European Journal of Agriculture and Food Sciences
www.ejfood.org

Recent Progress in Breeding for Beta-Carotene, Dry Matter Content and Sugar in Sweet potato [*Ipomoea Batatas* (L.) Lam]-A Review

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ABSTRACT

In several developing countries, root and tuber crops play a crucial role in food security as well as in agriculture. Based on production and consumption, sweet potato [*Ipomoea batatas* (L.) Lam] plays a significant role after potato among the root and tuber crops. Today, sweet potato breeding program focus on multiple purposes. There are four sweet potato breeding platforms (three in Africa) and in SSA there are four breeding centers (three in West Africa). High levels of β-carotene, phenolics, anthocyanins, vitamins, fiber, dietary, minerals, and other bioactive compounds content depends on the flesh color of sweet potatoes. The orange-fleshed sweet potato types contain high β-carotene levels and low dry matter content. White-cream fleshed color varieties have high dry matter (>30%). The purple-fleshed sweet potato varieties with attractive color and high anthocyanin content are the most preferred in Asia. Sweet potato with low in sweetness and higher dry matter (28–30%) are the specially of most parts of sub-Saharan Africa. Consuming β-carotene leads as a viable long-term food-based strategy for combating the deficiency vitamin A in the world. The sweet potato dry matter content up of 80-90% carbohydrates and exists in the form of starch and sugars non-starch polysaccharides. The primary contributors to the taste of the sweet potato are sugars and organic acids. The strong flavor and high levels of sweetness may have affected the popularity of sweet potato as a staple food. Due of the negative correlation between traits, breeding for high B-carotene and dry matter with low sugar in one variety has remained a challenge, although it was reported that recurrent mass selection should be possible to accumulate favorable alleles so that progress can be made over.

Keywords: b-carotene, dry matter, sugar, starch sweet potato.

Submitted: July 28, 2022
Published: January 9, 2023
ISSN: 2684-1827
DOI: 10.24018/ejfood.2023.5.1.551

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I. Introduction

In many developing countries, root and tuber crops facilitate food security and play a significant role in agriculture. The global production of roots and tubers crops of 2019 was 846 million tons [1]. For majority of the global population, root and tuber crops are part of the diet with 19.4 kg/year (2013–2015) world average per capita, consumption and projected to achieve 21.0 kg/year by 2025[2] . It also contributes to animal feeds and use starch to attain the industrial requirements [3]. Sweet potato is a crucial energy contributor [4]. Sweet potato is cultivated in more than 115 countries [5]. Compared to the other staple food crops, sweet potato possesses particular attributes such as good productivity in short durations, the capacity to grow in difficult condition, adaptability in wider topography, and balanced nutritional composition [6].

Based on the flesh color, sweet potatoes contain anthocyanins, dietary fiber, high levels of β-carotene, vitamins, minerals, phenolics, and other bioactive compounds [7], [8]. The storage roots of sweet potato have sensory versatility and high nutritional value in terms of the texture, taste, and flesh colors (cream, white, yellow, orange, and purple). In the tropics, consumers preferred high dry matter varieties (>25%), white-cream flesh color, and mealy firm texture after cooking are. These varieties are “camote”, “batiste”, and “bianito,”, and known as tropical sweet potato. In most parts of sub-Saharan Africa, cultivars with low in sweetness and higher dry matter (28–30%) are preferred, compared to those cultivated in United States of America (USA) [9], [10]. In the USA, orange-fleshed sweet potato is the commercially popular type with high β-carotene level, sweet, low dry matter (18–25%), and moist-texture after cooking [11]. The Asia types of sweet potato varieties are purple fleshed with high anthocyanin content and attractive color.

