Fruit, Vegetable and Cereal Science and Biotechnology ©2012 Global Science Books

Breeding of Sweet Potato for Enhanced Nutritional Status and Biofortification

B. Vimala* • **Binu Hariprakash** • **Bala Nambisan**

Division of Crop Improvement, Central Tuber Crops Research Institute, Thiruvananthapuram – 695 017, Kerala, India

Corresponding author: * **vimalactcri@yahoo.co.in**

ABSTRACT

Sweet potato (*Ipomoea batatas* (L.) Lam) is an important food crop belonging to the morning glory family (*Convolvulaceae*). It is cultivated throughout the tropics and warm temperate regions of the world for its edible storage roots. The crop has recently received more attention due to very high levels of pro-vitamin A in orange-fleshed sweet potatoes. Moreover, storage roots provide medium levels of iron and zinc. The nutritional profile of sweet potato leaves and tops reveal the presence of moisture content, crude protein, fibre and ash along with vitamin A and calcium. Since the storage roots of sweet potato possess a high nutritional profile, breeding strategies need to be developed to bring out new varieties which are scientifically feasible, farmer acceptable, with high nutritional status and cost effectiveness. In addition to its importance as human food, it provides raw material for animal feed and industrial purposes. Although, sweet potato is an important food crop, the improvement of the crop has been given very little attention. The genetics of sweet potato is little understood and the inheritance pattern is quite complex one. Genetic information on many traits of direct economic importance in sweet potato is not available and most published information is from the clones of similar genetic back ground. Studies on the entire spectrum of the variability are therefore necessary to acquire knowledge on the inheritance pattern. This chapter briefly reviews the nutritional qualities and breeding patterns of sweet potato with special focus on the chemical components of the sweet potato leaves and storage roots.

Keywords: dietary fibres, crude protein, β-carotene, minerals, phytohormones
Abbreviations: CIP, International Potato Centre; **DAP**, days after planting; **fw**, fresh weight; **LSRB**, Life Science Research Board; **OFSP**, orange-fleshed sweet potato

CONTENTS

INTRODUCTION ... 93
NUTRITIONAL AND CHEMICAL PROFILE OF SWEET POTATO LEAVES AND TOPS ... 94
Chemical composition ... 94
Lipids ... 95
Pigments ... 95
Flavonoids ... 96
Terpenes, phenolics and waxes ... 96
Volatile compounds ... 97
Vitamins ... 97
Minerals ... 98
Phytohormones ... 98
Stress metabolites ... 98
Breeding ... 99
Opportunities ... 99
Breeding methods ... 100
Open pollination ... 101
Incompatibility and sterility ... 101
Population improvement ... 101
CONCLUSION ... 102
REFERENCES ... 102

INTRODUCTION

Sweet potato (*Ipomoea batatas* (L) Lam), an important vegetable cum food crop is grown in the tropics, sub-tropics and warm temperate regions of the world for its edible tubers. Among the tropical tuber crops, sweet potato ranks second after cassava. It produces more edible energy per hectare per day than wheat, rice or cassava and is well adapted to salinity, drought and marginal soil conditions (Woolfe 1992). Sweet potato is a short duration, cross-pollinated and vegetatively propagated crop. The crop can be considered promoting nutritional security particularly in agriculturally backward areas. Today, it is cultivated in 117 countries in all tropical and sub-tropical regions of the world and ranks five among the most important food crops in over 50 countries. Asia is the world's major sweet potato producing region, with about 107 million tonnes of annual production, followed by Africa and the Americas, with

Received: 1 November, 2011. Accepted: 1 November, 2012.

Invited Review

approximately 15 and 30 million tonnes respectively. Sweet potato has one of the highest dry matter productivity rates among crops (Scott et al. 2000). It produces 152 MJ ha-1 day-1 calories as compared to 121 MJ ha-1day-1 calories in cassava, (CMIE 2007). The average storage root yield of sweet potato varies between 10 and 28 t ha-1 (CTCRI 2006). The limiting factors for the low yield of 8.3 t ha^{-1} is the prevalence of low yielding cultivars, poor cultivation practices including plant protection measures and absence of organized marketing facilities for the produce. The crop has recently received more attention due to very high levels of pro-vitamin A in orange-fleshed sweet potatoes (OFSP) and it act as a vehicle to reduce vitamin A deficiency problems in the world (Huang *et al*. 1999; Low *et al.* 2007). Moreover, storage roots provide medium levels of iron and zinc (Woolfe 1992).

NUTRITIONAL AND CHEMICAL PROFILE OF SWEET POTATO LEAVES AND TOPS

Sweet potato leaves and tops are consumed in many parts of the world as green vegetables. The tips were reported to contain moisture crude protein, fibre and ash along with vitamin A and calcium (Anon 1968). The dietary fibre content is reported to increase with age of the plant although at this stage it is not used for human consumption. The leaves are also a good source of vitamins especially β-carotene and vitamin C. The carotenoids in the leaves are observed to be decrease with increase in maturity (Sutoh *et al*. 1973). In addition to its importance as human food it is also used as an animal feed besides serving as a raw material for the production of alcohol.

Chemical composition

The chemical compositions that have been identified from the storage roots and leaves are carbohydrates, proteins, lipids, organic acids, pigments, terpenes, phenolics, waxes, volatiles, vitamins, minerals, phytohormones and stress metabolites.

1. Carbohydrates

Sweet potato is rich in carbohydrates which is made up of starch, cellulose, hemicellulose, sugars and pectin. Carbohydrates make up the major component constituting about 80-90% dry matter of the sweet potato storage roots. They are separated into three groups based on the subunits present and degree of polymerization- the monosaccharides, oligosaccharides and polysaccharides. The oligosaccharides yield 2-6 monosaccharides on hydrolysis. Sucrose and maltose form some examples for this. The total sugar in sweet potato is reported to range between 0.38-5.64% (Bradbury and Holloway 1988; Picha 1985b). Truong *et al*. (1986) observed a range of 5.6-38.3% on dry weight basis for the varieties grown in Philippines.

In raw roots, sucrose is the most abundant sugar followed by glucose and fructose. Varietal variations have also been reported in the glucose and fructose levels. Dominance of either sucrose or fructose has been observed in some cultivars (Bradbury *et al*. 1985; Picha 1985b). The common mono- and oligosaccharides identified in cooked sweet potato storage roots are sucrose (1.00), glucose (0.74), fructose (1.73), inositol, verbascose, stachyose, cellobiose, rafinose, maltose and maltotriose (Son *et al*. 1991). Cooking enhances the formation of maltose and maltotriose due to the action of amylase enzyme (Walter *et al*. 1975). Picha (1985b) had observed that 9.33% maltose was formed during baking in the roots of 'Centennial'. Koehler and Kays (1991) have reported that as the sugar concentration goes high during cooking, higher will be the sensory acceptance scores given by taste panels. Cultivars vary widely in the concentration of total and specific sugars (Kays and Horvat 1984). Sugar content remains high during storage in most cultivars but tends to decrease after several months (Picha 1987). Pathogen invasion and sprouting also significantly alter the carbohydrate composition in sweet potato (Kato and Uritani 1976; Collins *et al*. 1990).

2. Starch

Starch, a water insoluble granule, accumulates in storage roots of sweet potato, which, in turn increases the starch content per cell as well as the percentage of starch of the fresh and dry weight (Liu *et al*. 1985). In sweet potato, carbohydrates accounts about 80-90% of the total dry matter. The dry matter content varies depending on the cultivar, cultural practices and climate and it ranged from 13-48% and out of total dry matter starch accounts for 60-70% (Cereda *et al*. 1982; Bradbury and Holloway 1988). Dry matter has been used as an indicator of starch. Dry matter is positively correlated with the starch content. Wide variations occur in the starch content depending on the cultivar (Shanmugan and Venugopal 1975; Prabhudham *et al*. 1987). Gruenberg *et al*. (2009) has reported that a strong positive relation exists between dry matter and starch.

Starch content has been measured in a number of general studies. Sweet potato starch is composed of 30-40% amylase and 60-70% amylopectin (Madamba *et al*. 1973; Bertoniere *et al*. 1966). However, their properties differ considerably. The physiochemical properties of the starch strongly influence the potential uses and the characteristics of the roots after cooking. Spectral, microscopic, chemical and physical techniques are used to analyse starch properties (Bank and Muir 1980; Boki *et al*. 1990; Santha *et al*. 1990). There is a demand for non-sweet sweet potatoes, and few genotypes are non-sweet (Kays 2006). Starch content is controlled by poly genes mainly with additive effect and partly dominant effect caused to lower starch content (Tarumoto *et al*. 1988).

3. Non-starch polysaccharides

The non starch polysaccharide comprising cellulose, hemicellulose and pectin contribute towards the dietary fibre fraction of sweet potato roots. Though many studies have not been conducted on the relative content of soluble and insoluble fibre in the total dietary fibre, one report indicates that out of the total content of 3.14 g in baked roots, 1.01 g is contributed by soluble fibre and the rest by insoluble fraction. The pectic constituents of sweet potato have been studied in more detail by various workers, as they contribute to the rheological properties of cooked roots (Hainze and Appleman 1943).

As a group, non starch polysaccharides are classified as dietary fibre and play a role in nutritional value of the sweet potato. The pectic substances are polysaccharides found in the intercellular and middle lamella of the cell wall, while hemicellulose is cell wall polysaccharides classed according to the sugar present in their molecules and cellulose is a highly ordered fibrillar structure occurring in the cell wall. The pectic substance consists of water insoluble protopectins, soluble pectinic and pectic acids and small amount of sugars such as galactose, arabinose and rhamnose. It is formed by the hydrolysis of protopectin. Epidemiological and physiological studies have shown that dietary fibre is important in diet as it provides protection against diverticulitis, colon cancer, cardiovascular diseases and diabetes, etc.

The pectic constituents of dietary fibres play a key role is textural attributes such as firmness of the canned roots (Sistrunk 1971) and moistness or dryness of baked roots (Shin and Ahn 1985). It is reported that protopectin and other pectin fractions has been correlated with the hardcore phenomena of sweet potato roots which is caused by the chilling temperature in raw roots and establish as hard areas when baked (Daines *et al*. 1976). However, the permanent hardness after cooking resulting from submergence of roots in flooded fields are due to the reaction of middle lamella pectin with calcium and magnesium ions.

4. Proteins

Sweet potato protein is the well studied nutrient of the root. The crude protein content in most varieties ranges from 1.3 to 10% (Purcell *et al*. 1972). Many factors besides cultivar differences like cultural practices and environmental influences have been found to affect the protein content in sweet potato (Constantin *et al*. 1974). In sweet potato roots, the protein content was reported to be slightly more at the proximal end than at the distal end and also at outer layers than inner layers of roots (Purcell *et al*. 1976; Bradbury *et al*. 1984). Most of the storage protein in sweet potato is sporamin (75-80%). The crude protein content includes the non protein nitrogen also, occurring in high proportions and hence the value for protein in sweet potato does not represent the true protein value. Sweet potato is deficient in sulphur containing amino acids and tryptophan, but this is partially compensated by high levels of vitamin A and of C and some minerals. Purcell and Walter (1980) found that the main amino acids in the roots were asparagines (61%), aspartic acid (11%), glutamic acid (4%), serine (4%) and threonine (3%).

Sweet potatoes also possess several polypeptides and proteins that are potent inhibitors of these proteolytic enzymes. The presence of proteinase inhibitors was first reported by Sohonie and Bhandarker (1954). They represent a population of proteins with varying properties (Suguria *et al*. 1973). Generally, the concentration of these compounds decreases from the proximal end of the storage root to the distal end and in cross section, the highest activity is confined to cortical region (Dickey *et al*. 1984). Leaves also contain similar concentration of proteinase inhibitors as compared to roots. However, the major factors affecting the concentration are cultivar, planting time, rainfall and season (Bouwkamp *et al*. 1985; Lin and Ho 1986; Lin 1987).

