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The physicochemical properties, sugar compositions and sweetness indexes in sweet potato (*Ipomoea batatas* Lam) tubers cultivated in Malaysia

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Abstract

Sweet potatoes' physicochemical properties and taste are the main factors in determining the eating quality that leads to consumer acceptance. However, little information is available about these characteristics, which making it challenging for breeders to develop new sweet potato varieties with good eating quality. The purpose of this study is to determine the physicochemical properties, sugar compositions, and sweetness index of sweet potato tubers [*Ipomoea batatas* (L.) Lam] grown in Malaysia. MIb19 had the highest TSS (14.06 °Brix), while MIb11 had the lowest (7.80 °Brix). The pH values ranged from 5.81 to 6.55, with MIb33 having the lowest pH and MIb23 having the highest. TTA was highest in MIb16 (9.63%) and lowest in MIb29 (1.30%). MIb26 has the highest hardness value (12.74N), followed by MIb12 (12.45N). MIb11 sweet potato varieties with the lowest hardness value were mild, soft, and tender (7.66N). In terms of total sugar, sweetness index and total sweetness index, MIb11 is significantly better than other genotypes. Due to the high cumulative value of glucose and sucrose, SI revealed that MIb11 had the highest amount of sweetness index (5.76) as well as the total sweetness index, TSI (4.10). This study demonstrated that there is a wide variation among sweet potato accessions in terms of physicochemical properties, sugar composition, and sweetness index. Furthermore, it is possible to select among the accessions to improve sweet potato genetics through the breeding of new quality varieties.

Keywords: *sweet potato, physicochemical properties, sugar compositions, sweetness index*

Introduction

Sweet potatoes (*Ipomoea batatas* L. Lam) have been identified as a crop for food security due to their high nutritional value and rich in starch and carbohydrates. Sweet potato's tuberous roots are nutritional powerhouses with a high concentration of dietary fibre, minerals, vitamins and antioxidants (Tomins et al. 2007). This crop has a significant impact on the human body, either in terms of energy or oxidation prevention (Ngoma et al. 2019). Besides, sweet potatoes have a wide range of sensory versatility in terms of taste or flavour, texture and physical appearance that may influence their use for fresh consumption or product development (Truong et al. 2018). Total soluble solids, pH value, titratable acidity and texture are all important physicochemical characteristics (Alirezalu et al. 2020) as well as fermentable sugars (glucose, fructose and sucrose) (Bach et al. 2021). All of these factors contribute to the improved tuber quality and commercial value of sweet potatoes. There is significant genetic diversity among sweet potato genotypes collected around the world, in terms of sugar content and degree of sweetness, which contributes to consumer preferences for processed products (Leksrisompong et al. 2012).

Sensory evaluations of sweet potatoes are critical for determining consumer preference and acceptability (Maina 2018). Sweet potato consumers favour sweet, dry and mealy types that are not fibrous (Mwanga et al. 2021). Regardless, sweet potato breeding proceeded with minimal attention to physicochemical qualities as well as flavour until the hedonic evaluation was performed just before the variety was introduced (Ssemakula et al. 2014). Physicochemical qualities are an important selection criterion in early breeding and may aid in the development of sweet potatoes with consumer-preferred attributes. Many studies on the eating quality of sweet

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potatoes concentrate on roasted, boiled and steamed sweet potatoes, with fewer studies addressing their quality as raw tubers. Because heating alters the conversion of starch to maltose, raw sweet potato tubers contain less maltose sugar than cooked sweet potato tubers (Wei et al. 2017). Cooked sweet potatoes have more sugar than raw sweet potatoes because heat converts starches to maltose for simpler digestion, resulting in a sweeter flavour (Li et al. 2021). Therefore, sugar raises blood sugar levels after eating, raising concerns about hypertension and diabetes (Prada et al. 2022).

In Malaysia, there was little information available on the physicochemical attributes and sugar compositions as well as the sweetness index of potential sweet potato accessions. The majority of commercialised varieties are chosen based on sensory testing and economic impact. As a result of breeding programmes, hundreds of genotypes were screened per season. Although sensory panels and consumer acceptability tests are frequently used to assess human sensory perception and preference, time and other resources are still an issue. However, those parameters remained inaccurate because they are dependent on the panel's expertise and skills (Mariam et al. 2022).

To bridge this gap, a total of 39 sweet potato accessions from germplasm conserved in Malaysia were evaluated for their physicochemical properties, sugar content and sweetness index to analyse their sugar and sweetness variability. The goal of the study is to identify varieties with good physicochemical characteristics and taste. This information is very useful for breeders in selecting potential accessions with good eating quality and desirable physicochemical characteristics to be used as parents in a breeding programme. A new sweet potato variety with a sweeter taste can be developed for commercialisation and it can be recommended for fresh consumption or food processing.

Materials and method

Experimental design

Thirty-nine sweet potato genotypes consisting of imported hybrid, conventional and released varieties and breeding lines obtained from the Malaysia Agriculture Research and Development Institute (MARDI), Bachok, Kelantan (*Table 1*) were used. The potatoes were planted and grown as previously described by Nurul-Afza et al. (2023).