As the most affected continent, thirty African nations suffer from micronutrient malnutrition, undernutrition, and the increasing problem of being overweight [12] In SSA, the number of undernourished people rose from 181 million in 2010 to almost 222 million in 2016 [13]. Moreover, malnutrition of micronutrient remains a major public health concern in Sub-Saharan Africa and, when experienced early in life, can lead to irreversible negative health consequences for cognitive capacity and physical work. In as of 2011, SSA is one of the major regions of the world, that had the highest vitamin A deficiency, and the second for zinc, iron, niacin, calcium, and vitamin B12 [14]. In this region, about half of the children less than 5 years aged suffer from vitamin A deficiency and 60% suffer from iron deficiency, which is the major cause of anemia and the most common micronutrient deficiency in the world.

In many countries in sub-Saharan Africa, the sweet potatoes that have higher dry-matter content (28–30%) and little to no sweetness are the preferred types [9]. The low sugar and high dry matter varieties tend to be low in carotenoid content, thus, these varieties have low nutrition values compared to the orange-fleshed types [7]. Therefore, in SSA breeding work is based on semi-sweet OFSP development with higher dry-matter, and also high storage root yields [10]. This new direction aims in selection new sweet potato to combat children and women vitamin A deficiency to prevent malnutrition and enhance food security and nutrition [7], [15]. This article provides a contemporary sweet potato review for the breeding aspects of beta-carotene, dry matter and sugars and their inter-relationship with yield.

II. Sweet Potato Production and Farmers' Traits Perception

A. Production

In SSA, sweet potato grows from sea level to an altitude of 2,400 meters, and it can fit into diverse farming systems. Sweet potato worldwide production in 2020 was 89,487,835 tons, with an area of production of 7,400,472 ha [16]. Asia is the largest producer, followed by Africa (Table I) [16]. In West Africa, Nigeria ranked first sweet potato producer (3,867,871 tons), and Niger Fourth (209,864 tons) [16].

Over 20 years (1997–2016), sweet potato production in SSA has been increasing with a compound annual growth rate of 5.1% in production and 3.3% in area [5], showing the yield improvement. The production per capita of the top 15 SSA countries sweet potato producers in year 2018 indicated that the crop is a primary staple food (>50 kg/capita) in four nations (Tanzania, Burundi, Rwanda, and Malawi), and a secondary staple in other ten countries (10–50 kg/capita).

However, the average storage root yields in SSA, are still relatively low, with an average of 6 t/ha compared to South America (13 t/ha), China (22 t/ha) and Northern America (25 t/ha) (5). The average storage root yield gap between the SSA smallholder farms (6–10 t/ha), and the potential yields from commercial farms in South Africa (60–80 t/ha) is high (7). To reach the full potential of sweet potato contributing to improved nutrition in SSA, the causes of these yield gaps need to be addressed in conjunction with biofortification.

B. Sweet Potato Breeding Programs in SSA

Central America is the center of origin of America [17], [18] but International Potato Centre (CIP) in Peru is the center of diversification. Sweet potato was domesticated in either South America or Central America more than 5,000 years ago. The crop production geography is large with, from 40° north to 32° south latitude of the globe.

TABLE I: World and Regional Production During the Last Ten Years (2011–2020)

Area	Europe	Oceania	Africa	Americas	Asia
2011	49427	812729	17868530	3500129	72208849
2012	45300	831477	18782687	3500151	67695256
2013	53249	857728	21018779	3571913	64824649
2014	68501	879400	25240185	3832407	63611003
2015	66272	901587	24684459	3898757	62029832
2016	89465	906500	26021215	4003990	59604157
2017	96155	897568	28263555	4115381	59148457
2018	NR	900654	26112822	3643086	60818455
2019	NR	902734	27684317	4052732	58850520
2020	NR	901612	28798180	3808444	55979599
Total	468369	8791989	244474729	37926990	624770777