Lipids

Lipids are reported to have a diverse role in sweet potato. The lipid component of sweet potato storage roots consists of approximately 1.2-2.7% of the total fresh weight (Walter *et al*. 1971). A detailed analysis of the lipid component in sweet potato was done by Murata and Yamaya (1984). It is composed of neutral lipids, glycolipids and phospholipids. Detailed study were conducted by different authors regarding the components of lipids and fatty acids present in sweet potato roots and leaves (Boggess *et al*. 1970; Murata and Yamaya 1984) which were categorized into seven major classes: phosphatidyl glycerol (44%), phosphatidyl choline (20%), phosphatidylethanolamine (23%), phosphatidylinositol (46%), monogalactocyl diacylglycerol (3%), digalactocyl diacylglycerol (16%) and sulphoquinovosyl diacylglycerol (34%). Sweet potato starch contains a lipid fraction which is considered to play a role in starch metabolism. Fatty acids identified in root starch components were dodecanoioc acid (12:0), tertradecanoic (14:0), hexadecanoic (16:0), hexadecanoic (16:1), octadecanoic (18:0), octadecenoic (18:1), octadecadienoic (18:2) and jalapinolic (Fujimoto *et al*. 1971). The proportion of hexadecanoic fraction is found to increase and octadecanoic content decrease as the fatty acid components of starch increase (Fujimoto *et al*. 1971).

Pigments

The nutraceutical components of the sweet potato plants have enabled the plant to be recognized as a health food. Kusano and Abe (2000) have considered that the roots are highly functional, low calorie food with anti diabetic effects. It has been reported to lower the insulin resistance and stabilize blood sugar levels (Ylonen *et al*. 2003). The prominent nutraceutical studies in sweet potatoes are carotenoids and anthocyanins. In contrast to the earlier reports of phenolics as anti nutrients, their presence in food and crop plants is now regarded as have been high nutraceutical value. The studies on the distribution of phenols the various parts of sweet potato establish that more the 78% of the phenolics were located the skin. Histochemical localization of the phenolics showed that it was present in phellem, phelleogen and phelloderm as well as in latex of laticifers, phloem, cambium, etc. (Walter and Schadel 1981).

1. Chlorophyll

Chlorophyll gives the green colouration to the plants which help in efficiency of photosynthesis. These pigments are hydrophobic and hence are soluble only in organic solvents. In sweet potato, chlorophyll can be found in the leaves, stems and roots (Data and Kays 1991). The leaves of sweet potato contain both chlorophyll ‘a’ and ‘b’. Significant differences in their concentration are reported to be observed between cultivars (Bhagsari 1981). Bhagsari have reported that the leaf chlorophyll ‘a’ and ‘b’ concentrations ranged from 5.3-7.8 mg/g dw and 2.4-3.8 mg/g dw respectively while the total chlorophyll content varied between 7.6-10.6 mg/g dw for 15 genotypes under study.

2. Carotenoids

As far as the nutritional value is concerned, carotene content is recognized as a very important constituent in sweet potato (Woolfe 1992). The flesh colour of sweet potato storage roots varies from white to dark-orange depending upon the pigments present. Jones *et al*. (1969) and Jones (1977) reported a negative association of flesh colour and dry matter. Orange-flesh colour of the sweet potato is due to the presence of carotenoids which contain significant amounts of β-carotene, starch, dietary fibre, minerals, vitamins (especially vitamin C, B6 and folate), as well as antioxidants such as phenolics and tocopherol (Woolfe 1992). The pigment, β-carotene, is a pre-cursor of vitamin A. Carotenoids represent the most wide spread group of natural pigments that participate in many important nutritional functions which are synthesized by plants, bacteria, yeasts and molds. They are primarily of plant origin and β-carotene predominates. Though carotenoids are also found in the animal kingdom, animals cannot synthesize carotenoids *de novo* and therefore biofortified food is the only source of these compounds. β-carotene is largely responsible for the orange flesh colour in sweet potato storage roots (Purcell 1962; Purcell and Walter 1968; Takahata *et al*. 1993). Other carotenoids identified in orange fleshed sweet potato includes (≤ 1%) alpha, gamma and zeta carotenes, phytoene, phytofluene, β-carotene epoxide, β-carotene furanoxide and hydroxy zeta carotene (Purcell and Walter 1968). The depth of orange flesh colour is mainly a function of the concentration of all-*trans*-β-carotene as reported by Simonne *et al*. (1993). The total carotenoid pigment in sweet potato appears to be controlled by several genes. Previous reports suggests that there was a tendency of increasing carotene content of sweet potato during storage but varied with both varieties and storage period. The increase of carotene content within the early period of storage might be partly attributed to the increase of percentage of dry matter and decrease of moisture content (Wang 1974). Similar results were observed in studies conducted at Central Tuber Crops Research Institute, Trivandrum under an LSRB funded project involving orange-fleshed sweet potatoes (LSRB 2011). The dry matter and carotenoids were studied at regular intervals from 1st to 35th day after storage in ten orange-fleshed sweet potato clones. A gradual increase in dry matter was observed though there was not much variation within the clones during storage for total carotenoids and β-carotene content from 1st to 35th day. However, there was significant difference between the clones from the 1st day onwards. The results of the study confirmed that the total carotenoids and β-carotene content is a stable character during storage (LSRB 2011).

The influence of different processing procedures on the carotene content of orange-fleshed roots have been reported

in sweet potato (Huang *et al*. 1999), carrots (Debjani *et al*. 2005), and cassava (Chavez *et al*. 2007; Vimala *et al*. 2010). More than 100% retention of carotenoids was reported in spinach and winged Bean through steam and water blanching (Dietz *et al*. 1988). No loss of β-carotene in chopped or grated raw sweet potato was observed by Jaarsveld *et al*. (2006). This showed that there was no or little enzymatic oxidation in cut fresh samples which accounted for the 100% retention. Effect on retention of carotenoids was studied in the storage roots of ten sweet potato clones possessing different intensities of dark orange-flesh colour in four different processing methods oven drying, boiling, sun drying and frying (Vimala *et al*. 2011a). The results indicated that the extent of retention varied with the method of processing. The highest retention was observed in oven drying (total carotenoids 90-91% and β-carotene 89-96%) followed by boiling (total carotenoids 85-90% and β-carotene 84-90%) and frying (total carotenoids 77-85% and β-carotene 72-86%). The lowest retention of total carotenoids (63-73%) and β-carotene (63-73%) was recorded in the sun drying method. Variation in retention of carotenoids may be due to the difference in the enzymatic oxidation during processing. This was also in agreement with the study by Ameny and Wilson (1997). In all the other procedures, the occurrence of less retention values could be due to leaching of vitamin A precursor as in sun drying or thermo chemical reaction occurring during cooking times (Chandler and Schwartz 1988). Moreover, variation in processing is also affected by slice thickness of pieces, temperature, duration of frying, and stage of maturity (Adelaide *et al*. 2006). Effects of various traditional processing methods on carotene content of sweet potato have been reported by Bengtsson *et al*. (2008), Osambo *et al*. (1998), Hagenimana *et al*. (1997), etc. Bengtsson *et al*. (2008) had observed low retention values to the fresh unprocessed samples while Osambo *et al*. (1998) could find decreased carotene content in boiled samples. A loss of 20-30% was observed by Hagenimana *et al*. (2007) in CIP (International Potato Centre) cultivars subjected to boiling as well as drying into chips compared to initial carotenoid amount in fresh storage roots. Retention of carotenoids after boiling is more important since majority of common people consume sweet potato roots after boiling. Products like sweet potato juice or salads could be recommended for maximum absorbance of carotene content in diet. The people who were traditionally dependent on the consumption of white-fleshed local cultivars are unaware of the nutritive value of orange-fleshed sweet potato as most of the varieties selected by the consumers are based on the best taste, flavour and texture rather than those having a better nutrient profile (Chattopadhyay *et al*. 2006). The reduction of carotenoids in the sun-drying process may be due to the detrimental effect of the sun-light on the stability of carotenoid pigment. However moderate amount of β-carotene (63-73%) present in the sun-drying process may be useful for the production of sweet potato flour and orange coloured crispy chips.

Maturity studies in orange-fleshed sweet potatoes for finding out the range of variation in total carotenoids, β-carotene and dry matter content as well as appropriate harvest time for fourteen clones at different growth stages (60, 75, 90,105 and 120 days after planting (DAP)) showed that no difference in total carotenoids and β-carotene content was noticed within the clone on 60 and 75 DAP, however, significant variation was observed within the clone on 90 DAP and not much variation was noticed afterwards. Even though a gradual increase in dry matter content recorded throughout the harvest period no significant difference was observed after 90 days (LSRB 2011). Effect of different locations on carotene content was reported by Vimala *et al*. (2011b). Only little variation was noticed for the biochemical characters in the clones between the locations. Studies on carotenoid variation in forty orange fleshed clones possessing different intensities of dark orange flesh colour selected from a poly-cross breeding programme showed that the total carotenoids and β-carotene ranged from 7.28–15.33 mg 100 g^{-1} fresh weight (fw) and 6.8-13.66 mg 100 g^{-1} fw respectively. In this study, the ratio of β-carotene to total carotenoids varied between 78.56-94.23% which was considerably higher than the reported clones (Binu Hariprakash *et al*. 2011).

Flavonoids

In sweet potato, flavanoids have been studied in a number of selections that display varying degrees of red to purple pigmentation. Roots of some variety contain water soluble anthocyanin which gives red to purple colour to the flesh (Cascon *et al*. 1984). There is a new demand for purple-fleshed sweet potato due to the health-promoting effects of anti-oxidant anthocyanin substances, and cell lines for a potentially ongoing production for the food industry have been established (Konczak 2006). Purple-fleshed sweet potato are a rich sources of anthocyanins which is an anti-oxidants preventing cancer. Also, it is used as a natural food colorant in many parts of the world. Multiple physiological functions such as radical scavenging, antimutagenic, hepato-protective, anti-hypersensitive and hypoglycemic activities have been attributed sweet potato anthocyanins (Suda *et al*. 2003). The antimutagenic effect of purple coloured sweet potato was due to the cyanidine type of anthocyanin where as yellow, white, orange flesh varieties phenolics components contribute to the antimutagenic effect (Yoshimoto *et al*. 1999). The major sweet potato anthocyanins are acylated glycosides of cyaniding and peonidin substituted in the 3- or 5-carbon position of the flavylium nucleus (Kawai and Yoshitama 1987). Cyanidin glucoside is present in sweet potato callus in larger amounts than in peonidin glucoside whereas other anthocyanins are present in minor amount (Nozue *et al*. 1987). Sweet potato anthocyanin synthesis has been studied in cell culture with a view to high anthocyanin production for food processing purposes (Nozue and Yasuda 1985). Casscon *et al*. (1984) have observed that the concentration of anthocyanin pigment in purple fleshed cultivars was found to increase from the centre of the roots to periphery. The anthocyanin levels in these varieties were also dependent on genetic and cultivation factors as well as stage of development. With increasing worldwide interest in use of food colorants, synthetic ones are being replaced by natural pigments from different purple fleshed fruits such as berries, grapes, etc. However, stability of the pigment is a major problem encountered here which could be overcome by using purple- fleshed sweet potato varieties rich in acylated anthocyanins (Bassa and Francis 1987).

Terpenes, phenolics and waxes

In most plant species, terpenoids have a growth inhibitory and antifeedant role. Oleanolic and ursolic acids have been identified as the major component of surface of sweet potato leaves while boehmerol and boehmeryl acetate are present on the surface of storage roots. The latter has been shown to act as an ovipositional stimulant for the sweet potato weevil (Wilson *et al*. 1988). Removal of this factor by treatment from the skin of storage roots prevents the egg laying of the weevil while reapplication reinstates the response.