Harvesting and preparation of samples

Fresh tubers were harvested manually using a sickle and hoe at 110 days after planting. Harvested tubers from individual plants were placed in a perforated plastic bag to prevent damage, provide good ventilation while releasing moisture and maintain the quality of tubers after harvest. Three plants were chosen at random from each genotype. Only grade A tubers (medium to large size, approximately 150 – 250 g) were used as samples for physicochemical properties analysis. Five fresh tubers, cleaned and disease-free, weighing approximately 31 kg plants-1 were chosen for total sugar analysis. Before analysis, the freshly harvested tubers were stored in a cold room (4 °C storage temperature with a relative humidity of 75 – 85%).

Physicochemical attributes of tubers

Total soluble solids

Total soluble solids were determined using a digital refractometer with automatic temperature compensation. The tubers were sliced and crushed using a mortar and pestle. The juice from the homogenised sample was squeezed using gauze cloth and dripped on a digital refractometer (Milwaukee Instruments, Model No. MA871 Digital Sugar Refractometer). Three readings were recorded from randomly selected tubers from different individual plants. Each reading represents a replication.

pH

The pH of the tuber sample was determined using a pH meter (Hanna, Model No. HI2210-02 Benchtop pH Meter with 0.01 resolutions). About 10 g of grounded tuber was mixed with 100 mL of distilled water in a beaker. The mixture was shaken thoroughly for a few minutes and allowed to settle down (a few minutes) at room temperature before being filtered with a Whatman filter paper. The filtrate pH was measured in triplicate. The mean of pH was then calculated.

Total titratable acidity

A sample from pH identification was used for the percentage of total titratable acidity analysis. Approximately, three drops of phenolphthalein solutions (as the indicator) were added to 10 mL solution and titrated against 0.1 M Sodium hydroxide (NaOH). The endpoint was identified when the solution colour changed to pink. Titratable acidity was calculated as the percentage of citric acid. The mean (TTA) was then calculated from triplicate values (Equation 1).

Percentage acid = Titre *x* acid factor/10 ml juice x 100 ......(1)

Texture

The texture analysis was performed on fresh tubers at ambient temperature using a texture analyser (Stable Micro System, United Kingdom, TA. XTplus100). The texture analyser was equipped with a 2.0 mm cylinder probe and heavy duty platform. Based on the preliminary works, the instrument working parameters were determined based on compression, pre-test speed at 1.5 mm s^{-1}, test speed at 1.5 mm s^{-1}, post-test speed at 10.0 mm s^{-1}, distance 10.0 mm, trigger force at 25.0 g and data acquisition rate at 200 pp. The data were analysed using the Texture Expert Version 1.22 Software

Table 1. A list of sweet potato genotypes and their origin used to characterise the study

No.	Accession no.	Genotypes	Origin	No.	Accession no.	Genotypes	Origin
1	MIb-01	PASAR BORONG 2	Malaysia	21	MIb-29	VitAto	MARDI
2	MIb-02	CN-2067-7	AVRDC	22	MIb-30	BIRU	Malaysia
3	MIb-03	PEJABAT	Malaysia	23	MIb-31	Anggun 2	MARDI
4	MIb-08	SABAH B	Malaysia	24	MIb-32	V6 D2 15	IC01
5	MIb-09	M/BAYENG		25	MIb-33	C 76	Unknown
6	MIb-10	PASAR BORONG 1	Malaysia	26	MIb-34	GUNTUNG 2	Malaysia
7	MIb-11	PISANG KAPAS	Malaysia	27	MIb-35	JEPUN ASAL	Malaysia
8	MIb-12	SB-031	Malaysia	28	MIb-36	SABAH K	Malaysia
9	MIb-14	CN-94517-17	AVRDC	29	MIb-37	KARAK BAKAR	Malaysia
10	MIb-16	CN-254-13	AVRDC	30	MIb-38	SUNGAI CHUA 2	Malaysia
11	MIb-17	GUNTUNG 1	Malaysia	31	MIb-39	PH 4 (PURPLE)	Indonesia
12	MIb-19	TANJUNG SEPAT 1	Malaysia	32	MIb-40	Anggun 3	MARDI
13	MIb-20	V6 D1 13	IC01	33	MIb-41	BATU PAHAT 1	Malaysia
14	MIb-22	TANJUNG SEPAT 2	Malaysia	34	MIb-42	BATU PAHAT 2	Malaysia
15	MIb-23	TANJUNG SEPAT 3	Malaysia	35	MIb-43	BATU PAHAT 4	Malaysia
16	MIb-24	GENDUT	Malaysia	36	MIb-44	BANTING	Malaysia
17	MIb-25	OREN 2	Indonesia	37	MIb-45	CAMERON HIGHLAND 1	Malaysia
18	MIb-26	18G-257	Unknown	38	MIb-46	CAMERON HIGHLAND 2	Malaysia
19	MIb-27	UBI CAIRO	Egypt	39	MIb-47	CAMERON HIGHLAND 3	Malaysia
20	MIb-28	MERODA INTA	Indonesia				

*MARDI – Malaysia Agriculture Research and Institute; AVRDC - Asian Vegetable Research and Development Center; MIb – MARDI Ipomoea batatas (accessions number of sweet potato germplasm collected in MARDI); IC01 – Breeding lines accessions derived from Industrial Crops breeding programme)

(StableMicro System, United Kingdom) to measure the bio yield point and flesh firmness. The measurement was performed in parallel.

