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TROPICAL ROOT AND TUBER CROPS AS HUMAN STAPLE FOOD

"Importância das raizes tropicais na alimentaçao humana"

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1. INTRODUCTION

Root and tuber crops are used as staple food in most countries in the world but their contribution to the energy supply of population varies within a large range depending on the country (0 to 56% with a world mean of 5.0)[1]. Many species and varieties are consumed but three species (i.e., cassava, irish potato and sweet potato) provide 93% of the root and tuber (R&T) crops used for direct human consumption in the world.
Some species are restricted in limited area but the greatest number of them are widespread by the mere fact that they have been diffused by men outside their origin area during the two last millenaries. The dispersion was mainly performed during the last five centuries by the Portuguese with regard to their travels for slaves, by both the Portuguese and Spanish in their missionary journeys and by Arab traders (FAO, 1990).

Names, origin and present distribution of the main species are given in table 1. One can notice that the three main R&T crops and many species of less importance originated in Latin America.
Cassava (*Manihot esculenta Crantz*) originated in Central and/or northern South America (Silvestre and Arraudeau, 1983). It was first introduced into Central Africa as nearly as 1558 by the portuguese navigators. It then spread through Angola, Zaire, Congo and Gabon and later to West Africa. There was a separate introduction to the east coast of Africa and to Madagascar in the 18th century by Portuguese and Arab traders. In Africa, the cultivation of cassava increased during the colonial times as a result of encouragement by administration who recognized its interest to prevent food shortages. Real extension of the utilization of cassava in West and Central Africa is quite recent, it started at the end of the 19th century in Nigeria (Idusogie and Oyalide, 1973) and in the Congo (Trèche and Massamba, 1991) and after 1924 in Ruanda-Urundi (FAO, 1990). Cassava was taken to India by the Portuguese in the 17th century and transported directly from Brazil to Indonesia and Malaysia in about 1850. Its introduction to the South Pacific islands by missionaries and travellers occured during the first half of the 19th century.
Irish potato (*Solanum tuberosum*) originated in the high Andes of South America. It was introduced to Spain in 1573 and then to other european countries. Potatoes reached numerous other areas of the world through European colonial activities.

[1] All the statistics of production and utilization have been extracted from the FAOSTAT Agriculture statistics database. When there is no precision, data correspond to averages of the three last available years (1992-1994).

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Sweet potato (*Ipomea batatas*) originated from Yucatan peninsula of Mexico. It seems to be the widest dispersed root crop. It was common throughout the Central and South American tropics before 1492. The plant was dispersed by Spanish and Portuguese explorers to the Pacific area in the 16th century, then by Portuguese explorers to Africa, India and East Indies and by Spanish traders from Mexico to Manila. Later the sweet potato reached New Guinea and the eastern Pacific Islands and extended into China and Japan where it is nowadays grown extensively (FAO, 1990).
The distribution of yams is very particular. Asian (i.e, *Dioscorea alata, D. esculenta, D. bulbifera, D. opposita*), African (i.e., *D. cayenensis-rotundata, D. dumetorum, D. schimperiana*) and American (*D. trifida*) species have developed independently of each other. Exchange of species was performed by the Portuguese explorers. *D. alata*, originating from Southeast Asia (Degras, 1986), was used by Indian and Malayan ship crews because of their good storage ability and antiscorbutic properties. Portuguese adopted it and introduced it in Sao Tome. Subsequently, through the atlantic slave trade, they carried it as well as the African species (*D. rotundata, D. Cayenensis*) to the Caribbean islands. *D. trifida* appears to have originated on the borders of Brazil and Guyana, followed by a dispersion through the caribbean (Ayensu and Coursey, 1972).
Old cocoyam (*Colocasia esculenta*) originated in India and Southeast Asia; about 2000 years ago, it spread to Egypt and then to Europe to be taken from Spain to tropical America and West Africa. New cocoyam (*Xanthosoma spp.*) had its origin in South America; it moved from the Caribbean in the late 19th century, first to Sierra Leone before spreading in West Africa (Onwueme, 1978). Nowadays, old and new cocoyams grow together around many villages in Central Africa.

In a great number of areas many areas where they have been used as food, significance of R&T crops were not restricted to energy and nutrient supply. It also appeared to be deeply related to customs and way of life. The origin of cassava has been the subject of legends (Muchnik, 1995). Domestication of different species of potatoes and other less-used Andean root crops is strongly associated to the development of pre-Columbian civilizations in South America (NRC, 1989). According to Coursey (1972), «in both Africa and the indo-Pacific region yam-based cultures have arisen and survived into the ethnographic present, attaining sufficiently high levels of social organization to have led to their description as civilizations of the yam».

2. ROOT AND TUBER CROP WORLD CONSUMPTION

World production and quantity used for human direct consumption are given in figure 1. During the 1992-1994 period, 24 countries produced more than 1 million tons (dry equivalent) of roots and tubers per year (84% of the world production and 78% of the quantity used as human staple food). Among them there is 8 European, 7 African, 6 Asian and 3 American (Brazil, USA and Colombia) countries. There are great variations in the proportion of R&T crops which are used as human food: in 14 countries more than 75% of the production is reserved for human direct consumption. In some others (Thailand, Poland, Belarus, Netherlands, Paraguay), more than 70% of the production is diverted from human consumption: in these cases most of the production is exported, as cassava in Thailand, or used for animal feeding, as Irish potato in Poland and Netherland or cassava in Paraguay. Moreover, the proportion of cassava used for industrial processing (e.g., sodium glutamate production) is strongly increasing since 1994 in some countries from Southeast Asia.

During the 1992-1994 period, Irish potato, cassava, sweet potato, yams and other R&T respectively provided 37.5%, 35.3%, 20.2%, 4.3% and 2.7% of the total amount of R&T crops used as human staple food on a dry equivalent basis. Figures 2 and 3 give the comparative importance of the main species around the world indicating the main consumption areas according to each kind of R&T crops.

In Southeast Asia (including China) and Pacific area, R&T crops used as human staple food are quite diversified: sweet potato, Irish potato, cassava and other R&T represent respectively 48%, 31%, 18% and 3% of the total directly consumed R&T crops. In sub-saharan Africa, cassava (70%) and yams (16%) are predominant. In Latin America, cassava and Irish potato represent nearly 90% of the R&T crops used as human food. Irish potato corresponds to 96% of the R&T crops reserved for human consumption in other parts of the world[2] .
35% of total R&T crops and 85% of sweet potato used as human staple food are consumed in Southeast Asia. Sub-saharan African people consumes 27% of total R&T crops, 65% of cassava, 93% of yams and 50% of other R&T crops. Latin America which represents 8.4% of the world population use as food 7.0% of total R&T crops, 11.6% of cassava, 6.7% of Irish potato and 2.0% of sweet potato consumed in the world.

Figure 4 gives the amount of energy expressed as kilocalories provided by the main R&T crops for the 17 countries where total dietary energy from R&T crops represents more than 500 kcal per day and by inhabitant (14 African countries and 3 Pacific Islands). Cassava is the main R&T crops used as staple food for 11 African countries out of 14. It is to be outlined that Irish potato is an important food in none of these countries. It is only in Central-east African countries (Burundi , Rwanda and Uganda) and in two of the Pacific Islands (Salomon Islands and Papua New Guinea) that sweet potato is highy consumed. Yam is the main staple food in Ivory Coast and provides more than a third of energy from total R&T crops in 4 other African countries (Benin, Togo, Nigeria and Gabon). Other R&T crops are relevant in Vuanatu (93% of the energy supplied by total R&T crops), Papua New Guinea (33%) and Salomon Islands (21%).
In Latin America, R&T crops provide more than 200 kcal/d per inhabitant in 5 countries (Paraguay, Jamaica, Dominica, Colombia and Haiti). Among the 10 R&T crop higher consuming countries, Irish potato has the most important contribution in 3 Andean countries (Bolivia, Peru, and Colombia), cassava in 3 (Paraguay, Brazil, Haiti), yams in 2 caraibbean islands (Jamaica, St Lucia) and other R&T crops in 2 other caraibbean Islands (Dominica, St Vincent).