Phenolics are generally separated into three classes based upon the number of phenol rings present: monocyclic, dicyclic and polycyclic. These compounds give discolouration reactions in response to stress. Marked increase in polyphenol production in sweet potato was reported by various workers in response to mechanical damage and pathogen invasion (Uritani 1953; Uritani and Muramatsu 1953) as well as chilling stress (Rhodes and Wooltorton 1978). Discolouration of sweet potato storage roots during peeling affects the appearance of processed food samples (Scott *et al*. 1944). The degree of discolouration is reported to vary with cultivar and protocol used (Walter and Giesbrecut 1982). This discolouration is thought to be mediated

by the action of polyphenol oxidase on phenolics. Considerable genetic diversity is found in the gene pool of sweet potato for its ability to discolour (Jones 1972; Jones *et al*. 1979).

The function of waxes in plant kingdom is to provide protection to tissue parts present both on upper and below ground parts of plants. Their primary function is prevention of water loss and their presence significantly increases the surface diffusion resistance to water vapour. Waxes from the surface of storage roots are comprised of hydrocarbons, wax esters, fatty alcohols, fatty acids, etc. (Espelie *et al*. 1980).

Volatile compounds

In sweet potato, volatiles come from two sources- one which are present naturally and the other which is produced by stress over the life time of plant. The flavour components of sweet potato have been associated with cooked or baked sweet potato. Preliminary analysis of the volatiles present in the leaves indicated the presence of seven sesquiterpenes (Nottingham *et al*. 1989). Typical examples of natural in borne volatiles in leaves and roots can be demonstrated by the realization process of sweet potato weevil which orient in the dark to sweet potatoes placed in their vicinity. A wide list of volatiles has been identified from processed sweet potatoes (Purcell *et al*. 1990; Horvat *et al*. 1991). They include methanol, ethanol, acetone, phenol, decanal, octanal, etc (Purcell *et al*. 1980; Kays and Horvat 1984). Chemically these compounds include hydrocarbons, acids, alcohols, aldehydes, esters, furans, ketonnes and nitrogen containing compounds. The characteristic smell of cooked sweet potato is due to a variety of volatiles which vary with genotype and concentration (Horvat *et al*. 1991). Sun (1988) and Kays (1989) have reported studies on comparison of sweet potato volatiles from different selection and its incorporation into the breeding programe. Varietal differences have been reported among the volatile components by (Kays and Horvat 1983). The effect of cooking method on the aroma constituents of sweet potato was investigated by (Wang and Kays 2001). About 37 compounds were identified based on their odor activeness by olfactory analysis which were found be retained to a higher extent in conventionally baked components.

Vitamins

Vitamins in regard to dietary requirements have the same biochemical functions both in plants and animals. These organic compounds are required in relatively small amounts for normal metabolism and growth. They are commonly separated into two classes based on their solubility-the water soluble vitamins and lipid soluble vitamins. Examples for water soluble vitamins are ascorbic acid, biotin, folic acid, nicotinic acid, pantothenic acid, pyridoxine, riboflavin and thiamine. The most common lipid soluble vitamins are A, E and K. Reports on the general content of sweet potato storage roots and leaves have established the presence of ascorbic acid, biotin, provitamin A, folic acid, niacin, pantothenic acid, pyridoxine, riboflavin, thiamine and Vitamin E (Leung and Flores 1961; Garcia *et al*. 1970; Bureau and Bushway 1986).

β-carotene serves an important nutritional component in foods, as a major precursor of vitamin A, and provides pleasant yellow to orange colours to foods (Simon 1997). As the pigment cannot be synthesized in animal body, consumption of carotene rich foods that are cheaper and easily accessible source such as orange-fleshed sweet potatoes are the most reliable, readily available, and most sustainable approach to control vitamin A deficiency in rural areas where chronic deficiencies are still common. It is important to make available and sustainable food sources to improve their production, shelf life and consumer acceptance which could improve health and nutrition. It is believed that food supplementation is the fastest way to improve the vitamin A status of population in which deficiency of this nutrient is endemic. The major problems, which results in vitamin A deficiency in developing countries are the low dietary intake of vitamin A (Buycks 1996). Food-based approaches to increase micronutrient intake through the diet represent the most desirable and sustainable method of preventing micronutrient malnutrition. Biofortification offers a long-term, sustainable, food-based solution. Dietary vitamin A deficiency causes debilitating problems such as Xerophthalmia, corneal lesions, Keratomalacia, and in many instances death (Hagenimana *et al*. 1997). Sweet potato has been receiving increasing attention since it grows with limited fertility, is relatively drought tolerant and often cultivated without fertilizer or pesticide (Ezell 1990). It has remarkable provitamin activity (Woolfe 1992). Children, the group most at risk of vitamin A deficiency, particularly like sweet potato (Lowe *et al*. 1997). Widely consumed cultivars, however, have white or pale yellow flesh and contain very little β-carotene (Ameny and Wilson 1997). Compared to light-coloured, low β-carotene sweet potato, consumption of orange-fleshed sweet potato roots and sweet potato-based processed foods could provide sustainable, cost-effective, and much needed vitamin A foods. The efficacy of a β-carotene-rich orange-fleshed variety compared with a white-fleshed variety in preventing vitamin A deficiency has been demonstrated in primary school children from South Africa (Jaarsveld *et al*. 2005). It is reported that β-carotene rich orange-fleshed variety can make a major contribution in alleviating vitamin A malnutrition in Sub–Saharan Africa (Lowe *et al*. 2001). The incorporation of orange-fleshed sweet potato in meals eaten by 3-6 years old Indonesian children who were marginally deficient in vitamin A showed increased serum retinol concentrations (Jalal *et al*. 1996). Also, one of the most important health problems in developing countries like India is the prevalence of vitamin A deficiency in young children and adults. The people who are traditionally dependent on the consumption of white-fleshed local cultivars are unaware of the nutritive value of orange-fleshed sweet potato as most of the varieties selected by the consumers are based on the best taste, flavour and texture rather than those having a better nutrient profile (Chattopadhyay *et al*. 2006). The depth of the flesh colour is largely found to be a function of β-carotene. The percentage of total carotenoids present as β-carotene is high in yellow to orange fleshed varieties, but decreases as total carotenoids falls (Ezell and Wilcox 1946; Purcell and Walter 1968). White fleshed varieties contain little or no β-carotene (Wang and Lin 1969; Bradbury and Holloway 1988) while creamy or light yellow contain trace amounts (Garcia *et al*. 1970).

Ascorbic acid is a lactone of a sugar that is synthesized by plants from simple carbohydrates. Its content varies with cultivars due to root size and location in the root (Ezell and Wilcox 1948; Lanier and Sistrunk (1979). Spiers *et al*. (1945) and Jenkins and Moore (1954) have reported that the distal end of sweetpotato storage roots has a higher concentration than the middle or proximal region and outer surface contains less than the interiors. Production location, potassium fertilization rate and sampling time are the other factors affect the ascorbic acid content in the raw product (Spiers *et al*. 1953; Jenkins and Moore 1956; Sharfuddin and Voican 1984). Changes in ascorbic acid content during storage and processing had been monitored in several studies. Watada and Tran (1987) had reported a sudden decline of 18% during the first three weeks of storage which subsequently remained unchanged for the remaining portion of 120 days storage period. Degradation of ascorbic acid content during cooking due to high temperature and high degree of water solubility has been studied by Matsui *et al*. (1986).

Another important vitamin is thiamine (B_1), whose concentration in sweetpotato roots generally ranges from 0.04-0.12 mg 100 g^{-1} fw and 0.3-1.2 mg 100 g^{-1} fw in leaves. This is water soluble as well as highly stable at pH 7.0 and below. Though significant losses occur during processing

such as cooking baking or boiling, the thiamine concentration remains unchanged during storage (Bradbury and Singh 1986; Watada and Tran 1987).

The vitamin riboflavin also referred to as Vitamin B_2 or lactoflavin is a water soluble compound. No effect by storage is reported in sweetpotato, however, cooking results in a gradual decrease with baking having the lowest loss while boiling, steaming, microwaving and canning resulting in higher losses (Bradbury and Singh 1986; Watada and Tran 1987). The concentration of riboflavin in sweetpotato roots generally ranges from 0.3-0.5 mg 100 g^{-1} fw and 0.3-0.4 mg 100 g^{-1} fw in leaves.

Niacin or nicotinic acid content of the sweet potato cultivars varies with the genotype. The leaves contain higher amount of niacin content (0.6-1.0 mg 100 g^{-1} fw) compared to storage roots (0.2-0.8 mg 100 g^{-1} fw). Significant loss of this vitamin occurs during cooking, with baking resulting in the lowest loss while canning accounts for the highest (Lanier and Sistrunk 1979).

The concentration of pyridoxine ranges from 0.2 mg 100 g^{-1} fw in leaves to 0.3 mg 100 g^{-1} fw in storage roots of sweet potato. Generally, it exists in three forms in plants-pyridoxine, pyridoxal and pyridoxamine, of which the latter two forms are most active.

The content of pantothenic acid is reported to be very low in sweet potato roots as compared to other pulse crops such as dried peas and peanuts. However, the concentration tends to increase with increasing root size and is affected by processing methods with canning resulting in the highest loss (Lanier and Sistrunk 1979).

Presence of folic acid, a plant synthesized vitamin, is reported to be found in both free and conjugated forms in sweet potato (Keshinro 1983). However, folic acid is degraded at high temperatures. Biotin and Vitamin E (tocopherol) are other vitamins which have been reported in sweet potato, but the concentration is considered to be very low (Guilarte 1985).

Minerals

Sweet potato contains significant quantities of minerals and trace elements which represents the essential requisites for the normal growth of the plant. The minerals found in highest concentration in sweet potatoes are potassium, phosphorus, calcium and magnesium. However, with the exception of potassium, the mineral content of sweet potato does not represent a daily recommended allowance. General analyses of minerals and trace elements have been reported by a number of groups (Lopez *et al*. 1980; Pace *et al*. 1987; Bradbury and Holloway 1988). In addition to the essential minerals for plant growth, traces of heavy metals and trace elements (aluminium, arsenic, barium, cadmium, copper, fluorine, iodine, lead, mercury, etc. have been detected by various workers (Kim *et al*. 1981; Dong and Chen 1982; Shen and Jiang 1984; Liu *et al*. 1985; Dickinson *et al*. 1987). These chemicals can be phytotoxic when present in high concentration and prove fatal to humans and animals which consume them. Genotypic variation exists between the cultivars in relation to concentration of minerals (Picha 1985). Other factor includes production location, season, soil type, fertility, pH, plant population and the use of agricultural chemicals and soil amendments (Scott and Bouwkamp 1974; Makki *et al*. 1986).

Phytohormones

Kays (1991) have reported five classes of naturally occurring phytohormones in plants-cytokinins, gibberellins, abscisic acid, auxin and ethylene. The various physiological roles of these chemicals such as the relation between the different phytohormones and development of the storage roots, the role of gibberellic acid in producing short vines, etc. have been explored in sweet potato.

Cytokinins have been identified in sweet potato storage roots, leaves, stems and callus tissue (Matsui *et al*. 1984; Sugayama *et al*. 1988). About 14 compounds are known to exist in sweet potato roots (Sugayama *et al*. 1988). The *trans*-zeatin riboside concentration in the storage root of the sweet potato was found to be higher during the period of high root development (30-90 days) in the proximal end of roots (Matsui *et al*. 1983).

In sweet potato seeds, six forms of gibberellins (GA_1, GA_3, GA_5, GA_{19}, GA_{20} and GA_{23}) have been identified (Matsui *et al*. 1984). Of these GA_{19} and GA_{23} were found to be the dominant forms in mature seeds. Murakami (1968, 1970) have identified the presence of gibberellic acid in the storage roots also. The possible relationship between gibberellin concentration and synthesis of starch and extra cellular polysaccharides has been studied in isolated cells (Sasaki and Kainuma 1984). Analysis of the endogenous concentration, the response of normal and dwarf plants to exogenous application and dwarf lines indicated that differences in the internodal length were not due to the inhibited gibberellin synthesis or concentration and appeared that the dwarf plants had an impaired ability to respond to gibberellins (Suge 1979).

