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Cooking Treatment Effects on Sugar Profile and Sweetness of Eleven-Released Sweet Potato Varieties

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Abstract

Cooking can significantly alter sugar content of sweet potato roots. Sweet potato roots were processed using three different cooking treatments, with the aim of investigating the effects of these methods on sugar profile and sweetness levels. Significant contribution of the cooking treatment and genotype, and their interaction on levels of the sugars were also determined. Moreover, sugar values were converted to relative sweetness per sucrose equivalent. The results revealed that cooking treatment produced the highest effect on sugar except fructose. Variability due to the interactions was significant and ranged from 2.60% to 11.74%. Whilst sucrose was the predominant in the raw form, maltose increased dramatically during cooking. Sweetness level increased substantially upon cooking and was highly dependent on initial sugar content, amylase activity and cooking treatment. Thus, evaluation of sweetness levels in sweet potato clones should not only be on the uncooked samples but should take into account the cooking methods employed.

Keywords: Cooking treatments; Sugar profile; Sweetness level; Amylase activity; Maltose

Introduction

Sweetness, derived from sugars in the raw sweet potato root and maltose formed during cooking, is the predominant attribute controlling the taste of cooked sweet potato products [1,2]. The level of sweetness in the root determines the type of product or formulation that can be developed. A number of factors including maturity period, storage, amylase potential, curing and baking treatment significantly influence sweetness/sugar content of sweet potato roots [3-5]. Baking treatment and the amylolytic potential nonetheless have the greatest effect on sugar content of the final product [6-8]. Baking generally increases sugar content of sweet potato roots [9,10]. Increase in sugar content during baking can be dramatic, leading to a very sweet product [9]. Though effect of baking treatment on sugars of sweet potato roots has been extensively investigated, limited data is available on other cooking treatment such as steaming and microwaving. Nevertheless, sweet potato roots are cooked by different treatments including microwaving; baking, steaming and boiling prior to consumption with the aim to increase the culinary properties and enhance digestibility [11]. Temperature, time and mode of heat transfer differentiate these cooking methods. Conventional baking usually lasts for 60-90 min at 180-220°C, depending on the genotype and tuber size [9]. Baking temperature as reported by Simkovic [12] and Chan [6] can however cause sucrose caramelisation, a phenomenon, which results in conversion of sucrose to oligomers and polymers. Microwave cooking employs a high temperature, short time heating mechanism to cook food products [10]. Heat is transferred by convection and conduction during baking whilst electromagnetic waves penetrate food materials causing agitation and friction to produce heat for cooking during microwaving [5]. The effect of steaming on quality characteristics of sweet potato root has not been widely reported.

Although effects of some cooking methods, especially baking, on quality attributes of sweet potatoes have been evaluated comparative studies with the view of understanding the effects of different cooking treatments on sugar profiles, sweetness and utilisation of sweet potatoes are limited. Moreover the influence of cooking treatments on sugars of eleven officially released sweet potato varieties in Ghana has not been investigated. To better understand the contribution of different cooking methods on sugar formation and sweetness of sweet potato roots, individual sugar and sweetness levels of eleven released varieties were determined following baking, microwaving and steaming.

Methodology

Experimental design

Triplicates of eleven sweet potato varieties released by Council for Scientific and Industrial Research (CSIR) – Crops Research Institute (CRI) were planted in a randomized complete block design on May 2014 at the CSIR-CRI experimental station, Fumesua, Ghana [13-15]. Harvesting was done four months after planting (September, 2014) and each plot was treated as a separate sample during laboratory evaluations. Harvested roots were stored for a week at room condition (25 to 30°C) prior to processing.