One of the best indicator to evaluate the nutritional importance of a food in a given population is its contribution to the total energy supply: indeed it takes into account both the available quantity of this food and the total available energy for this population. According to the FAO's statistics, R&T crops directly provide more than 25% of the available energy in 17 countries in the world (figure 5). Now and then, they are 14 African countries and 3 Pacific Islands. Except in Burundi, Rwanda, Ivory Coast and the Pacific Islands, cassava is the main staple foods. In Zaire, cassava represents 54% of the total dietary energy. R&T crops provide more than 5% (the world average) of the available energy in 9 Latin America countries (Paraguay, 5 caraibbean Islands, 3 Andean countries, and Brazil).

Comparison of quantities of R&T crops used as staple food or of energy available from R&T exhibits a large disparity among continents and countries. In several African countries and Pacific Islands where they provide more than a quarter of the available energy, R&T crops seem unquestionably necessary for the survival of population. Within a given country, dependance for R&T crops may be even higher in regards to differences noticed in ecological zones or rural and urban areas. In some Congolese villages, cassava provides 84% of the total energy consumed by countrymen (Cresta et al, 1985). Rural consumption of cassava, in 1975, was respectively about 3, 4 and 5 times higher than the urban consumption in Colombia, Brazil and Paraguay (FAO, 1990).
In Latin America from where most of the edible R&T crops originated, the sum of R&T crops used as human staple food is inferior to world mean except for cassava; consequently average energy consumed per inhabitant from R&T crops is significantly less for Latin American people (111 kcal/d) than for the rest of the world (140 kcal/d).

[2] This includes Europe, septentrional America (USA+Canada), North Africa, West Asia (from Turkey to Pakistan) and North Asia (ex USSR republics, Japan, North and South Korea, Mongolia).

3. NUTRITIVE VALUE

Nutritive value of starchy foods depends mainly on their nutrient content, on physico-chemical properties of their starches and on the existence of anti-nutritional activities and toxic substances.

3.1. Nutrient content

It is often assumed that R&T crops have a poor nutritive value because the comparison of their nutrient content to other crops is usually made on a fresh weight basis as expressed in composition tables. In fact this way of comparison does not reflect the reality. With regards to nutritional aspects, chemical composition of different foods should be compared considering them either in the state they are eaten or on a dry weight basis. In the every day life, nobody eats dry uncooked rice or wheat grains. The dry matter content of drained cooked rice (22%) or macaroni (23%) is lower than this of most R&T usual consumption forms. Because of the diversity of consumption forms and their high fluctuation in dry matter content, the easier way to evaluate and compare nutrient content consists in considering it on a dry weight basis. On the other hand, as nutrient content of R&T crops changes depending on the varieties within each species and on cultivation practices (e.g., fertilizer, length of vegetative cycle), climate, soil and location, we might only consider afterwards average values for each genus or species which do not always reflect the real composition of a definite crop available in a particular setting.

Several R&T crops have very low dry matter content (oca, ulluco) but, for others, it goes beyond 30g/100g FW (achira, arrowroot, cassava, new cocoyam, sweet potato) (table 2). Protein content of certain R&T crops (e.g., achira, cassava, arracacha) is very low but, for few others (Irish potato, yams), it varies within the same range than cereals. Except for certain sweet potato varieties, R&T crop fat content is very low, it is mainly composed by structural lipids of the cell membrane. The low fat and relatively high fiber contents of R&T crops explains that they have a slightly lower energy content than cereal crops. Proximate composition of yams varies within a great range in relation with the important diversity of this genus: dry matter content and protein content of yams cultivated in Cameroon varies between respectively 23.2 g/100g FW and 9.6 g/100g DM for *D. dumetorum* and 36.1 g/100g FW and 3.2 g/100g DM for *D. liebrechtsiana* (Trèche, 1989a; Agbor-Egbe and Trèche, 1995).

Comparison of the main R&T and cereal crops amino-acid composition with suggested amino-acid requirements (table 3) shows that protein quality of R&T crops are often higher than this of cereal crops, in particular for lysin content of proteins. All considered crops have chemical score (CS) greater than 100 when calculated in relation to the suggested amino-acid requirement for adult, but when CS are obtained from the suggested amino-acid requirement for preschool children, Lysin, as for cereals, results as the most frequent limiting amino-acid. Lopez de Romana *et al* (1981) in Peru reported that potato can be used successfully to supply up to 80 percent of the daily requirement of protein and 50 to 75 percent of the energy of infants and young children if the remaining is provided by a non bulky easily digestible food.

Table 4 shows that mineral composition of R&T crops can strongly differ from one crop to another. Calcium content is higher and the Ca/P ratio is more advantageous in most R&T crops than in cereals. However, except with sweet potato and old cocoyam, calcium content is inferior to the Lower Threshold Density (LTD) for the whole diet. Consequently, calcium-rich foods must be eaten in the same time that R&T crops. Other mineral content varies within the same range in R&T and cereal crops; except for giant taro, they are higher than LTD and may noticeably contribute to human requirements when they are still present in a bioavailable form after processing.

Vitamin C content of R&T crops is considerably higher than cereal and LTD for a whole diet. Hence, R&T crops can noteworthily contribute to human vitamin C requirements if it is not destroyed during processing. Except for giant taro, vitamin B1 and nicotinamide contents of R&T and cereal crops fluctuate within the same range and appears to be enough comparing to the corresponding LTD. On the other hand, vitamin B2 and Vitamin A (except for some sweet potato varieties) contents remain too low to significantly supply human requirements. Hence, consumption of vitamin A and B2-rich foods must accompany that of R&T crops.

3.2. Physico-chemical characteristics of starches

Starch is the principal constituant of edible carbohydrate and consequently the main source of energy in R&T crops. Starches are made up of amylose, a straight chain glucose polymer which usually constitutes about 10 to 30 percent of the total, and amylopectin. Their functional properties (i.e., gelatinization, pasting and retrogradation properties, swelling power and solubility, susceptibility to amylases) depend on their composition and on the molecular structure of granules. They firmly influence processing qualities of R&T crops and their digestibility.
Physico-chemical characteristics of starches vary from crop to crop and with ecological and agronomic influences. Starch granules of each species are characterized by their shape, size, amylose content, molecular weight of each fraction, degree/length of branching, physical manner in which the constituents are organized within the granules. Large differences are observed in susceptibility to alpha-amylase, swelling and solubility patterns among the different genus and species and at times amid varieties within the same species (Delpeuch and Favier, 1980).

Concerning the effect of starch characteristics on nutritive value, to simplify, one can distinguish two groups within starchy food plants. The first one which includes cereals, cassava, sweet potato, cocoyams and some yam species (*D. dumetorum*) is often called A-type group by reference to the cristalline organization type of their starch. The second one, or B-type group, contains Irish potato, canna and most of the yam species (*D. alata, D. rotundata, D. trifida*). A-type starches are more easily degraded by alpha-amylases than B-type starches, in particular when they are uncooked. Differences in the nature and digestibility of starch between *D. dumetorum* and *D. rotundata* yam species have been shown to have repercussions on digestibility and metabolism of yam based diets. Raw and boiled *D. dumetorum* flours promote higher growth rate in growing rat and have higher nutritional value in both growing rat and young children than corresponding *D. rotundata* flours (Mbome lape et al., 1994; 1995).

3.3. Antinutritional factors and toxic substances

As cereals and leguminous seeds, R&T crops may contain different potential toxic substances and antinutritional factors. Apart from cassava, cultivated varieties of most edible R&T crops do not contain serious toxic substances. But wild species, occasionally used in times of food scarcity, may contain lethal levels of toxic principles.

