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The Contribution of Tropical Tuber Crops Towards Food Security

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Abstract

Tuber crops (with 5.4% energy) are the second most important group of crop plants providing food energy to humans after cereals (49%). Of them, the tropical tuber crops (TTCs) contribute 3.9% of human energy for an average consumption of 28.6 kg capita-1 year-1 (76 kcals capita-1 day-1).Three of the TTCs - cassava, sweet potato and yam - rank among the top 15 crop plants of the world in area under cultivation. Two of the most commonly used terms in development science, Food security and Staple foods, are defined here. The contributions of TTCs to them are highlighted. Cassava and yams are presently among the major crops that show the highest rates of increase in area under cultivation. This may be attributed to their resilience to climate changes.

It is proposed that TTCs should double their contribution to food security to 8% by 2030 AD. Towards this, the factors favouring and disfavouring the TTCs are discussed. Moreover additional steps needed to be taken to ameliorate/adapt them are dealt with. These include the present very low yields of TTCs, their low nutritional content, presence of antinutritional factors, high glycaemic index and their prolonged periods of maturity. The ongoing international efforts to mitigate some of them are summarized, including biofortification.

Key words: Tropical tuber crops, food security, staple food, climate change, antinutritional factors, glycaemic index, biofortification

Introduction

Food security and climate change are among the top themes included in present-day development agenda. In this paper, we shall define food security and look at the role of tropical tuber crops (TTCs) in providing food security, then overview the present state of R & D in these crops (TTCs), and finally, discuss what further needs to be done in R & D to enable them to meet the challenges for resolving food insecurity in the age of climate change.

Tuber crops are the second most important group of crop plants after the cereals (Table 1), though a distant one. While the cereals contribute 49% energy towards global food security, the share of the tuber crops is only 5.4%. The other main food groups that contribute towards this are: oils, 12.5%, meat and eggs, 9.5%; sugar, 9.0%, and fruits, 3.0% (FAO, 2009). The FAO collects production data for only five tuber crops: potato, cassava, sweet potatoes, yams, taro and cocoyam. Except for the potato, all the other tuber crops are considered as tropical tuber crops (TTCs). However, according to the present trends, potato is being increasingly tropicalized. We shall look at this aspect later in the text. Presently, TTCs are being consumed as staple food, as secondary staple food, and as vegetables, mainly in the topics.

The main TTCs are listed below:

i. *Manihot esculenta* Crantz (Euphorbiaceae): cassava, tapioca, manioc; the most widely grown tuber crop

Table 1. Top crop plants of the world, 2012

Crop	By area		By production	
	Ranking	In M ha	Ranking	In M t
Wheat	1	215.5	3	670.9
Maize	2	177.4	1	872.1
Rice paddy	3	163.2	2	719.7
Barley	4	49.5	7	132.9
Millet	5	31.8	11	29 .9
Sorghum	6	31.2	10	57.0
Cassava	7	20.4	5	262.6
Potatoes	8	19.2	4	364.8
Banana & plantain	9	10.4	6	139.2
Oats	10	9.6	12	21.0
Sweet potatoes	11	8.1	13	10.3
Grapes	12	7.0	8	67.1
Yams	13	5.0	9	58.7
Taro & cocoyam	very low	1.3	low	10.0
Cereals, total	NA	703.2	NA	2545.0
Tuber crops, total	NA	55.6	NA	80.9

Source: FAOSTAT (2014); downloaded on 12 March 2014

in the world; extensively used in tropical Africa and widely in south-east and south Asia and the Neotropics;

iii. *Dioscorea* species (Dioscoreaceae): yams; Numerous species are edible, some are cultivated, and a few are permitted to grow in the backyards. The most important ones are:

   a. D. *alata* L., white yam: Asian yam widely cultivated in the tropics, especially in southeast and south Asia, Oceania, eastern Africa, West Indies;

   b. D. *esculenta* (Lour.) Burk.: lesser yam, Chinese yam cultivated mainly in southeast and east Asia, Oceania and the Caribbean;

   c. D. x *cayenensis* Lam. (syn: *D. rotundata* Poir.): African yam, white yam; the most widely cultivated TTC in tropical west Africa;

iv. *Ipomoea batatas* (L.) Lam. (Convolvulaceae): sweet potato; cultivated throughout the world;

iv. Aroids (Araceae): Several species are cultivated, some are regional staples, some used for ethnobotanical purposes. The most important ones are:

   a. *Colocasia esculenta* (L.) Schott: cocoyam, taro, *Colocasia*; widely used in Pacific Ocean islands, south and southeast Asia, in the Caribbean islands as staple, secondary staple and vegetable;

   b. *Xanthosoma sagittifolium* (L.) Schott (Araceae): tannia; widely cultivated as a supplementary food; also as staple in some countries;

   c. *Amorphophallus paeoniifolius* (Dennst.) Nicolson: elephant foot yam; widely used in south and southeast Asia as vegetable;

   d. *Cyrtosperma merkuii (Hassk.)* Schott: swamp taro. A seasonal and/or secondary staple in Pacific Ocean islands.

v. Several other TTCs that are used for special purposes, such as: *Canna indica* L. (arrowroot), *Maranta arundinacea* L. (West Indian arrowroot) and *Plectranthus rotundifolius* (Poir.) Spreng.(Hausa potato).