Sugar compositions

Tubers estimated at 1.0 kg/plants were combined for the determination of total sugar extraction and analysis. Five medium sized intact tubers were washed using tap clean water, rinsed and air dried. Subsequently, tubers were quartered, rinsed with de-ionised water and dried using paper towels. Each quarter was sliced across longitudinally to approximately 1.0 cm thickness and divided into four groups (50 g each). The sample extractions were processed using high performance liquid chromatography (HPLC) of the raw tissue. The total sugar (comprised of glucose, fructose and sucrose) was determined based on the method provided by AOAC (2000).

Sweetness index

The sweetness index (SI) was calculated based on the content and sweetness properties of individual carbohydrates by multiplying the sweetness coefficient of each sugar (glucose = 1.00, fructose = 2.30 and sucrose = 1.35) (Equation 2) with a concentration of that sugar (Magwaza and Opara et al. 2015).

SI = (1.00 [glucose]) + (2.30 [fructose]) + (1.35 [sucrose])... ....(2)

Total sweetness index

The total sweetness index (TSI) was calculated based on the contribution of each major component of sugar is estimated relative to sucrose, which is assigned an arbitrary value of 1 (Equation 3) (Magwaza and Opara et al. 2015).

TSI = (1.00 x [sucrose]) + (0.76 x [glucose] + (1.50 x [fructose]).......(3)

Statistical analysis

The analysis of physicochemical properties and total sugar was carried out in three replicates for all determinations. The mean and standard deviation of means were calculated. Data obtained were subjected to analysis of variance using a Statistical Analysis System (SAS). Significant differences among means were assessed using the Least Significant Difference (LSD) at a probability level of 5%. The sweetness of the sweet potato genotypes was classified using hierarchical cluster analysis (HCA) based on sweetness characteristics.

Results and discussion

Total soluble solids

Total soluble solids (TSS) in tubers were significantly different (p <0.05) among the genotypes (*Table 2*). TSS ranged between 7.80 and 14.06 °Brix and was composed of sucrose, glucose and fructose. MIb19 had the highest TSS, followed by MIb30 and MIb37, which did not differ significantly, with TSS values of 13.40 and 13.33 °Brix, respectively. MIb11 had the lowest TSS value (7.80 °Brix). TSS is a critical quality factor for determining the quality of processed food products. TSS alterations have been identified in the study among the varieties 38 due to maturity, cultivars, environment and agronomic practices, as previously stated. TSS estimation methods are used to determine the sugar content of syrup, fruit and vegetable juices, or dairy products, as well as the total concentration of monosaccharides and disaccharides in any solution (Cejpek 2012). Hegedusová et al. (2018) stated that TSS is a quantity of the concentration of dissolved substances in vegetable extracts primarily sugars.

Brix degrees (°Brix) are the TSS measurement unit. The purple cultivar ‘Vinjica purple’ had the highest average concentration of TSS (10.13 °Brix), followed by the orange cultivars ‘Dubaian’ (9.72 °Brix) and ‘Beauregard’ (8.52 °Brix), and the white cultivar ‘Vinjica white’ (5.57 °Brix), according to Slosar et al. (2019).

Tuber pH

Results showed pH in tubers amongst sweet potato genotypes was not much different (P>0.05), ranging from 5.81 to 6.55, (*Table 2*). MIb33 had the lowest pH value, while MIb23 had the highest. Similar pH values were found by Ali et al. (2015), where the values of Ethiopian sweet potato cultivars ranged from 5.04 to 7.26. The pH of a sweet potato is important because it affects most of its functional properties. The pH value of sweet potatoes has been documented to be in the range of 5.50 to 6.70 (Woolfe et al. 1992). This MIb19 was also in line with the observation of Haile et al. (2015). Citric acid had a greater effect on MIb22 the pH level of sweet potato compared to sodium meta-bisulphite because of its high acidity. On the other hand, Araoujo et al. (2014) found that the average pH values of sweet potato cultivars planted under an organic planting management system ranged from 4.50 to 4.60. Low pH values have been reported to be caused by high amylase activity which increases the level of acidity (Nabubuya et al. 2012). Variation in tuber pH has previously been reported in cultivated potatoes and associated with economic traits (Alecia and John 2009). An extensive survey of potato germplasm for tuber pH, including wild Solanum species, discovered cultivar pH ranged from 5.5 to 6.2, while six wild species were significantly lower. If this is the case, the pH test could be used as a quick and low-cost screening tool in breeding programmes. The relationship between pH and useful traits may also provide hints for further research into the underlying genetic and physiological mechanisms in sweet potatoes. Economic characteristics, including disease resistance, nutrition and tuber quality, are attributed to pH physiologically. Sweet potatoes are one of the foods recommended on the alkaline diet as well as digestible fibre. Proponents of the Acid Alkaline Diet recommend eating at least 80% alkaline foods, such as sweet potatoes and no more than 20% acid forming foods to help your body maintain a healthy pH level. It is beneficial in controlling stomach acid, which can cause GERD and heartburn (Schwalfenberg 2012).