Abscisic acid occurs naturally in plants and the presence of which have been identified and monitored in sweet potato storage roots development (Matsui *et al*. 1988; Nakatani 1989). The concentration of this phytohormone is very low and uniform in developing storage roots while changes occur during the development of roots for the entire growing season although no correlation was observed between the concentration and development of roots (Matsui *et al*. 1988).

Of the different auxins in plants, indoleacetic acid exhibits a strong polarity in transport, moving basipetally away from the tip of plants. In sweetpotato, polarity is in acropetal direction (Tanaka and Uritani 1979).

Presence of ethylene in sweetpotato storage roots have been reported by (Sakai *et al*. 1970; Kato and Uritani 1972). The concentration of ethylene is found to increase rapidly and markedly in response to physical chemical biological and temperature stresses (Imaseki *et al*. 1968; Paterson *et al*. 1979; Hyodo and Uritani 1984).

Stress metabolites

Stress metabolites are normally not present in plants are synthesized in response to stress imposed by infestation by sweetpotato weevil, fungal pathogen, mechanical damage and contact with chemicals. Ipomeamarone is most abundant of stress metabolite found in stressed sweetpotato tissues which is a pulmonary toxic that prove fatal to cattle (Hiura 1943; Wilson 1970). Other metabolites includes ipomeamaronol, 4-ipomeanol, 1-ipomeanol 1,4-ipomeadiol, ipomeanine, dihydroxypomeamarone, dihydro-7-hydroxymyporone, 7-hydroxymyoporone, 4-hydroxymyoporone, myoporone, 6-myoporol 7-hydroxycostal, 7-hydroxycostol and 1-(3-furyl)-6, 7-dihydroxy-4, 8-dimethylnon-1-one (Wood and Huang 1975; Vurka 1978; Wilson 1979; Vilegas and Kojima 1985; Addy *et al*. 1987). Most of these chemicals vary in their biological toxicity and several have been shown to the hepatotoxins that cause kidney necrosis (Wilson 1973; Boyd *et al*. 1975). However a simple method of diminishing toxicity is thermal degradation such as microwaving and baking (Cody and Haard 1976). Phytoalexins are compounds synthesized by the plant as part of defense reaction against invading organisms (Kojima 1976). Ipomeorone is a phytoalexin which is capable of inhibiting several physiological steps in life cycle of sweetpotato pathogenic fungus *C. fimbriata*. The accumulation of phytoalexins is also known to be cultivar dependent (Martin *et al*. 1968). Uritani *et al*. (1960), Catalano *et al*. (1977) and Fujita (1985) had reported that known pathogenic stresses that cause phytoalexin response are physical damage and heavy metals mercury and cadmium.

Breeding

Sweet potato belongs to the family *Convolvulaceae*; section Batatas which includes 13 species. Majority of the species in the section Batatas are diploids. It is a cross-pollinated and hexaploid crop with a chromosome complement of (2n=6x) 90 chromosomes (Jones 1965a). Both storage roots and leaves are used as source of carbohydrates, proteins and minerals. The plant is mainly cultivated for storage roots which are used as vegetable and in the preparation of various products. According to Hartwell (1967-1971) the leaf decoction is used in folk remedies for tumour of mouth and throat. In addition to its importance as human food it provides raw material for animal feed and industrial purposes. Although sweet potato is an important food crop, the improvement of the crop has been given very little attention. The genetics of sweet potato is little understood and the inheritance pattern is quite complex one. Genetic information on many traits of direct economic importance in sweet potato are not available and most published information are from the clones of similar genetic back ground (Jones *et al*. 1969; Jones 1986). Studies on the entire spectrum of the variability are therefore necessary to acquire knowledge on the inheritance pattern.

The major problems in breeding are non-blooming, erratic blooming habit and low fertility of blossoms, and are due to self and cross incompatibility as well as sterility (Wamke and Cruzado1949; Fujise 1964; Martin 1965, 1967; Sreenivasan and Vimala 1981; Vimala 1989). Seed set is very rare even in the most compatible combinations. High seed set may indicate good physiological balance or genetic load since it may lead to long term yield improvement (Jones and Dukes 1975). The improvement in any crop depends on the genetic variation associated between qualitative and quantitative characters, heritability estimates, nature of gene action and adaptability. One of the limiting factor for poor production are the prevalence of low yielding cultivars adapted to low fertility conditions including plant protection measures and absence of organized marketing channel for the produce. Tuber weight is an important component of yield and it was found that most of the morphological characters do not have a stable correlation with tuber yield and yield components. Sometimes the genotypic and environmental source of variations may also affect yield through direct physiological mechanism. Variations in tuber yield may be due to the differences in number of tubers /plant or size of individual tubers or difference in bulking rate (Lowe and Wilson 1975). The knowledge of the total genotypic variance in a plant population is of great importance to the breeder in order to manipulate the variance for the improvement of the character. In any crop improvement programme, plant breeding plays an important role in creating new variability and better chances of selecting improved varieties for commercial cultivation. A large population is needed to select a desirable clone of commercial importance. The advances so far made in varietal improvement of sweet potato have been obtained by selecting only for yield without taking account of physiological characteristics. Part of the difficulty is that yield formation is complex and it depends on the interaction of many factors. Hahn (1977) reported that the crosses between genotypes with high photosynthetic efficiency did not produce progenies that were above average. Also, there are striking differences between cultivars in shape, number and size of storage roots. It would be worth attempting to combine large source potential and large sink capacity of the varieties to increase yield further by making crosses between such varieties. However, in sweet potato the source is a more complex component than the sink, and is affected by many factors both by genetic and environmental. Therefore screening for source potential is more complicated and more difficult than sink capacity (Hahn 1982). The sink characteristics influence photosynthesis and yield more than source characteristics. Sweet potato yield improvement can be achieved more easily by selecting for the sink capacity alone (Hahn and Hozyo 1984). It is easier to study and understand physiologically and genetically each individual character influencing yield than to study yield formation as a whole. One approach, therefore, is to select individual characteristics and then select parents for crosses on the basis of complementation of physiological components, aiming in this way to improve the probability of finding superior segregates (Wallace *et al*. 1972). The bushy cultivars' accumulates more tuber dry matter than the spreading cultivar. The proportion of total dry matter partitioned to the tuber of bushy cultivar was greater than that in spreading cultivar at all stages of growth. Tuber dry matter production was more efficient in the bushy cultivar because it had less foliage that competition with the tubers for assimilates was reduced (Pardales and Beemonte 1989).

In breeding for consumption, it has to be considered that people in different regions have different taste preferences; the extremes are low dry matter content, moist mouth feel, sweet taste and deep orange flesh colour versus high dry matter, bland dry mouth feel, low sweet taste and white, yellow or orange and purple flesh colour. In breeding for human consumption, focus is more on high dry matter OFSP varieties with elevated iron and zinc concentration and a dry and less-sweet mouth taste. This breeding is hampered by a strong genetic correlation between storage root dry matter, pro-vitamin A, iron and zinc contents. The breeding for high dry matter and starch is relatively easy. However, currently, in many regions of the world the price of sweet potato starch cannot compete with the price of cassava starch. The breeding of purple-fleshed varieties is relatively new trend and so far only carried out on a small scale in Japan, Indonesia and Peru. Future targets are the non-sweet sweet potato and cooking features (Katayama *et al*. 2006) as well as suitability for processing into chips, puree, juice, weaning and baby food and bread on the basis of wheat-sweet potato flour mixture (Woolfe 1992). These trends appear nearly exclusively in East Asia (Liu 2008). Other constraints on high yields are pests and diseases, especially sweet potato weevil. The prevailing disease and insects affecting sweet potato vary from region to region. There are about 35 bacterial and fungal diseases, more than 20 nematodes and 20 insect species known to affect sweet potato (Martin and Jones 1986). Breeding sweet potatoes has been reviewed by Martin and Jones (1986), Laurie and van den Berg (2002) and Gruneberg *et al*. (2009). The major breeding objectives are:

1. High storage root yield
2. Palatability
3. High keeping quality
4. Improved quality in terms of consumer acceptance like high starch, sugar and carotene and anthocyanin content
5. Low sugar and high starch for industrial uses
6. Processing and nutritional quality
7. Early maturity

Problems in breeding include:

1. Majority of clones are non-flowering types
2. Both self- and cross- incompatibilities are present and it is very difficult to attempt desirable cross combinations and the crop is highly cross-pollinated
3. The average seed set per fruit is 1.0-1.5.
4. Difficulty to attempt crosses in the early morning since anthesis of the crop takes place very early in the morning and majority of pollen dries before 7.00 am.

Opportunities

In spite of many problems involved in sweet potato breeding, the genetic nature of the crop provides enough opportunities to the breeder to make better use of these problems such as:

1. Because of the hexaploid and heterozygous nature of the crop wide range of segregation takes place in the first generation (F_1) itself.
2. Effective selection of desirable genotypes on the basis

of desired traits like yield, root shape, colour, taste etc could be made in the first generation.
3. The maximum heterotic effects are exhibited in F_1 generation and enough variability is available for the breeder to make effective selection in F_1.
4. Vegetative propagation- once a desirable clone is identified, it can be easily maintained through vegetative propagation and clonal selection for many generations without any genetic deterioration or genetic change.

There is a growing recognition that optimization of the nutrient content of food through conventional plant breeding and agronomic practices or genetic manipulation is a viable strategy (Lindsay 2000; Miettinen 2001). Manipulation of the nutrient metabolism by molecular techniques was believed to give little improvement than that achieved by traditional agricultural procedures (Parr and Bowell 2001). Biofortification is a new approach that relies on conventional plant breeding and modern biotechnology to increase the micronutrient density of the crop (Graham *et al*. 2001; Bouis 2003). This approach also holds great promise for improving the nutritional status of the poorer mass of rural and urban areas of developing countries (Underwood 2000). Though it appears just a process that incorporate a novel trait, biofortification is entirely a new approach that makes improved public health a goal for agricultural research. For a successful biofortification program, the micronutrient levels should be set according to the requirement of human health for which critical information is needed on the bioconversation and bioavailability of injested nutrients, retention of the micronutrient after storage or processing and potential levels of consumption by target population (Nestel *et al*. 2006). Hence, it requires a direct linkage between plant science research, the human health and nutrition sectors which thus become integral part of crop improvement and product development program (Wolfgang and Bonnie 2007).

The conventional breeding methods to achieve these objectives are introduction, selection and hybridization. Breeding success depends on good genetic variability, effective selection systems and innovative ways of evaluation of the various traits. Every trait in sweet potato has a wide range of variation.

Breeding methods

True seed occurs easily in nature through cross pollination by insects, mainly bees. For breeding purposes, the flower architecture of sweet potato allows easy emasculation and controlled hand pollination. The extreme genetic makeup of the crop (hexaploid, highly heterozygous, open-pollinated by insects with true seed set), short duration of the crop (4-5 months) and the rapid propagation permits the design of a very efficient and rapid breeding system. Breeding success depends on genetic variability, effective selection systems and inheritance pattern. The genetic diversity available in the germplasm can be exploited by selection and hybridization.

1. Introduction and selection

The initial step in any crop improvement is the collection and systemic evaluation of germplasm. The germplasm available from indigenous and exotic sources should be collected and these collections are being evaluated based on the objectives in the breeding programme. The next important component of breeding is the selection of new varieties. A variety is always determined by several traits. A better variety must have good performance over all traits and clearly superior to all other varieties. It is not possible to compare a set of new genotypes with all existing varieties across all target environments. Therefore, the new genotypes are evaluated and compared with standard check varieties. Genetic gain from mass selection depends on the selection intensity, additive genetic variance, the number of years or cycles of selection and the precision of measurements. The larger the population size one can handle the higher the selection intensity that can be imposed on the population and retain the genetic diversity for the improvement of the trait. Selection can be made for yield, palatability and nutritional qualities from a large number of cultivars and breeding lines. Mass selection and recurrent selection techniques have been used for sweet potato improvement in Taiwan, Japan, Nigeria China and USA.

