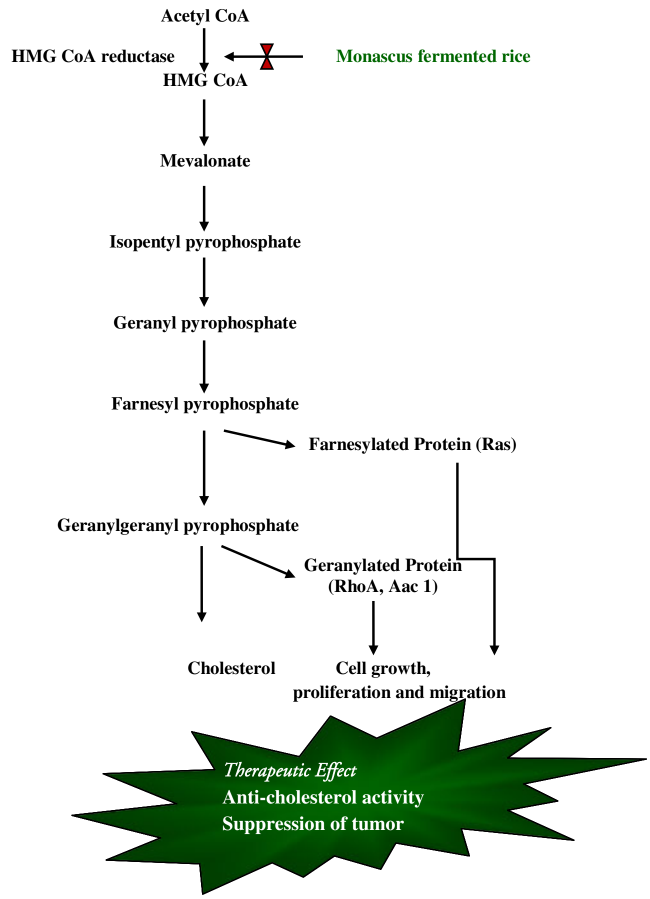

Fig. 2 Schemetic representation of mechanism of action of Monacolins present in *Monascus* fermented rice

Phytosterols enriched designer food

Phytosterols are isoprene compounds present in different food products, among which the most important are beta-sitosterol, campesterol and stigmasterol. Plant sources of phytosterols are oily seeds, nuts, plant oils, grains, and pulses. Studies have reported the reduction in total cholesterol and LDL cholesterol level on regular consumption of 2–3 g phytosterols fortified foods per day (Lugasi 2009), which in turn reduces the risk of cardiovascular diseases. Polagruto et al. (2006) and Escurriol et al. (2009) also reported the reduction in total chloesterol and LDL—cholesterol on consumption of food products fortified with phytosterols. Intake of phytosterols enriched designer oil (0.45 g/day (as free sterol) (Seki et al. 2003) significantly reduced total cholesterol, very low density lipoprotein (VLDL) cholesterol and remnant-like lipoprotein (RLP) cholesterol compared with the control vegetable oil, which is helpful in reducing the risk of coronary heart disease (CHD) in the population. Clifton et al. (2004) reported that phytosterol ester-enriched milk and yoghurt significantly reduce LDL and total cholesterol. Plasma sitosterol was increased by 17%–23 % and campesterol by 48%–52 % with phytosterol-enriched milk and bread. Phytosterols, fat-soluble fractions of plants are consumed at levels of 200–400 mg/day in Western diets. Phytosterol chemically resembles cholesterol, inhibits the absorption of cholesterol. Addition of phytosterol in diet is effective in reducing the risk of CHD (Jones et al. 1997).

Phytosterol ester-enriched margarine (Mussner et al. 2002) also significantly reduces total cholesterol, LDL—cholesterol, HDL—cholesterol, apolipoprotein B and LDL/HDL cholesterol ratio compared with the control margarine (Cerrato 1999).

Designer grains

Wheat germ-enriched bread has been prepared by al-Hooti et al. (2002) using white flour, 20 % raw wheat germ, 0.5 % sodium stearoyl-2-lactylate, 30 ppm potassium bromate and 50 ppm ascorbic acid. Maternal supplementation of folic acid in early pregnancy reduces the risk of severe language delay in children at 3 years of age (Roth et al. 2011). Sittig et al. (2011) recommended dose of folate at 400 ug/day for adolescents and nonpregnant adults. US had implemented mandate of folic acid fortification of grains (Johnston and Tamura 2004). Due to lack of stringent regulations, there are reports on higher than expected fortification. Over dose of folate supplementation in adolescence may lead to motivational and spatial memory deficits (Johnston and Tamura 2004; Sittig et al. 2011). Chilean Ministry of Health recommended the fortification of wheat flour with folic acid at a concentration of 2.2 mg of folic acid/kg for women of child bearing age in order to reduce the risk of neural tube defects in newborns (Hertrampf et al. 2003). Folic acid fortification of grains are recommended also in Iran (Abdollahi et al. 2008). Vitamin deficiency diseases are common in the countries where rice is the staple food. Golden rice to combat vitamin deficiency was developed by fortifying rice with vitamins (Potrykus 2003). Apart from biotechnological approach there are maize and wheat with higher levels of iron, zinc, β—carotene, lysine and tryptophan are available due to natural variation in its germplasm (Hoisington 2002).

