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REVIEW PAPER

Are Roots and Tuber Crops the New Super Foods? Some New Evidences

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Abstract

Low-calorie intake among poor, in our society, have resulted in deficiencies due to inadequate diet, however the nutritional concern of the present day is related more to over-nutrition with rise in chronic metabolic disorders. While enormous efforts have been directed globally, to grow nutritionally rich foods, in the coming years, it will be prudent to systematically evaluate the effect of consumption of nutritionally-dense food. Emerging evidences indicate that traditional food system of cereals, legumes lentils and more importantly roots and tubers, when integrated into diet, can enhance the health status and the nutritional security of the populace. This review explores the merits of tuber-enriched diet and tries to evaluate whether roots and tuber crops are poised to be the super foods?

Keywords: Functional foods, Tubers, Diabetes, Cholesterol reduction, Traditional diet

Today's nutritional threats are no more restricted to low caloric intake among the poor in our society and wide spread deficiencies due to unbalanced diets. Nutritional concerns also include over-nutrition, with fast rises in diabetes and obesity associated with over consumption of high caloric foods in both poor and rich nations. While on one side it will be important to increase production of nutritionally rich foods it will be equally important to integrate agricultural production with nutrition, and health to attain sustainable global nutrition security. Throughout the world, communities traditionally employ a wide range of locally available food resources in daily diets. However, in past, a large body of literature has been reported on socio-economic changes and its influence on the dietary patterns and food habits which have further contributed to nutrition and diet-related health problems (Shang *et al.* 2012; Yusof *et al.* 2012; American Diabetes association, 2014; Poulsen *et al.* 2014; Fontana & Patridge 2015; Schwingshackl and Hoffmann, 2015; Katan 2017). In today's age, the food suppliers, food manufacturers, processors, distributors, are all well integrated even at the global level. This has led to a decline in production of coarse grains, roots and tubers, legumes. This integrated food system may well have contributed to world-wide dietary shift (Anand *et al.* 2015).

Modern feeding habits have brought in a number of life-threatening nutritional disorders. Fortunately, it is also true that the traditional food systems of cereals, legumes and lentils and more importantly roots and tubers, when effectively integrated, mobilized and promoted, can enhance food availability and ensure nutritional and health status of the populace. This comes from the basic understanding of different aspects of diet-diseases which has further helped in practical formulation of dietary recommendations for the public. In 2003, Hu reported an extensive review on effect of plant-based diet and concluded that intake of whole grain carbohydrate and unsaturated fats were related to reduction of cardiovascular disease (CVD) risks. Similarly, special diets have been formulated like the Harvard's healthy eating plate, Mediterranian Diet, DASH-Eating plan; the core of all these diets contain whole grains, fruits and vegetables and plant based protein. Several studies have established that high diet quality may reduce the risk of All-cause CVD and cancer mortality. The study by Reedy *et al.* (2014) affirmed that increased consumption of these diets resulted in reverse relation to CVD and cancer risks. A year earlier, in 2013, Estruch and colleagues established the protective role of Mediterranean diet against specific CVD end points like stroke, myocardial infarction in a randomized trial of 4.8 years. Similarly, in 2015, Makarem *et al.* carried out a trial in 2983 Framingham subjects from 1991-2008. The study was evaluating, among other things, the effect of plant-based and animal-based foods and the effect of food processing and preservation methods on risk of obesity-related cancer. The results from the study confirmed that consumption of plant-based diet coincided with reduced frequency of cancers.

Nutrition security is not only related to promotion of healthy growth and development but also related to attaining optimal health and preventing chronic diseases. Some recent articles have focused on the significance of crop diversity on food security (Massawe *et al.* 2016), especially with respect to cassava and yams (Ferraro *et al.* 2016). However, a systematic review has rarely inspected the possibility of utilization of roots and tubers for attaining and addressing global food and nutritional needs. We are reexamining roots and tubers because they not only are energy contributors, have also established them as antioxidative, anti-inflammatory and hypoglyceamic foods as revealed by the research efforts made in this direction. Sweet potato has been endorsed as a cancer-preventing food by the American Cancer Society. Due to the re-emergence of root and tuber foods this review focuses on the lesser explored role of roots and tubers and tries to ebaluate whether they may be the next super foods (Fig. 1).