Note: There have been much controversies and confusion about the nomenclature and species delimitations of *Plectranthus/Solenostemon* genera, after they were separated over four decades ago from the genus *Coleus.* Consequently, the Latin name of Hausa potato too has been undergoing nomenclatural changes from time to time. Flora Malesiana has recognized only one large genus *Plectranthus.* Various periodically updating sites such as Mansfield, ePIC, GRIN, AGRICOLA, NPGS, etc. have been using various names for Hausa potato such as *Plectranthus rotundifotus, P. verticillum* and *Solenostemon rotundifolius* from time to time. Presently, most of these sites show the names of Hausa potato as: '*Plectranthus rotundifolius,*(Poir.) Spreng. (synonym: *Solenostemon rotundifolius* (Poir.) Spreng.)'.

Present contribution of TTCs to food security

Out of the total contribution of 5.4% energy from all the TCs (from annual consumption of 61.1 kg capita^{-1}year^{-1}), cassava contributes 1.9% energy (from 14.3 kg capita^{-1}year^{-1}); sweet potatoes, 1.5% (from 8.3 kg capita^{-}

^{1}year^{-1}); yams, 0.3% (from 3.0 kg capita^{-1}year^{-1}); and aroids, 0.2% (from kg capita^{-1}year^{-1}) (Table 2).

The Consultative Group on International Agricultural Research (CGIAR) had sponsored a study in 2000 AD to determine the present contribution of TCs to food security and to draw out a plan of action for 2020 AD. The study conducted jointly by the International Food Policy Research Institute (IFPRI), Washington, DC and International Potato Centre, Lima, Peru (CIP) had estimated that in 2000 AD, the TCs contributed 5% energy towards food security. The study then recommended that this might be enhanced to 6% by 2020 AD (IFPRI, 2000). But, no follow-up action seems to have been taken on this afterwards.

TTCs presently (in 2009 AD, the latest year for which data are available) constitute a staple crop in 29 countries/entities of the world and a secondary staple in another 25 countries, out of a total of 236 countries/entities in the world (Table 3). In the year 1961, the respective numbers of countries/entities were: 33 countries as staple food and 35 countries as secondary staple. Here, a staple food is defined as a food item that contributes a minimum 10% energy daily on per capita basis, and a secondary staple as one contributing 5% daily energy per head.

Food security: definition and status

The UN (2012) has indicated that food security “exists when all people at all times have both physical and economic access to the basic food they need”. Like the term ‘staple food’, ‘food security’ is also a widely misused concept. The FAO (1995) had stated that a staple food as “one that is eaten regularly and in such quantities that it constitutes a dominant portion of the diet and that supplies a high proportion of energy and food needs”.

Table 2. Area, production and yield of tuber crops, 2012

Crop	Area (10^6 ha)	Production (10^6 t)	Yield (t ha^{-1})
Cassava	20.4	262.6	12.8
Sweet potatoes	8.1	10.3	12.9
Yams	5.0	58.8	10.7
Taro	1.3	9.6	7.8
Cocoyam	0.04	0.4	8.4
Potatoes	19.2	364.8	19.1
Tuber crops, total	55.4	80.9	14.1

Source: FAOSTAT (2012); downloaded on 12 February 2014

Table 3. Number of countries where tuber crops form staple/ major food, 1961/2009

Commodity	Number of countries/entities Total: 172/236	
	Staple* (1961/2009)	Major** (1961/2009)
Cassava	18/19	14/9
Sweet potato	5/2	4/5
Yam	4/4	6/6
Roots, other (Taro & cocoyam)	6/4	11/5
Tropical tuber crops	33/29	35/25
Potatoes	9/8	22/47

*Staple: when the daily consumption is 100 or more kcal head^{-1}

** Major: when the daily consumption is <100 kcal head^{-1}

Source: FAOFBS (1961; 2009)

The countries political entities of the world where TTCs constitute the staple and secondary staple in the year 2009 are listed below (FAO, 2009). The figure within parenthesis after a country is the amount of kilocalories contributed by the TTCs daily per person in the particular country.

***Cassava*:** Angola (415), Benin (441), Brazil (99), Burundi (224), Cameroon (110), CAR (140), Columbia (93), Comoros (265), Cote d’Ivorie (318), DR Congo (677), Gabon (229), Ghana (649), Guinea (301), Indonesia (126), Liberia (389), Madagascar (301), Malawi (135), Nigeria (226), Paraguay (304), Peru (127), Rwanda (269), Sao Tome (104), Sierra Leone (203), Timor (80), Uganda (288), Tanzania (225), Venezuela (493), Zambia (261). As staple food: 27 countries, as secondary staple: 2 countries; **Total: 29 countries.**

***Sweet potatoes*:** Algeria (131); Angola (121), Burundi (234), Mozambique (87), Rwanda (192), Solomon Islands (482), Uganda (191). As staple food: 6 countries, as secondary staple: 1 country; **Total: 7 countries.**

***Yams*:** Benin (418), CAR (82), Cote d’Ivorie (496), Dominica (88), Ghana (400), Guinea Bissau (146), Jamaica (97), Nigeria (246), Solomon Islands (167), Togo (235). As staple food: 8 countries, as secondary staple: 2 countries; **Total: 10 countries.**

Roots, other: Ethiopia (217), Gabon (176), Ghana (113), Kiribati (275), St. Vincent (92), Samoa (261), Solomon Islands (192), Swaziland (88), Vanuatu (426). As staple food: 7 countries, as secondary staple food 2; **Total: 9 countries.**

We can see from the above (and also from Table 3) that in the case of TCs, the number of countries where they form a staple or secondary staple food has been coming down over the years; also; further, that TTCs constitute staple food in three major regions of the world, viz, tropical Africa, Oceania and Caribbean Islands.