2. Hybridization

The introduced as well as the indigenous collections can be exploited in hybridization programme to combine the desirable characters, Genetic study of sweet potato, a hexaploid, has been limited by problems commonly associated with genetic studies of polyploids compounded by infrequent flowering and low seed set. Poor fruiting and seed setting together with shyness in flowering are the greatest obstacles in sweet potato improvement. Environmental, physiological, cytological, genetical and pathological factors must be considered influencing the fertilization process (Wang 1982). Wang (1964b) reported that when the average daily temperature was beyond 20-25°C, flowering and seed setting was reduced. Montelaro and Miller (1951) observed a decline in seed setting during hot or cold periods and maximum seed set occurred when the daily temperature was about 24°C. The flowering habit in sweet potato is greatly influenced by seasonal conditions (Sreenivasan and Vimala 1978) which forces the breeders to limit the crossing programme to a particular period of the year. Sweet potato flowers are bisexual and emasculation is required for hybridization. Since, incompatibility exists among the cultivars, it is necessary to find out the compatible relationship of the selected accessions before attempting any intervarietal hybridization (Sreenivasan and Vimala 1981; Vimala 1988). The flower opening starts in the early morning and dehiscence of anthers occurs before anthesis. The dehiscence of anthers starts at 3.00 am and opening of flowers occur around 5.00-6.00 am followed by shedding of pollen. Hence emasculation is done in the previous day (Sreenivasan 1977). After the outbreak of sunlight the anthers become empty devoid of any pollen. Maximum fruit set was recorded when the pollination were done between 3.00-4.00 am, but reasonably good fruit set can be obtained when the pollination was done up to 7.00 am and after wards the fruit set was very much reduced. The entire corolla tube is cut off and the stamens are removed by a pair of forceps or needle. The emasculated flower buds as well as the intact flower buds to be used as male parent are covered with butter paper bags. Hand pollination is done by dusting the pollen from the stamens of selected male parent. The pollinated flowers are again covered with butter paper bags. By 4^{th} or 5^{th} day after pollination the top of the cover is cut off to allow aeration to the developing fruit. All the ovules grow but the growth of the fertilized ovules increase rapidly in size whereas the growth of the unfertilized ovules remains arrested. When the fruit dries, the mature seed shrinks to a diameter of 3-5mm. and the aborted ovules dries to insignificant scale of 0.5-1.5 mm in length (Martin 1962). The mature seeds can be collected 25-30 days after pollination. The number of seeds per fruit from the successful crosses varied from1-4. Controlled crossing is very expensive compared to open pollination. However, the chances of getting desirable combinations are much higher than from open pollination. The controlled crosses must be more efficient and high selection intensities can be reached, which depends on technical skills and costs. A skilled technician can make 200 crossings per day, however the frequencies of successful crosses differ tremendously between parental combinations and about one third of all parental combinations are incompatible with no seed formation. Controlled mating of desirable genotypes belonging to the compatibility groups can shift the genetic variability towards positive direction.

Hybridization also can be done carried out using cut

floral branches (Sreenivasan and Vimala 1981). The floral branches with fully matured buds which are due to open the following day are cut on the previous day evening along with vine of about 20-30 cm length and transferred to a conical flask containing water. The vines with floral buds to be used as female parent in the cross combination is transferred to different flasks containing varying concentrations of sucrose solutions ranging from 2-10%. The flowers are to be hand pollinated around 8-9 am. Satisfactory fruit set was obtained in the compatible crosses. Fully ripened fruits were collected 25-30 days after pollination. However, with the increasing concentration of sucrose solution the intensity of rooting was found to be less. The specific biparental crosses are rarely attempted in sweet potato because of the hard labour involved in emasculation, bagging and pollination.

Open pollination

Under natural conditions the flowers are insect pollinated. The chances of getting seeds are much more easy than the controlled pollination but of uncertain parentage. By taking advantage of sterility and incompatibility mechanisms prevalent in sweet potato, screening of open pollinated seedlings also provide the opportunities of identifying promising varieties. Since sweet potato is heterozygous seedlings obtained from open pollination behave differently from each other like different genotypes. The various parental clones are allowed to inter-mate randomly and seeds are collected from female clones. In this method there is no control on males and seeds are the product of superior or inferior males and females. But this type of selection procedure has the disadvantage of allowing undesirable parents in the open pollination which reduces the probability of getting superior segregates. It is very difficult to achieve the desired objectives through this method. The studies of Kamalam *et al*. (1977) in the open pollinated progenies from 12 mother plants indicated the possibility of selecting plants with higher yield and other attributes.

Incompatibility and sterility

Both self- and cross-incompatibilities exist in sweet potato. Compatibility is determined by the success or failure of pollen germination and seed set after controlled pollination. Self-incompatibility limits the selfing programme in sweet potato. The presence of self- and cross-incompatibility coupled with shyness in flowering (Fujise 1964; Martin 1965, 1967; Williams and Cope 1967) act as stumbling blocks in hybridization programme in sweet potato. Any controlled hybridization programme will be rewarding only when the parents chosen possess high cross- compatibility and profuse flowering types besides the desirable agronomic attributes. Cross-incompatibility is also prevalent but the relative amount of the trait varies with variety.. Since sweet potato is a hexaploid the incompatibility locus must have been duplicated or triplicated during the evolution. The multiple alleles act sporophytically to determine the phenotype of the pollen. The alleles can have independent effect on the incompatibility or one can determine over the other on the stigma and pollen. Hernandez and Miller (1962, 1964) stated that the presence of self and cross incompatibility made it difficult to obtain seed from crosses between certain parents and suggested that incompatibility in sweet potato is determined by genes that form a multiple allelomorphic series. Martin (1965, 1968) suggested that poor seed set is caused by duplicate or triplicate self-incompatible systems of multi-allelic sporophytic type expressed in many stages, contributing to genetic imbalance and hexaploidy and the presence of unilateral incompatibility is due to the existence of dominance relations among alleles involved in the control of self-incompatibility.

Sterility is common in polyploids and is caused by errors in meiosis resulting in gross defects in the genetic complement and recombination and segregation that leads to so called unbalanced gene distribution. This means that certain proportion of gametes and embryo fails to function adequately in certain circumstances. Sterility can occur at many stages of development process before and after pollination resulting in aborted or malformed seeds. Low seed set even in the compatible cross combinations may be due to partial homologies between chromosomes resulting in elimination of weak or unbalanced gametes as suggested by Martin and Cabanillas (1966). Martin and Jones (1971) showed that flowering can be increased by open pollination. However, open pollination did not result in increase of sterility or self and cross-incompatibility in spite of strong natural selection that open pollination imposes. Thus, it seems that either sterility or incompatibility is not influenced by selection process.

Population improvement

In hybridization or biparental crosses lot of labour is involved in emasculation, bagging and pollination in the early morning. Hence biparental crosses are attempted for conducting genetic studies on the inheritance of various traits. In addition to the conventional breeding methods, population improvement is also being used to in order to exploit the additive and non-additive genetic variance to meet the specific needs. The quantitative inheritance of ten root traits in sweet potato showed that the additive genetic variance was relatively more important than the non-additive for all the traits except veining and number of edible roots (Jones 1965; Jones *et al*. 1969). As far as nutritional value is concerned, carotene content is recognized as a very important constituent to plant breeders. Hernandez *et al*. (1965) indicated that white flesh colour is incompletely dominant over orange and the total carotenoid pigments appeared to be controlled by several genes, possibly six which are additive in nature. Dry matter has been used as an indicator of starch (Purcell *et al*. 1976). Dry matter is positively correlated with starch content. Sakai (1984) reported that starch content is determined by the additive effect of polygenes. A negative association of flesh colour and dry matter has been reported by Jones *et al*. (1969), and Jones (1977). Application of quantitative inheritance in sweet potato breeding based upon a randomly intercrossing population was first proposed by Jones (1965b). Recurrent selection system used in population improvement programme is half-sib family testing and selection within families.

This system aims to, increase population means, retain high degree of genetic variability through continuous cyclic evaluation, selection and recombination. This procedure can make use of both intra and inter chromosomal recombination and maximum expression of epistasis by using more number of parents in the base population greater genetic potential could be achieved. The first step is to acquire the source population from which the desirable characters could be selected and grown in isolation. Promising clones selected from the base population which shows good performance for the important traits are inter-crossed in isolation to make the next generation and this has been repeated. If the number of parents used is small, controlled crossing is necessary to assure equal parental representation in the first generation. About 20 plants are suggested as an optimum number to allow good sampling of available variability without using closely related plants. If large numbers of parents are used, replication is necessary and sufficient isolation should be maintained. Equal number of seeds from each parent would be bulked for the next generation. Selection for simply inherited characteristics should be avoided until four or five generations of inter-mating, since such selections would tend to fix chromosome segments and reduce the frequency of effective recombination. Advantage of the procedure are that it would utilize both inter- and intra-chromosomal recombination's, allow expression of new epistatic effects each generations' and provide an orderly improvement in parental types each year. The disadvantage is the time required to establish a randomly inter-

mating base population (Vimala *et al.* 1988; Vimala 1989).

There are marked variations in leaf shape, skin and flesh colour, root shape and other characters. A large population is necessary to make effective selection for the desired trait. Each seedling represents an independent genotype which could become a variety. Each seedling has to be evaluated for the economic traits and better ones must be promoted for subsequent testing and selection and the rest are rejected in each cycle of evaluation. Vegetative propagation is a good tool to utilize the heterosis expressed in F_1 generation. Once a desirable clone is identified, it can be easily maintained through vegetative propagation for many years without any genetic deterioration. Thus, selection can be made for yield, palatability, tenderness, flavour and nutritional quality from a large number of cultivars and breeding lines. The orange flesh colour showed as a typical quantitative character and several additive genes were involved in controlling the carotenoid pigment. The range of variation observed for all the traits makes it difficult to classify it into discrete classes. All studies showed no clear-cut demarcation was visible for any of the morphological characters. The existence of continuous and overlapping variation points towards the quantitative nature of inheritance for all the characters. Tuber yield is the most variable and complex character. The progenies of some parents exhibited more variability indicating the pre-potency of some clones giving superior progenies. Some parental combinations with high frequency of superior genotypes will increase the selection intensity when there was a high mean and variance for all the attributes. The parental combinations having high frequency of superior genotypes will increase the selection efficiency when there is a high mean and variance for the attributes (Vimala *et al.* 1988; Vimala 1989; Vimala and Binu Hariprakash 2011).

CONCLUSION

The potential use of sweet potato is great because of its versatility. Micronutrient malnutrition affects more than half of the world's population. The goal to reduce the child and maternal mortality ratio between 1990 and 2015 will require additional technologies and approaches to improving nutritional status. Biofortification of staple food crops is a new public health approach to control vitamin A, iron, and zinc deficiencies in poor countries. Scientific evidence shows this is technically feasible without compromising agronomic productivity. Predictive cost-benefit analyses also support biofortification as being important in controlling micronutrient deficiencies. The challenge is to get producers and consumers to accept biofortified crops and increase their intake of the target nutrients. With the advent of good seed systems, the development of markets and products, and demand creation, this can be achieved. Food-based approaches have been reviewed and judged to have a promising role in integrated strategies. Sweet potato is less labour intensive than most other staple crops and can be planted over a broad range of time without considerable yield loss. Breeding better sweet potatoes is important to improving acceptance and utilisation of sweet potatoes. Sweet potato offers a versatile staple for controlling vitamin A deficiency. OFSP is a good source of energy as well as easy to cultivate, vegetatively propagate, and fairly drought resistant. Once established, these characteristics make OFSP an excellent food security crop. The antioxidant properties of anthocyanins present in the purple fleshed sweet potato provides protection against cancer. Moreover, it can be used as a fresh vegetable or as processed or canned food. The high starch varieties with white flesh can be used to eradicate poverty as well as in making value added products. Apart from this, all parts of the plant can be used as animal feed also. In sweet potato, the prevalence of incompletely incompatibility mechanism super imposed by self sterility and cross pollination offers a wide array of variability. Because of the hexaploid and heterozygous nature of sweet potato wide range of variability and segregation for the different morphological and biochemical characters, root yield, skin and flesh colour, palatability, flavor and nutritional qualities takes place in the first generation itself. Since sweet potato is heterozygous, the characteristic of all varieties the seedlings developed from hybridization or open pollination differ from each other. The selection of families based on high mean and variance for tuber yield, tuber number, harvest index and other characters like tuber shape, flesh and skin colour dry matter and starch content and field tolerance to sweet potato weevil seems to be promising. The selection of number of superior F_1clones for yield and other attributes would provide a larger gene pool for recombination and sib-mating from which promising varieties of considerable value could be generated. In the future breeding programmes for improving the nutritional qualities, more emphasis should be given to develop early maturing varieties with high yield, starch and carotene content, high starch and anthocyanin content with good storage or keeping quality.