Sample preparation

Four medium-size intact roots of each variety were washed with clean water, rinsed and air-dried. The clean roots were then quartered, rinsed with de-ionised water and dried using paper towels. Each quarter was sliced across its longitudinal axis to approximately 1.0 cm thickness and composite samples from each plot, divided into four groups of 50 g. One group was designated as raw and the rest were subjected to three different processing methods; baking, steaming and microwaving. For baking, one group of the sliced samples was wrapped in aluminium foil and placed in a forced air oven (Genlab MINI/50/DKG), which has been preheated to 205°C, for 30 mins. For steaming, another group of

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root samples was placed in a Kitchen steamer with boiling water and cooked for 10 min. The third group of the root samples was wrapped in paper towel and moistened with about 5 mL of portable water and microwaved (sharp microwave model R-228H) for 5 min inside a plastic microwaveable food container. Cooked samples were allowed to cool to room temperature for about 20 min, transferred to whirl-Pak polyethylene bags and frozen at –20°C before drying using the freeze dryer (True Ten, Ind, YK18-50, Taiwan). Dried samples were milled and sieved as described in chapter four (under methodology) prior to sugars determination.

Sugar determination

Freeze-dried and milled sweet potato samples were sent to the Quality Plant Product Laboratory (Department of Crop Science, University of Gottingen, Germany) for sugar analysis. Water extract of the freeze-dried sweet potato samples (0.1 g in 100 mL) was used. The samples were incubated in a water bath at 60°C for 1 h and treated with 0.2 mL Carrez I and Carrez II solution to remove proteins. Samples were purified by centrifugation (Sorvall RC-5B Refrigated Superspeed, GMI, Ramsay, USA) at 10,000 rpm for 10 min at 20°C. Sugars were determined from the membrane-filtered supernatant (pores size 0.45 µm). Glucose, fructose, sucrose, and maltose were separated using a LiChrospher 100 NH_2 (5 µm) 4 x 4 mm pre-column in combination with a LiChrospher 100 NH_2 (5 µm) 4 x 250 mm separation column (Merck KGaA, Darmstadt, Germany) and an acetonitrile: pure water solution (80:20 v/v) as mobile phase at a flow rate of 1.0 mL min^{-1} at 20°C and an injection volume of 20 µL. Sugars were detected with a Knauer differential refractometer 198.00 (Knauer, Berlin, Germany).

Determination of amylase activity

The 3,5-dinitrosalicyclic acid (DNSA) method for reducing sugars was employed to determine the total amylase activity of the freeze-dry sweet potato roots [16,17].

A unit (U) of amylase activity was defined as the amount of enzymes required to release reducing sugars equivalent to one µmole of maltose/min under the above stated conditions [16].

Calculation of sweetness level

In order to ascertain and compare sweetness levels among the varieties, sweetness (sucrose equivalent) was calculated from the equation: Sucrose Equivalent (SE) = 1.2 fructose + 1 sucrose + 0.64 glucose + 0.43 maltose [1,18]. Based on the SE values obtained, the varieties were classified into four categories: non sweet (SE ≤ 12 g/100g dry weight); low sweet (SE 13 – 20 g/100 g); moderate sweet (SE 21 – 28 g/100 g); and high sweet (SE29 – 37 g/100 g) [1].

Statistical analysis

Experimental means were calculated from triplicate values of each variety per treatment. Data obtained were subjected to analysis of variance using Statistical Analysis System (SAS) [19]. Significant differences among means were assessed using Least Significant Difference (LSD) at probability level of 5%.

Results and Discussion

Effect of cooking treatment, genotype and interaction on sugars of cooked sweet potato roots

The effect of cooking, genotype and their interaction were significant on all sugars (maltose, sucrose, glucose and fructose), though the percentage contributions varied considerably (Tables 1 and 2).