Cassava toxicity is caused by the presence in all parts of the plant of cyanogenic glycosides (i.e., linamarin, lautostralin) which are converted to toxic hydrocyanic acid by linamarase, an enzyme that is released when the cells of cassava roots are ruptured. HCN is a volatile compound which can be removed by evaporating at temperature over 28°C or dissolving in water. The concentration varies greatly between varieties and with cultural and environmental conditions. Different processes (e.g., retting, grating) can bring linamarase into contact with linamarine, convert it into HCN and then allow solubilization or evaporation of HCN. When these processes are not correctly performed, HCN can be ingested by men at levels susceptible to caused diseases. In the Bandundu region of Zaire, for example, decrease in the duration of cassava root soaking had resulted in high dietary cyanide exposure and apparition of «konzo», an upper motor neuron disease with permanent spastic paralysis of both legs (Banea *et al*, 1992). Among diseases related to cassava toxicity, we may notice:

- acute cyanide intoxication which can result in death after different symptoms (vertigo, vomiting, collapse);
- endemic goitre: a chronic cyanide overload leads to high level of serum thiocyanate which is the result of the conversion of HCN and sulphur-containing amino-acid derivatives by rhodanase. As thiocyanate interferes with iodine uptake by the thyroid gland, high cyanide intake and low iodine intake (<100 mg per day) end on apparition of endemic goitre or even in endemic cretinism. (Delange and Ahluwalia, 1985).
- nutritional neuropathies: cyanide intake from cassava-rich diet seems to be a determining factor in different forms of neuropathies. Tropical ataxic neuropathy appears when cassava with residual cyanide content is consumed and when the sulphur amino-acid content of the total diet is low. The clinical picture of tropical ataxic neuropathy, quite common in Nigeria, is dominated by damage to one of the sensory tracts in the spinal cord producing an uncoordinated gait called ataxia (Osuntokun, 1981; FAO, 1990). Cases of epidemic spastic paraparesis («konzo») have been observed in Zaire (Banea *et al*, 1992) and also in Mozambique (Cliff *et al*, 1985)

Phytic acid has the potential to inhibit some proteases and to bind calcium, magnesium, iron, zinc and other bivalent cations, thereby reducing their bioavailability. Phytate is present in different R&T crops (e.g., cassava, cocoyam, yam) but in a lower content than in cereals and leguminous seeds. Fermentation reduces phytate level owing to the action of phytase naturally present in the tubers or secreted by microorganisms.

Alpha-galactosides (raffinose, stachyose and verbascose), present in sweet potato, are not digested in the upper digestive tract. As they are fermented by colon bacteria to produce hydrogen and carbon dioxide, they are responsible for flatulence .

Some varieties of sweet potato show trypsin inhibitor activity but heating to 90°C for several minutes unactivates them. Proteinase inhibitors and lectins are also present in potato but they are destroyed by heat during cooking. Hence, they usually do not constitute a problem for human consumption.

In some potato varieties, alkaloid concentration arises up to 80 mg/100g in the tuber. At concentration higher than 20 mg/100g, they cause a burning and persistant irritation and solanine and other potato glycoalkaloids are toxic. They are inhibitors of choline esterase and cause damage to the gastro-intestinal tract as well as to the retina (FAO, 1990).
Wild forms of *D. dumetorum* and *D. hispida* contain bitter compounds which have been identified as alkaloids (respectively, dihydrodioscorine and dioscorine). They are water soluble alkaloids which, on ingestion, produce severe and distressing symptoms.

Polyphenols or tannin-like compounds tend to accumulate in immature tuber tissues of some yam species. Some varieties of cocoyams have high content of calcium oxalate crystals which have been implicated in the acridity or irritation caused by cocoyams and in a reduction of the bioavailability of calcium (Bradbury and Holloway, 1988).

4. EFFECT OF VARIATION FACTORS ON NUTRITIONAL VALUE

Differences between species and varieties are not the only sources of variation of nutritional value for plants used as human food. As previously reviewed for yams (Trèche, 1989a), cultural practices, storage conditions, and technological processes can strongly affect different characteristics of R&T tuber crops which determine their nutritional value. Consecutive changes in R&T crops nutritive value may consequence a variated kinds of risks, such as toxicity or decrease in processing aptitude or nutrient contents. (Trèche, 1989b).

4.1. Cultural practices

Chemical composition of R&T crops (e.g., dry matter, starch, amino-acid, mineral, vitamin contents) is affected by location and year of cultivation, seed quality, plant density, nitrogen and phosphorus fertilization, and duration of the vegetative cycle.
Granule size and some physico-chemical properties of potato starch change noteworthily with location and potassium fertilization. Nitrogen application affects amylose content of potato starch. Granule size and amylose content of starch from various species increase as roots or tubers grow.
Solanine content of potato depends on climate and state of maturity and on injuries of tubers at the harvest time. Cyanogenic glucoside content is influenced by depths of ploughing, soil amendments, nitrogen fertilizer application and harvest date.
Cultural practices usually affect acceptability of R&T crops by modifying shape, size, colour or taste of roots or tubers. Fertilization interfers with colour modification after cooking.
Nitrogen fertilization has been shown to affect potato protein digestibility and retention by rats and pigs.

4.2. Storage conditions

During storage, R&T crops generally loss weight and their dry matter content can strongly increase. Decrease in starch content and increase in free sugar and dietary fibre contents are often observed. Changes in other nutrient contents are often passive variations due to the decrease in starch or water content. But sometimes, decrease in ascorbic acid and some other vitamin contents occurs during prolonged storage.
Viscosity of Irish and sweet potato starch paste decreases with storage duration and temperature.
For some species, sweetness of R&T crops increases during storage. An increase in polyphenol content is often observed in yam tubers and has repercussions on tuber susceptibility to discoloration.
In some cases, minor changes in chemical composition can have severe results: tubers of *D. dumetorum* become unsuitable for human consumption few days after harvest because of the hardening phenomenon characterized by the deposition of a xylose-containing polymer and of additional cellulose and by the lignification of the tubers (Brillouet *et al*, 1981).

4.3. Processing

It is out of our purpose to examine the effects of all kind of processes on nutritive value of the different R&T crops but we will enumerate some effects of cooking, the most common process used during R&T crop processing into edible food.
Cooking improves R&T crop safety, keeping quality and digestibility, promotes palatability, and inactivates enzyme inhibitors and other antinutritional factors. However, it can reduce their nutritional value as a result of losses and changes in nutrient content including proteins, carbohydrates, minerals and vitamins. Nutrients may be lost during cooking in two ways. First by degradation which can occur by destruction or by other chemical changes such as oxidation, and secondly by leaching into the cooking medium. Minerals are affected only by leaching. Free amino-acids could be leached or may react with sugars to form complexes (e.g., Maillard reaction which makes lysin unavailable). Vitamins are susceptible to both processes: vitamin C is the most thermolabile and it is easily leached into cooking water; unlike the other B group vitamins, thiamine is also thermolabile and boiling can result in significant losses (about 25% for potatoes). To limit nutrient losses by leaching, to peel after boiling is often advisable.
The nature and the importance of nutrient losses which can occur during cassava root processing into traditional african forms of consumption are illustrated on figure 6: by comparison with energy and nutrient contents in whole roots, the processing yields varie between 27 and 85% for energy, 13 and 47% for protein, 27 et 52% for calcium, 5 and 42% for iron, 3 and 42% for vitamin B1 and 0 and 62% for vitamin C (Favier et al, 1971).

On the other hand, cooking has drastic effects on physico-chemical properties of starches, in particular amylase susceptibility, and on organoleptic characteristics (color, taste, texture). It strongly improves digestibility and metabolism of diets prepared from R&T crops with B-type starch. Nevertheless, cooking can not completely remove differences in nutritional value between A-type and B-type starch based diets.

