



Research article

Effects of two pre-treatments, blanching and soaking, as processing modulation on non-enzymatic browning developments in three yam cultivars from Ghana

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HIGHLIGHTS

- Soaking effectively in decreased non-enzymatic browning in both fried and roasted products of yam varieties.
- Blanching affected non-enzymatic browning in the processed yam tissues differently for the different varieties.
- pH, titratable acidity and soluble solids are important in non-enzymatic browning of soaked yam tissues.
- Pre-treated yams have high reducing power as antioxidant activity.
- Reducing power of processed yam is dependent on the variety and the processing method.

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ABSTRACT

Non-enzymatic browning develops in dry-cooked foods and those with high carbohydrate develop acrylamide, a neurotoxin and potential carcinogen. However, some non-enzymatic browning products have reducing properties. We hypothesized that non-enzymatic browning and reducing power, a measure of antioxidant activity, of processed yam are affected by pre-treatment. Peeled yam cultivars (KM, RKD and SO89) in chunks were pre-soaked (0, 3, 6, 12, 18, and 24 h) in distilled water or pre-blanching (0, 1, 2, 3, 4, and 5 min) in steam. Pre-treated samples were deep-fried at 180 °C for 15 min or roasted at 220 °C for 30 min. Soluble solids, titratable acidity and pH of yam tissues and soaking water were determined. pH of the soaked yam tissues showed a positive relation with non-enzymatic browning. Pre-soaked fried KM and roasted RKD showed a significant decrease in non-enzymatic browning intensities. The reducing power of the cooked yams ranged between 78.94 and 185.92 % of ascorbic acid, and was affected by the different pre-treatment and dry-cooking methods.

1. Introduction

Yam (*Dioscorea sp.*) is one of the few tuber crops that are popular among West Africans and the people of the tropics. Yam has a large food base, derived from both wet and dry cooking methods. Wet cooking includes boiling and pressure cooking, while dry cooking methods are frying and roasting. Of the two broad cooking methods, it is the dry cooking method that results in non-enzymatic browning (NEB) in the development of products. Moreover, these dry cooking methods have been found to produce acrylamide in foods rich in carbohydrates such

as potatoes, biscuits and other flour products (Coughlin, 2003; Swedish National Food Administration, 2002). Acrylamide is a known neurotoxin and a potential carcinogen (Crump, 2001; Swedish National Food Administration, 2002). There are efforts to decrease its occurrence in high carbohydrate foods and the attendant health issues associated with it.

However, non-enzymatic browning products from dry-cooked foods have been reported to have antioxidant properties (Phisut and Jiraporn, 2013; Wijewkreme and Kitts, 1997; Bedinghaus and Ockerman, 1995; Wijewkreme and Kitts, 1998a, b). They are reported to have protective

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benefits against oxidative stress-related diseases and conditions such as cancer, arteriosclerosis, diabetes, inflammation, arthritis, immune deficiency and ageing (Coughlin, 2003).

Of the non-enzymatic browning processes, it is Maillard reaction, involving reducing sugars with amino acids, protein and protein derivatives, that has received much attention from workers like Quayson and Ayernor (2007), Hemmler et al. (2018) and Yu et al. (2018). Although the reaction results in loss of essential amino acids, various studies in model systems and natural foods have reported the presence of products that have antioxidants activities (Phisut and Jiraporn, 2013; Wijewickreme and Kitts, 1997; Bedinghaus and Ockerman, 1995; Wijewickreme and Kitts, 1998a, b). Maillard reaction products (MRPs) have been reported to be formed from reducing sugar-amino compound combinations (Tamanna and Mahmood, 2015).

Antioxidant properties of both preformed and *in situ* MRPs have been reported in many studies (Wagner et al., 2002; Antony et al., 2002; Yanagimoto et al., 2002; Steinhart et al., 2001).

The present study investigated the reducing power (antioxidant potential) of the browning products in pre-treated fried and roasted yams. The study was conducted to find out the effect of pre-treatment (blanching or soaking) methods as processing modulation on non-enzymatic browning development in fried or roasted yams. Blanching and soaking are processing steps that invariably affect the composition of the food material. They also affect the aesthetic and physicochemical properties as well as nutritional properties of the final product after processing. Blanching disrupts the cell structure of the material (Sobukola et al., 2008) and enhances moisture removal during drying. Soaking, on the other hand, removes water soluble components such as sugars and some organic acids through leaching.