Variety	Skin Colour	Skin Shape	Flesh colour	Yield (t/ha)
Apomuden	Reddish brown	Obovate	Reddish orange	48.9
Bohye	Purple	Obovate	Pale orange	16.8
Dadanyuie	Dark purple	Round elliptic	White	10.5
Faara	Deep purple	Long elliptic	Cream	16.9
Hi-Starch	Creamy	Elliptic	Cream	14.7
Ligri	Cream	Round elliptic	Pale yellow	16.3
Okumkom	Cream	Long elliptic	Cream yellow	19.91
Ogyefo	Purple	Long elliptic	White	25.9
Otoo	Cream	Long elliptic	Light orange	30.7
Patron	Dark yellow	Long elliptic	Dark yellow	15.9
Sauti	Cream	Long elliptic	Yellow	15.4

Table 1: Phenotypic attributes and yield of the sweet potato varieties used for assessment of changes in sugar content [3-5].

Source of Variation	*Variance (%)			
	Maltose	Sucrose	Glucose	Fructose
Genotype (G)	7.26**	16.93**	38.82**	45.68**
Cooking treatment (CT)	90.12**	79.04**	52.60**	43.12**
GxCT	2.60**	4.03**	8.65**	11.47**
**Significant at p < 0.05. *Calculated from sum of squares.				

Table 2: Percentage variability of cooking treatment, genotype, and interactions on sugars of cooked sweetpotato roots.

Cooking treatment showed the highest effect of the total variability on the sugars except fructose. The effect was more profound on maltose content with percentage variability of 90.12%. Nearly 80% and 53% of the total variation in sucrose and glucose contents of the cooked roots were due to the cooking treatment. Effect of genotype was highest on fructose relative to the other sugars. While 45.68% of the variation in fructose resulted from the genotypic composition of the roots, only 7.26% of the difference in maltose content was due to genotypic effect. Percentage variability resulting from genotypic effect on sucrose and glucose was 16.93% and 38.82% respectively. Overall variation from interactions between cooking treatment and genotype ranged from 2.60% to 11.47% of the entire differences noticed. Although it was significant, it contributed the least of the total variation.

The results from the analysis of variation depict that changes in sugar concentrations during cooking are significantly dependent on cooking treatment, genotype and interaction. Among these factors cooking treatment exerted the highest effect. Its effect was more profound on maltose content, which increased from 7.26% prior to cooking to 90.12% afterward. Cooking increases temperature intensity and penetration, and also facilitates breakdown of hydrolytic bonds holding starch granules and other compounds. Such conditions enhance the activity of native amylase resulting in starch degradation and the production of sugars mainly maltose as observed in the study [8,20]. Apart from fructose, changes in individual sugars were remarkable. Response from fructose was higher for genotype effect rather than cooking treatment.

Effect of cooking treatment on sugars of sweet potato roots

Table 3 shows the means and ranges in sugars as a result of the different cooking treatments. Wide variation existed among the sugars of the cooked sweet potato roots, with maltose and sucrose showing the highest variability. Maltose was hardly present in the raw form whilst sucrose (10.58%) predominated. This finding agrees with Morrison [8] and Sun [10] who reported that sucrose is the major sugar in raw forms and the most important sugar for predicting sweetness in sweet potatoes [6]. Sucrose concentration, generally, increased slightly

Individual Sugars (% DM)	Cooking Treatment			
	Raw	Baking	Microwaving	Steaming
Sucrose	10.58 (9-23)^{a}	11.01 (6-20)^{a}	10.72 (7-16)^{a}	4.30 (0-8)^{b}
Glucose	2.69 (1-4)^{a}	1.10 (0-3)^{b}	1.63 (0.4-5)^{b}	1.55 (0-5)^{b}
Fructose	1.58 (0-3)^{a}	0.84 (0-2)^{a}	0.92 (0-2)^{a}	0.95 (0-4)^{a}
Maltose	0.63 (0-1)^{a}	20.13 (5-36)^{b}	5.07 (2-15)^{c}	14.35 (2-27)^{d}
Ranges of maeans are presented in brackets. ^{a,b,c} Figures in rows with the same superscripts are not significantly different ($p < 0.05$).				

Table 3: Means and ranges of individual sugars in raw and cooked sweet potato roots.