5. FUTURE FOR ROOT AND TUBER CROP UTILIZATION AS FOOD

5.1. Recent evolution of R&T crop consumption

During the last twenty years (1972-1974 *versus* 1992-1994), the amount of energy supplied by R&T crops for human direct consumption have declined in most parts of the world (figure 7). For the Asian and Pacific area, and Latin America, dietary energy from R&T crops is, respectively 42% and 32% less during the 92-94 period than during the 72-74 period. However, the amount of energy consumed per capita from R&T crops have lightly increased in Africa. If we consider the evolution in the 15 most consuming countries during these last twenty years, R&T crop direct consumption has highly increased in West Africa (Nigeria, Ghana and Benin) and strongly decreased in some Central African countries (Central Africa Republic, Congo, Gabon, Angola). Level of consumption had remained quite constant in Zaire, Ivory coast and Uganda. In the Pacific Islands, R&T crop consumption has increased in Vuanatu but decreased in Papua New Guinea and Salomon Islands. In Latin America, since the 1972-1974 period, the relative importance of R&T crops in human diets has increased in Jamaica and Colombia but in Brazil, Peru and Bolivia, the decrease in energy consumed from R&T crops is superior to 40%.
Owing to some processing and marketing constraints of R&T crops (e.g., high water content, transportation cost, perishability) and enhancement of food habit evolution by urbanization, it is likely that variations observed in some countries are related to the change in the proportion of urban people. In Zaire where this proportion has slightly shortened during the last twenty years (30.1% to 28.5%), importance of R&T crops has remained at the same level. On the other hand, in other African countries where proportion of urban people has markedly increased (Congo, Togo, Mozambique, Gabon) direct consumption of R&T crops has decreased. Therefore, changes in the proportion of urban population do not explain all the occured evolutions: in Nigeria, where urban population has increased from 22% to 38%, R&T crop consumption alongs with it; in Central Africa Republic where urban population has not markedly changed (32 to 38%), a drastic decrease in the dietary energy provided by R&T crop has intervened.

Recent evolution (1980-1982 *versus* 1990-1992) of the energy supplied by the various R&T crops in the different regions of the world is characterized by (figure 8):
- a strong decrease in the utilization of sweet potato, in particular in Asia. Considering world averages, relative importance of other R&T crops has remained quite constant;
- a light diminution of potato consumption in Europe (7 kcal in average);
- a raise of the energy consumed from all R&T crops except sweet potato, in Africa and Oceania;
- a decline in the direct consumption of all R&T crops in South America.

Moreover we can conclude that, except in Africa and Oceania, dietary energy supply from R&T crops have diminished during the two last decades. Sweet potato and Asia are the most concerned by this evolution. However, in South America, a shorten in cassava and Irish potato direct consumption per capita was also observed.
What is expected for the tomorrow R&T crop consumption ? It is difficult to forecast in this domain but in regards to recent evolution it is likely that it will still decline, especially in countries where R&T crops supply high proportion of available dietary energy and with extention of urban population. But there is no reason to think that R&T crops could not remain staple foods

for a large number of populations as bread and pasta have remained basic foods in certain European countries.

5.2. Desirable evolution from a nutritional point of view

R&T crops are well adapted to diverse climate and soil and have the potential to provide more dietary energy per hectare than cereals. In addition, nutrient content of most of them is comparable to that of other starchy crops when considered on a dry weight basis. Therefore, their contribution to food security appears to be a vital part for many populations and their production for food must be enhanced.
However, partially in the world, mainly in Central Africa, the heaviness of cassava in human diets is noticed to be very high and might be reduced and substitued by some other kind of food. Toxicity problems observed in Zaire, Mozambique and Nigeria would not be so acute if food supply were more diversified. On the other hand, a given biological organism can be jeopardized by new aggressors. Recent informations from AIDS and «mad cow» disease alongs well with it and we must never forget that the great famine caused by a potato-blight killed millions of Irish people in the middle of the 19th century. In areas where a single R&T crop provides more than 50% of dietary energy, diversification of production has to be encouraged. Inversely R&T crop production and utilization as food where monotonous diets based on a single other production are observed should be enhanced.

5.3. Research and transfer needs

During the last decade, biotechnological research in regards to tropical R&T crops has been extensively developped and new applications in genetics, agronomy, plant disease control, industrial processing are emerging. Simultaneously, in Africa where they are invaluable importance for food security, few efforts has been done to improve and to standardize quality of R&T crop based foods or to great their availability by adapting processes to urban conditions. In addition, when some proposals have derived from the few studies carried out, they hardly ever been applied in satisfactory conditions to concerned people. Most difficulties occured in African countries where noticed a lack of the required means to assure by themselves research and development. Efficacy of European cooperative programmes to diffuse innovations is limited by the fact that tropical R&T crops are culturally foreign to European civilization. Then, we shall hope that South to South collaborations will be developed, particularly among the present cassava consumers, the African populations, and the descendants of cassava discoverers and domesticators, Latin American people.

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Table 1: Common names, origin and present distribution of the main root and tuber crops

Scientific name	Common names	Origin	Present distribution
Alocasia macrorrhiza (L.) Schott	Giant taro (E)	Asia	Sri Lanka, Southeast Asia, Pacific Islands
Arracacia xanthorrhiza Bancr.	Arraccacha, Peruvian carrott Arracacha (P)	Andean higlands from Venezuela to Bolivia	Latin America, in particular South America
Canna edulis Ker.	Achira, Edible canna (E) Achira (P)	Tropical America	Latin America, Asia, Pacific Islands
Colocasia esculenta (L.) Schott	Old cocoyam, Dasheen, Taro (E) Name (P)	Southeast Asia India	All parts of the tropics in particular Tonga Isl and Western Samoa
Dioscora spp.	Yams (E) Cara (P)	Asia, Africa, America	Asia, Africa, Caribbean Pacific islands
Ipomea batatas (L.) Lam.	Sweet potato (E) Batata (P)	Central (Yucatan peninsula), north-western South America	All (sub)tropical parts and warmer areas of temperate regions
Manihot esculenta Crantz	Cassava (E) Yuca (P)	Northeast Brazil Central America (?)	All tropical and subtropical parts
Marantha arundinacea L.	Arrowroot (E) Araruta (P)	Tropical America	Tropical America, Tropical Asia
Oxalis tuberosa Mol *O. crenata.*	Oca (P) Oca, New Zealand Yam (E)	Andean region	Andean region, Mexico, New Zealand
Pachyrrizus ahipa	Ahipa (E) Ahipa (P)	Andean region	Peru, Bolivia
Polymnia sonchifolia	Yacon (E) Yacon (P)	Andean region	South America and Southeast Asia
Solanum tuberosum L.	Irish potato (E) Papa (P)	Andean area	All tropical, subtropical and temperate regions
Ullucus tuberosus Caldas	Ulluco (P) Ulluco (E)	Andean region	Andean region
Xanthosoma spp.	New cocoyam, Tannia (E) Mangarito (P)	Tropical America	Tropical America, South-E Asia, Pacific Is., Africa

E: English P: Portuguese

Table 2: Comparison between R&T and cereal proximate composition.