2. Materials and methods

2.1. Sample selection

Three yam cultivars consisting of two accessions of *Dioscorea rotundata* (RKD/01/013 [RKD] and KM/01/013 [KM]) and one accession of *Dioscorea alata* (SO89 128 [SO89]) were obtained from the Plant Genetic Resource Institute (PGRI) of the Council for Scientific and Industrial Research (CSIR), Ghana. The samples were kept at room temperature (25 ± 2 °C) until ready for use.

2.2. Yam pre-treatments and preparation

A 250 g of washed, peeled and cut yam chunks ($1 \times 2 \times 3$ cm) was either soaked in 250 mL of distilled water for 0, 3, 6, 12, 18, and 24 h or steam-blanching for 0, 1, 2, 3, 4 and 5 min in a steam jacket that was supplied with steam from a high-powered steam generator. Each batch of pre-treated yam samples was, then, further processed either by deep-frying in vegetable oil pre-heated to 180 °C in an open utensil for 15 min or by roasting in an electric oven (General Electric, KV 10.6, USA) set at 220 °C for 30 min. Due to limited quantities of the three yam accessions available at the germplasm of the Plant Genetic Resource Institute (PGRI) of the Council for Scientific and Industrial Research (CSIR), Ghana, samples were given one pre-treatment or another and cooked in one form or another. KM was only soaked and fried; RKD was either soaked or blanched and roasted while SO89 was blanched and either fried or roasted. The five prepared samples were kept at -18 °C until used for further analysis.

2.3. pH, titratable acidity and soluble solids determination

The pH, titratable acidity and soluble solids in the drained soaking water and the soaked yam tissues were determined, using standard methods (AOAC, 1990). pH was determined, using the TOA HM 30S pH meter (TOA Electronics Co. Ltd, Tokyo, Japan). Titratable acidity was determined by titrating drained water and prepared yam tissue slurries

against 0.1N sodium hydroxide (NaOH) with phenolphthalein as indicator. Soluble solids contents were determined, using the Abbé refractometer (Mouri Industries Co. Limited, Tokyo, Japan). Determinations were done at ambient temperatures (25 ± 2 °C) and adjustments made for the calculation of the soluble solids.

For the soaked yam tissues, 10 g of each of the different soaked yam tissues was ground into slurry in 40 mL of distilled water in a Kenwood blender (Kenwood Manufacturing Co. Ltd, UK). The pH, titratable acidity and soluble solids of the slurries were determined as described above, in duplicates.

2.4. Determination of non-enzymatic browning

Non-enzymatic browning in the fried and roasted samples was determined according to the method reported by Quayson and Ayernor (2007). Briefly, fried and roasted yam samples were crushed and ground in a laboratory mortar with a pestle. Extracts were obtained from 1 g samples with 50 mL of distilled water in triplicates. The filtered extracts were centrifuged in a refrigerated centrifuge (TOMY CX 250, Tokyo, Japan) for 30 min at 23,000 g. The clear supernatants were acidified with 0.5 ml of 40 % v/v acetic acid. Browning intensity was measured at 420 nm in the Shimadzu Spectrophotometer (UV – 120, Tokyo, Japan) against control (without test samples). Five readings were taken per replicate.

2.5. Determination of reducing power

Reducing power, a measure of antioxidant potential, of the processed yam samples was measured according to the method of Yen and Chen (1995) with some modifications. Sample solutions of 0.2 mg/mL concentration were prepared by weighing 20 mg aliquot of each sample into a 100 mL standard flask, filling it half full with distilled water, vortexing for 15 min and filling it to 100 mL with additional distilled water. It was, then, filtered to obtain a clear supernatant. Ascorbic acid of the same concentration (0.2 mg/ml) was prepared. Aliquots (1 ml) of the sample or ascorbic acid solutions were mixed with 2.5 mL of sodium phosphate buffer (pH 7.4) and 2.5 ml of potassium ferricyanide (1%, v/v). Samples were incubated at 50 °C for 20 min in water bath (Grant SS40-D Shaking Bath, Grant Instruments Ltd., Cambridge, England). A 0.5 mL of ferric chloride (0.1%, w/v) and 2.5 mL of deionised water were added to 2.5 mL of reaction mixture. Absorbance was read at 700 nm against a control (without test samples) in a Shimadzu UV- 120 Spectrophotometer (Shimadzu Scientific Instruments Inc., Japan). The reducing power of the samples was calculated as the percentage of ascorbic acid, with ascorbic acid absorbance taken as 100 % as illustrated in Eq. (1).

$$RP = \frac{S}{A} \times 100\% \quad (1)$$

where RP is the reducing power, S is the absorbance of the test sample at 700 nm and A is the absorbance of ascorbic acid at 700 nm.