The situation is different in the potato vis-à-vis the TTCs. Until after the Second World War, and almost from the beginning of 19th century, potato used to constitute the staple food in entire Europe. Several countries in eastern Europe, for example,–Poland, – used to consume at that time 1.5 – 2.5 kg potato - head - day-. Many of us may have heard of how in the mid-19th century, the late blight disease of potato had wiped out almost the entire potato crop in Ireland during the Great Famine (1846 AD), and how it had resulted in halving the population of that country by death and/or mass migration of people to North America.

In the last five decades, what we see is that as the income levels go up, the population consumes less of vegetarian diet and more of non-vegetarian items. Further, even in vegetarian diets, the population shifts their food preferences from 'inferior' vegetal items like the millets and TTCs, and switches over to wheat, rice, and the potato. The area-production figures of TTCs for 1961 –2011 (Table 4) may not indicate this trend in full, because of the influence of other factors.

Some food security-related aspects

The world population is expected to rise to 9.4 billion by 2050 from the present 7.2 billion (UN, 2012). The rate of increase in population has been slowly coming down in recent years. It is now 1.2% annually. This rate of increase is also unsustainably high for achieving zero population growth. Most of the population increases are now taking place in the developing world. It is actually steadily shrinking in most developed countries, except in a handful of countries such as the USA, Australia, etc., where the increase is being maintained by immigration.

According to the UN estimates, as much as one in seven persons – more than one billion people –is going to bed hungry every day (Table 5). Almost all of them are in developing countries, mostly in sub-Saharan Africa and south Asia. In recent years, China has made remarkable progress in nearly eliminating the number of undernourished people in the country. This goes to show that with strong leadership and determined action, this serious issue can be tackled effectively. This is incidentally one of the priority aspects of the Millennium Development Goals of the United Nations.

wo worrisome aspects of the food-security-related parameters (Table 6) are obesity and food wastage. Almost one-fifth of the present population (viz., 1.5 billion people) is obese or overweight. A percentage of this may be obese, because of congenital disorders, but

Table 4. Production and yield trends in tropical tuber crops

Crops*	1961			2011		
	Area (M ha)	Yield (t ha^{-1})	Production (M t)	Area (M ha)	Yield (t ha^{-1})	Production (M t)
Cassava (105)	9.6	7.4	71.3	20.01 (+ 109.4%	12.78	256.0 (+ 59.0%)
Sweet potatoes (120)	13.4	7.4	98.2	8.2 (- 38.8%)	12.9	105.0 (+ 6.9%)
Yams (61)	1.2	7.2	8.3	5.0 (+ 316.6%)	11.5	56.8 (+ 584.3%)
Taro (48)	0.8	5.9	4.5	1.3 (+ 62.5%)	0.8	9.6 (+ 113.8%)
Cocoyam (13)	0.023	5.1	0.117	0.043 (+ 6.9%)	8.4	0.363 (+ 17.7%)
Potato (155)	22.2	12.2	271.0	19.2 (-12.2%)	19.5	373.0 (+ 37.6%)
All tuber crops	47.6	9.6	445.3	54.9 (+ 15.3%)	14.8	810.8 (+ 79.8%)

* Figures in parenthesis under crops give the number of countries reporting information
Source: FAOSTAT (1961; 2011)

Table 5. Contribution of tuber crops to food and nutrition, 2009

Item	Food supply (kg capita^{-1} year^{-1})	Energy (kcals capita^{-1} day^{-1})	Contri-bution (in %)
Tuber crops	61.1	136	5.4
Cassava	14.3	37	1.9
Sweet potatoes	8.3	22	1.5
Yams	3.8	11	0.3
Roots, other (yautia, tannia)	2.0	6	
Cereals	146.7	1292	49.0
Rice	52.9	532	20.5

Others items' contribution: Oils = 12.5%; Meat & eggs = 9.5%; Sugars = 9.0%; Fruits = 3.0%
Source: FAOSTAT FBS (2009); 'Contributions' calculated by author

Table 6. Status of selected global parameters

Population (2011)	7 billion +
No. of undernourished people (2010)	0.9 billion
No. of overweight/obese people (+20 yr) (2008)	1.5 billion
No. of overweight/obese people in India (ICMR, 2011)	10.2 million (9% population)
Area of agricultural land (2009)	4.9 billion ha
Area of crop lands & pasture (2009)	3.7 billion ha
Annual growth in agricultural production (1997-2007)	2.2%
Annual growth in population (2011)	1.2%
Food wasted annually (2011)	One-third of production, 1.3 billion approximately

Source: FAO (2009; 2011)

even after allowing a discount for this, a vast majority of this 1.5 billion populace is obese because of excessive food consumption and unhealthy lifestyle. It should be possible to make some savings in food by reducing excessive food consumption by launching effective awareness and public health educational programmes, as is being successfully done on several public health issues.