The breeding network for sweet potatoes comprises four breeding platforms: the CIP in Peru, the National Crop Resources Research Institute (NaCRRI) in Uganda, the Mozambique Institute of Agricultural Research (IIAM), the Council for Scientific and Industrial Research-Crop Research Institute (CSIR-CRI) in Ghana. Furthermore, there are 12 sweet potato national breeding programs (Table II) including the IIAM, the NaCRRI, the CSIR-CRI, the Agricultural Research Council (ARC) in South Africa, the Kenya Agricultural Research Institute (KARI), the Zambia Agricultural Research Institute (ZARI), the Agricultural Research Institute (ARI) in Tanzania, the Department of Agricultural Research Services (DARS) in Malawi, the Rwanda Agriculture Board (RAB), the Ethiopian Institute of Agricultural Research (EIAR), the National Root Crop Research Institute (NRCRI) in Nigeria, and the Environmental and Agricultural Research Institute (INERA) in Burkina Faso (19). However, today, the West African sweet potatoes breeding platforms is located in Nigeria.

Work has been done through the SSA support platform, and a released OFSP varieties are presented in Table III. The catalogue contains pictures and from all OFSP varieties released since 2009. The contributions of some countries to the catalogue are in Table III. The SASHA focus countries had released 84 varieties of 36 OFSP since 2009.

TABLE II: Sweet Potato Nars Breeding Programs In Ssa

Region	Country	Number
West Africa	Ghana, Nigeria, and Burkina Faso	3
East Africa	Kenya, Rwanda, Ethiopia, Uganda, Tanzania, Zambia, Mozambique, and Malawi	8
South Africa	South Africa	1
Central Africa		0

C. Farmer Preferred Traits

Abiotic and biotic sweet potato constraints are those facing SSA in increased production and productivity. Drought is a major abiotic constraint prevalent in sweet potato producing areas, in which 52 million people are affected annually, while serious biotic constraints include viruses, mainly sweet potato virus disease (SPVD), sweet potato weevils, and fungal diseases, mainly *Alternaria bataticola* blight [20].The frequency and severity of drought stresses are expected to increase under climate change, particularly in West Africa [21]. Drought stress, poor access to planting material, pests and pathogens, and poor soil fertility are the most frequently mentioned sweet potato constraints, contributing to yield gaps [22].

TABLE III: Sweet Potato Variety Releases In Sasha Focus Countries Before The Sasha Project Was Implemented (1999–2008) And During The Project (2009–2013)

Country	Number of varieties released		Total
	1999 to 2008	2009 to 2013 (Orange flesh)	
Ethiopia	10	0(0)	10
Ghana	0	4(2)	4
Kenya	5	7(5)	12
Malawi	6	7(5)	13
Mozambique	12	20(15)	32
Nigeria	3	5(2)	8
Rwanda	8	11(2)	19
Sought Africa	11	18(5)	29
Tanzania	6	7(2)	13
Uganda	19	3(2)	22
Zambia	7	5(3)	12
Total	87	84(36)	171

In SSA, the most relevant criteria used by smallholder farmers to adopt OFSP include yield, drought tolerant, earliness, resistance to pests and pathogens, nutritive value, taste, multipurpose utilization, market demand and external appearance of roots leaves [23], [24]. A study conducted in the Niger republic found that the most preferred traits in the Western part are earliness, taste, root size and resistance to pests and diseases [25]. Moreover, in Niger, farmers preferred high yielding white color and drought tolerant cultivar, while in Nigeria they preferred high yielding white cream and low-sweet [26]. In Ghana, the study revealed that consumers preferred non-sweet sweet potatoes with high storage root yield and dry matter content [27].

Results showed that more a farmer is implicated in the development and dissemination of new variety; more he adopted easily this variety. Study in Uganda exhibited that farmers implicated in participatory cultivar selection and participatory plant breeding were 7 and 37 times more likely to adopt improved sweet potato variety than those who were not implicated [28]. Besides, the author added, that farmers who have been specifically trained in sweet potato production were 9 times more likely to accept new cultivar compared to those who have not been trained in this particular aspect [28].