Food	Ref.	Dry matter g/100 g FW	Protein	Fat	A. CHO	Fibre	Energy kcal/100gDM
			g / 100 g dry matter				
Main R&T crops					(a)	(c)	
Cassava	(1)	31.3	2.7	0.62	86.9	7.9	364
Irish Potato	(1)	22.2	9.2	0.50	66.7	9.3	316
Sweet potato	(1)	30.8	5.3	1.95	78.2	10.2	351
Yam	(1)	31.1	6.4	0.42	72.8	17.9	318
Other R&T crops					(b)	(d)	
Achira	(2)	33.2	2.7	0.30	94.3	1.5	392
Arracacha	(2)	27.0	3.0	0.74	92.2	2.2	385
Arrowroot	(2)	42.8	5.6	0.23	91.1	4.4	367
Cocoyam (old)	(2)	25.4	6.3	0.79	88.2	3.1	362
Cocoyam (new)	(2)	34.1	5.0	0.88	90.6	1.8	387
Giant taro	(3)	29.7	7.2	0.34	75.6	6.2	361
Oca	(2)	16.2	6.2	3.70	85.2	4.9	389
Ulluco	(2)	14.1	7.1	traces	88.6	4.3	362
Cereal crops					(a)	(c)	
Maize	(1)	87.5	9.8	4.34	73.9	10.5	374
Rice	(1)	86.9	8.3	2.53	85.2	2.6	397
Sorghum	(1)	88.6	11.6	3.61	78.6	4.2	393
Wheat	(1)	86.8	13.5	2.30	70.2	11.9	355

(a) Available carbohydrate
(b) Total carbohydrate (difference method)
(c) Total dietary fibre: enzymatical methods or difference method [100 - (protein + fat + A. CHO + ash)]
(d) crude fibre
FW: fresh weight - DM: Dry matter
Sources: (1) Souci and al, 1994 - (2) INCAP-ICNND, 1961 - (3) Bradbury and Holloway, 1988

Table 3: Comparison of main R&T and cereal amino-acid composition with suggested patterns of amino-acid requirement (SPR).

Crops	Ile	Leu	Lys	Met+Cys	Phe+tyr	Thre	Tryp	Val	CS (a)
	amino acid (mg / g crude protein)								
Cassava	28	40	**41**	27	**41**	26	12	33	61
Cocoyam (old)	35	74	**39**	40	87	41	14	61	67
Irish Potato	39	59	60	30	78	39	14	51	89
Sweet potato	37	54	**34**	28	62	38	14	45	58
Yams	37	65	**41**	28	80	36	13	47	71
Maize	37	125	**27**	35	87	36	7	48	47
Rice	38	82	**38**	34	86	39	12	55	65
Sorghum	39	133	**20**	29	76	30	12	50	34
Wheat	33	67	**29**	40	75	29	11	44	50
SPR child (2-5yr)	28	66	58	25	63	34	11	35	
SPR adult	13	19	16	17	19	9	5	13	

(a) Chemical score according to the SPR for preschool child (FAO/WHO/UNU, 1986)
Deficient amino-acids are in heavy type - Limiting amino-acids are underlined.
Source: FAO (1970)

Table 4: Comparison between R&T and cereal mineral composition.

Food	Ref.	Calcium	Phosphore	Magnesium	Iron	Zinc
				(mg / 100 kcal)		
Main R&T crops						
Cassava	(1)	23.8	28	48	0.88	0.41
Irish Potato	(1)	8.8	71	28	0.57	0.49
Sweet potato	(1)	32.3	42	23	0.78	0.83
Yam	(1)	25.3	44	-	0.91	0.11
Other R&T crops						
Achira	(2)	11.5	48	-	1.08	-
Arracacha	(2)	27.9	56	-	1.15	-
Arrowroot	(2)	12.7	15	-	2.00	-
Cocoyam (old)	(2)	104.3	96	-	1.30	-
Cocoyam (new)	(2)	10.6	42	-	0.60	-
Giant taro	(3)	10.5	12	14	0.23	0.42
Oca	(2)	6.3	54	-	1.27	-
Ulluco	(2)	5.9	69	-	0.59	-
Cereal crops						
Maize	(1)	4.6	78	36	0.44	0.76
Rice	(1)	6.7	95	45	0.75	0.44
Sorghum	(1)	4.8	95	197	1.63	1.10
Wheat	(1)	12.4	110	41	1.07	0.87
LTD		28	21	10	0.50	0.40

LTD: Lower Treshold Density (Golden *et al*, 1995)

Sources: (1) Souci *et al*, 1994 - (2) INCAP-ICNND, 1961 - (3) Bradbury and Holloway, 1988

Table 5: Comparison between R&T and cereal vitamin composition.

Food	Ref.	Vitamin A	Vitamin B1	Vitamin B2	Nicotinamide	Vitamin C
		µg eq ret/100kcal	µg / 100 kcal			mg / 100 kcal
Main R&T crops						
Cassava	(1)	3.7	45	22	446	22.3
Irish Potato	(1)	1.2	157	67	1737	24.2
Sweet potato	(1)	1321.1	59	46	554	27.7
Yam	(1)	1.7	91	30	607	10.1
Other R&T crops						
Achira	(2)	traces	23	8	308	5.4
Arracacha	(2)	57.6	58	38	3269	26.9
Arrowroot	(2)	traces	51	19	446	5.7
Cocoyam (old)	(2)	5.4	87	43	761	7.6
Cocoyam (new)	(2)	7.6	98	23	530	3.8
Giant taro	(3)	traces	6	5	133	4.7
Oca	(2)	traces	79	111	635	58.7
Ulluco	(2)	traces	78	39	588	45.1
Cereal crops						
Maize	(1)	56.5	110	61	459	traces
Rice	(1)	0.0	119	26	1507	traces
Sorghum	(1)	1.0	97	43	947	traces
Wheat	(1)	1.1	149	35	1651	traces
LTD		20	23	43	440	0.8

LTD: Lower Threshold Density (Golden *et al*, 1995)
Sources: (1) Souci *et al*, 1994 - (2) INCAP-ICNND, 1961 - (3) Bradbury and Holloway, 1988

Figure 1: Comparison of food utilization and total production of root and tuber crops in the world and latin Americán main producing countries (period 1992-1994).