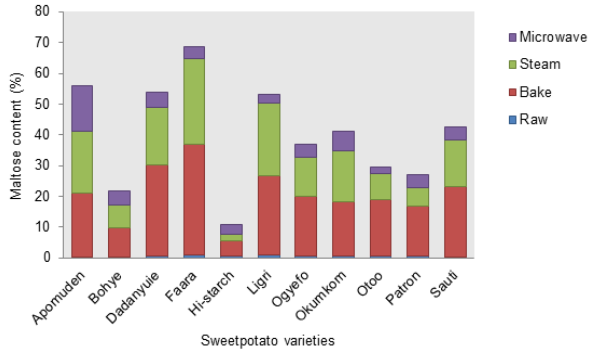

Figure 1: Changes in maltose content of sweetpotato roots as affected by different cooking treatments; microwaving, steaming and baking. LSD=0.30.

when baked, though it was not significant compared to the raw, but remained constant at microwaving and decreased significantly during steaming. Glucose and fructose contents were not significantly affected by the different cooking treatments, although the levels were generally lower compared to raw roots. Maltose content rose from 0.63% before cooking to 20.13%, 14.35% and 5.07% after baking, steaming and microwaving respectively. It became the principal sugar following baking and steaming. Increase in maltose content following cooking has been observed in several sweet potato varieties [7,8,10]. Changes in maltose and sucrose (the major sugars) concentrations per variety during cooking were also assessed and results presented in Figures 1 and 2 respectively. Maltose, which was not detected in most of the varieties prior to cooking increased dramatically after baking and steaming (Figure 1). Faara, Dadanyuie, Ligri Sauti and Apomuden had the highest increase and Hi-Starch the lowest in maltose content following baking and steaming. Though the effect of microwave cooking was also positive and significant on maltose content for all the varieties, it was comparatively much lower to both baking and steaming. In contrast, sucrose content decreased in some of the varieties while increasing slightly or remaining the same in others during cooking (Figure 2). Apomuden, Dadanyuie, and Hi-starch recorded a decrease whilst Bohye, Faara, Otoo, Sauti and Ligri showed an increase after baking. Sucrose contents in Ogyefo, Okumkom and Patron were not significantly affected by baking treatment. Steaming reduced sucrose content in all the varieties. The magnitude of reduction was extremely high in Faara, which lost almost 96% of its sucrose content. Effect of microwave treatment on sucrose was similar to that of baking. While negatively affecting sucrose content in Apomuden, Bohye, Hi-Starch, Ligri, Patron, and Sauti, microwaving enhanced sucrose levels in Dadanyuie, Faara, and Otoo. Sucrose content in Ogyefo, and Okumkom were not significantly affected.

Concentration of sugars in sweet potato roots varies significantly during cooking, with the extent of variability being highly dependent on; 1) initial sugar concentration, 2) amylase activity and 3) cooking method employed. The impact of cooking treatment on sugar content is related to temperature, time, and mode of heat transfer. Baking treatment resulted in the highest sugar (maltose) formation mainly due to the long cooking period (30 min) coupled with the high temperature (205°C) employed. Moreover there was no direct contact between the sample and the heating medium, a system that prevented possible leaching of soluble sugars, during baking. Heat is transferred from the periphery to the centre of the root by conduction in baking as compared to microwaving for instance where electromagnetic radiation penetrates the entire root causing agitation and friction to produce heat for cooking instantaneously [5]. Hence baking utilises more time, a system that allows adequate starch gelatinisation and subsequent conversion to maltose by amylases [21,22]. It has been demonstrated that increasing heating temperature over a time frame increases starch degradation and maltose production [8,10]. Baking treatment at higher temperatures can however cause sucrose caramelisation, a phenomenon, which results in conversion of sucrose to oligomers and polymers as reported by Simkovic [12] and Chan [6]. Hence the reduction in sucrose content of some of the varieties (Figure 2) may be attributed to this effect. This finding corresponds with Chan [6] and Morrison [8] who reported a decrease in sucrose content of several sweet potato cultivars during baking. The rapid heating mechanism of microwaving deactivated the native amylases responsible for maltose formation, and consequently the reduction in