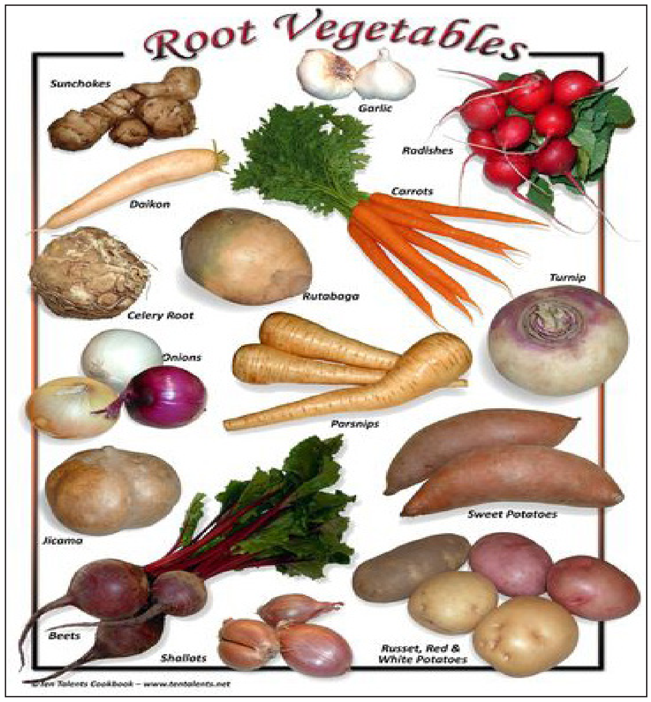

Fig. 1: Inter-relation between causes of chronic dieases and role of roots and tubers crops in reducing risk of chronic diseases

Tuber crops

Roots and tubers are generally referred to as the growing plant that stores edible material in subterranean root, corn or tuber. These are broadly categorized as tropical tubers: Cassava (*Manihot esculenta* Crantz), Sweet potato (*Ipomoe batatas* L.), Yams (*Dioscorea* spp.), Taro (*Colocasia esculenta, Colocasia antiquorum*), Cocoyams (*Colocasia esculenta*); and temperate tubers are (Potato (*Solanum tuberosum* L.), sugar beet (*Beta vulgaris* L.), Onion (*Allium cepa* L.), Garlic (*Allium sativum* L.), Ginger (*Zingiber officinale*), Carrot (*Daucus carrota*, Radish (*Raphanus raphanistrum* subsp. sativus), Turnip (*Brassica rapa* subsp. rapa), Parsnip (*Pastinaca sativa*).

These form a major staple food group in Africa, Asia and Latin America. In past roots and tubers were generally considered as sources of dietary energy in the form of carbohydrates. Interestingly, they produce more edible energy per hectare per day than any other crop groups (Edison *et al.* 2006). However, recently it has come to light that roots and tuber matrices contain several of compounds like saponins, bioactive proteins, glycoalkaloids and carotenoids and phenolics which have shown encouraging evidences of disease prevention (Chandrasekara and Kumar, 2016).

DISEASE PREVENTION & HEALTH PROMOTION

Clinical evaluations of tuber-rich diet on chronic conditions like glyceamic index, type 2 diabetes, Vit A deficiencies and inflammation has been reviewed in the following section.

Effect of tuber diet on Glyceamic index and Type 2 diabetes

The glyceamic index is defined as the incremental area under the two-hour blood glucose curve produced by a standard amount of carbohydrate in a food (usually 50 g) relative to the incremental area produced by a standard of either glucose or white bread (Willett *et al.* 2002).The glycaemic index (GI) and glycaemic load (GL) are well known indicators of carbohydrate quality. In past, many reports have established that there is an inverse relation between consumption of food with low GI and GL and risks of type 2 diabetes. Though majority of the scientific reports are on the evaluation of the influence of cereal-based diet on GI and GL, there are a few systematic records that have focused on evaluating the influence of roots and tubers consumption on the GI and Gl. Mbanya and colleagues (2003) established that mixed meals of plantain, corn, yams and cassava was low GI. Though one must be cautious of over extrapolation, since the GI and GL relationship are not always straight forward, but these indicators do help in classifying foods that can be integrated in the diet to manage or minimize post-prandial glucose spikes.