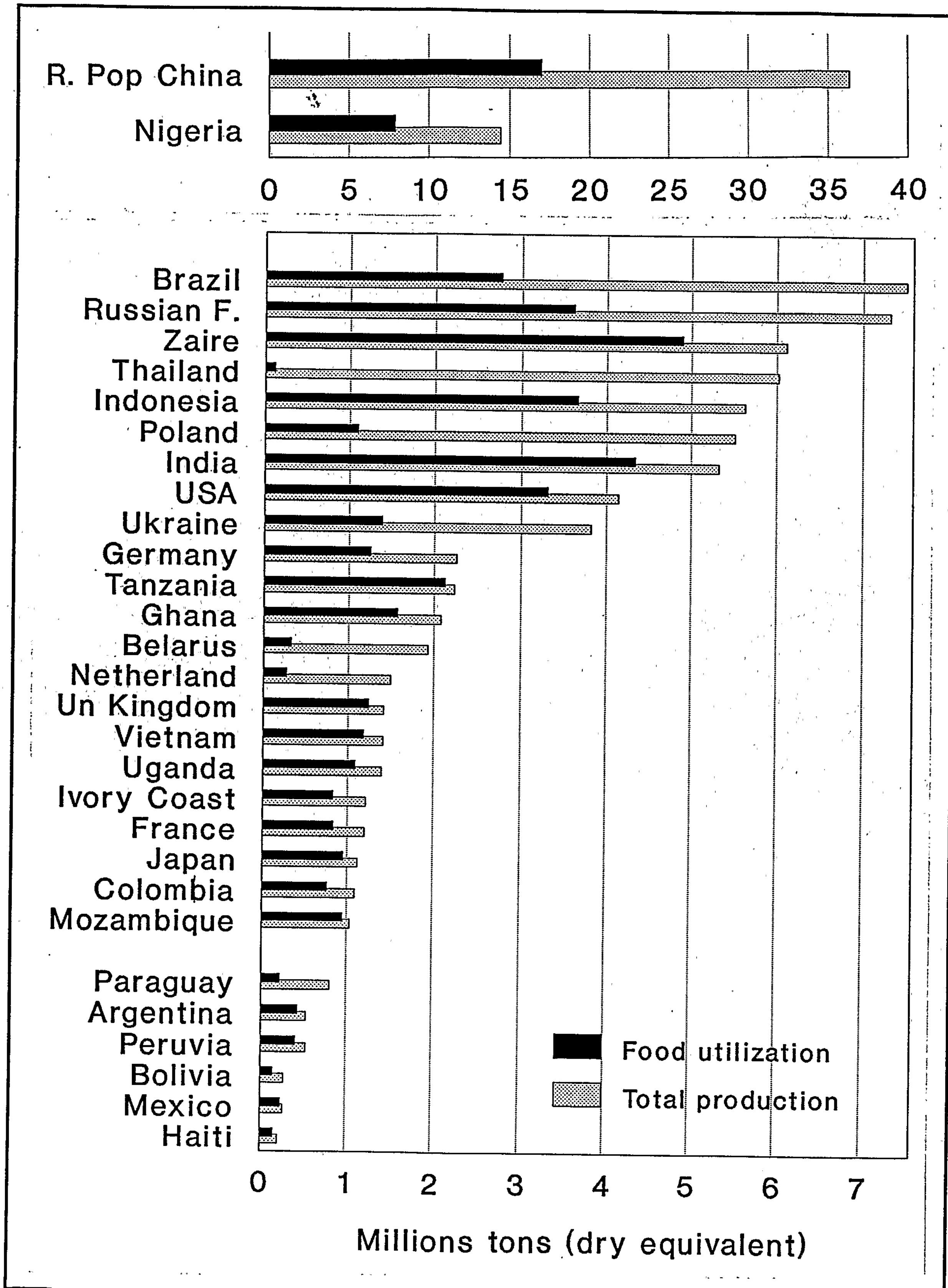

Figure 2: Consumption of root and tuber crops in different parts of the word (1992-1994)

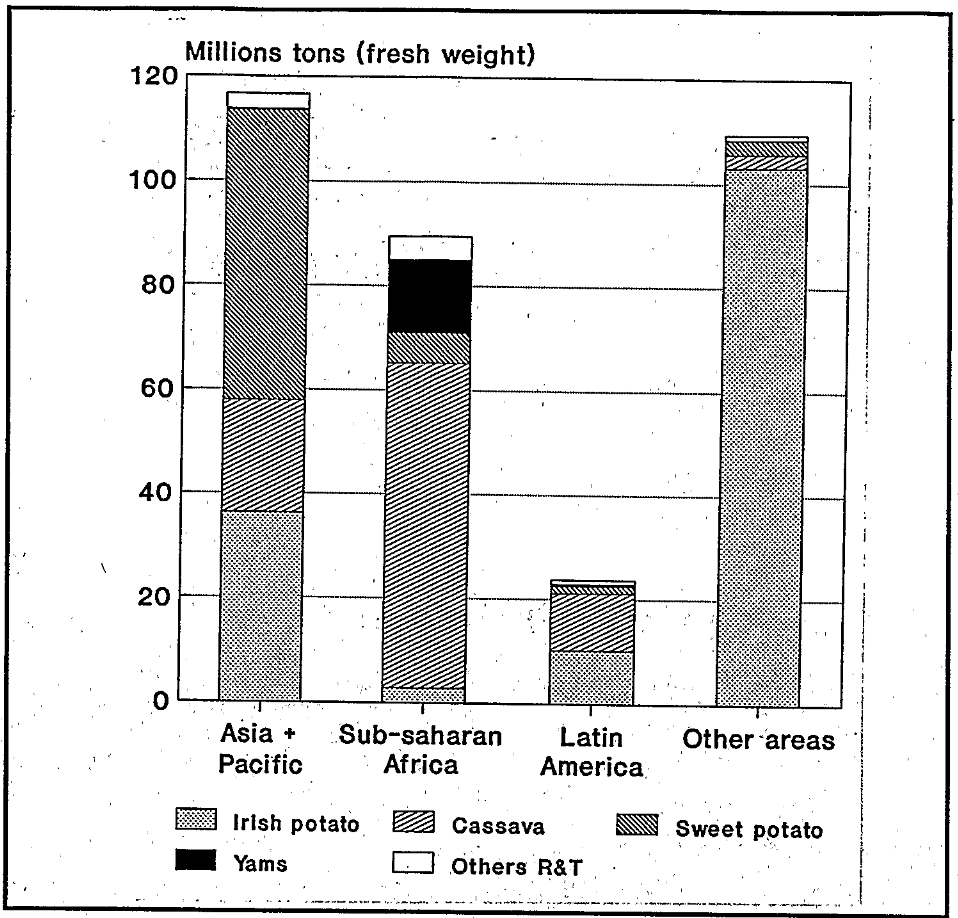

Figure 3: Comparison of the quantities of the different R&T crops used as food in the world (period 1992-1994)

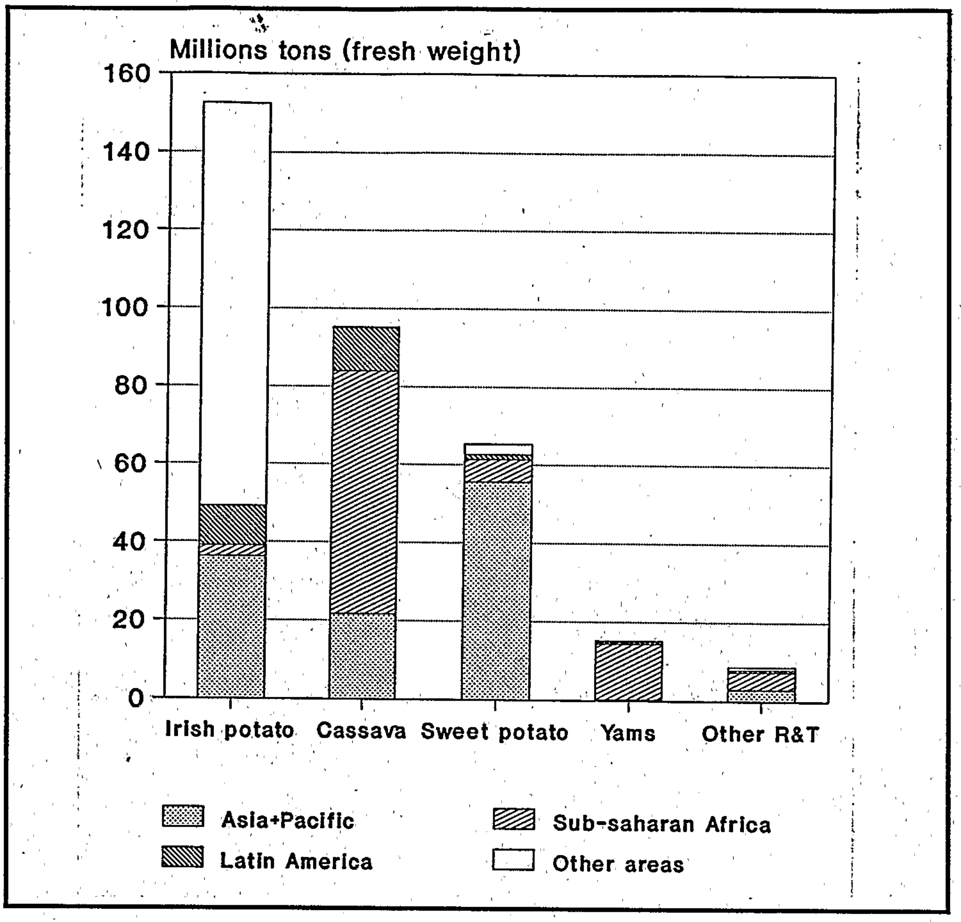

Figure 4: Energy supply from different root and tuber crops in the world and Latin American countries with highest cálorie intake from R&T crops (period 1992-1994).