The second aspect is even more distressing, but fortuitously, more easily manageable. It is the fact that about one-third of all the food produced now is lost on a global basis – 1.3 billion tons approximately (FAO, 2011). This varies from 19% to 36% in different regions of the world (Table 6; Figs. 1 and 2), during the various stages of the production to consumption food chain: production, postharvest handling, processing, distribution and consumption. Very interestingly, the losses during the production process are higher in less developed and economically backward countries and wastages during consumption stage are highest and proportionally very high in developed countries. The per capita food wasted in North America and Europe is estimated at 95 -115 kg head^{-1} year^{-1}, while it is only 6–11kg head^{-1} year^{-1} in sub-Sahara and south of south-east Asia. In tuber crops the maximum losses in the potato

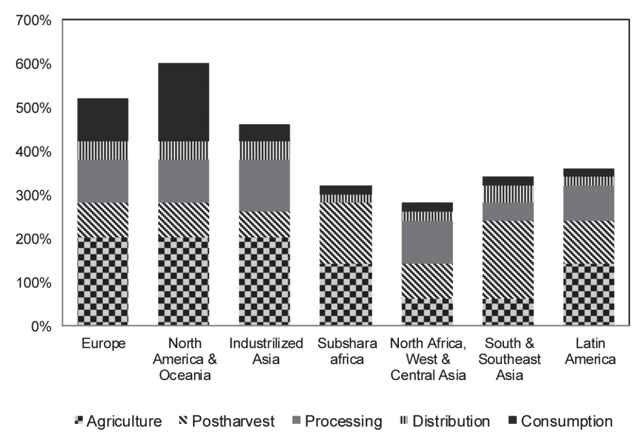

Fig. 1. Part of the initial production lost or wasted at different stages of the FSC for root and tuber crops in different region
Source: FAO (2011)

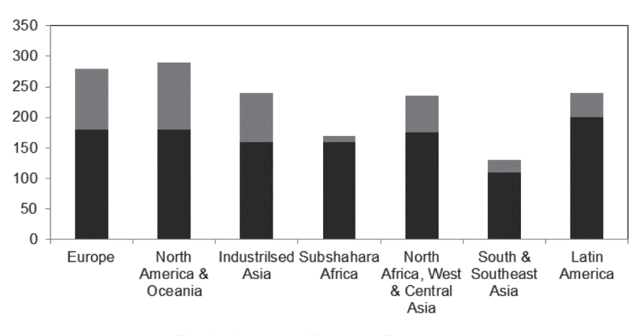

Fig. 2. Per capita food losses and waste, at consumption and pre-consumption stages, in different regions
Source: FAO (2011)

take place in medium and high income countries during grading and consumption, while in the cassava, in sub-Saharan Africa, the losses happen during production and postharvest handling (FAO, 2011). (Figs. 1 and 2; Table 6).

This aspect – the avoidance of food wastage – should be a less difficult task to manage/ overcome than reducing obesity through appropriate political and social actions and political leadership decisions and actions.

Food security in the development agenda

The UN had appointed a High Level Taskforce on Food Security to study food security recently. This Taskforce (UN, 2012) identified the three greatest challenges in the 21st century as: ensuring food security, mitigating climate change and adapting to climate change. We are aware that food security is closely influenced by the latter two challenges. Several other agencies have also examined this aspect from their respective perspectives (FAO, 2009; 2012; IFPRI, 2010; NAS, 2010; CGIAR, 2012; UN, 2012). All of them have concluded that the longstanding challenges on food security have undergone a drastic transformation on account of climate change.

Climate change

There continues to exist, mainly in the USA a minority of leaders, but still very influential and vociferous, who insist that a phenomenon as climate change does not exist, that the variations that we experience presently in different regions of the world and at different times of the year are not any more extensive or serious than the earth has always been experiencing in the past. But, the latest report of the Intergovernment Panel on Climate Change (IPCC) (IPCC, 2007; 2014;) set up jointly by the World Meteorological Organization (WMO) and United Nations Environment Programme (UNEP), has further reinforced the findings after detailed study and analyses conducted by it on a global basis (IPCC, 2007; 2014). They have concluded that an average increase of 2°C in the near-term appears not only inevitable, but an increase of 3°C mean temperature appears possible. The just-released report of the IPCC (2014) has discussed mostly about only mitigation. It has observed that the total anthropogenic greenhouse gases (GHGs) have continued to increase with larger absolute decadal increases (2.2% $year^{-1}$ during 2000–2010) than during 1970–2000 (1.3% $year^{-1}$). Even a 2°C increase would reduce food production in most of the lowland tropical and subtropical farmlands, but it may increase it in the highlands and the traditional very cold temperate areas of the world, such as Siberia and Canada. These will have a profoundly destabilizing effect on global food production (Foley et al., 2011; Nature, 2013).