2.6. Statistical analysis

Data were input into Microsoft Excel 2007. Graphs and correlations were obtained, using Microsoft Excel 2007. Analysis of variance (ANOVA) was done using Statgraphics Plus 3.0 (Graphics Software System, STCC, USA). Where ANOVA results showed significance ($p \leq 0.05$), the means were separated, using Least Significance Difference (LSD) defined at $p \leq 0.05$.

3. Results and discussion

3.1. pH, titratable acidity and non-enzymatic browning in pre-soaked yams

The pH values for the soaked tissues of KM and RKD yam cultivars and the drained water after soaking are presented in Table 1. The pH for the yam tissues showed a downward trend in both KM and RKD cultivars as

soaking time increased. However, in KM, there was no significant ($p > 0.05$) decrease in pH up to 6 h of soaking while in RKD, the lowest significant ($p \leq 0.05$) pH occurred after 24 h soaking. The results indicate that the soaking period was sufficient enough to occasion fermentation that was appreciable enough to result in increased acidity in the yam tissues. This was possible by the combined action of inherent amylase enzymes and probably microorganisms (lactic acid bacteria) inadvertently introduced through the preparation. For example, Afoakwah and Sefa-Dedeh (2002) reported the presence of enzymes in yam that degrade starch into sugars during post-harvest storage. In addition, John et al. (2009) indicated the involvement of lactic acid bacteria in the conversion of sugars to lactic acid, especially in low sugar concentration systems, as was the case in the present study.

A decreasing trend with respect to increasing soaking time was also observed in the non-enzymatic browning development in KM cultivar which was deep-fried after soaking (Figure 1). In RKD, the pH showed a moderately high correlation ($r = 0.53$) with non-enzymatic browning developed after roasting. This concurrent decrease in both pH and non-enzymatic browning development agrees with the study by Buera et al. (1987) in model systems which showed that a decrease in pH (high acidity) resulted in decreased non-enzymatic browning intensity. In addition, it could reasonably be inferred that the internal pH of the food sample may be a good determinant of the extent of non-enzymatic browning when completely cooked, at least for the RKD yam cultivar.

The trends for the percentage titratable acidity in soaked KM and RKD (Table 1) were more erratic than orderly. There was no significant ($p > 0.05$) difference among the means for the different soaking times for each of the soaked samples. The changes in the internal pH of the soaked yam tissues did not seem to correlate with the acidity, which in most studies have been found to be the case, especially in solid fermentation systems such as cassava dough fermentation (Dziedzoave et al., 2000) and maize dough fermentation (Sefa-Dedeh et al., 2004). The difference could be attributed to the limited association between substrate and enzymes in the yam chunks (in the case of the present study) as opposed to dough where milling and mixing bring the substrate into close and near uniform association with the enzymes (microorganisms).

Drained soaking water of the KM cultivar showed a consistent decrease in pH and a corresponding increase in titratable acidity as soaking time increased (Table 1). This trend was similarly observed in the soaking water for the RKD yam tissues. Indeed, the margin of change in pH between the start and end of soaking was greater in the soaking water than those observed for the solid soaked yam tissues (Table 1). This is understandable since the solid yam tissues were compact and had components that regulated the pH change, unlike the soaking water where the water with the extracted components from the yam tissues

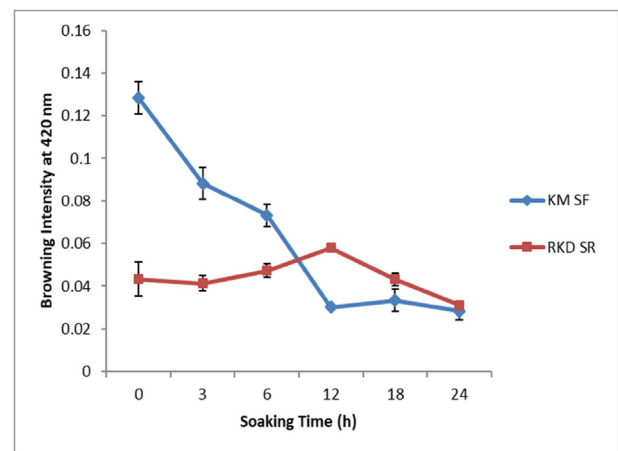


Figure 1. Non-enzymatic browning intensities in pre-soaked fried or roasted yams. Error bars represent standard deviation (SD); KMSF = Pre-soaked and fried KM yam cultivar; RKDSR = Pre-soaked and roasted RKD yam cultivar.

served as an excellent medium for microbial activity and so the observed greater margin of decrease in pH and the corresponding titratable acidity.