In 2012, Satija and Hu confirmed that tubers like yam and taro contain high percentage of resistant starch and have been demonstrated to lower postprandial glucose, insulin and lipid levels.

New observations have since emerged which establish that carrots are also good source of dietary fibres. Nawirska and Uklànska in 2008 reported that 'Dolanka' carrots have the highest percentage of soluble fibre compared to cabbage, strawberry, black currant. In a study by Gustaffson *et al.* (1994), it was recorded that isocaloric meals, containing 100, 200 and 300g of carrots that contained 2.9, 5.8 and 8.7 g of fibre respectively, increased satiety score, lowered the glucose response, decreased the insulin/C-peptide responses. More recently in 2007, Brynes and colleagues confirmed the role of carrots in management of glycaemic load in type 2 diabetic human subjects who were fed with carrot cakes in a 24 days trial.

An alarming 415 million people were reported to suffer from diabetes in 2015 within the age group of 20-79 yrs and 5 million deaths attributed to diabetes. A rise in this number to 642 million cases is predicted by 2040 (Oqurtsova *et al.* 2017). Several authors conceded to the fact that the emergence and the steep increase in the prevalence of type 2 diabetic cases worldwide, is characterized by unhealthy diet, especially the quality of carbohydrate and lower levels of physical activities. (Drewnowski and Popkin, 1997; Astrup *et al.* 2008; Kearney 2010; Hu 2011; Popkin *et al.* 2012). At the same time, a popular scientific notion arose that both the type and amount of carbohydrate found in foods influence postprandial glucose levels and can also affect overall glycaemic control in individuals with diabetes.

In this context, several research groups have directed their efforts on evaluating the potentials of different tuber foods in management of type diabetes. Ludvik and co-workers, in the years 2002 and 2004, conducted two separate trials to evaluate the effects of extract of white skinned sweet potato on glucose metabolism and serum cholesterol. In 2002 trial, the authors reported a reduction in fasting blood glucose after 6 weeks ingestion of 4g of the white skinned sweet potato extract. The 2004 trial, which was performed for a longer time of 3 months, confirmed the beneficial effects of the extract on glucose and serum cholesterol. Furthermore, it was indicated that the beneficial effect of the extract could be due to reduced insulin resistance. Long term glucose control, as a result of ingestion of the extract, was also reported by the authors based on the decreased levels of HbA1c.

Meanwhile, Wu *et al.* in 2005, conducted an interesting trial on postmenopausal women subjects who were divided into two groups, I[st] group was fed with yam diet and the 2[nd] (control) group was fed with sweet potato for 30 days. The subjects in the first group showed increased levels of serum sex the hormone binding globulin (SHBG), as compared to control, which in turn had a protective effect against type-2 diabetes mellitus in these subjects. Authors Ludvik and coworkers in 2002 and 2008, have confirmed that type 2 diabetic patients when given a diet of sweet potato, showed an increase in adiponectin levels, and beneficial effect on blood glucose and cholesterol levels.

Yacon (*Smallanthus sonchifolius*) roots are tubers of Andean origin. Yacon syrup demonstrated beneficial effects against insulin resistance when tested on obese pre-menopausal women as per a double blind placebo controlled trial of 120 days (Genta *et al.* 2009).

Case study

Recently Mattie and colleagues (2015) coordinated the Global Nutrition and Epidemiology Transition Initiative (GNET). The GNET project documented simultaneously the epidemiological and nutrition patterns over the period of 1950-2010 in 11 countries viz., Nigeria, Tanzania, Kenya, India, China, Malaysia, Brazil, Mexico, Costa-Rica, Kuwait, Puerto Rico and USA. The project focused on the carbohydrate quality of the staple food contributed by the diet of rice, wheat, maize, millet, sorghum, roots and tubers (potatoes, cassava, yams and taro) and legumes. The over-reaching goal of the project was to improve the traditional diet as strategy for prevention of type 2 diabetes for the future generations. The survey results brought out some very interesting findings:

Among the countries surveyed, Nigeria Tanzania, and Kenya were classified under 'early transition countries' featuring high mortality rates due to infectious diseases and nutritional deficiencies. India, China, Malaysia, Brazil and Mexico were classified under 'ongoing transition countries' featuring higher mortality rates due to non communicable diseases like diabetes, obesity and cardiovascular conditions and low mortality rates due to infectious diseases. Meanwhile Costa Rica, Kuwait, US and Puerto Rico were classified as 'transitioned countries' featuring higher mortality rates due to non communicable diseases. Among the non communicable diseases, type 2 diabetes has been considered to be single most important since it is not only harbinger of other similar underlying patho-physiological conditions, but is also projected to reach a pandemic level by 2030 (Hossain *et al.* 2007; Lindblom *et al.* 2015). One of the most striking observation of this study was the countries with 'early transition' had very low prevalence (3-5%) of diabetes; Among the countries under the 'on-going transition' showed the prevalence 9-16%, Brazil China and India being hot spots. The 'transitioned countries' showed a diabetic prevalence of 8.8% to 23.9%.

In order to explain this observation, the investigators examined the dietary pattern. Overall, it was observed that cereals predominantly contributed to the carbohydrate intake and roots and tubers contributed much less. Also over the years there had been a decrease in the consumption of roots and tubers. Furthermore, the percentage of energy contribution from roots and tubers (e.g., cassava, plantains, potatoes, sweet potatoes, yams, yautica and taro) was highest (30%) in Nigeria around 25% in Tanzania, to almost negligible in case of Kuwait. This clearly indicated there may be a link between the prevalence of diabetes to the shift of dietary intake from coarse whole grains, roots and tubers to refined carbohydrate and added sugars. This interpretation has been confirmed by several other workers (Schmichuber *et al.* 2005; Joint WHO/FAO, 2008; Dyson 1999). A vital observation in the GNET project was that, countries in 'early transition' for instance in Nigeria, where there was low prevalence of diabetes, the traditional carbohydrate came from fufu (made with cassava, yam etc). Though over the years consumption of rice and wheat has increased but fufu still remains a major component of their diet. In contrast Puerto Rican staple diet, in the first half of 20th century, mainly comprised of rice, beans along with starchy roots and tubers like cassava, taro and cocoyam. But in the second half of the century there was sharp decrease in legume and tuber consumption and increase in processed cereals, which has been cited as one of the major reasons behind decline in quality of health and prevalence of diabetes in these areas.

TUBER ENRICHED DIET AND OTHER HEALTH BENEFITS

The idea of using roots and tubers as gut microbiota modifiers or for management of glycemic and insulin response is relatively current. These foods were already famous as potential solutions to alleviating micronutrient deficiencies.

Tsou and Hong (1992) reported that yellow and orange-fleshed sweet potato roots contain 3 mg/100g of β-carotene, and that a regular consumption of 100g (half a cup, daily) can provide the recommended daily amount of Vit A in children less than 5 yrs old. Interestingly, orange-fleshed sweet potato cultivars contain 20-30 times more β-carotene than golden rice (Ye at al., 2000). More recently, Low *et al.* (2017, 2013) have recorded a case study on systemic dietary intervention of orange-fleshed sweet potato as a strategy to combat Vit A deficiency in Zambezia district of Mozambique. The study was carried out in 498 mother-child pairs with control groups of 243 mother-child pair where no intervention was done. Serum retinol data was used as a biomarker for evaluation. Results were evaluated after two agricultural cycles and was found that Vit A intake through regular consumption of orange-fleshed sweet potato, was higher in test group (426 μg retinol activity) as compared to control group (56 μg retinol activity). In the year 2007, the same authors (Low *et al.* 2007) had reported a 15% decline in prevalence of Vit A deficiency due to the sweet potato dietary interventions. A few years earlier, van Jaarsveld and coworkers (2005) had also reported a similar finding on improved Vit A status in children of developing countries on consumption of at least 125g of orange-fleshed sweet potatoes.