Consumer desires and gender [29] need to be seriously taking in account for sweet potato adoption [30]. Quality traits related to storability and storage root texture are of particular importance. Hence, while biofortifying sweet potato through breeding, it is also necessary concurrently to develop well adapted cultivars to increasingly risky rainfed conditions, mainly drought stress, that are resistant to key diseases, especially viruses, and pests, and that contain preferred quality attributes to be widely adopted.

III. Beta-Carotene

A. *Beta-Carotene Background*

The concentration of β-carotene, anthocyanins, dietary fibre, phenolics, minerals, vitamins, and other bioactive compounds, depend on the flesh colors of sweet potato. However, all flesh colors are good sources of vitamins C, K, E, and several B vitamins, and minerals (Table IV). Table IV showed the very high concentration of vitamin A (727 ug/100g) in orange fleshed varieties, while concentration for other vitamins remained slightly constant across all the flesh colors.

The β-carotene presents in OFSP can play a significant role as a long-term nutritive strategy to combat vitamin A deficiency in the world. In Africa, researchers showed that more the lactating mothers, pregnant women, and children increase their consumption of OFSP, more they improve their vitamin A status [7], [8]. Furthermore, polyphenolics from purple-fleshed sweet potatoes showed various biological activities, including protective antioxidant, antidiabetic, anticancer, anti-inflammatory, and hepatoprotective activity effects [31].

TABLE IV: Vitamin and Mineral Composition in Sweet Potatoes per 100 G

Nutrients	Unity	OFSP	YFSP	WFSP	Leaf SP
Vitamin A (RAE)	ug	727	150	3	51
Iron	mg	0.61	0.61	0.61	1.01
Zinc	mg	0.3	0.3	0.3	0.29
Thiamine (B1)	mg	0.078	0.078	0.078	0.156
Riboflavin (B2)	mg	0.061	0.061	0.061	0.345
Niacin (B3)	mg	0.557	0.557	0.557	1.13
Vitamin B6	mg	0.209	0.209	0.209	0.19
Folic acid (total)	ug	14	14	14	80
Vitamin E	mg	0.26	0.26	0.26	NR
Vitamin C	mg	22.7	22.7	22.7	11
Protein	g	1.57	1.57	1.57	4
Fiber	g	3	3	3	2
Vitamin K	ug	2.1	2.1	NR	109

AAD (2000).
USDA (2003) for Vitamin K.

As Africa the most affected continent, thirty African countries suffer from micronutrient malnutrition, undernutrition, and the increasing problem of being overweight [12]. In sub-Saharan Africa, the number of undernourished people rose from 181 million in 2010 to almost 222 million in 2016 [13]. Moreover, micronutrient malnutrition remains a major public health concern in SSA and, when experienced early in life, can lead to irreversible negative health consequences for physical work and cognitive capacity. In 2011, SSA had the highest vitamin A deficiency and second for zinc, iron, niacin, calcium, and vitamin B12 compared to other major regions of the world [14]. In SSA, around half of the children less than 5 years old suffer from vitamin A deficiency and 60% suffer from iron deficiency, which is the anemia major cause and the most common deficiency of micronutrient in the world [32].

B. Alpha (A) and Beta (B) Carotene Forms (AC And BC) and Their Importance

Alpha-Carotene (AC) and Beta-Carotene (BC) are prime bases for Vitamin A (VA); they metabolize to retinol in humans. Vegetables and Fruits with green, yellow, and orange color are rich sources of these two carotenoid types [33]. Vitamin A conversion efficacy of Beta-Carotene is twice compared with Alpha-Carotene, one portion of Beta-Carotene yields double portions of retinol, but Alpha-Carotene yields only half a portion. Due to the high level of BC shared with AC in plant sources, little has been done in its medicinal values [34].