The pH and titratable acidity in the KM soaking water had a strong correlation with NEB ($r = 0.95$ and -0.78 , respectively), contrary to those of RKD soaking water which did not seem to affect NEB in the cooked yams because of the weak correlation with NEB ($r = 0.36$ and -0.29 , respectively). Varietal differences may explain the observed differences in the behaviour of the samples and their respective soaking waters even though they are of the same species, *D. rotundata*.

3.2. Soluble solids and non-enzymatic browning in pre-soaked yams

The percentage soluble solids in soaked yam tissue and the drained water of the KM cultivar showed a consistent decrease as soaking time increased. As evident in Table 1, the value consistently decreased (about 40%) from 2.48% for the non-soaked to a significantly ($p \leq 0.05$) low value of 1.48% after soaking for 18 h, after which there was no further decrease. The decrease of soluble solids in the soaking water after 24 h, however, was comparatively low (14%). The trend in soluble solids in the solid yam tissue is consistent with the non-enzymatic browning colour developed after frying of the soaked yam tissues. Indeed, the soluble solids in the yam tissues showed a positively high correlation with non-enzymatic browning ($r = 0.85$). The decreased soluble solids in the soaked KM yam tissue suggests a loss of components to the soaking water.

Table 1. pH, titratable acidity and soluble solids of drained water and tissue of pre-soaked yams (KM and RKD).

Soaking component	Time/hrs	pH		Titratable acidity (%)		Soluble solids (%)	
		KM	RKD	KM	RKD	KM	RKD
Drained water	0	6.89 ± 0.01a	6.86 ± 0.01a	0a	0a	0a	0a
	3	6.49 ± 0.04b	5.85 ± 0.01b	0.08 ± 0.0b	0.08 ± 0.01b	1.14 ± 0.00b	1.56 ± 0.00b
	6	6.12 ± 0.01c	5.59 ± 0.48c	0.12 ± 0.02c	0.08 ± 0.02b	1.06 ± 0.00c	1.56 ± 0.00b
	12	4.39 ± 0.01d	5.46 ± 0.02d	0.32 ± 0.0d	0.14 ± 0.01b	1.06 ± 0.00c	1.48 ± 0.00c
	18	4.01 ± 0.02e	4.67 ± 0.01e	0.90 ± 0.04e	0.36 ± 0.06c	0.98 ± 0.00d	1.48 ± 0.00c
	24	4.0 ± 0.01e	4.41 ± 0.05f	1.17 ± 0.01f	0.25 ± 0.04d	0.98 ± 0.00d	1.98 ± 0.00d
Drained yam tissue	0	6.65 ± 0.21a	6.42 ± 0.18a	0.47 ± 0.01a	0.26 ± 0.01a	2.48 ± 0.00a	2.56 ± 0.00a
	3	6.23 ± 0.05ab	6.21 ± 0.04b	0.46 ± 0.07ab	0.23 ± 0.00a	1.64 ± 0.00b	1.56 ± 0.00b
	6	6.05 ± 0.01bc	6.25 ± 0.04ab	0.40 ± 0.02ab	0.32 ± 0.06ab	1.64 ± 0.00b	1.56 ± 0.00b
	12	5.90 ± 0.20bc	5.93 ± 0.01c	0.46 ± 0.02ab	0.27 ± 0.01a	1.64 ± 0.00b	1.56 ± 0.00b
	18	5.73 ± 0.11c	5.96 ± 0.07c	0.37 ± 0.01bc	0.27 ± 0.01a	1.48 ± 0.00c	2.48 ± 0.00c
	24	5.70 ± 0.43c	5.31 ± 0.04d	0.35 ± 0.06c	0.39 ± 0.00b	1.48 ± 0.00c	2.06 ± 0.00d

Values are averages of duplicate determinations ($n = 2$) ± standard deviations. Means followed by different letters in the same column within a block indicate significant difference at $p \leq 0.05$.