Total titratable acidity

The TTA (%) results varied between varieties (*Table 2*). MIb16 had the highest TTA (9.63%), while MIb29 (1.30%), MIb17 (1.60%), and MIb01 (1.66%) had the lowest TTA, which may alter the flavour. De Oliveira et al. (2019) discovered that the TTA level, which quantifies the concentration of organic acids in the evaluated germplasm collection of sweet potatoes at Midwest State University in Brazil, was lower, ranging from 1.11 to 2.99%. The varieties UGA34 (2.95%) and UGA49 (2.99%) had higher acidity, whereas Amorano (1.11%) and Valentina (1.27%) had lower acidity. TTA levels are frequently determined by a few parameters such as protein concentration (acid amino composition) and salts in the tuber, which acts as a buffer for the TSS level (McCarthy et al. 1991).

Hardness of tubers

Results also showed a variation in the texture of storage tuber among the sweet potato genotypes. The hardness values of fresh sweet potatoes significantly differed (P <0.05) among the accessions (*Table 2*). MIb26 has the greatest hardness value (12.74N), followed by MIb12 (12.45N). MIb11 sweet potato varieties that were mild, soft, and tender had the lowest hardness value (7.66N). Sweet potato carbohydrate metabolism is related to starch synthesis, and an increase in the accumulation of starch is related to tuberous root hardness. The textural properties of tuberous roots may be influenced by different cultivation seasons. This indicates that carbohydrate metabolism is essential for changing the textural properties of tuberous roots. Texture properties are a series of comprehensive concepts that can accurately determine the quality of sweet potatoes. At the moment, most sweet potatoes are consumed after a few factors such as hardness, and the eating quality. Nevertheless, the development of fresh consumption of sweet potatoes in future will be a value added to this crop. The hardness of raw tubers is a post-harvest physiological evaluation. The trait is intended to understand sweet potato shelf life throughout distribution and logistics, as well as to preserve fresh tuber quality in the market and attract consumer acceptance. Xu et al. (2023) stated that, the hardness of tuberous roots is an important aspect of their texture properties, and a sweet potato with a high raw eating quality tends to have a low hardness. Yoon et al. (2018) found that the hardness

Table 2. Physicochemical attributes of thirty-nine sweet potato accessions evaluated in MARDI Bachok, Kelantan

Genotypes	TSS	pH	TTA	Hardness
MIb1	9.66 a-d	6.30a-h	1.66de	9.53 a-e
MIb2	11.16 a-d	6.18b-j	3.20cde	11.93a-d
MIb3	10.76 a-d	6.16c-j	2.46cde	10.55 a-e
MIb8	10.73 a-d	6.44abc	2.50cde	9.97 a-e
MIb9	9.30bcd	6.30a-h	2.03cde	9.61 a-e
MIb10	11.43 a-d	6.30a-h	4.33c-e	10.97 a-e
MIb11	7.80d	6.19b-j	4.20c-e	7.66e
MIb12	10.86 a-d	6.25a-i	3.50cde	12.45ab
MIb14	11.16 a-d	6.21b-j	3.33cde	11.16 a-e
MIb16	10.40 a-d	6.04g-k	9.63a	10.72 a-e
MIb17	10.06 a-d	6.07f-k	1.60de	9.07c-e
MIb19	14.06a	6.38a-f	5.36c-e	9.73 a-e
MIb20	11.30 a-d	6.08d-k	4.76 c-e	9.20c-e
MIb22	9.90 a-d	5.90jk	5.96abc	8.81cde
MIb23	12.33a-d	6.55a	3.76cde	10.42 a-e
MIb24	11.46 a-d	6.41a-d	3.00cde	11.61 a-d
MIb25	10.40 a-d	5.94ijk	3.00cde	9.40 a-e
MIb26	12.73abc	6.33a-h	3.86cde	12.74a
MIb27	8.56cd	6.39a-e	2.90cde	9.61 a-e
MIb28	12.40abc	6.08d-k	5.93abc	10.92 a-e
MIb29	9.80 a-d	6.36a-g	1.30e	10.58 a-e
MIb30	13.40ab	6.05f-k	4.16c-e	11.00 a-e
MIb31	12.90abc	6.04g-k	4.83c-e	10.70 a-e
MIb32	9.33bcd	6.00h-k	6.06ab	9.37 a-e
MIb33	9.83 a-d	5.81jk	4.43 c-e	9.05c-e
MIb34	12.30 a-d	6.24a-i	3.63cde	12.27abc
MIb35	9.93 a-d	6.32a-h	5.50bcd	9.07c-e
MIb36	11.03 a-d	6.51ab	2.23cde	11.38 a-d
MIb37	13.33ab	6.04g-k	5.66a-d	10.58 a-e
MIb38	11.13 a-d	6.03g-k	8.26ab	9.96 a-e
MIb39	10.53 a-d	6.35a-g	3.00cde	9.77 a-e
MIb40	9.56 a-d	6.40a-e	5.50bcd	9.62 a-e
MIb41	10.40 a-d	6.38a-f	2.46cde	8.67de
MIb42	11.36 a-d	6.18b-j	4.70 c-e	10.07 a-e
MIb43	12.33 a-d	6.19b-j	5.66a-d	11.64 a-d
MIb44	8.43cd	6.08d-k	3.16cde	9.16c-e
MIb45	12.06 a-d	6.43abc	4.50 c-e	11.64 a-d
MIb46	12.76abc	6.31a-h	4.00cde	10.49 a-e
MIb47	11.50 a-d	6.31a-h	3.00cde	11.31 a-d
Mean	10.99	6.21	4.07	10.29
S.E	0.16	0.17	0.18	0.13