REFERENCES

Addy SK, Singh A, Srivastava S (1987) Some metabolic aspects of fungal infected sweet potato (*Ipomoea batatas* (L.) Poir) tubers. *Current Science* **56**, 713-714

Adelaide DM, Gouado I, Leng M, Ejoh AR, Njinkoue JM, Tchouanguep MF (2006) Losses in β-carotene and vitamin C due to frying of plantain (*Musa paradisiaca*) chips. *African Journal of Biotechnology* **6 (3)**, 280-284

Ameny MA, Wilson PW (1997) Relationship between Hunter colour and β-carotene content in white-fleshed African sweet potato. *Journal of Science and Food Agriculture* **73**, 301-306

Anon (1968) *AVRDC Progress Report for 1980*, AVRDC, Shanhua, Tainan, 171 pp

Bank W, Muir DD (1980) Structure and chemistry of the starch granule. In: Press I (Ed) *Biochemistry of Plants* (Vol 3), Academic Press Neoch, pp 321-369

Bassa IA, Francis FJ (1987) Stability of anthocyanins from sweetpotato in a model beverage. *Journal of Food Science* **52**, 1753-1754

Bengtsson A, Namutebi A, Larsson AM, Svanberg U (2008) Effects of various traditional processing methods on the all-*trans*-β-carotene content of orange-fleshed sweet potato. *Journal of Food Composition Annual* **21**, 134-143

Bertoniere NR, Mc Lemore TA, Hasling VC (1966) The effect of environmental variables on the processing of sweet potatoes into flakes and on some properties of their isolated starches. *Journal of Food Science* **31**, 574-582

Bhagsari AS (1981) Relation of photosynthetic rates to yield in sweetpotato genotypes. *Horticultural Science* **16**, 779-780

Binu Hariprakash, Vimala B, Bala Nambisan (2011) Tuber yield and carotenoids variation in Orange Fleshed Sweet Potato (*Ipomoea batatas* (L.) Lam). In: *Proceedings of ISRC-NSCFT*, CTCRI, Thiruvananthapuram, pp 181-185

Boki K, Ohino S, Shinoda S (1990) Moisture sorption characteristic in kudzu starch and sweetpotato starch. *Journal of Food Science* **55**, 232-235

Bouis HE (2003) Micronutrient fortification of plants through plant breeding: Can it improve nutrition in man at low cost? *Proceedings of the Society for Nutrition* **62**, 403-411

Boukamp JC, Tsou SCS, Lin SSM (1985) Genotype and environment effects on the relationship between protein concentration and trypsin inhibiter level in sweet potatoes. *Horticultural Science* **20**, 886-889

Boyd MR, Burka LT, Harris S, Wilson BJ (1975) Distribution, excretion and binding of radioactivity in the rat after intra peritoneal administration of the lung toxic furan (^{14}C) 4-ipomenol. *Toxicology and Applied Pharmacology* **32**, 147-157

Bradbury JH, Singh U (1986) Ascorbic and dehydroascorbic acid content of tropical root crops from the south Pacific. *Journal of Food Science* **51**, 975-978

Bradbury JH, Baines J, Hammer B, Anders M, Miller JS (1984) Analysis of sweetpotato (*Ipomoea batatas)* from the highlands of Papua New Guinea: Relevance to the incidence of *Enteritis necroticans*. *Journal of Agriculture and Food Chemistry* **32**, 469-493

Bradbury JH, Hammer B, Hguyen T, Anders M, Miller JS (1985) Protein quantity and quality trypsin inhibiter contents of sweetpotato cultivars from the highlands of Papua New Guinea. *Journal of Agriculture and Food Chemistry* **33**, 281-285

Bradbury JH, Holloway WD (1988) *Chemistry of Tropical Root Crops: Significance for Nutrition and Agriculture in the Pacific*, Australian Centre for International Agricultural Research, Canberra, pp 53-77

Bureau JL, Bushway RJ (1986) HPLC determination of carotenoids in fruits and vegetables in the United States. *Journal of Food Science* **51**, 128-130

Cascon SC, Carvalho MPM, Moura LL, Guimarães ISS, Philip T (1984) Natural colourence from purple sweetpotato for use in foods. *EMBRAPA*,

Centro Tecnologica Agricultura Ailment, No. 9, 25 pp
Catalono EA, Hasling VC, Dupuy HP, Constantin RJ (1977) Ipomeamarone in blemished and diseased sweet potato (*Ipomoea batatas*). *Journal of Agriculture and Food Chemistry* **25**, 94-96
Cereda MP, Conceição FAD, Cagliari AM, Heezen AM, Fioretto RB (1982) Comparative study of sweet potato (*Ipomoea batatas*) varieties to estimate their utilization in the food industry. *Turrialba* **32 (4)**, 365-370 (in Portuguese)
Chandler LA, Schwartz SJ (1988) Isomerisation and losses of trans beta carotene in sweet potatoes as affected by processing treatments. *Journal of Agriculture and Food Chemistry* **36**, 129-133
Chattopadhyay A, Chakraborty I, Mukopadhayay SK, Kumar PK, Sen H (2006) Compositional changes of sweet potato as influenced by cultivar, harvest date and cooking. *Acta Horticulturae* **703**, 211-218
Chavez AL, Sánchez T, Ceballos H, Rodríguez-Amaya DB, Nestel P, Tohme J, Ishitani M (2007) Retention of carotenoids in cassava roots submitted to different processing methods. *Journal of Science and Food Agriculture* **87**, 388-393
CMIE (2007) Economic Intelligence Service, Centre for Monitoring Indian Economy Pvt., Ltd., Agriculture, April-2007, 284 pp
Cody M, Haard NF (1976) Influence of cooking on toxic stress metabolites in sweet potato roots. *Journal of Food Science* **41**, 469-470
Collins WW, Walter WM, Torgersen B (1990) Carbohydrate changes in sprout in sweet potato roots. *Horticultural Science* **25**, 979
Constantin RJ, Hernandez TP, Jones LG (1974) Effects of irrigation and nitrogen fertilisation on quality of sweet potatoes. *Journal of the American Society for Horticultural Science* **99**, 308-310
CTCRI (2006) Tuber crop varieties. Central Tuber Crops Research Institute. *Technical Bulletin* **24**, 64
Debjani D, Utpal R, Runu C (2005) Retention of β-carotene in frozen carrots under varying conditions of storage. *African Journal of Biotechnology* **4 (1)**, 102-103
Dickenson NM, Lepp NW, Surtain GTK (1987) Lead and potential health risk from subsistence food crop in urban Kenya. *Environmental Geochemistry and Health* **9 (2)**, 37-42
Dickey LF, Collins WW, Young CT, Walter WM Jr. (1984) Root protein quantity and quality in a seedling population of sweet potato. *Horticultural Science* **19**, 689-692
Dietz JM, Kantha SS, Erdman JW Jr. (1988) Reversed phase HPLC analysis of α- and β-carotene from selected raw and cooked vegetables. *Plant Food and Human Nutrition* **38**, 333-341
Dong K, Cheng J (1982) Relationship between the growth of plants polluted with cadmium and its accumulation. *Huang Jing Kexue* **3**, 31-34
Espelie KE, Sadek NZ, Kolattukudy PE (1980) Composition of suberin associated waxes from the subterranean storage organs of seven plants. *Planta* **148**, 468-476
Ezell BD, Wilcox MS (1946) The ratio of carotene to carotenoids pigments in sweet potato varieties. *Science* **103**, 193-194
Ezell BD, Wilcox MS (1948) Effect of variety and storage on carotene and total carotenoid pigments in sweet potato. *Food Research* **13**, 203-212
Ezell BD, Wilcox MS (1958) Variation in carotene content of sweet potatoes. *Agriculture and Food Chemistry* **6**, 61-65
Fujise K (1964) Studies on flowering, fruit setting and self- and cross-incompatability in sweet potato varieties. *Bulletin Kyushu Agriculture Experiment Station* **9**, 123-146
Fujita M (1985) Stimulation of cytochrome P-150 synthesis in sliced sweet potato root tissue by chemicals applied to surface. *Agriculture and Biological Chemistry* **49**, 3045-3047
Garcia EH, Querido IB, Cahanap AC (1970) The revelations of carotene and starch content of some 26 varieties of sweet potato (*Ipomoea batatas*). *Philippine Journal of Plant Introduction* **35 (3-4)**, 203-213
Graham R, Welch R, Bouis H (2001) Addressing micronutrient malnutrition through the nutritional quality of staple foods: Principles, perceptive and knowledge gaps. *Advanced Agronomy* **70**, 77-142
Gruneberg WJ, Mwanga R, Andrade M, Dapaah H (2009) Sweet potato breeding. In: *Unleashing the Potential of Sweet Potato in Sub-Saharan Africa: Current Challenges and Way Forward*, CIP-SSA, Nairobi, 345 pp
Guilarte TR (1985) Analysis of biotin levels in selected foods using a radiometric microbiological method. *International Nutrition Reporter* **32**, 837-845
Hagenimana V, Carey EE, Gichuki ST, Oyunga MA, Imungi JK (1997) Carotenoid contents in fresh, dried and processed sweet potato products. *Ecology and Food Nutrition* **37**, 455-473
Hagenimana V, Oyunga MA, Low J, Njoroge SM, Gichuki ST, Kabira J (1999) *The Effects of Women Farmer's Adoption of Orange-Fleshed Sweet Potatoes: Raising Vitamin A Intake in Kenya*, International Centre for Research on Women Research Report Series 3, Washington, DC, 52 pp
Hahn SK (1982) Screening sweet potato for source potentials. *Euphytica* **31**, 13-18
Hahn SK, Hozyo Y (1984) Sweet potato. In: Goldsworthy PR, Fischer NM (Eds) *The Physiology of Tropical Field Crops*, John Wiley & Sons, Chichester, UK, pp 551-567
Hartwell JL (1967-1971) Plants used against cancer. A survey. *Lloydia*, 30-34
Hernandez TP, Miller JC (1962) Self- and cross-incompatibilities in the sweet potato. *Proceedings of American Society of Horticultural Science* **81**, 428-433
Hernandez TP, Miller JC (1964) Further studies on the incompatibilities in the sweet potato. *Proceedings of American Society of Horticultural Science* **85**, 426-429
Hiura M (1943) Studies in storage and rot of sweet potato. *Representative of Gilu Agricultural Column* **50**, 1-5
Holloway WD (1983) Composition of fruit, vegetable and cereal dietary fibre. *Journal of Science and Food Agriculture* **34**, 1236-1240
Holloway WD, Argall ME, Jelous WT, Lee JA, Bradbury JH (1989) Organic acids and calcium oxalate in tropical root crops. *Journal of Agriculture and Food Chemistry* **37**, 337-341
Holloway WD, Monro JA, Gurnsey JC, Pmare EW, Stace NH (1985) Dietary fiber and other constituents of some Tongan foods. *Journal of Food Science* **50**, 1756-1757
Horvat RJ, Arrendaale RB, Dull GG, Chapman GW Jr., Kays SJ (1991) Volatile constituents and sugars of three diverse cultivars of sweet potato (*Ipomoea batatas* (L)Lam.). *Journal of Food Science* **56**, 714-742
Huang AS, Tanudjaja L, Lum D (1999) Content of beta-carotene and dietary fiber in 18 sweet potato varieties grown in Hawaii. *Journal of Food Composition and Analysis* **12**, 147-151
Hydo H, Uritani I (1984) Ethylene production in sweet potato root tissue infected by *Ceratocystis fimbriata*. *Plant Cell Physiology* **25**, 1147-1152
Imaski H, Asahi T, Uritani I (1968) Investigations on the possible inducers of metabolic changes in injured plant tissues. In: Hirai, Hidaka, Uritani I (Eds) *Biochemical Regulations in Diseased Plants for Injury*, Phytopathology Society of Japan, Tokyo, pp 189-201
Jaarsveld PJ, Faber M, Tanumihardjo SA, Nestel P, Lombard CJ, Benadé AJ (2005) β-carotene-rich orange fleshed sweet potato improves the vitamin A status of primary school children assessed with the modified-relative-dose response test. *American Journal of Clinical Nutrition* **81**, 1080-1087
Jaarsveld PJ, Marais DW, Harmsea E, Nestel P, Rodríguez-Amaya DB (2006) Retention of β-carotene in boiled, mashed orange-fleshed sweet potato. *Journal of Food Composition and Analysis* **19**, 321-329
Jalal F, Nesheim MC, Agus Z, Sanjur D, Habicht JP (1996) Serum retinol concentrations in children are affected by food sources of β-carotene, fat intake, and antihelminthic drug treatment. *American Journal of Clinical Nutrition* **68**, 623-629
Jenkins WF, Moore EL (1954) The distribution of ascorbic acid and latex vessels in three tissue regions of sweet potato. *Proceedings of the American Society of Horticultural Science* **63**, 389-392
Jenkins WF, Moore EL (1956) Carbohydrates and ascorbic acid in sweet potatoes as affected by time and sampling techniques. *Proceedings of the American Society of Horticultural Science* **67**, 490-492
Jones A (1965a) Cytological observations and fertility measurements of sweet potato (*Ipomoea batatas* (L.) Lam). *Proceedings of the American Society of Horticultural Science* **86**, 527-537
Jones A (1965b) A proposed breeding procedure for sweet potato. *Crop Science* **5**, 191-192
Jones A (1977) Heritability of seven sweet potato root traits. *Journal of the American Society of Horticultural Science* **102**, 440-442
Jones A (1986) Sweet potato heritability estimates and their use in breeding. *Horticultural Science* **21**, 14-17
Jones A, Dukes PD (1975) Some seed, seedling and maternal characters as estimates of some commercial performance in sweet potato breeding. *Journal of the American Society of Horticultural Science* **101**, 385-388
Jones A, Dukes PD, Cuthbert FP (1976) Mass selection in sweet potato: Breeding for resistance to insects and disease for horticultural characteristics. *Journal of the American Society of Horticultural Science* **103**, 374-376
Jones A, Steinbauer CE, Pope DT (1969) Quantitative inheritance of ten root traits in sweet potatoes. *Journal of the American Society of Horticultural Science* **94**, 271-275
Kamalam P, Hrishi N, Rajendran PG (1977) Genetic variability in the open pollinated progenies of sweet potato. *Journal of Root Crops* **3**, 13-23
Kashinro OO (1983) The free and total folate activity in some commonly available tropical food stuffs. *Food Chemistry* **11**, 87-93
Kato Y, Uritani I (1972) Ethylene biosynthesis in diseased sweet potato root tissue with special reference to methionine system. *Agricultural Biology and Chemistry* **36**, 2601-2604
Kato Y, Uritani I (1976) Changes in carbohydrate content of sweet potato in response to cutting and infection by black rot fungus. *Annuals of the Phytopathological Society of Japan* **42**, 181-186
Kays SJ (1989) Strategies for selecting conventional and new flavour types of tropical root crops. In: *8th Symposium of International Society for Tropical Root Crops*, Bangkok, Thailand, 188 pp
Kays SJ (1991) *Post Harvest Physiology of Perishable Plant Products*, Van Nostrand Rein Holt, New York, 533 pp
Kays SJ (2006) Flavour the key to sweet potato consumption. In: *Proceedings of the 2nd International Symposium on Sweet Potato and Cassava – Innovative Technologies for Commercialization*, Kuala Lumpur, Malaysia, pp 97-105
Kays SJ, Horvat RJ (1984) A comparison of the volatile constituents and sugars of representative Asian, Central American and North American Sweet