These components could be organic acids and/or phenolic substances (Bhandari and Kawabata, 2004) and possibly sugars and water-soluble vitamins. This is supported by the high negative correlation of the soluble solids in the soaking water with non-enzymatic browning ($r = -0.71$). This is consistent with earlier works that suggested that sugars contribute significantly to non-enzymatic browning development (Phisut and Jiraporn, 2013; Leszkowiat et al., 1990). Fermentation of 40% soluble solids from soaked tissues and 14% from the soaking water might have contributed to the significant decrease in pH as was observed in the KM cultivar for both the soaked tissue and the drained water (Table 1).

Unlike the KM cultivar, soluble solids in RKD showed an erratic trend for the entire soaking period, which of course was consistent with the non-enzymatic browning developed in the tissues after roasting. The results of soluble solids for both the KM and RKD yam cultivars show its importance in non-enzymatic browning development in dry-cooked products, especially high carbohydrate foods as observed in this case.

3.3. Non-enzymatic browning in pre-soaked and pre-blached yam tissues

Non-enzymatic browning intensities of pre-soaked fried or roasted yams are presented in Figure 1. Browning intensity in pre-soaked and fried KM cultivar significantly ($p \leq 0.05$) decreased as soaking time increased, from 0.128 to 0.028 optical density (O.D) after 24 h of pre-soaking (Figure 1). Pre-soaked and roasted RKD cultivar, on the other hand, showed a comparatively low non-enzymatic browning with values ranging between 0.031 and 0.058 O.D.

Browning intensity for the fried KM cultivar significantly ($p \leq 0.05$) decreased during soaking for 12 h after which there was no further significant decrease (Figure 1). This may suggest that pre-soaking KM cultivar for 12 h before frying is effective in decreasing non-enzymatic browning, as additional soaking beyond this point did not impact on non-enzymatic browning development. In the case of RKD cultivar, a significant ($p \leq 0.05$) decrease in browning was recorded for 24 h pre-soaked roasted sample, suggesting that pre-soaking of this yam cultivar for 24 h before roasting could be effective in decreasing non-enzymatic browning.

Figure 2 shows the non-enzymatic browning intensities in pre-blached fried or roasted yam tissues. Pre-blached and roasted RKD cultivar had values ranging between 0.085 and 0.031 O. D (Figure 2) with the 2 min pre-blached yam tissue showing the highest significant ($p \leq 0.05$) value. This may suggest that 2 min of pre-blanching was sufficient to cause tissue disruption or openings that facilitated removal of water during the roasting period. It is also possible that the samples

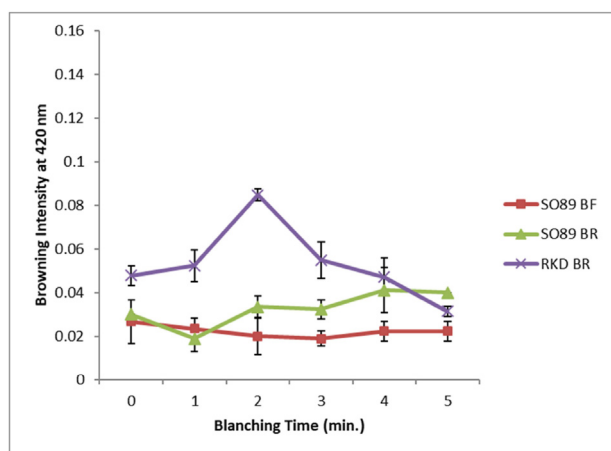


Figure 2. Non-enzymatic browning intensities in pre-blached fried or roasted yams. Error bars represent standard deviations (S.D); SO89BF = Pre-blached and fried SO89 yam cultivar; SO89BR = Pre-blached and roasted SO89 yam cultivar; RKDBR = Pre-blached and roasted RKD yam cultivar.

pre-blached beyond 2 min accumulated water which was removed during roasting with decreased impact on the carbohydrate and protein molecules, components important in non-enzymatic browning development (Quayson and Ayernor, 2007). This is evidenced by non-enzymatic browning in the 5 min pre-blached sample which showed the lowest significant ($p \leq 0.05$) value (Figure 2). Indeed, blanching is reported to result in increased moisture content in blanched tissues (Fernández et al., 2006), as it increases the permeability of cytoplasmic membranes, allowing water to penetrate cells and intercellular spaces (Canet and Hill, 1987).