The means in a column with the same letters did not significantly differ (P <0.05).
Total soluble solid (TSS); titratable acidity (TTA)

of raw tuber was related to the hardness ratio of the cooked tuber. They concluded that the texture of sweet potato tubers could be predicted based on the hardness of cooked tuber and its relationship to alcohol insoluble solids, starch contents and raw powder peak viscosity. Nwosisi et al. (2019) discovered a positive relationship between the texture variables springiness, gumminess, chewiness, resilience and hardness of sweet potato tubers. Springiness and resilience were not related to cohesiveness or each other. Gumminess was significantly correlated with hardness and chewiness, indicating a relationship. In general, hardness and other parameters decreased with processing, but the extent of the decrease varied depending on the variety.

Sugar compositions and sweetness index

Results analysis of the variance of sugar content and sweetness index are presented in *Table 3*. The content of fructose, glucose, sucrose and total sugar was found to be significantly different (P <0.05) among the accessions (*Table 4*). The mean fructose concentration ranged from 0.01 to 1.36 g/100 g fwb. MIb37 and MIb22 had the highest fructose content among the accessions, with values of 1.36 and 1.23 g/100 g, respectively. MIb30 (0.03 g/100 g), MIb23 (0.03 g/100 g), and MIb38 (0.02 g/100 g) exhibited low fructose content which was lower than 0.04 g/100 g. On the other hand, MIb32 and MIb16 (0.00 g/100 g) were considered non-detected fructose values. The glucose level of fresh sweet potato was higher than the fructose content, which ranged from 0.00 to 1.59 g/100 g fwb (*Table 3*). MIb11 had the highest glucose content (1.59 g/100 g), while MIb08, MIb16 and MIb32 had the lowest (0.01 g/100 g, respectively) and MIb25 was considered non-detected glucose (0.00 g/100 g). The sucrose content of these fresh sweet potatoes was slightly higher than the fructose level. Sucrose content ranged from 0.00 to 3.27 g/100 g fwb. The highest sucrose content was MIb23 (3.27 g/100 g), followed by MIb27 (2.69 g/100 g), MIb38 (2.65 g/100 g), MIb30 (2.49 g/100 g) and MIb16 (2.49 g/100 g) (2.45 g/100 g).

Based on the findings, sucrose was the most abundant sugar in fresh tubers of all sweet potatoes and includes fructose, sucrose and glucose. Both fructose and glucose had lower concentrations than sucrose. The soluble sugar level determines the taste quality of raw sweet potatoes and different varieties have different soluble sugar fractions (Xu et al. 2023). This finding was consistent with Xu et al. (2023), where the fructose content varied from 3.42 (Zheshu75) to 113.50 mg /g (Taishu14), with an average value of 24.64 mg/g. The sucrose contents of tuberous roots varied from 22.50 (Qining19) to 146.41 mg/g (Zheshu21), with an average value of 86.42 mg/g. The glucose content of tuberous roots varied from 3.81 (Zheshu75) to 131.48 mg/ g (Taishu14), with an average value of 27.81 mg/g. According to Adu-Kwarteng et al. (2014), the reducing sugar concentrations of all cultivars studied were typically low at all harvest phases where glucose is 0.13 – 1.00 g/100 g and fructose is 0.06 – 1.68 g/100 g dwb. The total sugar content of fresh sweet potatoes ranged from 4.00 to 0.01 g/100 g dwb. Sugar (sucrose, glucose, and fructose) levels are associated with tuber weight/size during development, with glucose and fructose levels gradually declining and sucrose and starch contents increase with tuberous extension (Adu-Kwarteng et al. 2014).

The total sugar concentration of MIb11 was the highest among the genotypes. Accessions MIb32, on the other hand, had the lowest level of expression of sugar concentration. A similar result was reported by Miyasaka et al. (2019), where total sugars differed between the 'Beauregard', 'Murasaki-29' and 'Darby' varieties. Total sugars for all entries ranged from 45.18 to 76.88 mg/g fresh weight (fwb) and were higher than those listed (41.8 mg/ g fwb) in the USDA Food Composition Database for raw, orange-fleshed roots. Aina et al. (2009) observed that the total sugar concentrations of Caribbean fresh sweet potato cultivars namely Lovers ranged from 1.80 (Big Red) to 4.70 mg/ 100 mg dwb. Nonetheless, the acquired results are marginally lower than the other findings. In contrast to Ali et al. (2015), the total sugar concentration in Ethiopian sweet potato accessions ranged between 9.53 (CN-1752-15) to 17.25 mg/ 100 g (CN-2059-7). However, the majority of these studies have been conducted with physiologically mature roots. Sweet potato does not have a fixed harvest maturity and can be harvested over many months. In addition, the total soluble sugar content in immature sweet potatoes is only about 50% of the mature roots (Adu-Kwarteng et al. 2014). Thus, immature sweet potato roots are low in sweetness and proper curing is greatly needed to increase the sensation of moistness and sweetness, enhance the aroma and decrease the starch content while increasing the sugar to improve their eating quality.