potatoes. In: *6th International Symposium on Tropical Root Crops*, International Potato Centre, Lima, Peru, pp 577-586

Kim MC, Sung NK, Shim KH, Lee MH, Lee I (1981) The contents of heavy metals in fruits and vegetables collected from Jinju district, Korea. *Korean Journal of Food Science and Technology* **13**, 299-306

Koelher PE, Kays SJ (1991) Sweet potato flavour: Quantitative and qualitative assessment of optimum sweetness. *Journal of Food Quality* **44**, 374-376

Kojima (1976) Possible involvement of furanoterpenoid phytoalexins in establishing host parasite specificity between sweet potato and various strains of *Ceratocystis fimbriata*. *Physiology and Plant Pathology* **8**, 97-111

Konzczak I (2004) Anthocyanin-rich polyphenoloc complex with enhanced physiological activity from sweet potato cell line. *Biomedical and Biotechnology* **5**, 287-292

Kotyama K, Kato T, Tamiya S, Kuranouchi T, Komaki K, Nakatani M (2006) New sweet potato cultivar 'Quick Sweet' having low gelatinization temperature and altered starch structure. In: *Proceedings of the 2nd International Symposium on sweet potato and cassava-Innovative Technologies for Commercialization*, Kuala Lumpur, Malaysia, 380 pp

Lanier JJ, Sistrunk WA (1979) Influence of cooking method on quality attributes and vitamin content of sweet potato. *Journal of Food Science* **44**, 374-376

Laurie SM, van den Berg AA (2002) A review of recent progress in breeding sweet potato in South Africa for resource- poor farmers. In: *12th International Society for Tropical Tuber Crops (ISTRC)*, Tsukuba, Cultio Corp., Ibaraki, Japan, pp 216-219

Leung WT, Wu XYZ, Flores M (1961) *Food Composition Table for Use in Latin America*, Institute of Nutrition of Central America and Panama, Guatemala/Inter Departmental Committee on Nutrition for National Defence, Bethsda, MD, 145 pp

Lin YH (1987) Some factors affecting levels of trypsin inhibiter activity of sweetpotato (*Ipomoea batatas* Lam) roots. *Botany Bulletin Academy Sinica* **28**, 139-149

Lin YH, Ho HP (1986) Soluble leaf protein of sweet potato cultivars. *Botany Bulletin Academy Sinica* **27**, 175-186

Lindsay DG (2000) The nutritional enhancement of plant foods in Europe 'NEODIET'. *Trends in Food Science and Technology* **11**, 145-151

Liu GF, Cheng F, Gao S, Li M (1985) Effect of arsenic in soil on plants - Research "arsenic-toxic field" in South China. *Zhongguo Nongye Kexue (Beijing)* **4**, 9-16

Lopez A, Williams HL, Cooler FW (1980) Essential elements in fresh and in canned sweet potato. *Journal of Food Science* **45**, 675-680

Low J, Walker T, Hijimans R (2007) The potential impact of orange-fleshed sweet potatoes on vitamin A intake in Sub-Saharan Africa. The VITAA Project, vitamin A and orange-fleshed sweet potatoes in Sub-Saharan Africa, Nairobi, Kenya. Available online: http://www.cipotato.org/vita/Publications/Paper

Lowe SB, Wilson LA (1975) Yield and yield components of six sweet potato (*Ipomoea batatas* L.) cultivars. 1. Contribution of yield components of tuber yield. *Experimental Agriculture* **11**, 39-48

LSRB (2011) Evaluation of orange-fleshed sweet potato and mapping of genetic loci associated with β-carotene. Life Science Research Board Report, Central Tuber Crops Research Institute, Thiruvananthapuram, pp 13-23

Madamba LSP, Bustrillos AR, San Petro EL (1973) Sweet potato starch: Physicochemical properties of the whole starch. *Philippines Agriculture* **54**, 350-353

Makki HM, Abdel Rahman AY, Khalil MKM, Mohamed MS (1986) Chemical composition of Egyptian sweet potatoes. *Food Chemistry* **20**, 39-44

Martin FM, Jones A (1971) Breeding sweet potatoes. *Plant Breeding Review* **4**, 313-345

Martin FM (1986) Sugars in staple type sweet potatoes as affected by cooking and storage. *Journal of Agricultural University, Puerto Rico* **70 (2)**, 121-126

Martin FW (1965) Incompatability in sweet potato: A review. *Economic Botany* **19**, 406-415

Martin FW (1967) The sterility-incompatibility complex in sweet potato. In: *Proceedings of International Symposium on Tropical Root Crops*, Trinidad, pp 1-15

Martin FW (1968) The system of self-incompatibility in *Ipomoea*. *Journal of Heredity* **59**, 262-267

Martin FW, Cabanillas E (1966) Post pollen-germination barriers to seed set in *Ipomoea*. *Euphytica* **15**, 404-411

Matsui M, Asuma K, Morimoto S (1986) Suppressive effect of seasoning on heat degradation of ascorbic acid in potatoes and sweet potatoes. *Nippon Eiyo Shokuryo Gakkaishi* **39**, 479-483

Matsui M, Itto S, Murofushi N, Takahashi N, Kobayashi M, Chishiki T (1984) Identification of gibberellins in the seeds of sweet potato (*Ipomoea batatas* Lam) and several other Convolvulaceae plants. *Agriculture Biology and Chemistry* **48**, 2935-2941

Matsui T, Mitsuzone H, Okada R, Itoo S (1988) Variations in the levels of major free cytokinin and free absicisic acid during tuber development of sweet potato. *Journal of Plant Growth Regulation* **7**, 249-258

Miettinen TA (2001) Phytosterols - what plant breeders should focus on? *Journal of Food Science and Agriculture* **81**, 895-903

Montelaro J, Miller JC (1951) A study of some factors affecting seed setting in the sweet potato. *Proceedings of the American Society of Horticultural Science* **57**, 329-334

Murakami Y (1968) Gibberellins like substances in roots of *Oryza sativa*, *Pharbitus nil* and *Ipomoea batatas* and the site of their synthesis in the plant. *Botany Magazine (Tokyo)* **81**, 334-343

Murakami Y (1970) A survey of gibberellins in shoots of angiosperms by rice seedling test. *Botany Magazine (Tokyo)* **83**, 312-324

Murata N, Yamaya J (1984) Temperature dependent phase behavior of phosphatidylglycerols from chilling sensitive and chilling resistant plants. *Plant Physiology* **74**, 1016-1024

Nestel P, Bouis HE, Meenakshi JV, Pfeiffer WH (2006) Biofortification of staple food crops. *Journal of Nutrition* **136**, 1064-1067

Pace RD, Bonsi C, Phills BR, Forrester IT (1987) Iron content and iron availability in sweet potato tips collected at different times during seasons. *International Journal of Nutrition and Reproduction* **35**, 1151-1156

Pardales F Jr, Beemonte DV Jr. (1989) Comparative patterns of dry matter production in bushy and spreading sweet potato cultivars. *Experimental Agriculture* **25 (2)**, 243-246

Parr AJ, Bowell GP (2000) Phenols in the plant and in man. The potential of possible nutritional enhancement of the diet by modifying the phenol content or profile. *Journal of Food Science and Agriculture* **80**, 985-1012