The present total area under croplands is estimated at 4.9 billion ha. Of this, an "astonishing ~ +75% area" is currently used for animal-based agriculture (Foley et al., 2011). It has been estimated that production of one kg meat requires 10 kg grains, and further, it causes one ton CO_2-emission. While 1kg meat provides only 3,440 kcal energy, even one kg food grains yield 2174 kcal energy. An approximate estimate is that one third of the population in the world lives on meat-based diets and the rest on plant-based diets (Pimental and Pimental, 2005; Foley et al., 2011). This calls for reducing the intake of animal food in the human diet. The top meat-consuming countries of the world are Luxembourg, USA, Australia, New Zealand, and Spain, with 137 kg $head^{-1}$ annually as the highest consumption, according to the FAO estimates (2009). This begs for serious introspection. Should we not make an effort to reduce the extent of meat consumption and substitute it with vegetal food, or at least marine resources?

India's state of hunger

The state of hunger in India has become a hugely controversial topic in the Indian development scenario, after the Indian Planning Commission in 2012 had estimated that with 1,632 kcals person day^{-1} consumption, 20% of the Indian population would go undernourished. The seventh Global Hunger Index (GHI) released by the IFPRI in October 2012 ranks India, a low 65th among 120 rated countries, below Sri Lanka and even Bangladesh in south Asia. What is worse, India GHI has been stagnating for the last 10 years in spite of a near-doubling of GNP during the period (FAO, 2013). This has been primarily because 43.5% of the children in India's are estimated to be underweight. The situation is expected to change for the better if and when the recently enacted Food Security Act gets implemented.

With an estimated annual food production of ca. 260 M t presently and the rate of increase in food production outpacing the rate of population increase, again, the situation is likely to further improve. There are, however, two fundamental issues that need to be kept in mind, vis-à-vis food security, particularly in the Indian context – availability of food, especially in remote areas, and difficulties in accessing food, because of lack of purchasing power.

TTCs and food security

We had seen earlier (Table 2) that TCs contribute 61.1 kg head^{-1}year^{-1} towards food supply and provide 136 kcals energy head^{-1}day^{-1}. This amounts to 5.4% of total energy consumed by a person in a day. After deducting the contribution of the potato, the TTCs supply 28.5 kg food annually and 75 kcals energy head^{-1}day^{-1}. That is almost half the contribution of TCs contributed by the TTCs.

While the area under TTCs increased by only about a third during the period 1961–2011 (Table 4), the production increased by as much as two and half times. The area– production trends in TCs, especially in TTCs, have been inconsistent during 1961-2011, except in the case of two factors. They are: (i) in all the crops, productivity has increased by about 60%; (ii) in cassava and yams, both the area and production have been steadily increasing in recent years, though they have not been making the kind of dramatic increases being shown by the two major cereal crops, wheat and rice.

There are several reasons for these. (i) Most of the R & D efforts are being made in only the major cereal crops (ii) The recent increases in cassava and yams production may be attributable to the greater resilience of these two crops to climate changes in sub-Saharan Africa. Incidentally, the FAO has identified so far cassava and quinoa (*Chenopodium quinoa* Willd., Chenopodiaceae), a grain crop, as the most climate- resilient crops. Very soon, it is felt that some more crops such as yams and grain amaranths (*Amaranth* spp., Amaranthaceae) may also be identified as climate-resilient crops. This will prove advantageous as this could help in attracting more funds for R & D work.

The situation in other TTCs is somewhat inconsistent. In sweet potato, for instance, until some years ago, nearly three-fourths of all the sweet potato grown in the world used to be cultivated in China. In China, sweet potato is used for both food and feed. Then, China took a policy decision to substantially reduce the area under this crop. At the same time, several countries in middle Africa, such as Uganda, Rwanda, and Burundi, have taken up sweet potato cultivation in a big way. This has partially offset the otherwise major reduction in area and production of this crop globally following China's decision. The two aroid crops, taro and cocoyam, have made only moderate increases in area and production (Table 4).

Incidentally, we have noted that all the TTCs (except the aroids) are among the top 15 cultivated crops of humankind (Table 1). Interestingly, the situation in the potato is somewhat unique. It is traditionally identified as a temperate region crop, even though the potato had originated in the tropics – in the highlands of Andes mountains in south America. The American Indians living there have been using from prehistoric times several tuber-bearing *Solanum* species as food, as also some other tuber crops and some also nongraminaceous grain crops, such as quinoa and grain amaranths. After the discovery of Americas in late 15th century, the Spaniards introduced

Table 7. Food balance sheets of tuber crops, 1961/2009

Particulars	All tuber crops	All cereals	Potato	Cassava	Sweet potato	Yam	Roots, other
Production (Mt)	445.2/720.4	779.0/2251.6	270.4/331.4	62.4/219.8	97.1/101.8	8.0/47.0	6.6/20.3
Feed (000 Mt)	99.3/163.8	288.4/746.2	70.9/37.7	16.3/79.0	10.4/39.8	0.9/6.6	0.8/0.7
Processing (000 Mt)	79.8/62.2	31.6/95.2	24.2/25.3	6.0/22.5	5.3/6.6	0.9/5.2	0.8/2.7
Food (000 Mt)	407.5/406.9	590.5/976.7	108.9/219.3	37.6/95.0	80.3/55.4	46/25.6	4.7/13.6
Food supply (kg capita^{-1} yr^{-1})	77.4/61.1	128.0/146.7	35.7/32.6	12.3/14.3	26.3/8.3	1.5/3.8	1.5/2.0
Food supply (kg capita^{-1} day^{-1})	176/136	1078/1292	65/61	32/37	71/22	4/11	4/6

Note: The figures given on the left are for the year 1961 and those on the right for 2009

Source: FAO FBS (2009)

potato into Europe, where it got acclimatized as a long-day crop, and very soon, it became a popular staple food.