Sweetness index

One of the most prevalent measurements of horticultural crop acceptability is the sweetness index (SI), which is based on the proportion of individual non-saturated sugar components (Beckles 2012). Plant breeder desires to know the potential varieties with important eating quality traits. Due to the high cumulative value of glucose and sucrose, results revealed that MIb11 had the highest SI (5.76) as well as the TSI (4.10). Furthermore, MIb11 showed the highest glucose content (1.59 g/100 g). In addition, the SI of sweet potatoes studied revealed that MIb27 and MIb23 had high values of 4.59 and 4.54, respectively, where this indicator is consistent with the TSI (3.34 and 3.36, respectively). The TSI estimates the contribution of each main component of sugar relative to sucrose, which is assigned an arbitrary value of 1 (Baldwin et al. 1998; Beckles 2012). This SI and TSI were followed by MIb37, which had values of 4.01 and 2.71, respectively. MIb32, on the other hand, is the least sweet, with SI and TSI values of 0.01 and 0.01, respectively (*Table 4*).

Correlation analysis results of the sugar compositions and sweetness are shown in *Table 5*. Correlation analysis was used to justify if there was a linear relation between all the sugar and sweetness parameters. Postharvest sweetening refers to the phenomenon where fruits or vegetables become sweeter after they are harvested. This process occurs due to changes in the fruit's composition and metabolism, leading to the accumulation of sugars and a reduction in acidity over time. All relations are initially assumed to be linear then run the correlation analysis. When the correlation number was close to 1, the relations between sugar and sweetness parameters were linear. Otherwise, the relation was non-linear. The trend between fructose and sucrose revealed a positive correlation, with both sugars nearly 50% high ($r = 0.50$, $p < 0.01$). Meanwhile, the fructose and sucrose correlations were negative, with fructose being high and sucrose being low. Glucose and sucrose were found to be significantly correlated with total sugar ($r = 0.48$; $r = 0.78$, $p < 0.01$), sweetness index ($r = 0.53$; $r = 0.64$, $p < 0.01$), and total sweetness index ($r = 0.50$; $r = 0.70$, $p < 0.01$). Glucose accounts for nearly half of the total sugar, sweetness index, and total sweetness index. The total sugar and sweetness index had strong correlations (close to 1.0).

The sweetness of the sweet potato genotypes was classified using a hierarchical cluster analysis (HCA) based on sweetness characteristics (*Table 6*). *Figure 1* presents the dendrogram analysis among the 39 sweet potato genotypes with Euclidean distance dissimilarities ranging from 0.00 to 1.85. In general, the 39 sweet potato genotypes were classified into two categories (A and B). The dendrogram revealed two large clusters with an average distance of 0.50 between them. The first group (A) was sub-sub-clusters A1 and A2 sub-clusters. A1 is consist of 21 genotypes, including MIb1, MIb41, MIb12, MIb36, MIb40, MIb46, MIb44, MIb8, MIb19, MIb42, MIb17, MIb28, MIb2, MIb35, MIb24, MIb43, MIb20, MIb34, MIb31, MIb25 and MIb32. Subclustered A2 has 17 genotypes, including MIb3, MIb22, MIb10, MIb29, MIb37, MIb9, MIb39, MIb47, MIb33, MIb14, MIb45, MIb26, MIb16, MIb30, MIb38, MIb23 and MIb27. MIb11 was the only genotype grouped in Cluster B. The genotypes in group A1 were less sweet than the sweet potatoes in group A2, which were moderately sweet. The MIb11 genotype exhibited the most sweetness characteristics. MIb11 has similar characteristics to MIb16 and MIb37, which have intermediate cream skin and dark cream flesh, respectively. These three varieties are grouped (CL7). Unlike MIb22, the skin is pale pink, and the flesh is dark cream.

The sweetness of sweet potatoes is based on endogenous sugars including sucrose, glucose and fructose (Morisson et al. 1993). These sugars are present at harvest, whereas maltose is synthesised during cooking when amylase enzymes are hydrolysed into starch. During heating, alpha-amylase and ß-amylase convert a large portion of the starch into saccharides such as maltose (Walter et al. 1975). As previously mentioned, one of the most demanding qualities of sweet potatoes is their sweetness level. The sort of product or composition that may be made is determined by the degree of sweetness

Table 3. Analysis of variance (ANOVA) for the sugar contents (%) and sweetness index of fresh sweet potatoes evaluated in MARDI Bachok, Kelantan