Paterson DR, Earhart DR, Fuqua MC (1979) Effects of flooding level on storage root formation, ethylene production and growth of sweet potato. *Horticultural Science* **14**, 739-740

Picha DH (1985) HPLC determination of sugars in raw and baked sweet potatoes. *Journal of Food Science* **50 (4)**, 1189-1190

Picha DH (1987) Chilling injury, respiration and sugar changes in sweet potatoes stored at low temperatures. *Journal of American Society of Horticultural Science* **112**, 497-502

Prabhudham S, Tantidham K, Poonperm N, Lertbawornwongsa C, Tongglad C (1987) A study of sweet potato quality and processing methods. In: Woolfe JA (Eds) *A Sweet Potato: An Untapped Food Resource*, Cambridge University Press, Cambridge, UK, 643 pp

Purcell AE (1962) Carotenoids of Goldrush sweet potato. *Food Technology* **16**, 99-102

Purcell AE, Pope DT, Walter WM Jr. (1976) Effect of length of growing season on protein content of sweet potato cultivars. *Horticultural Science* **11**, 31-32

Purcell AE, Swaisgood HE, Pope DT (1972) Protein and aminoacid content of sweet potato cultivars. *Journal of the American Society of Horticultural Science* **97**, 30-33

Purcell AE, Walter WM Jr. (1968) Autoxidation of carotenes in dehydrated sweet potato flakes using ^{11}carbon beta carotene. *Journal of Agriculture and Food Chemistry* **16**, 650-653

Purcell AE, Walter WM Jr. (1980) Changes in composition of the nonprotein nitrogen fraction of 'Jewel' sweet potato (*Ipomoea batatas* (Lam)) during storage. *Journal of Agriculture and Food Chemistry* **28**, 842-844

Rhodes MJC, Wooltorton LSC (1978) Changes in the activity of hydroxycinnamal, CoA: quinate hydroxycennamal transferase and in the levels of chlorogeneic acid in potatoes and sweet potatoes stored at various temperatures. *Phytochemicals* **17**, 1225-1229

Sakai S, Imaskei H, Uritani I (1970) Biosynthesis of ethylene in sweet potato root tissue. *Plant Cell and Physiology* **11**, 737-745

Sasaki T, Kainuma K (1984) Control of starch and exocellular polysaccharide biosynthesis by gibberellic acid with cells of sweet potato cultured *in vitro*. *Plant Cell Reproduction* **3**, 23-26

Scott GJR, Best R, Rosegrant M, Bokango M (2000) Roots and tubers in the global food system: A vision statement to the year 2020, Lima Peru: International Potato Centre, 111 pp

Scott LE, Appleman CO, Wilson W (1944) The discolouration of sweet potatoes during preparation for processing and the oxidase of the root. *MD Agricultural Experiment Station Bulletin* **33**, 11-26

Scott LE, Boukamp JC (1974) Seasonal mineral accumulation by the sweet potato. *HortScience* **9**, 233-235

Shannmugan A, Venugopal K (1975) Starch content of sweet potato (*Ipomoea batatas* Lam.) varieties. *Science Culture* **41 (10)**, 504-505

Sharafudin AFM, Voican V (1984) Effect of plant density and NPK dose on the chemical composition of fresh and stored tubers of sweet potato. *Indian Journal of Agricultural Sciences* **54**, 1094-1096

Shen Y, Jiang J (1984) Flouride in water, soil, foods and fluoride stains on teeth. *Zhonghua Yufangyixue Zazhi* **18**, 230-231

Shin MS, Ahn SY (1985) Studies on physiochemical properties of starches from sweet potatoes of Korean cultivars. *Hanguk Nonghwa Hakhoe Chi* **26**, 137-142

Sistrunk WA (1971) Carbohydrate transformation, colour and firmness of canned sweet potatoes as influenced by variety, storage, pH and treatment. *Journal of Food Science* **36**, 39-42

Son KC, Severson RF, Snook ME, Kays SJ (1991) Root carbohydrate, organic acids and phenolic chemistry in relation to sweetpotato weevil resistance. *Horticultural Science* **26**, 1305-1308

Spiers M, Cochran HL, Peterson WJ, Sherwood FW, Weaver JG (1945) The effects of fertilizer treatments, curing, storage and cooking on the carotene and ascorbic acid content of sweet potatoes. *Sweet Potato Cooperative*

Service Bulletin pp 3-21

Spiers M, Dempsey AH, Miller J, Peterson WJ, Wakeley JT, Cochran FD, Reder R, Cordner HB, Fieger EA, Itollinger M, James WJ, Louise H, Eheart JF, Eheart MS, Andrews FS, Young RW, Mitchell JH, Garrison OB, Mclean FT (1953) The effect of variety, curing, storage and time of planting and harvesting on the carotene, ascorbic acid and moisture content of sweet potatoes grown in six southern states. *Sweet Potato Cooperative Service Bulletin* pp 30-48

Sreenivasan G (1977) Factors influencing fruit set in sweet potato. *Journal of Root Crops* **3 (2)**, 55-59

Sreenivasan G, Vimala B (1978) Influence of season on flowering and fruit set in sweet potato. *Journal of Root Crops* **4 (2)**, 69-70

Sreenivasan G, Vimala B (1981) Hybridization in sweet potato using cut floral branches. *Journal of Root Crops* **7 (1)**, 67

Sreenivasan G, Vimala B (1981) Studies on compatibility and fruit set in different cultivars of sweet potato. *Journal of Root Crops* **7**, 21-24

Suda I, Furuta S, Nishiba Y, Yamakawa O, Matsugano K, Sugita K (1997) Hepato-protective activity of purple-colored sweet potato juice. *Sweet Potato Research Front* **4**, 3

Tanaka I, Uritani I (1979) Polar transport and content of indole-3-aceticacid in wounded sweet potato root tissues. *Plant Cell Physiology* **20,** 1087-1096

Tarumotto I, Ishikawa H, Kato S (1988) Inheritance mode of starch contents in *Ipomoea batatas*. In: *Proceedings of 8th International Symposium for Tropical Tuber Crops*, 483 pp

Truong Van Dan, Beiermann CJ, Marlett JA (1986) Simple sugars, oligosaccharides and starch concentrations in raw and cooked sweet potato. *Journal of Agriculture and Food Chemistry* **34**, 421-425

Underwood BA (2000) Overcoming micronutrient deficiencies in developing countries: Is there a role for agriculture? *Bulletin of Food and Nutrition* **21**, 356-360

Uritani I (1953) Phytopathological chemistry of black rotted sweet potato. Part 7. Isolation and identification of polyphenols from the injured sweet potato. *Nippon Nougeikagaku Kaishi* **27**, 165-168

Uritani I, Muramutu K (1953) Phytopathological chemistry of black rotted sweet potato, Part 4 Isolation and identification of polyphenols from the injured sweet potato. *Nippon Nougeikagaku Kaishi* **27**, 29-33

Villareal RL (1977) Sweet potato: its present and potential role in the food production of developing countries. *South Pacific Commission Technical Paper* **174**, 170-182

Villareal RL (1979) Sweet potato tips as vegetables. *HortScience* **14**, 469

Villegas RJA, Kojima M (1986) Purification and characterization of hydroxylcinnamoyl D: glucose: quinate hydroxycinnamoyl transferase in the root of sweet potato, *Ipomoea batatas* Lam. *Journal of Biological Chemistry* **26**, 8729-8733

Vimala B (1989) Fertility and incompatibility in sweet potato (*Ipomoea batatas* L.). *Annals of Agricultural Research* **10**, 109-114

Vimala B, Bala N, Hariprakash B (2011b) Retention of carotenoids in orange-fleshed sweet potato during processing. *Journal of Food Science and Technology* **48 (4)**, 520-524

Vimala B, Hariprakash B (2011) Variability of morphological characters and dry matter content in the hybrid progenies of sweet potato (*Ipomoea batatas* (L) Lam). *Gene Conserve* **10 (39)**, 65-86

Vimala B, Lakshmi KR, Nair RB (1988) Yield variability in the hybrid progenies of sweet potato. *Journal of Root Crops* **14**, 33-36

Vimala B, Nedunchezhiyan M, Ramanathan S, Jayaprakas CA (2011a) Evaluation of orange-fleshed sweet potato for tuber yield and carotene content at different locations of Orissa. In: *Proceedings of NSCFT*, CTCRI, Thiruvananthapuram, pp 157-160

Vimala B, Thushara R, Bala N, Sreekumar J (2010) Effect of processing on the retention of carotenoids in yellow-fleshed cassava (*Manihot esculenta* Crantz) roots. *International Journal of Food Science and Technology* **46**, 166-169

Walter WM Jr., Giesbrecht FG (1982) Effect of lye peeling condition on phenolics destruction, starch hydrolysis and carotene loss in sweet potatoes. *Journal of Food Science* **47**, 810-812

Walter WM Jr., Purcell AE (1971) Characterization of a stable water dispersible carotene fraction from dehydrated sweet potato flakes. *Journal of Agriculture and Food Chemistry* **19**, 175-178

Walter WM Jr., Purcell AE, Nelson AM (1975) Effect of amylolytic enzymes on "moistness" and carbohydrate changes of baked sweet potato cultivars. *Journal of Food Science* **40**, 793-796

Walter WM Jr., Schadel WH (1981) Distribution of phenols in 'Jewel' sweet potato (*Ipomoea batatas* (L) Lam) roots. *Journal of Agriculture and Food Chemistry* **29**, 904-906

Wang H (1964) A study on self- and cross incompatibilities and the factors affecting seed setting in the sweet potato. *Journal of Agricultural Association China New Series* **48**, 3-12

Wang H (1982) The breeding of sweet potatoes for human consumption. In: Villareal RL, Griggs TD (Eds) *Sweet Potato Proceedings of the First International Symposium*, AVRDC, Taiwan, China, pp 297-311

Wang H, Lin CT (1969) The determination of carotene content of sweet potato parental varieties and their offspring. *Journal of Agricultural Association of China* **65**, 1-5

Warmke HE, Cruzado HJ (1949) Observations on flowering and fertility in some varieties of Jersey and moist flesh sweet potatoes. *Proceedings of the American Society of Horticultural Science* **54**, 391-398

Watada AE, Tran TT (1987) Vitamin C, B1 and B2 contents of stored fruits and vegetables as determined by HPLC. *Journal of the American Society for Horticultural Science* **112**, 794-797

Williams DW, Cope FW (1967) Notes on self incompatability in the genus *Ipomoea.* In: *Proceedings of International Symposium on Tropical Root Crops*, Trinidad, pp 16-30

Wilson BJ (1973) Toxicity of mould damaged sweet potatoes. *Nutrition Review* **31**, 73-78

Wilson BJ (1979) Naturally occurring toxicants of foods. *Nutrition Review* **37**, 305-312

Wilson BJ, Yang DTC, Boyd MR (1970) Toxicity of mould damaged sweet potatoes. *Nature* **227**, 521-522

Wilson DD, Severson RF, Son KC, Kays SJ (1988) Ovipositional stimulants in sweet potato periderm for the sweet potato weevil, *Cylas formicarius elegantus*. *Environmental Entomology* **17**, 691-693

Wolfgang HP, Bonnie MC (2007) Harvest Plus: Breeding crops for better nutrition. *Crop Science* **47 (53)**, 88-105

Wood, Huang (1975) Detection and quantitative determination of ipomeamarone in damaged sweet potatoes (*Ipomoea batatas*) Garnett. *Journal of Agriculture and Food Chemistry* **23 (2)**, 239-241

Woolfe JA (1992) *Sweet Potato: An Untapped Food Resource*, Cambridge, UK, Cambridge University Press, 643 pp

Yoshimoto H, Yahara S, Okuno S, Islam MS, Ishiguro K, Yamakawa O (1999) Isolation and characterization of the ATF2 gene encoding alcohol acetyltransferase II in the bottom fermenting yeast *Saccharomyces pastorianus*. *Yeast* **15 (5)**, 409-417