Carotenoids are very important for body defense mechanisms and intercellular signal transmission [35], vision problems and coronary health [36], and lung cancer. Carotenoid Shortage leads to broader medical symptoms related to the eye and vision and weaken innate, adaptive immunity. In the suppression of malignant tumor cells, BC is very effective [37].

Many researchers found the OFSP as good source of carotenoids, and they recommended the use of the OFSP to combat the problems of vitamin A deficiency (VAD) in developing countries. It was reported 1–15 (µg/g fw) [38], and 13.11 (µg/g db) [39] of AC in OFSP. The levels of BC are higher than AC concentrations in fresh and dry basis as reported by many researchers. Based on fresh weight, the concentrations BC in US OFSP varieties were from 44.9–226 (µg/g fw) [40]. The highest range of the BC in Uganda OFSP varieties was from 20 to 364 µg/g (db) [41]. Both types of carotenes have high concentrations in OFSP compared to the common growing yellow to orange fruits and vegetables. OFSP contain the higher concentration of BC compared to the carotenoid concentration in different foods, such as tomato (2.17–2.83 µg/g), mango (10.9–12.1 µg/g), and carrot (43.5–88.4 µg/g) [42]. In the case of total carotenoids, 570 µg/g (db) of the carotenoids was reported in OFSP from Korea [43]. These concentrations were not reported from any other fruits and vegetables.

C. Breeding Sweet Potato for Beta-Carotene

In the case of breeding for high β-carotene content, Orange-fleshed sweet potato is a good source. White-fleshed varieties with flecks of orange color may, however, also contribute to β-carotene production [44]. Previous studies reported high heritability for BC [45], [46], several additive genes appear to control total carotene content [45]. Reference [44] suggested that; the accumulation of favorable or loss of deleterious alleles in the progeny from sweet potato crosses results in transgressive segregation for certain preferred traits such as dry matter, starch, and beta-carotene content [47]. This is due because of the high levels of heterozygosity of the parents that allowed complementation between favorable alleles. Eight QTLs were identified in the variation of β-carotene content and the author suggested that β-carotene, dry matter, and starch showed a quantitative mode of inheritance [10].

There is negative correlation between Beta-carotene and dry matter [44]. This can be a major challenge to selecting orange fleshed sweet potato with high dry matter content. Cultivar with higher concentration of β-carotene is more likely to have lower levels of starch and, therefore, lower levels of dry matter [48]. However, progresses have been achieved using recurrent mass selection method, in breeding cultivar that combine both traits high levels of beta-carotene and high dry matter content [15].

D. Method of Determination of Beta-Carotene

To determine β-carotene contents in sweet potato, the method using High-performance liquid chromatography (HPLC) was used. However, this method is tedious and [49] developed a rapid method that links the color chart of OFSP and BC. Significant advances were reached in recent years, in the precision of quantitative measurements in sweet potatoes for individual beta-carotene and sugars. These advances include use of Near-infrared reflectance Spectroscopy (NIRS) and Nuclear magnetic resonance (NMR) spectroscopy. Researchers stated that sweet potato flesh color is significantly correlated with β-carotene, with the orange fleshed varieties being highest in β- carotene content [49], [50]. Therefore, using a color chart developed at CIP, β-carotene concentration may be determined in the field [51].

Because of the presence of minor carotenoids, spectrophotometry overestimates the HPLC values for beta-carotene content [52]. Near-infrared (NIRS) technique is good for improving the efficiency of breeding for crop quality [53]. The NIRS analysis may be a relevant technique to determine simultaneously the concentration of beta-carotene, dry matter, starch, and sugar in sweet potato. Despite the importance of this method, many factors can affect the accuracy of NIR predictions for a given variety. Reference [54] reported that due to the environment, errors of prediction vary greatly, i.e., year and location effects and the assay temperature.