Pre-blached roasted SO89 (*D. alata*) cultivar showed increased non-enzymatic browning levels as blanching time increased (Figure 2) with values ranging between 0.020 and 0.040 O.D. The 1 min pre-blached sample showed the lowest significant ($p \leq 0.05$) non-enzymatic browning. Increased non-enzymatic browning could be attributed to earlier explanation proffered for similar observations that blanching removed some water and caused tissue disruption in the fresh yam tissues, with the intensity increasing as blanching time increased. Consequently, roasting these pre-blached yam tissues in the oven for the same period caused increased browning. This is contrary to the observation made in pre-blached and roasted RKD. This difference in behaviour of the tissues in response to blanching and roasting could be attributed to varietal differences. RKD, a *D. rotundata*, is known to have high dry matter (Polycarp et al., 2012), and would interact with water (steam) differently from *D. alata* that has comparatively low dry matter (high moisture content).

In respect of different cooking but the same pre-cooking method, it was observed that non-enzymatic browning in SO89 pre-blached and fried was lower than that for pre-blached and roasted. Indeed, roasting and frying as dry cooking methods have different mechanisms. In roasting, there is only removal of water, while in frying, oil substitutes the vaporized water that escapes from the surface of the tissue into the oil (Mujumdar, 2006). It is possible that the frying regime that was employed in the present study could not effectively remove much water, with a concomitant decrease in crust development, and, therefore, caused low non-enzymatic browning. This may suggest that for SO89 and by extension, yam in general, pre-blanching and frying may not be ideal since water removal will not be effective.

3.4. Reducing power in pre-soaked and pre-blached yams

Reducing power determined the ability of extracts from the samples to donate electrons to free radicals to convert them to more stable forms, and thus terminate radical chain reaction. The results for reducing power (RP) of pre-soaked yams fried or roasted is presented in Table 2. Apart from 3 h soaking, the RP of KM and RKD yam cultivars decreased during soaking. The trend observed for reducing power in the pre-soaked and fried KM cultivar was different from that observed for non-enzymatic browning. This notwithstanding, there was moderate positive association between reducing power and browning intensity of

Table 2. Reducing power (RP) in pre-soaked fried or roasted yams.

Soaking time (hrs)	RP KM fried (%)	RP RKD roasted (%)
0	113.89 ± 20.87a	103 ± 22.96ab
3	127.73 ± 24.48ab	119.55 ± 24.71a
6	93.43 ± 7.11ace	97.74 ± 23.33ab
12	87.59 ± 23.65ade	78.94 ± 31.45b
18	110.95 ± 12.27ae	90.23 ± 18.17b
24	106.57 ± 20.55abe	95.49 ± 27.78b

Values are averages of fifteen readings from three replicate determinations ($n = 3$) ±SD.

Means followed by different letters in the same column indicate significant difference at $p \leq 0.05$.

Table 3. Reducing power (RP) in pre-blanching and fried or roasted yams.

Blanching time(min)	RP RKD Roasted (%)	RP SO89 Roasted (%)	RP SO89 Fried (%)
0	124.24 ± 40.03a	181.82 ± 64.28d	185.92 ± 102.97f
1	140.91 ± 30.7ab	136.36 ± 32.14d	143.66 ± 32.12f
2	124.24 ± 15a	154.55 ± 40.66d	140.85 ± 66.99f
3	118.18 ± 8.64a	154.55 ± 40.66d	125.35 ± 38.38f
4	111.36 ± 26.86a	145.45 ± 20.33d	109.86 ± 17.68g
5	96.97 ± 27.78ac	127.27 ± 20.33e	125.35 ± 5.89f

Values are averages of fifteen readings from three replicate determinations (n = 3) ±SD. Means with different letters in the same column show significance difference at $p \leq 0.05$.

Table 4. Correlation coefficients and p-values of non-enzymatic browning with reducing power (RP) in prepared yams.