		Fructose	Glucose	Sucrose	Total sugar	Sweetness index	Total sweetness index
Genotypes	37	0.4029*	0.3059*	2.487*	2.369*	4.375*	2.311*
Rep	2	0.001	0.005	0.028	0.066	0.119	0.063
Error	76	0.005	0.011	0.009	0.027	0.061	0.03

Table 4. Sugar contents (g/100 g) and sweetness index of fresh sweet potatoes evaluated in MARDI Bachok, Kelantan

Genotypes	Fructose	Glucose	Sucrose	Total sugar	Sweetness index	Total sweetness index
MIb1	0.52h-k	0.47c-j	0.00l	1.00m-q	1.68qrs	1.14lmn
MIb2	0.34k-n	0.17j-m	0.85ef	1.37j-n	2.12n-q	1.50jkl
MIb3	1.13abc	0.25f-m	0.35h-k	1.73g-k	3.32d-k	2.24c-h
MIb8	0.50h-k	0.01m	0.06jkl	0.57pqr	1.26rs	0.83mn
MIb9	0.77d-g	0.67bcd	0.87ef	2.32c-f	3.64d-g	2.55c-f
MIb10	1.22ab	0.25f-m	0.02l	1.49i-m	3.09e-l	2.04e-j
MIb11	0.97bcd	1.59a	1.43cd	4.00a	5.76a	4.10a
MIb12	0.48i-l	0.08lm	0.37hij	0.93n-q	1.68qrs	1.15lmn
MIb14	0.23l-o	0.38c-l	1.45c	2.07d-g	2.89g-n	2.10d-i
MIb16	0.00o	0.01m	2.45b	2.47cde	3.34d-j	2.47c-g
MIb17	0.23l-o	0.36d-l	0.15i-l	0.76opq	1.13st	0.79no
MIb19	0.47i-m	0.04lm	0.04kl	0.55qrs	1.17rs	0.77no
MIb20	0.811d-g	0.54c-i	0.00l	1.35j-n	2.41l-q	1.63i-l
MIb22	1.23a	0.55c-h	0.15i-l	1.95e-i	3.61d-h	2.43c-g
MIb23	0.03o	0.05lm	3.27a	3.36b	4.549bc	3.36b
MIb24	0.63f-j	0.12j-m	0.77fg	1.53h-m	2.63j-o	1.82h-k
MIb25	0.15o	0.00m	0.00l	0.16rs	0.36tu	0.23op
MIb26	0.21mno	0.10klm	1.56c	1.89f-j	2.72i-o	1.97g-j
MIb27	0.31k-n	0.24g-m	2.69b	3.25b	4.59b	3.34b
MIb28	0.18o	0.20i-m	0.46ghi	0.84n-q	1.24rs	0.88mn
MIb29	0.96bcd	0.60b-f	0.12jkl	1.69g-k	3.00f-m	2.03e-j
MIb30	0.03o	0.03lm	2.49b	2.57cd	3.50d-i	2.58cde
MIb31	0.90cde	0.21h-m	0.18i-l	1.29k-o	2.52k-p	1.69h-l
MIb32	0.00o	0.01m	0.00l	0.01s	0.01u	0.01p
MIb33	0.38j-n	0.57c-g	1.53c	2.49cde	3.52d-i	2.54c-f
MIb34	0.78d-g	0.39c-l	0.05jkl	1.23k-o	2.27m-q	1.52jkl
MIb35	0.50	0.34d-m	0.45ghi	1.31k-n	2.14n-q	1.49jkl
MIb36	0.668e-i	0.04lm	0.15i-l	0.86n-q	1.78p-s	1.18lmn
MIb37	1.36a	0.72bc	0.11jkl	2.20c-g	4.01bcd	2.71c
MIb38	0.02o	0.08lm	2.53b	2.63c	3.54d-h	2.62cd
MIb39	0.83d-g	0.95b	0.66fgh	2.45cde	3.76c-f	2.63cd
MIb40	0.75d-h	0.14j-m	0.14i-l	1.05m-q	2.09n-q	1.40klm
MIb41	0.41i-n	0.66b-e	0.00l	1.08l-q	1.62qrs	1.12lmn
MIb42	0.48i-l	0.06lm	0.00l	0.55qrs	1.18rs	0.78no
MIb43	0.60g-j	0.37d-l	0.64fgh	1.62h-l	2.64j-o	1.84h-k
MIb44	0.66e-i	0.45c-k	0.00l	1.12l-p	1.98o-r	1.34k-n
MIb45	0.35k-n	0.26f-m	1.28cd	1.89f-j	2.80h-n	2.00f-j
MIb46	0.81d-g	0.08lm	0.00l	0.89n-q	1.95o-r	1.28k-n
MIb47	0.86def	0.31e-m	1.13de	2.31c-f	3.83b-e	2.67cd
Mean	0.56	0.32	0.73	1.61	2.60	1.81
CV	65.61	102.18	123.82	55.21	46.68	48.49

The means of a column with the same letters were did not significantly different (*P* <0.05).