Designer foods: role in cancer prevention

There are numerous anti-carcinogens available naturally in food or herbs. The effective use of those constituents is important in preventing cancer. The “designer foods” approach is one of the best approaches, by which the constituents having anti-cancer potential can be fortified into the regular diet (Pariza 1992). Various studies have proved the designer food approach for the prevention of cancer. Dietary administration of bovine milk lactoferrin and black tea polyphenols combination significantly reduced the tumor incidence, development of hamster buccal pouch carcinomas, carcinogen-metabolizing enzymes and cellular redox status (Chandra Mohan et al. 2005, 2006; Mohan et al. 2008).

Polyphenolic compounds such as anthocyanins and flavonoids in red grape wine were proved to have inhibitory effect on breast cancer cells. A study by Hakimuddin et al. (2004) also supported that red wine polyphenolic fractions have anticancer property against breast cancer cell lines (MCF-7) and the authors also reported relatively low cytotoxicity towards normal human mammary epithelial cells (HMEC) and a non-tumorigenic MCF-10A cells, which is contrast to the authentic flavonoids such as quercetin, naringenin and catechin which inhibited the growth of HMEC much more than that of MCF-7 cancer cells. In another study, Hakimuddin et al. (2006) reported the effect of red grape wine polyphenol in gene expression and biochemical pathways. The polyphenols induced calcium release by disrupting mitochondrial function through membrane damage, which results in selective cytotoxicity toward MCF-7 cells. Apart from its anticancer activity, the polyphenolic fractions showed discrete antioxidant action on cancer cell lines (Damianaki et al. 2000). The above studies suggested that consumption of wine or other polyphenol-rich foods and beverages, could have a beneficial antiproliferative effect on breast cancer cell growth.

Tea is consumed as beverage in many countries in the world. Studies have also showed beneficiary effect of tea in reducing the risk of a variety of illnesses such as cancer and coronary heart disease. Tea plant, *Camellia sinesis* is cultivated globally and contains polyphenols as one of the active constituent. Among tea, both black tea and green tea were proved to have potential in preventing lung, stomach, esophagus, duodenum, pancreas, liver, breast, colon (Weisburger et al. 1998) and skin cancers and also have preventive effect on atherosclerosis and coronary heart disease, high blood cholesterol concentrations and high blood pressure. The health benefits of polyphenols from tea can be extended by combining them with other food in the form of designer food (Mukhtar and Ahmad 2000). Among flavonoids, flavone, flavonol, flavanone and isoflavone classes possess antiproliferative effects on various cancer cell lines LLC-PK1 (renal tubular cell line), MCF-7 (human breast cancer cell line), Caco-2 (human colon cancer cell lines) and HT-29 (resembling colonic crypt cells) (Kuntz et al. 1999).

Designer food enriched with macro and micronutrients

In a survey by Wagner et al. (2005) on fortified foods in Austria showed that about 470 fortified products are available commercially. The most frequently added nutrients were vitamin C (73 %), vitamin B6 (43 %), niacin (37 %) and among mineral and trace elements calcium (23 %) was the most added. Among people who are buying fortified foods the contribution of vitamins and minerals increased up to 74 and 19 %, respectively and no risk due to overdose was found. To address micronutrient deficiency in European population, micronutrients are added safely to foods at levels recommended by European Commission Recommended Daily Intake (EC RDA): the micronutrients includes vitamin B12, vitamin C, vitamin E, riboflavin, panthothenic acid, niacin, thiamine, vitamin B6, vitamin D, folic acid, biotin, copper, iodine, selenium, iron, zinc, calcium, phosphorus and magnesium (Flynn et al. 2003). Dietary micronutrient deficiencies lead to diseases such as iodine deficiency disorders, iron-deficiency anemia, and vitamin A deficiency, and other serious public health problems in the developing world. Fortification of salt with iodine, iron, and vitamin A is an easier approach and is followed in most of the developing countries including India (Raileanu and Diosady 2006).