The costs of chemical technique are very high that unless a simple screening tool is available, it is difficult to include the root quality traits for routine screening [55]. Using NIRS, main quality traits of storage root can now be quantified [56], and this method is used by the CIP as well as sweet potato breeding centers including the CSIR-CRI in Ghana. The use of NIRS method can be justified as each year several thousand samples of sweet potato are required to be analyzed through evaluation and screening, and fewer samples can be analyzed per day using chemical method such as HPLC (8–10 samples for ß-carotene per day). Chemical analysis high cost combined with chemical waste disposal are also another problem. The NIRS is a technique based on correlations between chemical properties, and absorption of energy at different wavelengths in the near-infrared region of the electromagnetic spectrum. Thus, the absorption of near-infrared light as energy by different molecules is measured. In the near-infrared wavelength area, C-O, C-H, O-H, and N-H bonds absorb specific energy. The absorbed energy produces spectra which are interpreted to produce results on a computer connected to the NIRS.

IV. Dry Matter

A. *Dry Matter Content*

Sweet potato storage root dry matter content is defined as the remaining part of the edible root after draining away completely its water. In sweet potatoes, carbohydrates constitute most of the dry matter [57]. The sweet potato dry matter is constituted about 80-90% carbohydrates [57], and finds in the form of sugars and starch [58] non-starch polysaccharides. The most quantitatively important component of dry matter of storage root of sweet potato is starch [59] and it exits in two general forms amylose and amylopectin. The amylose and amylopectin ratio varies between lines and is controlled by genetic action [60]. The non-starch polysaccharides were classified as cellulose, hemicelluloses and, pectic substances, which are found in the middle lamella [59]. These are also referred to as dietary fiber and play an important role in the sweet potatoes nutritional value. The pectic constituents play also a key role in textural attributes in the storage root utilization, including moistness, dryness or firmness.

Starch constitutes an average of 60–70% of dry matter [59]. However, in SSA, most sweet potato varieties have too low dry matter content (ranged from 25 to 30%) that to be used as raw material in the processing industry, which required dry matter above 35% [61].

B. *Sweet Potato Breeding for Dry Matter*

The dry matter content is a good selection index for traits such as cooking quality and starch content in root and tuber crops. Positive and highly significant correlation (r=0.926) was found between dry matter and starch content for Taiwanese sweet potato genotypes, indicating that starch content can be assessed through storage root dry matter content [59]. This makes indispensable the determination of dry matter in sweet potato breeding program.

Starch is mainly determined by the additive effect of polygenes. Therefore, for achieving high dry matter content, the accumulation of genes controlling high starch content is recommended [52]. In Japan, the strategy used for accumulating genes controlling starch content was inbreeding in self-compatible clones and sib mating [52]. A high starch is a preferred attribute of the low sugar, staple types which generally the most cultivated in the tropics [9]. White to cream flesh are typically staple sweet potato with dry weight (DW) contents ranging from 30 to 35 % [62]. Dessert sweet potato types generally have cream to orange flesh with low dry matter content ranging from 17.7 % to 26.3% [57]. High heritability for dry matter content was reported including 75-88 % [63], 69.84 % [46] and 64 % [56]. High variation was also reported in the trait, ranging from 14% to more than 44% in sweet potato genotypes. Therefore, with high heritability and huge genetic variation, quick progress can be achieved in breeding for high dry matter content.

C. *Method Of Determination of Dry Matter*

To quantify sweet potato dry matter, the most commonly used method is as follows: the fresh weight (about 200 g) of thinly sliced roots is measured, followed by oven-drying at 60 or 70 °C for 2–5 days. Then, dry-matter content is calculated by determining the fresh and dry weight, and estimating the percentage of dry weight (10).

Root dry matter content (%DMC)=[(Dry weight/Fresh weight) x 100].