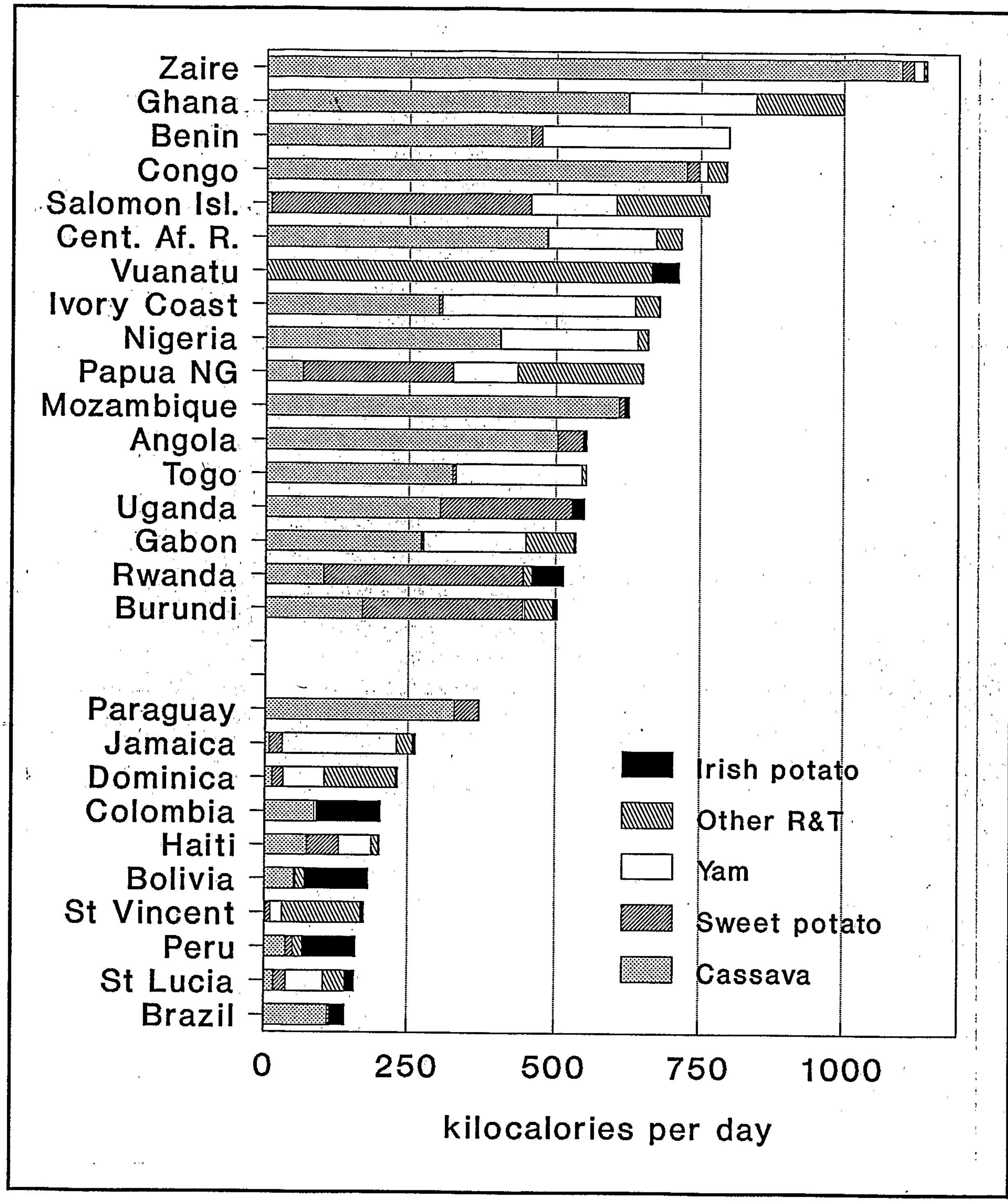

Figure 5: Contribution of cassava and total root and tuber crops to total dietary available energy per capita in the world and Latin American countries with highest calorie intake from R&T crops (period 1992-1994).

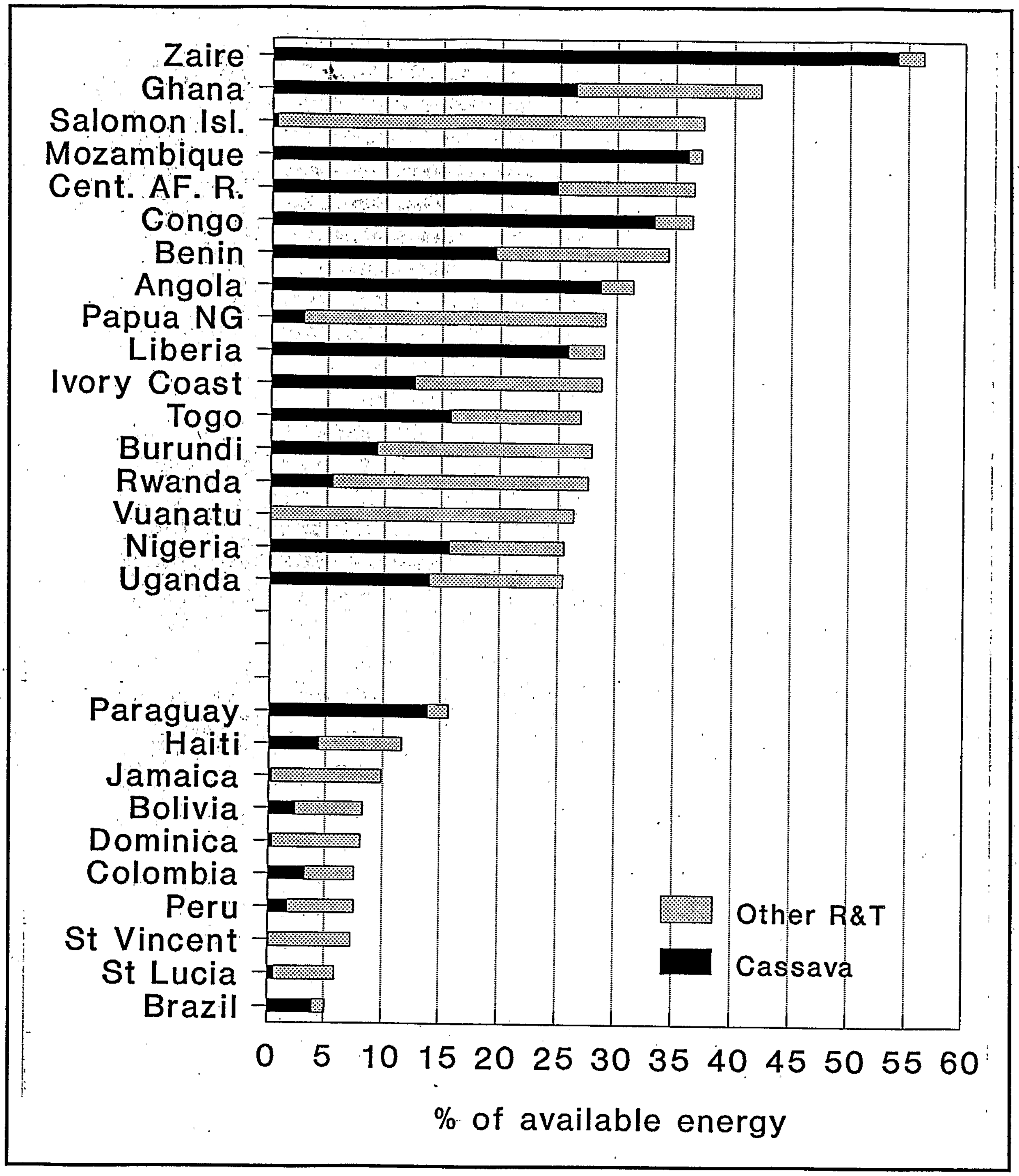

Figure 6: Energy and nutrient yields of the processing of cassava roots into different African forms of consumption.