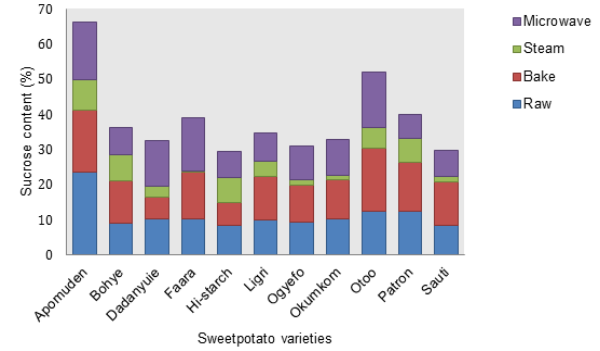

Figure 2: Changes in sucrose content of sweetpotato roots as influenced by three cooking treatments; microwaving, steaming and baking. LSD=0.86.

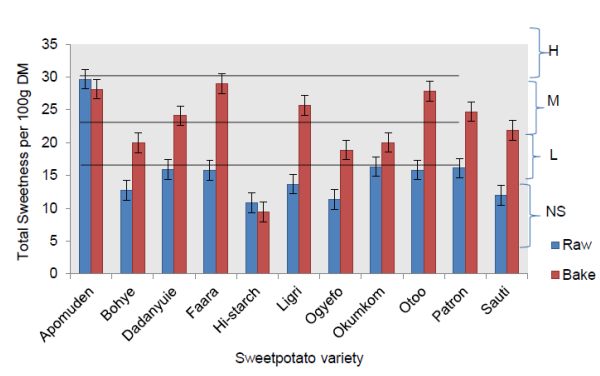

Figure 3: Changes in sweetness levels of sweet potato roots after baking. Standard error bars represent LSD at $p<0.05$.

its levels [6,10]. Moreover, the short heating period of microwaving does not enhance starch gelatinisation, a rate-determining step in initial stages of hydrolysis [7,21]. Whereas baking resulted in a dramatic increase in maltose content of Jewel, microwaving inhibited its formation, reducing the total sugar content of the cooked product [10]. Microwave cooking can therefore be an ideal method for food preparations where high sugar content is not a desirable attribute. In regions like Sub-Sahara Africa where less sweet potato varieties are perceived to be the preferred choice Tumwegamire [23], microwave cooking could be the recommended choice.

Steaming treatment resulted in an increase in maltose content in all the varieties. On the contrary, it caused a reduction in sucrose content in all the varieties compared to the raw roots. The heat transfer mechanism of steaming treatment allowed direct contact between the roots and the heat source. Such heat exchange technique allows movement of soluble substances; where solutes move from high concentration to low concentration. Sucrose, which was initially high in the raw roots, may have consequently moved from the roots to the steam. Hence the reduction in sucrose content observed in the roots after steaming.

Increase in sugars, particularly maltose, levels of sweet potato root can also be attributed to the hydrolytic ability of native amylases present in the uncooked roots. Sweet potato roots contain high levels of amylases, mainly α- and β-amylase, which significantly influence levels of sugar in processed sweet potatoes [24]. Amylases hydrolyse gelatinised starch into maltose and short-chain branched oligosaccharides (limit dextrins) during cooking resulting in a sweet taste [8,22]. The amylase activity of the varieties was therefore determined to ascertain the general hypothesis that amylases are also responsible for the increase in sugar content.