Product	Processing methods	Correlation coefficient (r)	p-value
KM	Soaked and fried	0.52	0.35
RKD	Soaked and roasted	-0.43	0.36
RKD	Blanched and roasted	0.53	0.32
SO89	Blanched and roasted	-0.13	0.79
SO89	Blanched and fried	0.73	0.08

pre-soaked and fried KM yam tissues ($r = 0.52$; Table 4). This is indicative of moderate correlation between non-enzymatic browning products and reducing power (Milton, 1992). The high reducing power as a measure of antioxidant activity recorded in the present study compared with that reported in model studies (Wijewickreme et al., 1999) could be due to the presence of ascorbic acid and chlorogenic acid. Rodriguez-Saona et al. (1997) reported that in the presence of reducing sugars at significant levels, these antioxidants (ascorbic acid and chlorogenic acid) do not participate in non-enzymatic browning. There was, however, a moderate negative relationship between reducing power and browning intensity of pre-soaked and roasted RKD yam samples ($r = -0.43$; Table 4).

The difference in the relationship between non-enzymatic browning and RP in the KM and RKD cultivars may be mainly due to the different cooking methods (frying and roasting) and probably to varietal differences even though the two belong to the same species (*D. rotundata*).

The reducing powers of roasted or fried pre-blanching yams are shown in Table 3. The reducing power of the RKD cultivar decreased consistently from a high value of 140.91 % at 1 min pre-blanching to a low value of 96.97 % at 5 min pre-blanching. A positive moderate correlation (Milton, 1992) was observed between reducing power and browning intensity of roasted pre-blanching RKD yam samples ($r = 0.53$; Table 4). Similar observations between browning intensity and reducing power (antioxidant effect) have been reported in both natural and model food systems (Dworschak and Szabo, 1986).

The RP of roasted pre-blanching SO89 showed an erratic trend with the highest value (181.8 %) occurring in the non-blanching sample. There was a negative weak correlation between reducing power and browning intensity of pre-blanching and roasted SO89 yam samples ($r = -0.13$; Table 4). This shows that for SO89, it is best roasted without pre-blanching when reducing power is of concern since pre-blanching before roasting results in increased browning. The RP in pre-blanching and fried SO89, however, had a high positive correlation ($r = 0.73$; Table 4) with the brown colour developed. The trend observed in RP for SO89 is consistent with that reported by Dworschak and Szabo (1986).

A test of significance ($p \leq 0.05$) for the correlation determined for RP and non-enzymatic browning of the dry-cooked pre-treated products showed that the relation between the two are not significant for all the five products (Table 4). This suggests that the contribution of non-enzymatic browning to RP in the products may not be significant and that there are components in the prepared yam tissues that may be

contributing to the observed RP. Current studies are exploring these components or factors that may be contributing to the RP in pre-treated dry cooked yams.

The RP obtained in the present study for all the prepared samples are far higher than those reported in model studies (Wijewickreme et al., 1999). The difference in reducing power between reported work and the present study may be due to high concentrations of MRPs in the prepared samples or the presence of other components apart from MRPs that also contribute to reducing power.

Processing method also seems to be important in the different correlation values obtained for non-enzymatic browning and RP for the different yams. This is evident in Table 4 where RKD soaked and roasted showed a negative and weak correlation, while RKD blanched and roasted, on the other hand, showed a positive and moderate correlation. Similarly, the blanched and roasted SO89 gave a negative and weak correlation while the blanched and fried SO89 showed a positive and moderate correlation. However, a good correlation between non-enzymatic browning and RP cannot be pinned to specific treatment(s). This reinforces the earlier suggestion that non-enzymatic browning development and the associated RP in yams are dependent on the cultivar.

From Tables 2 and 3, there is a clear indication that RP in the processed yams is dependent on the species. Values obtained for the *D. rotundata* (KM and RKD) are comparatively lower than those obtained for the *D. alata* (SO89) irrespective of the processing method.

3.5. Conclusion

Different yam cultivars showed different trends in non-enzymatic browning development. Pre-soaking was effective in decreasing non-enzymatic browning in both fried and roasted products of the selected yam varieties. Blanching was effective in decreasing non-enzymatic browning in two of the yam cultivars that were pre-treated this way before dry cooking. All the processed products showed high reducing power with processing method and variety contributing to this. Non-enzymatic browning products in pre-treated roasted or fried yam have some potential antioxidant properties, evident in the inconsistent correlation characteristics between reducing power and non-enzymatic browning of the products. Further studies could investigate the factors studied here in other yam samples so as to inform processing methods for specific cultivars to derive maximum benefits in terms of health and nutrition.

Declarations

Author contribution statement

Enoch T. Quayson: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Wrote the paper.

George S. Ayernor: Conceived and designed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

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Data will be made available on request.

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The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

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