While discussing proVitA, one can hardly ignore the contribution of carrots, which is most popular as a rich source of β-carotene, proVitA, carotenoids and anthocyanins. It had been estimated that carrots supplied as high as 37% of β-carotene and proVitA carotenoids in U.S diet in the year 2007 (Arscott and Tanumihardjo, 2010). It is well known (Simon and Wolf, 1987) that carrots have, in total, six carotenoids (α, β, γ, ξ-carotenes, β-zeacarotene, lycopene). But what is probably lesser known is that carrots with higher carotenoids content appear to contain higher polyacetylenes like falcarinol, falcarindiol, falcarindiol-3-acetate (Christensen and Brandt, 2006). The contents of polyacetylenes can range from 20-100mg/kg (Czepa and Hofmann, 2004). Carrot polyacetylenes have shown *in vitro* anti-inflammatory activities in macrophages (Metzger *et al.* 2008). Simon and colleagues (2009) reported the 'high-carotene-mass' dark orange carrot which has been developed to contain 500 ppm carotene, is the highest source of beta carotene among natural food sources. This 'high-carotene-mass' carrot, when administered to human subjects showed a spike in their serum β-carotene. The purple orange variety of carrot contains anthocyanin and β-carotene. In 2009, healthy human subjects were engaged in a trial to assess the bioavailability of β-carotene. Different groups were administered purple-orange and orange carrot as smoothies with white carrot as control. The plasma β-carotene was measured from 0-144 h. The results showed a 5.4 and 4.5 fold increase in plasma β-carotene in the subjects fed with orange and purple-orange carrot respectively as compared to the control group fed with white carrots. This study conducted by Arscott *et al.* (2009), confirmed that the purple varieties of carrots are equally good sources of β-carotene along with anthocyanins.

It is well documented that roots and tubers are good sources of dietary carbohydrate and dietary energy, but what is noteworthy, is that, they are also storehouses of phenolic compounds, saponins, bioactive proteins, glycoalkaloids and fibres. More specifically, sweet potatoes, cassava and yam contain Vit C, yellow sweet potatoes, yam and cassava contain β-carotene while Taro is a good source of potassium. The humble potato is also not just a starch depot, it contains Vit C and potassium. Different varieties of sweet potatoes viz., white, yellow, orange and purple, contain different carotenoids. In past Suda and colleagues, (1998) have confirmed that human volunteers who consumed the Ayamurasaki, a purple-fleshed sweet potato, in trial of 44 days, showed decreased serum levels of λ-guanidine triphosphate, glutamine-oxaloacetate transaminase (GOT) and glutamine-pyruvic transaminase (GPT), which are indicators of liver injury. More recently, in 2011, Kaspar and colleagues conducted randomized trial on human participants who were kept under dietary intervention of white, yellow and purple-fleshed sweet potatoes once a day. After six weeks they reported that the experimental groups fed on pigmented potatoes showed reduction in inflammatory cytokine and C-reactive protein concentration.

In 2005, Wu and co-workers demonstrated significantly high levels of serum estrogen and sex hormone binding globulin (SHBG) when post menopausal women subjects were put on a yam diet and sweet potato (control) diet. Interestingly, the serum levels of estrogen, estradiol and SHBG remained unchanged in control (sweet potato diet) group. The authors further indicated that the high levels of estrogen were balanced by high levels of SHBG thereby decreasing the risks of breast cancer in these subjects.

Evidences have also come to light that along with phenolics, sweet potato contain two major proteins, sporamins A & B, which account for almost 80% of the total protein (Gichuhi *et al.* 2004; Scott and Symes, 1996). Several authors have shown that the sporomins exert antiproliferative and anti-metastatic effects on human colorectal cancer in *in vitro* and *in vivo* experiments (Cambie and Ferguson, 2003; Li *et al.* 2013).

Therefore strong evidences (Table 1) indicate that inclusion of roots and tubers in the diet offers several desirable physiological reactions leading to antioxidative, anti-inflammatory, anti diabetic, hypercholesteroleamic, anti cancer and immunomodulatory potentials. These evidences also point out very clearly to the fact that the key to management of several life style diseases probably lies in integration and conscious inclusion of roots and tubers in daily diets.