Table 4 presents amylase activity of the sweet potato varieties investigated. It ranged from 927.14 U/g in Ligri to 387.06 U/g in Hi-starch. Based upon levels of activity found, Ligri, Dadanyuie, Sauti, Ogyefo and Okumkom were grouped as very high amylase varieties. Faara, and Otoo are high-class varieties whilst Patron, Apomuden, Bohye and Hi-Starch are considered moderate types. The level of amylase activity correlated positively with the formation of maltose after cooking (Figure 1). Most of the high amylase varieties including Dadanyuie, Ligri, and Faara of low initial total sugar content (Figure 1) showed very high increase in maltose content after baking and steaming. Similarly, Hi-starch with a lower amylase activity but similar initial sugar content as that of Ligri for instance produced little extra maltose, and was not significantly different from the uncooked roots. Apomuden with moderate amylase potential produced moderate maltose content though it had the highest content prior to cooking. This result supports previous findings that maltose content in cooked sweet potato is a function of amylase activity of the roots [7,8]. However, it should be noted that different cooking treatments produced significantly different effects on sugar content of the cooked roots (Figure 1). Baking treatment however results in the highest final sugar contents.

Baking treatment and sweetness of sweet potato roots

To study the effect of cooking treatment on sweetness levels of the varieties, baking treatment, which resulted in the highest increase in sugars, was selected. Individual sugars in raw and baked roots were first converted to sucrose equivalent (SE) based on sweetness factors [25]. Such conversion allows easy comparison of sweetness among sweet potato varieties. Kays [1] employed this method to evaluate the sweetness levels of 272 baked sweet potato clones and categorised the clones into five main groupings based on SE: Very high ≥38; high 29-37; moderate 21-28; low 13-20 and non-sweet ≤ 12 g per 100 g dry mass.

Sweetness among the sweet potato varieties prior to and after baking is presented in Figure 3. The levels increased significantly after baking in majority of the varieties, and the effect was more pronounced in the high amylase types (Table 4); Faara, Ligri, Otoo and Sauti. The increase also corresponded well with the maltose content after baking (Figure 1). Apomuden had the highest sweetness value of 29.79 SE, and Hi-Starch the lowest of 10.79 SE prior to baking (Figure 3). The other varieties had values in the range of 12 to 16 SE. Using the grouping by Kays [1], the varieties fell under the following classes prior to baking: Apomuden–High sweet; Bohye, Dadanyuie, Faara, Ligri, Okumkom, Otoo, Patron and Sauti–Low sweet; and Hi-starch, Ogyefo and Sauti–non sweet. However the levels of sweetness and subsequently the sweetness categories of the varieties changed significantly following baking. Whereas Apomuden dropped slightly, but not significant, from high sweet category (29.79 SE) to moderate sweet (28 SE), majority of the varieties including Dadanyuie, Faara, Ligri, Otoo and Patron moved from low sweet to moderately sweet category. The increase in SE of Bohye and Okumkom were not significant enough to place them in the moderate class. Whilst Ogyefo and Sauti increased in SE values and were categorised as low and moderate sweet respectively, Hi-starch, remained in the same non-sweet category following baking [26,27].

Sweetness in sweet potatoes is a function of cultivar, amylase activity, storage condition, and cooking treatment [1,5,6]. Nonetheless, amylase activity, initial sugar concentration and maltose formed during cooking are the most critical in determining the final sweet sensation of cooked root [1,8]. These factors can completely change the sweetness status of a variety as observed in Dadanyuie, Faara, Ligri, Sauti, Otoo, Patron and Ogyefo (Figure 3) which were low or non-sweet prior to cooking, but changed to moderate sweet when baked.

The sweet potato varieties in this study were also classified into four general groups based on initial sucrose equivalent (SE) and starch hydrolytic potential [8]. These are low initial SE/low starch hydrolysis; Low initial SE/high starch hydrolysis; High initial SE/low starch hydrolysis and High initial SE/high starch hydrolysis. Figure 4