However, after the Europeans, especially the French, Portuguese, Spanish, and Dutch, sailed across the oceans from the late15th century to discover new lands and establish new European colonies, they, especially the Portuguese, went on to spread several of the South American crops into these new lands also. This included the potato, which after it was attempted to be grown in the lowland tropics as in the Ganga plains of India, soon got adapted itself as a short-day crop. It is now grown typically as a late autumn-winter crop.

The present and future contributions of TTCs to food security

Presently, the TTCs contribute 3.4% energy to global food security. We should now endeavour to double this by 2030 AD. There are several limitations to this including human habits and prejudices, the inadequate R & D efforts in these crops, etc. We need to overcome them, if we have to meet this target (Table 8 a and b).

Narrowing the yield gap

It is the least difficult and fasted procedure to increase crop production. This can be achieved by providing sound technical advice, making available the needed inputs like seed, manure, etc., and making arrangements to buy the excess produce from the farmers. The examination of the current yields of the TTCs (Table 8) shows that the highest, lowest, and world average yields in cassava and

Table 8. Yield gaps in tuber crops, 2012

a. Actual yields

Crop	Yield (t ha^{-1})		
	Highest	Lowest	Average
Cassava	36.4 (India)	1.4 (Burkina Faso)	12.8 (World)
Sweet potatoes	32.7 (Reunion)	1.5 (Bhutan)	12.9 (World)
Yams	22.1 (Japan)	3 (Bhutan)	11.5 (World)
Taro	22.9 (China)	1.2 (Cote d' Ivorie)	2.3 (World)
Yautia	10 (Cuba)	4.2 (Mexico)	8.4 (World)

Source: FAOSTAT (2012), downloaded on 12 February 2014

b. Ratios of yield levels

Crop	Ratios between…..	Ratio
Cassava	Highest to lowest	26.0
	Highest to average	2.8
	Lowest to average	9.1
Sweet potatoes	Highest to lowest	21.8
	Highest to average	2.5
	Lowest to average	8.6
Yams	Highest to lowest	7.2
	Highest to average	1.9
	Lowest to average	3.8
Taro	Highest to lowest	19.2
	Highest to average	10.0
	Lowest to average	1.9
Yautia	Highest to lowest	2.4
	Highest to average	1.2
	Lowest to average	2.0

Source: Calculated by author

sweet potato are very comparable. Cassava is a very long duration crop (10 – 12 months) and the sweet potato, a medium duration (3-4.5 months) crop. This shows the unique ability of the sweet potato to produce potentially high yields. At the other end, the aroids (taro, yautia) shows the lowest world average yields. However, the optimistic indicator here is the prevailing wide gap in yields (x 10.0) between the highest yield- giving country – China, 22.9 t ha^{-1} and world average yield.

The universal habit of humans is that as their prosperity increases, they reduce their consumption of 'inferior' foods like TTCs, millets, etc., and correspondingly, increase the use of wheat or rice and animal products. A second habit is that most of the TTCs are traditionally affected by various anti-nutritional factors. Their intensity has, however, come down of late. A third disadvantage is the long period of maturity of all the TTCs. There are some other less pressing factors also. We shall now go into the most important of them in some detail.

Nutritional aspects of TTCs

The main nutritional value of all the TCs lies in they being the cheapest source of carbohydrates/starch. Further, some of the TTCs, especially the sweet potato, produce more energy per unit area than even the cereals (FAO, 1999; 2000). The protein content of all the TTCs is generally low, only 1–2%. All of them are generally deficient in minerals and vitamins. But, they contain higher amounts of dietary fiber – up to 5% on fresh weight basis and 20% on dry weight basis. Taro is high in potassium. The starch granules of aroids are only about one-tenth in size of other starch crops. This makes them very suitable for infants and invalids (FAO, 1999; 2000).

A second nutritional factor that has gained much relevance in recent times is the Glycaemic Index (GI). It is a measure of the ability of a carbohydrate food to increase the level of glucose in the blood when consumed (ADA, 2008). Values of 50 or less are considered as low, 51–69 as medium and 70 and more high. The incidence of all the lifestyle diseases – and this includes diabetes – is steadily increasing.

The TCs show much variation in their GI values. The values of various TCs are given in Table 9. While almost all the TCs show high GI, except the sweet potato,- that of cassava is very high. There is also much variation in the GI values of the same crop when processed in different ways. For instance, in a *gari* preparation made of cassava in Kenya, the GI value was a low 39. This calls for further studies to see if varietal differences exist for this property. It also calls for developing processing methods by which GI values can be reduced: as in *gari*, as stated above. We shall need to develop various means to lower the GI values, and in the long run, see if this could be reduced by some molecular biology means in various TTC's.