EFFECT OF SHIFTS FROM ROOTS AND TUBER-BASED DIETS

Several literature citations are available that confirm that dietary trends and shifts which have led to compromised or decreased consumption of roots, tubers and whole grains have significantly contributed to the metabolic conditions predisposing the population to non-communicable diseases.

Lako, in 2001 reported of an in-depth study carried out on Fijian population. The author documented the nutritional trend over a span of 50 years from 1952-1994. The documentation reveals that in the early Fijian diet, the sources of carbohydrate were cereals, sugar, cassava, yam, taro, sweet yam and wild yam. From 1963 onwards when potato was introduced in the diet, there was decline in the consumption of yams, sweet yam, taro and plantain. In the span of 1952-1994, the energy derived from sugar increased from 9 to 13% and from cereals from 5-26%. This study also reported that a shift from traditional staples to energy dense cereals had led to a 50% drop in complex carbohydrate intake which was mainly provided by yams and taro. As a result, a 25 fold increase in impaired glucose tolerance was observed in reported urban cases from 1965 to 1980. Further investigation was done to document the emergence and prevalence of diabetes; and as expected, it was found that from 0.6% in 1965 it had increased to an alarming 5.4% in 1980.

Many in the scientific world believe that ancient diets are more in agreement with law of human evolution than the modern day cereal diet. Several studies have been conducted to support this belief. Jönson and colleagues in 2006 designed a study to evaluate the effects of Paleolithic diet on specific markers like glucose, post prandial insulin response, blood

Table 1: Bioactivities demonstrated on consumption of tuber based diet

Tubers/tuber product	Health benefits/Biomarker effected	Reference
Yam and Taro	Low GI, high percentage of resistant starch, lowered post prandial glucose, insulin, lipid	Satija and Hu, 2012
Carrot dietary fibre	Increased satiety, lowered glucose response, decreased insulin/C-peptide response	Gustaffson *et al.*, 1994
Carrot dietary fibre	Aided in management of glycaemic load in type-2 diabetic human subjects	Brynes and Frost, 2007
White skinned sweet potato extract	Decreased levels of HbA1c, reduced insulin resistance, beneficial effects on glucose and cholesterol levels	Ludvik, 2002 and 2004
Yam diet	Increased levels of serum sex hormone binding globulin (SHBG) in post menopausal diabetic human subjects	Wu *et al.*, 2005
Sweet potato diet	Increased levels of adiponectin in type 2 diabetic patients	Ludwik, 2002, 2008
Yacon syrup	Beneficial effects on insulin resistance in obese premenopausal human subjects	Genta *et al.*, 2009
Burdock or Gobo	Demonstrated Prebiotic effect	Wilcox *et al.*, 2009; Salen and Lorgeril, 2011
Carrot juice fermented with *Lb planatrum*	Increased production of short chain fatty acids in rat colon	Li *et al.*, 2014
Orange-fleshed sweet potato	Increased retinol activity retinol activity to 426 μg compared to 56 μg in control in mother-child human subjects	Low, 2013; Low *et al.*, 2017

pressure. They also measured the levels of C-reactive protein, which a subclinical inflammation marker and is known to be associated with insulin resistance and cardiovascular disease (CVD) (Eckel *et al.* 2005). The Paleolithic diet included temperate roots and tubers (turnip, carrot, beetroot, parsnip, black radish) along with other vegetables, fruits, beef and fish meal. The Paleolithic diet had a total portion of 6.6 kg/day compared to a portion of 1.56 kg/day for cereal based diet. Interestingly, a 20% lower energy intake was seen in group fed with Paleolithic diet as compared to the cereal based control diet. Furthermore, the Paleolithic diet group showed a higher insulin sensitivity and lower insulin response. The most compelling evidence in support of a Paleolithic diet which is rich in temperate roots and tubers, came from the fact that there was a significant lowering in levels of C-reactive protein (4μg/ml) compared to the control group (21.7 μg/ml). The cardio protective and beneficial role of Paleolithic diet on insulin sensitivity has been reported by several other authors (Eckel *et al.* 2005; Lindberg *et al.* 1999). Therefore, modern researches related to evolution and diets are laying out unambiguous evidences in support of the claim that ancient diets mainly based on roots, tubers, vegetables, fruits confer protection against disease of affluence and can bring down the prevalence of non-communicable diseases (Cordian *et al.* 2005; Jonsson *et al.*2005, 2006; Freeman and Herron 2004).