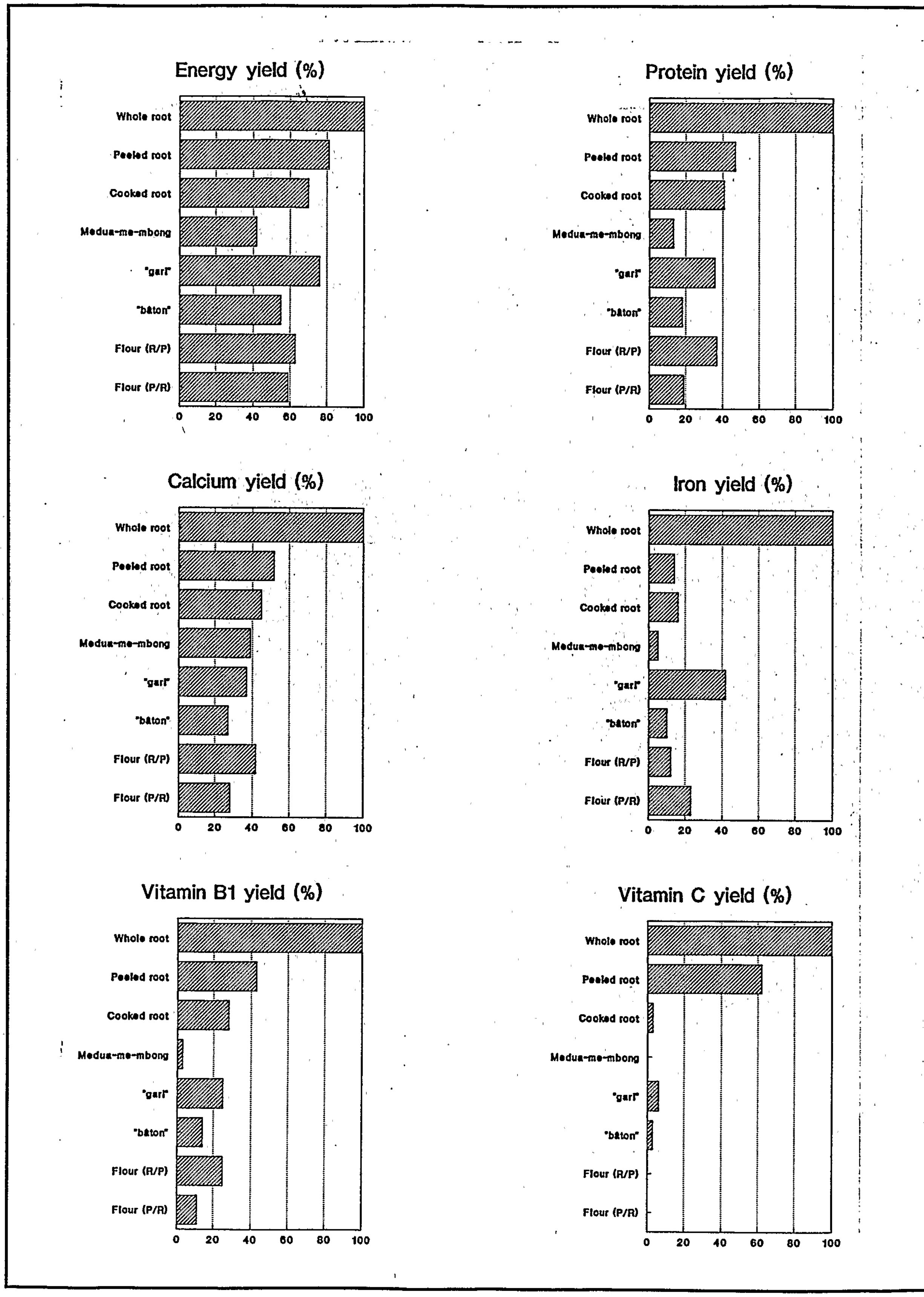

Figure 7: Variation (%) in the energy supply from R&T crops between the 1972-1974 and the 1992-1994 periods in different regions of the world and in Latin American countries with highest calorie intake from R&T crops.

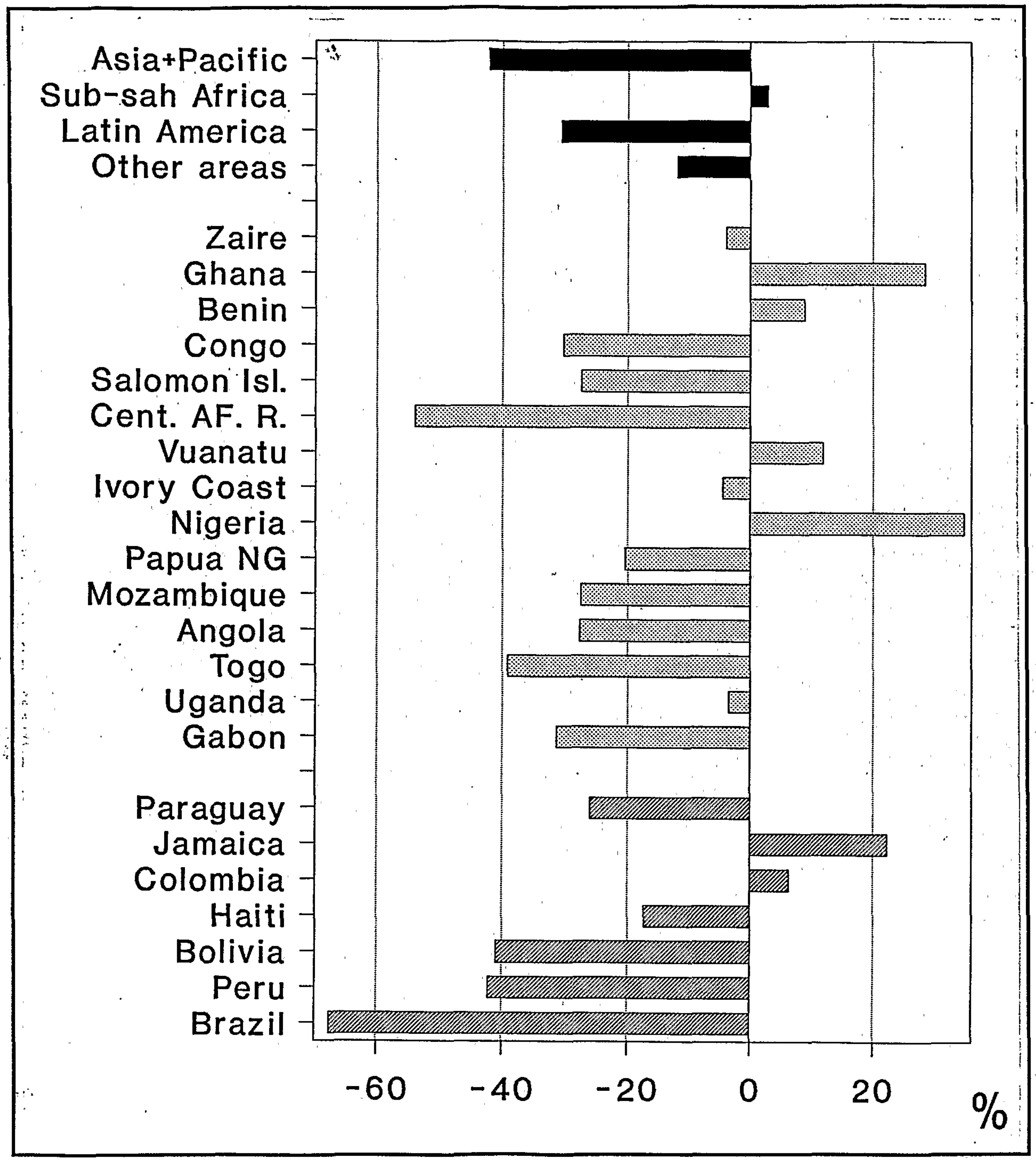

Figure 8: Variation of the average available energy per capita from different root and tuber crops in different regions of the world between the 1980-1982 and the 1990-1992 periods.