Table 9. Glycaemic index (GI) of tuber crops

Item	GI
Cassava, peeled and boiled	99
Cassava, steamed for one hour	75
Sweet potato, boiled	44
Sweet potato, orange type, peeled boiled	64
Sweet potato, peeled, baked	98
Yam, peeled, boiled	37
Yam, steamed	53
Yam, (*D. alata*) peeled, boiled	78
Yam, (*D.* x *cayenensis*) (as *D. rotundata*), boiled	75
Taro, peeled, boiled (US)	54
Taro, peeled, boiled (New Zealand)	53
Potato, French fries, baked	67
Potato, mashed	76
Potato, cv. Desiree, mashed	108
Bread, white, wheat flour	71

Source: ADA (2008)

Biofortification

This is the process by which the nutritional values of food items are increased through biological means. In recent times, this line of study has been gaining increasing momentum. Molecular or genetic engineering procedures are being used to 'fortify' or improve the nutritive values of several crop plants.

Presently, biofortification research is underway in the following crops (WHO, 2014): (i) rice, beans and sweet potato for enhancing iron content; (ii) rice, wheat, beans, sweet potato, and maize for enhancing zinc content; (iii) carotenoid biofortification in rice, sweet potato, maize; and (iv) cassava for increasing provitamin A content.

However, it has been the work done on rice–popularly known as the Golden Rice programme to enhance the â carotene content–that has received the most attention. The objective of the project has been to increase the â carotene content through genetic engineering of rice, as â carotene is the precursor of vitamin A. The first rice variety produced in this manner by Ingo Potrykus and Peter Bayer, designated SGR1, contained three times more â carotene than the usually cultivated rice varieties (Ye et al., 2000). The second generation cultivar GR2 (Golden Rice 2) contains 23 times more â carotene in laboratory trials, and in several field trials conducted in the USA, Philippines and Bangladesh, it has been seen to contain 4–5 times more â carotene than that of the traditional varieties.

Biocassava Plus (BC+) programme

The Bill and Melinda Gates Foundation has now funded an ambitious project for engineering cassava to impart several positive attributes to it. Cassava is presently the staple food of more than half the population of tropical Africa. The area under this crop is expanding at a fast pace. The FAO has recognized cassava as the most climate-resilient food plant. It is highly adaptable to diverse environments and it is capable of giving high yields under good management, as we have noted before. But, it suffers from several drawbacks. Except for carbohydrates, it is low in most nutritional parameters, even when compared to other tuber crops. A typical cassava diet (500 g day^{-1}) provides only 30% MDE (minimum dietary energy) of protein and 10-20% of iron, zinc and vitamin A (Fregene et al., 2000). It has the poorest tuber keeping quality among all the TCs.

Most of the cassava tubers are rendered unfit in 48–72 h after harvest. It is affected by a serious virus disease, the cassava mosaic disease (CMD), and further, it is afflicted by a serious antinutritional factor, hydrocyanic acid.

The first cultivar #60 444 released under the BC+ programme contains up to 40 μg dry weight of â-carotene (1.5-2.5 $\mu g\ g^{-1}$ in control), 40 $\mu g\ g^{-1}$ iron (1 $\mu g\ g^{-1}$in control) and 10% protein in storage roots (2% in control). All the data are on dry weight basis. The shelf-life of the tubers has been enhanced to 28 days (80% spoilage in seven days in control). It is also significantly resistant to the cassava mosaic disease. The studies are progressing (Fregene et al., 2000; Sayre et al., 2012).

Biofortification in sweet potato

Among the other TTCs, biofortification has been taken up also in sweet potato (WHO, 2014). This crop too ranks among the top 15 crop plants of the world (Table 1). Nearly 80% of this is grown in China. Other major sweet potato producing countries are Uganda, Nigeria, Indonesia, Tanzania, Vietnam, India and the USA. Sweet potato constitutes a staple in Papua New Guinea (500 kg $head^{-1}year^{-1}$), Solomon Islands (160 kg $head^{-1}year^{-1}$), Burundi and Rwanda (both 130 kg $head^{-1}$ $year^{-1}$) and Uganda (100 kg).

Sweet potato possesses several positive attributes–good adaptability, relatively shorter maturity period, higher productivity, low GI (glycaemic index) and good keeping quality. The biofortification work taken up in sweet potato has been done to enhance its vitamin A content by increasing the anthocyanin content of the tubers and leaves and popularizing the cultivars possessing these attributes. This work is being carried out by Harvest Plus, an initiative of CGIAR. Cultivars having high carotenoid content possess deep orange or yellow flesh tubers. This work is now underway in Uganda and Mozambique. Funding for this programme is also being provided mainly by the Gates Foundation.

Aroids programmes

Aroids, mainly taro, too has been receiving some international support, mainly from Australia, the European Union (EU), and Bioversity International (BI). These programmes are TAROGEN and TANSAO (SPC, 2001). The project Tarogen, funded by AusAid which has been concluded, was meant to collect and catalogue taro germplasm of the Pacific, including PNG. Under this project, nearly 20,000 accessions were collected and they were studied for their variability (Tarogen, 2014).The International Network for Edible Aroids (INEA), www.EdibleAroids.org) is an ongoing project with a broader mandate covering some countries in south-east and south Asia, and tropical Africa also, besides Oceania. It is meant to test the adaptability and performance of selected taro material for yield and field reaction to leaf blight.