V. Sugar

A. *Types Of Sugars*

The primary contributors to sweet potato taste are sugars and organic acids [64]. Type of sweet potato cultivars with strong flavor and high levels of sweetness may have reduced its popularity as a staple food and made it difficult for combination with other foods in a variety of dishes [59]. These factors play a significant role in reducing the esteem of sweet potato to end user. Among sweet potato cultivars, variability in sugars is very high, and it has been recorded as high as 38.3% of dry matter in American cultivars [55]. A local variety of Vanuatu presents total sugar content as low as 1.49% of dry matter [56]. Sucrose, glucose, and fructose are major sugars occurring in raw storage roots of sweet potato [59]. However, it has been reported low content of maltose in raw sweet potato storage roots [65]. In raw storage roots, the most abundant sugar is sucrose [65], and is found three times sweeter than maltose, while fructose and glucose are, respectively, 5 and 2 folds sweeter than maltose, with maltose seeming to be the most desired sugar by user used [66]. In cooked roots, starch is hydrolyzed to produce maltose. About 42 to 95 % of the starch in several sweet potato varieties was converted during baking and that most (72–99%) of the converted starch accumulated as maltose [67]. Baking converted more starch to sugars than boiling, but boiled roots were higher in percent total sugars, starch cellulose, and hemicellulose, and lower in water-soluble pectin [68].

B. *Breeding for Sugars*

The concentrations of sucrose, fructose, and glucose depend on the type of cultivar, and can account for as much as one-half of the perceived sweetness of a cooked sweet potato [59]. Sweet potato contains many enzyme systems, which catalyze individual synthetic and degradative processes within the tissues [59], and alpha- and beta-amylases are the most important enzymes in both cooked and processed roots. For the lack of sweetness in the staple sweet potato -type, genetically, two phenomena have been suggested. These are low background levels of sucrose, fructose and glucose; and/or low levels of ß-amylase-mediated starch hydrolysis and maltose formation [69]. It has been reported that in homozygous genotypes, a recessive allele of the gene, β-amy is a responsible for the low β-amylase activity [70]. Varieties that are sweet types have high enzyme activity, while those with low-sweet have low enzyme activity [69]. This suggests that the recessive allele of β-amy, either fails to synthesize the protein or produces an inactive form of it. Large variation in total endogenous sugars and maltose was reported in a study of 272 sweet potato clones [71].

Due to sufficient variation in both traits; increasing or decreasing the sweetness of sweet potato involves altering the two groups of genes [71]:

1) Genes controlling the starch formation, which influence latent pools of mono and disaccharides within the storage roots and
2) Genes control starch hydrolysis and the formation of maltose.

Diversity studies and physiological assessment in flavor and sugars are the most studies done on root sugars [62]; [72] with no focus on breeding to decrease levels of sugar. However, heritability for reducing fructose, sucrose, and glucose in raw roots was reported by [40], whereas heritability for maltose which is the most abundant sugar in cooked roots was not reported. The latter also reported that 6 QTLs were associated with decreased dry matter content and starch, and 8 QTLs were associated with increased sugar content in Beauregard US cultivar [40]. The study discovers also 2 QTLs in Tanzania variety which each was associated with increased starch and decreased starch content. Negatively correlation was reported between sugar and starch as well as dry matter content [52], [73]. Therefore, selecting low sugar sweet potato variety leads directly to selection sweet potato with high starch and dry matter content. It has also been reported negative correlation between sugar and beta-carotene.

C. Method of Determination of Sugars

Flavor (sugar and aroma) analysis involves the measurement and evaluation of the sensory characteristics of the cooked product, typically using a descriptive test with trained panelists. Reference (74) developed the HPLC technic for sugars quantitative analysis in raw and baked sweet potato storage roots, but the procedure is tedious and expensive method (49). In addition, refractive index and near-infrared transmittance (54) were the other procedures of sugar determination that have been used. Significant advances have been made in recent years, in the precision of quantitative measurements for individual beta-carotene and sugars in the sweet potato crop. These include both Near-infrared reflectance Spectroscopy (NIRS) and Nuclear magnetic resonance (NMR) spectroscopy. NIRS technique is well adapted to developing countries conditions, and can be used for the high-throughput screening of a large samples number (56). It is a non-destructive method, rapid, and cost-effective, permitting the simultaneous determination of major constituents in a mixture by multivariate data analysis (56).