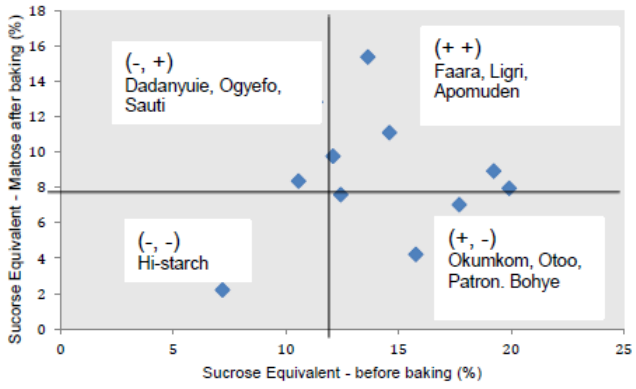

Figure 4: Classification of eleven sweetpotato varieties based on sucrose equivalent (SE) derived from starch hydrolysis (using maltose as indicator) during bakingand endogenous sugars (sucrose, glucose and fructose).

(-, -) – Low initial SE/low starch hydrolysis; (-, +) - Low initial SE/high starch hydrolysis; (+, -) – High initial SE/low starch hydrolysis; (+, +) – High initial sugar/High starch hydrolysis [11,14].

shows the classification of the sweet potato varieties assessed under this grouping.

Hi-starch was the only variety belonging to the class of low initial SE content coupled with low starch hydrolysis (-, -). It produced small amount of maltose upon cooking (Figure 1) as a result of its low amylase activity (Table 4). Natural inhibitors and starch-based structural resistance to hydrolysis are also probably inhibitory mechanisms for the low starch hydrolysis [8]. This lack of activity has been attributed to a recessive allele called β-*amy* for which the variety Satsumahikari was homozygous [8]. It is probable that Hi-Starch is the same variety since it was introduced to Ghana from Japan. Amylase activity in this variety was detected in vitro, but apparently was below the threshold required for effective hydrolysis during baking. Dadanyuie, Ogyefo and Sauti had low initial SE but produced significant amounts of maltose when baked (-, +) whilst Okumkom, Otoo, Patron and Bohye have moderate to high initial sugar content and produced low levels of maltose upon baking (+, -). The last group, Faara, Ligri and Apomuden, had relatively high initial SE and moderate to high starch hydrolytic (+, +) potential following baking. The outcome of this investigation establishes that final sweetness of cooked sweet potato roots is a function of initial sugar content and amylase potential of the raw root. Hence it would be unreliable to classify sweet potato clones in terms of sweetness prior to cooking.

Conclusion and Recommendations

The findings of this study indicate that cooking method, genotype and their interactions significantly influences sugars and sweetness of sweet potato root. Among these factors cooking treatment showed the highest variability. Baking which lasted for longer time resulted in the highest maltose formation. Maltose was barely absent in raw roots but increased considerably after cooking. The amount of maltose synthesized was however dependent on the level of amylase present in the raw root. Activity of amylases was facilitated by temperature, time, and mode of heat penetration by the cooking method. Whilst baking conditions enhances hydrolysis, electromagnetic radiation generated by microwave cooking deactivates amylases, suppressing maltose formation and rendering the product less sweet. Sweetness was found to be dependent on initial sugar content, amylase activity and cooking method. Cooking treatment should therefore be considered as a key criterion when evaluating quality attributes of sweet potatoes for appropriate utilization.

Sweet potato varieties	Total amylase activity	Groupings
Ligri	927.14 (40.56)	Very high
Dadanyuie	882.05 (26.82)	"
Sauti	809.24 (30.45)	"
Ogyefo	804.10 (30.67)	"
Okumkom	779.25 (37.76)	"
Faara	687.32 (50.34)	High
Otoo	650.67 (20.45)	"
Patron	489.81 (15.56)	Moderate
Apomuden	454.10 (21.56)	"
Bohye	414.26 (13.24)	"
Hi-starch	387.06 (25.67)	"
Grouping was based on ranges of amylase activity found: Very High (≥ 750), High (749-550), moderate (549- 350), low (≤ 349). Standard deviations are presented in brackets. LSD = 14.45		

Table 4: Means and levels of amylases in sweet potato varieties.

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