Micronutrient-fortified, cereal-based infant foods are recommended for reducing multiple micronutrient deficiencies in infants (Gibson et al. 2011). Home fortification of foods with multiple micronutrient powders is an effective intervention to reduce anemia and iron deficiency in children of 6 to 23 months age (De-Regil et al. 2011). Micronutrient deficiency in pregnant women leads to low birth weight, lower cognition and reproductive performance and anemia. Deficiencies of micronutrients (zinc, iron, folic acid and iodine) is highly prevalent in pregnant women in South Asia, India and other developing countries (Seshadri 2001; Pathak et al. 2004; Haider and Bhutta 2006), which may be due to poor dietary intake of food and low frequency of consumption of foods rich in micronutrients. UNICEF/United Nations University/World Health Organization jointly proposed a formulation for a multiple micronutrient supplement for pregnant women. Use of multivitamin supplementation among pregnant women is effective in improving anemia status (Sunawang et al. 2009). Multiple micronutrient supplements increases hemoglobin and improves micronutrient status in pregnant women better than iron supplements alone or iron with folic acid (Allen and Peerson 2009). Micronutrient fortified flour reduced both iron and zinc deficiency postpartum among breast-feeding women (Stuetz et al. 2011)

Designer protein

The synthesis of proteins with high essential amino acid content has potential applications in animal nutrition (Gagnon et al. 2000; Doucet et al. 2002). Cysteine-rich proteins, such as keratin, may have advantages over the simple amino acid or its derivatives, which improves antioxidant status in health and disease management (McPherson and Hardy 2011).

Biotechnology in designer food

Gene technology had created a platform for genetic manipulation in farming and the use of plants as 'pharma' factories to manufacture therapeutics (Chang 2001). Transgenic technology can improve functional properties of dairy milk by altering major component of milk in high producing dairy cows (Karatzas 2003). In a study by Brophy et al. (2003), casein concentration in the milk was enhanced by introducing additional copies of the genes encoding bovine beta- and kappa-casein (CSN2 and CSN3, respectively) into female bovine fibroblasts. In another study by Hyvönen et al. (2006) human lactoferrin content was increased in cow's milk. Fastest growth in dairy biotechnology, particularly for altering the milk composition paved a path for designer milk (Sabikhi 2007). To address vitamin A deficiency, an important nutritional problem in India, advances in biotechnology had developed genetically modified mustard (*Brassica juncea*) to express high levels of β—carotene, the precursor of vitamin A (Chow et al. 2010).

Biofortification

To meet the nutritional needs of fast growing global population at the rate of 1.4 % per year, i.e. 8 billion by 2030, there is a need for 50 % more food grains with higher and more stable yields (Khush 2002; Yan and Kerr 2002). Macronutrient and micronutrient deficiencies are prevalent in most of the developing countries and there is a decline in natural resources such as arable land and water. To meet these challenges biotechnology is a valuable tool to improve nutritional value in plants and crops (Yan and Kerr 2002). Plant biotechnology has made important contributions in developing designer grains enriched with vitamins, amino acids and micronutrients. The use of conventional breeding techniques and biotechnology to improve the quality of staple crops is a new strategy to address nutrient deficiencies in developing countries, which is referred to as "biofortification". Potential of biofortification is proved in improving iron, zinc, and vitamin A status in low-income populations (Hotz and McClafferty 2007). Biofortification is the cost effective way as it does not require a change in dietary habits. In the year 1992 International Rice Research Institute, Manila, Philippines, had initiated a project to improve the iron and zinc content of rice, which was followed by many other researchers and developed lines of rice with increased iron, zinc and β—carotene content. Rice lines with improved iron contents were developed (Sautter et al. 2006). The biofortification with nutrients was extended to wheat, maize, cassava, sweet potatoes and beans. Maize with improved amino acid balance was developed and grown in several African countries (Khush 2002; Friedrich 1999). The rapidity of research in food biotechnology, regulatory issues, legislation and intellectual property rights will enhance the discovery and innovation, but public education on awareness about biotechnologically produced products should be continually enhanced for its acceptance among the people (Chang 2001).

Conclusion

Advantages of designer food approach are that it does not require change in dietary habit/pattern of the population and it can deliver recommended amount of nutrients regularly. It can be easily merged with existing system of food production and distribution. In developed countries designer foods played a major role in improving the diet and eliminating nutritional deficiencies. For example, elimination of vitamin A deficiency leading to night blindness was achieved by vitamin A fortified margarine in Denmark and vitamins A and D fortified milk eliminated vitamin D deficiency and rickets in Europe and North America. In the developing countries, food fortification has gained importance since 1990s. Fortification of wheat flour with iron, vitamin A, folic acid and other B vitamins in Asian countries such as India, Indonesia and the Philippines was successful in eliminating these micronutrient deficiencies, whereas in Thailand, foods such as noodles and fish were fortified with micronutrients.