VI. Inter Relationship between Beta-Carotene, Dry Matter and Sugar Content

A. Inter Relationship

It has been reported a negative correlation between Beta-carotene and dry matter content. [44] This was corroborated by [75] who reported significant ($p<0.5$) negative correlation ($r=-0.622$) between B-carotene and dry matter. Thus, this may make challenge to selecting OFSP cultivar containing high dry matter. Varieties with higher levels of β-carotene are more likely to contain lower levels of starch and, therefore, lower levels of dry matter [48]. Successes have been attained using recurrent mass selection in breeding varieties that combine both high beta-carotene with dry matter [15].

Negative correlation between sugar and both starch and dry matter content has been found [52], [73]. Therefore, selecting low sugar sweet potato variety leads directly to selection sweet potato with high starch and dry matter content. The negative correlation that exists between β-carotene and dry matter content, as well as between β-carotene and sugars, and sugar and dry matter, may impede progress in combining together all these three traits. Nowadays, it should be possible by using recurrent mass selection to accumulate favorable alleles so that progress can be made over time.

B. Comparison Sweet Potato with Other Traits

In other root and tuber crops with sweet potato (Table V), sweet potato has better B-carotene content (0 to 30000 ug/100g) than potato (20–35 ug/100g), yam (21–40 ug/100g), and cassava (30–40 ug/100g). For dry matter content, they have slight differences, but sweet potato contains lesser starch (6-20 (%FW) than yam (18–25 (%FW), potato (20–30 (%FW), and cassava (27–36 (%FW). The percentage of total sugar of sweet potato fresh weight is higher than yam, cassava, and potato with 0.5 to 1%, 0 to 2% and 0.5 to 2.5%. Sweetness is a major constraint that causes people to turn away from sweet potato as a staple food [27].

TABLE V: Beta-Carotene, Dry Matter and Sugar Content of Sweet Potato Compared to Potato, Cassava and Yam

Characteristics	Sweet potato	Cassava	Potato	Yam
Dry matter (%FW)	19–40	30–40	20-35	21–40
Starch (%FW)	6–20	27.36	20-30	18–25
Total sugar (%FW)	1.5–5	0.5–2.5	0-2	0.5–1
Beta-carotene (ug/100 g)	0–30000	0–900	Trace	84
Vitamin A (ug RAE/100 g FW)	0–2500 (300–1200)	0-75	Trace	0–7
Amylose (% total starch)	8–32	15–29	22–25	10–30

VII. Conclusion

Orange-fleshed sweet potato is rich in β-carotene, while the white-cream flesh color varieties have higher dry matter and the purple-fleshed sweet potato varieties contain anthocyanin. β-carotene plays a significant role in combating vitamin A deficiency. Sweet potato (especially the OFSP) has higher Beta-carotene and sugar contents than cassava, yam, and potato as well as in other staple food such as wheat, rice and maize. However, cassava, yam and potato have higher dry matter than sweet potato. Dry matter is one of the very important energy sources for consumers. The primary contributors to sweet potato taste are sugars and organic acids. However, it has been reported using pairwise correlation that Beta-carotene, dry matter and sugar are negatively correlated. Therefore, these results may impede breeding progress in combining together all three traits.

ACKNOWLEDGMENT

We are very grateful to Intra-Africa Academic Mobility Scheme, funded by the European Commission's Education, Audiovisual and Culture Executive Agency (EACEA), for granted me as scholarship holder, as well as GENES consortium. Thanks are due to Ebonyi State University in Nigeria (EBSU) which accept me as my host university.

CONFLICT OF INTEREST

Authors declare that they do not have any conflict of interest.

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