Table 5. Correlation analysis of the results of sugar compositions and sweetness index of fresh sweet potatoes evaluated in MARDI Bachok, Kelantan

	Fructose	Glucose	Sucrose	Total sugar	Sweetness index	Total sweetness index
Fructose	1.000	0.50**	–0.50**	0.06	0.30	0.23
Glucose		1.000	–0.08	0.48**	0.53**	0.50**
Sucrose			1.000	0.78**	0.64**	0.70**
Total sugar				1.000	0.97**	0.98**
Sweetness Index					1.000	0.99**
Total Sweetness Index						1.000

**Significant at P >0.05

Table 6. The classifications of sweet potato genotypes using hierarchical cluster analysis (HCA) based on sugar compositions and sweetness indexes

Number of clusters	Clusters joined		Freq	Norm RMS distance
38	MIb19	MIb42	2	0.0177
37	MIb30	MIb38	2	0.0345
36	MIb08	CL38	3	0.0413
35	MIb01	MIb41	2	0.0858
34	MIb16	CL37	3	0.0945
33	MIb20	MIb34	2	0.0947
32	MIb40	MIb46	2	0.1033
31	MIb24	MIb43	2	0.1039
30	MIb12	MIb36	2	0.11
29	MIb14	MIb45	2	0.1146
28	CL29	MIb26	3	0.1341
27	MIb17	MIb28	2	0.1359
26	MIb09	MIb39	2	0.141
25	CL33	MIb31	3	0.1424
24	CL32	MIb44	3	0.15
23	MIb25	MIb32	2	0.1652
22	MIb02	MIb35	2	0.1662
21	MIb10	MIb29	2	0.1725
20	CL30	CL24	5	0.1911
19	MIb03	MIb22	2	0.1932
18	CL36	CL27	5	0.1975
17	CL35	CL20	7	0.2279
16	CL26	MIb47	3	0.2366
15	MIb23	MIb27	2	0.2394
14	CL19	CL21	4	0.2486
13	CL22	CL31	4	0.2569
12	CL13	CL25	7	0.2946
11	CL16	MIb33	4	0.3165
10	CL17	CL18	12	0.3471
9	CL14	MIb37	5	0.4138
8	CL10	CL12	19	0.4907
7	CL11	CL28	7	0.503
6	CL9	CL7	12	0.5682
5	CL34	CL15	5	0.5889
4	CL8	CL23	21	0.8644
3	CL6	CL5	17	0.9395
2	CL4	CL3	38	1.1657
1	CL2	MIb11	39	1.8473

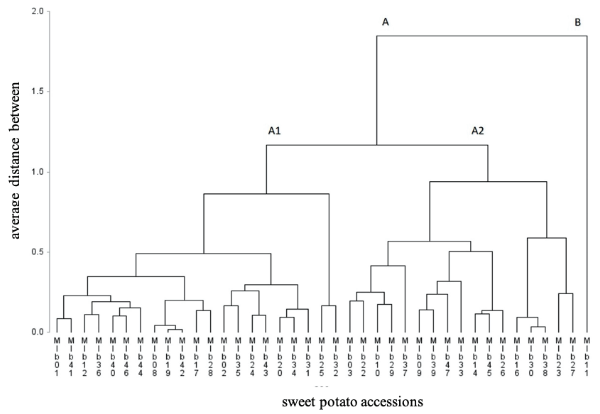

Figure 1. The dendrogram (based on Euclidean distance coefficient) of 39 sweet potato genotypes generated by average linkage cluster analysis based on the sugar compositions and sweetness parameters

in the root. The sweetness and/or sugar content of sweet potato roots are influenced by a variety of parameters such as maturity, storage, amylase potentials, curing and baking treatment (Wang and Kays 2000; Dziedoave et al. 2010; Adu- Kwarteng et al. 2014). It is well established that different sugars, at the same concentrations, have differing perceived sweetness levels (Lewthwaite et al. 1997). Although the sugar compositions of sweet potato tubers mainly depend on the type of cultivar (Aina et al. 2009), Koehler and Kays (1991) reported that the taste of baked tubers was mainly determined by their sugar content. Previous studies revealed that fresh sweet potatoes contained sucrose, glucose and fructose (Picha 1986) but not maltose (Zhang et al. 2002). Sucrose is the major sugar component of fresh sweet potato tubers (Zhang et al. 2002) and the most important sugar for predicting sweetness (Corrigan et al. 2000).

Conclusion

The analysis of various sweet potato genotypes revealed significant differences in fructose levels, with MIb22 and MIb37 exhibiting high fructose content, while MIb16 and MIb32 showed undetectable levels. Notably, MIb11 stood out as superior to other genotypes in terms of total sugar content, sweetness index, and total sweetness index. The utilisation of multiple indices to assess sweetness posed challenges in this study, underscoring the importance of standardising measurement and analytical approaches to enhance the traceability and comparability of results in both industry and research communities.

The research showcased a wide range of physicochemical properties, sugar composition, and sweetness index among various sweet potato accessions. The level of sweetness in the root significantly impacts the type of product or composition that can be developed. Standardising measurement approaches will facilitate comparative analysis of results within the industry and among researchers. Furthermore, these findings hold promise for the improvement of sweet potato genetics through selective breeding, leading to the development of new and improved quality varieties. This study lays a foundation for future advancements in sweet potato cultivation and breeding practices, ultimately benefiting both producers and consumers alike.

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