Over the years several workers have applied evidence-based approaches to evaluate the effect of region-specific traditional diet. One such diet is the Okinawa diet consumed by the people of Okinawa, which is the southern-most part of Japan. The Okinawa population is characterized by relatively higher average life expectancy, more number of centenarians along with reduced risk of non-communicable and age related diseases. The traditional Okinawa diet comprises of sweet potato, tofu soup, Champuru (radish-based dish), fish or lean meat with sanpin (jasmine tea) and awamori (millet brandy) (Salen and de Lorgeril, 2011). The most significant point of this diet is the fact that the staple carbohydrate is sweet potato and not rice. The variety of sweet potato that is included in the Okinawa diet is Satsuma Imo with a GI of 55. Apart from the tuber, the sweet potato leaves called 'kandaba' is eaten as greens. The Okinawa diet is high on vegetable carbohydrate, low on fat and high on antioxidant rich yellow and orange root vegetables. Several authors (Willcox *et al.* 2007, 2009, Suzuki *et al.* 2001; Jenkins *et al.* 2003) have conducted impressive trials confirming that Okinawa diet results in decreased risks of diabetes and CVD. It must be mentioned here that along with sweet potato, there is another tuber which are commonly used in this Japanese diet. The yam-like tuber is called devil's tongue which is made into traditional food Konnyaku. The devil's tongue has high contents of glucomannan and has been reported to be beneficial for type 2 diabetes and cholesterol control (Vuksan *et al.* 2000; Gallaher *et al.* 2002).

Thus, the evidences on health benefits of root and tuber based diet (summarized in Table 1) are definitely compelling and deserves attention. Future explorations (Summarized separately) should be guided towards application of roots and tuber crops for designing personalized diets as a strategy to prevent chronic diseases.

FUTURE PERSPECTIVES

Tremendous opportunities exist for appropriate utilization of root and tuber crops in future years. These crops will all benefit from applying product development concepts into approaches for technology transfer. There are a growing number of programs of research throughout the world on both tropical and temperate tuber crops addressing genetic enhancement, seed systems, production, marketing and nutrition impacts. Different outreach programmes have targeted approaches to improve the quality of production, for example making available newer technologies to smallholder; new varieties have been developed and distributed to farmers, training of farmers to produce quality seed for their own use, provision for small-scale seed enterprises etc. Partnerships involving both national and international actors have been created in past to expedite access and availability of the improved technologies to small holders. However, several factors still persist and have been purported, that impede the increasing intake of roots and tubers, for instance lack of proper awareness among the younger generations, low interest amongst media compared to other nutrients, varied taste preferences, lack of specific dietary recommendations.

A lot can still be done to sustain and further enhance the real and potential opportunities for example, interventions and future investments on the following areas like:

- ❑ accelerated breeding methods and tools for the breeding of improved varieties;
- ❑ newer technologies, diagnostic tools, and business models for improving seed systems;
- ❑ newer technologies for sustainable intensification of production;
- ❑ models and tools for nutrition and behavior change;
- ❑ models, tools, and technologies for upgrading value chains;
- ❑ partnership models for going to commercial scale;
- ❑ capacity development, both institutional and human capacity, will be needed to realize the full potential of these crops, not just as food crops but functional food crops.

CONCLUSION

It is anticipated that the future food and nutrition demands will be infinitely more complex. To successfully address the food security concerns, a more integrative and multi-disciplinary approach will be required. Several studies that have been described in this review strongly support the notion that improvement in quality of main staple foods, by systematic dietary intervention of roots and tubers along with whole grains can definitely lower the risks of life style diseases. More importantly, the scientific evidences surveyed in this review indicate that dietary adaptation of roots and tubers may significantly increase nutrition security. Thus, roots and tubers may be considered as the "super foods".

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