Yams, as a group, haven't received any international notice. They constitute the staple or secondary staple in several countries of tropical west Africa. It is also a significant food item in several other tropical regions of the world, viz., West Indies, south and south-east Asia, and some Pacific island countries. The "yam belt" of West Africa is composed of five countries (Nigeria, Benin, Togo, Ghana and Ivory Coast) totalizing together more than 95% of the world yam annual production.

The way ahead

If the TTCs have to maintain their positions among the top food crops of humankind and double their contributions to food security from the present < 4% of daily energy to about 8% by 2030 AD, then we will have to substantially strengthen R & D efforts in TTCs on a more continuing basis, say, for at least a decade or more. Further, the following research imperatives are proposed to be taken up:

i. Change the life history trait to annual forms having determinate growth
ii. Reduce the period of maturity of all the TTCs to 110 – 150 days
iii. Improve the tuber shape and make them more definitive in shape
iv. Improve plant architecture to attain a harvest index of 0.70
v. Eliminate antinutritional factors and improve nutritive values
vi. Impart resistance to the three major biotic problems afflicting the TTCs: CMD (cassava mosaic disease), taro leaf blight and sweet potato weevil

This list is not meant to be a comprehensive one of all the research programmes that need to be taken up in the major TTCs, but those that require priority attention. Thankfully, several of them have been taken up by the Cassava Plus and INEA programmes. There are also some programmes whose relevance has come down to some extent, thanks to the ongoing improvement programmes that are underway and also the farmer selection of better and more improved forms. The antinutritional factors of cassava (cyanogen content) and taro (acridity) are not as relevant today as they were, say, five decades ago.

(i) Introduce determinacy in cassava and yams

Some of the TTCs like cassava, yams, etc. are basically perennial in nature. Genomic research carried out in arabidopsis has shown that genes for determinacy are indeed available. However, most of them relate to seed crops – as AGAMOUS, APETALA, and so on. The *dt1* gene family of Arabidopsis (*GmTfl I / flrs (Tfl 1)*) has been found to confer 'annualness' to the soybean, *Glycine max* (Tian et al., 2010). Further research should uncover determinacy genes acting on vegetatively propagated crops.

(ii) Reduce the period of maturity of all the TTCs

This aspect can be considered as a continuum or corollary to the determinacy factor discussed above. All the TTCs, especially cassava and yams, take 5–12 months to produce mature harvests. In the traditional farming system prevalent in some of the communities in West Africa, it is a common practice to retain cassava and yam plants indefinitely, especially the plants standing in home backyards. As and when the household requires tubers for cooking, they would remove soil from the base of the plant carefully; take out the amount of tubers required for that day, and put the soil back at the base of the plants. It is worth recalling in this context that the remarkable change over done in the potato in converting the long-day adapted, medium period maturity (140 – 155 days) crop as grown in Europe to a short-day adapted, short duration (105 – 120 days) crop, as is being successfully cultivated in the Gangetic plains. This has become such a success, that presently, more than one-fifth of the global production of potato is raised in this manner. And, this area and production is increasing steadily, even while the area under the potato in the temperate regions of the world is gradually coming down. It is possible of course that the photoperiod response system in potato is weak. But in the TTCs too, it would be worth the while to seek recourse to molecular biology techniques to reduce the maturation period, if conventional system are not able to resolve the issue. In any case, it imperative to reduce the period of maturity to 4.0 – 4.5 months.

(iii) Improve plant architecture

The third and last issue that requires to be taken up as a challenge programme is to improve the plant architecture and increase the harvest index of all the TTCs. We are already aware from the pioneering work of de Vries, Al-Sharkawi and others, that TTCs are among the most photosynthetically efficient crop plants. It is strongly suggested that basic and systematic work is initiated in this area also, especially because of the challenges posed by climate change.

Conclusions

i. The main TTCs that are used as staple or secondary staple foods are cassava, sweet potato, some yam species, taro, swamp taro, and yautia. Minor ones include arrowroot, elephant foot yam and hausa potato.

ii. All the tuber crops together presently contribute 5.4 per cent of the total energy needs to the humans from 61.1 kg tubers per head annually. Of this, the contribution of the TTCs is 3.9 per cent energy, i.e., 72.2 per cent.

iii. It is now proposed that this contribution should be doubled to 8 per cent by 2030 A.D.

iv. This has become imperative in view of the emerging food crisis and the ongoing changes in climate with its attendant problems of temperature rise, increasing drought, sea level rise, and the unpredictable spurt in extreme environmental variations. In this scenario, the innate advantages and climate resilience of TTCs to such extreme and unpredictable variations are recognized. These include cassava and yams against water and temperature stress, and taro, yautia, and swamp taro against flooding.

v. The negative attributes possessed by several TTCs are also pointed out. They include the extended maturity periods of most TTCs, presence of antinutritional factors in several of them, the low keeping quality of few of them, and the poor nutritional attributes of most of them.

vi. The ongoing international efforts in ameliorating them are outlined. The need to strengthen and expand these efforts are stressed.

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