Designer foods approach is one of the major strategies to reduce micronutrient deficiency in developing countries, which can be done systematically to reach entire population by public and private partnership. Best example for commonly used designer food was iodized salt, which is widely used by the population and had eliminated iodine deficiency and its related disorders. The success of the drive for universal iodization of salt shows that the diets of children, women and families world-wide can be changed in small but very beneficial ways in just a few years as a result of concerted global, national and local action (UNICEF 2005).

Malnutrition is substantial in India. Data from National family Health Survey-3 (NFHS 2007) in India showed children upto the age of five are under weight due to malnutrition, which ranges from <25 % in states like Kerala, Sikkim, Punjab, Manipur, Mizoram to >40 % Madhya Pradesh, Bihar and Jharkhand (Fig. 3). The success of iodine fortification of salt leads to supply of other nutrient through designer food approach such as vitamin D and calcium fortified milk for bone health, folic acid fortified cereals, sterols fortified yogurt, margarine, chocolate, cheese and juice in the management of cholesterol, iron fortified milk, salt and condiments for management of anemia. In India, there is a cultural relationship between food and health, which is well recognized and used in day to day life. Food is considered as medicine in Indian systems of medicine. Regularly used foods in India such as tea, green tea, oil, sugar, dhal, etc. can be positively explored for designer foods approach in improving health of the society. Prior experience in designer foods indicate that fortification of food is completely safe but fortification should be done rationally i.e. it is usually less than one third of the total

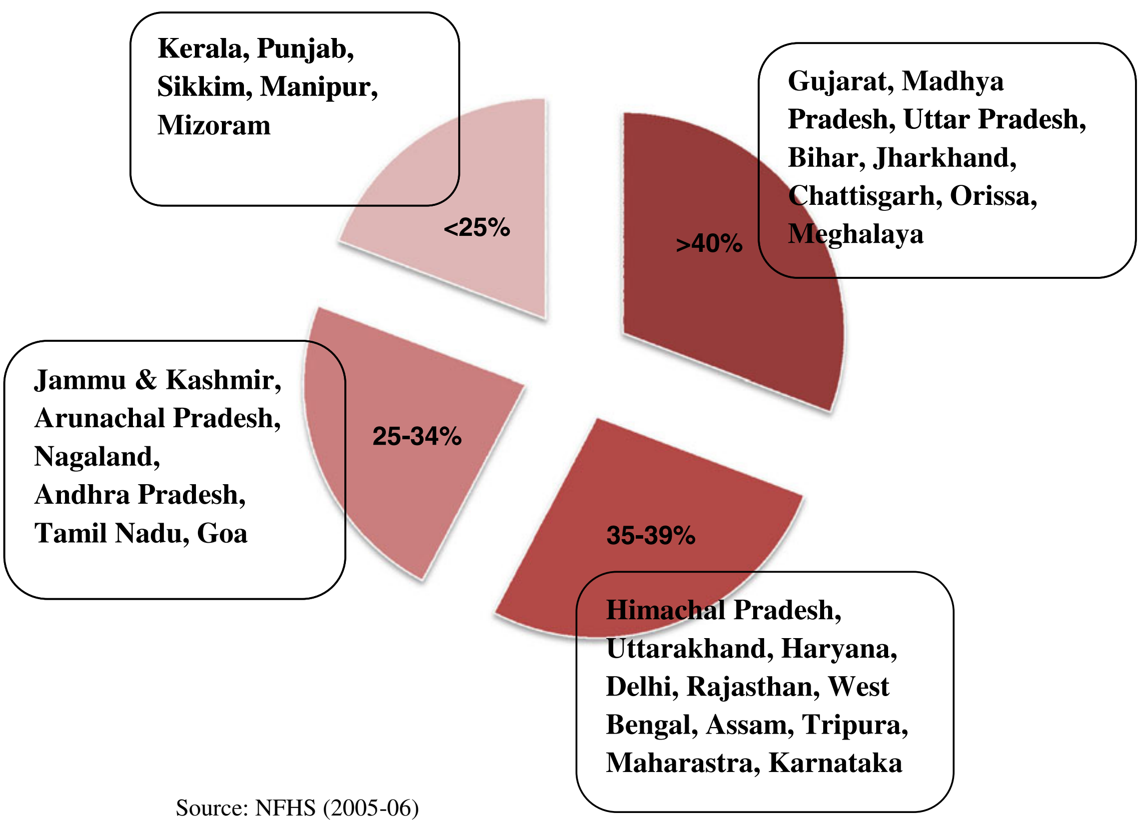

Fig. 3 Percentage of underweight in children due to malnutrition in different states of India. Source: NFHS (2007)

Recommended Daily Allowance (RDA). It should be strictly regulated with stringent quality control measures to ensure that there is no excessive intake of specific nutrients.

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