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Yam pectin and textural characteristics: a preliminary study

Liticia Effah-Manu[a,b], Bussie Maziya-Dixon[b], Faustina D. Wireko-Manu[c], Jacob K. Agbenorhevi[c], and Ibok Oduro[c]

[a]Department of Food Science and Technology, Ho Technical University, Ho, Ghana; [b]Postharvest and Nutrition Laboratory, International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria; [c]Department of Food Science and Technology, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana

ABSTRACT

The texture of yams is a key determinant in the selection of yams for boiled and pounded yams. This study was conducted to quantify pectin from local and newly developed yam varieties and to correlate pectin and its degree of esterification (DE) with instrumental textural profile parameters of boiled and pounded yam. Isolation of pectin from yam cell wall material (CWM) was achieved with citric acid and the degree of esterification (DE) was determined. The textural parameters were obtained using a texture analyzer. All the new *D. rotundata* (Poir) varieties had low CWM which varied from 11.88 to 18.95% compared to the *D. alata* varieties which ranged from 27.60 to 32.79%. Pectin yield (%) for CRI *D. alata* varieties ranged from 4.47 to 11.35 while CRI *D. rotundata* (Poir) varieties ranged from 5.18 to 5.50%. Generally, CRI *D. alata* yam varieties had higher pectin than *D. rotundata* (Poir) varieties. The DE for all samples ranged from 22.54 to 51.37%, making yam pectin low methoxy. Positive correlations existed between the textural parameters and pectin content as well as the DE but were not significant ($p > .05$). This study shows that low methoxy yam pectin has no effect on textural characteristics of boiled and pounded yam.

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Introduction

Yam is produced in large quantities and consumed in Ghana as a staple for boiling (*ampesi*), frying, roasting, mashing (*eto*), pudding (*mpotompoto*), and pounding (*fufu*). In these food products, non-starch polysaccharides such as pectin, cellulose and hemicellulose are the basis for the structural integrity of the yam cells and subsequently affect the texture. Cellulose provides rigidity and resistance to tearing to the cell wall, while pectic polymers and hemicelluloses confer firmness and elasticity. The textural and rheological properties of many plant-based foods such as fruits and vegetables are attributed to the pectin content.[1] Other functions of pectin include ion transport, hydration, and control of wall porosity.[2] According to,[3] the functions are dependent on pectin structure and concentration in the cell walls.

Although yam starch is reported to be the dominant factor affecting textural characteristics of yam-based food products,[4] pectin has been identified as a potential factor contributing to the textural properties of potatoes and is affected by tuber pectin methylesterase (PME) activity.[5] Research has also shown that during cell formation, calcium binds to PMEs bringing about rigidity.[6] Also, methyl esterification of pectins controls the activities of cell wall PMEs. A study by[5] found that tubers with higher levels of PME activity had reduced degree of methylation of cell wall pectin which demonstrated a clear link between PME activity and degree of methylation of cell wall pectin and cooked

CONTACT Liticia Effah-Manu effahmanuliticia@gmail.com Department of Food Science and Technology, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana

This article has been corrected with minor changes. These changes do not impact the academic content of the article.

tuber textural properties. Further work on PME resulted in pectin engineering which showed that a reduced level of pectin methylation in the transgenic lines was associated with firmer processed texture.[5] Recently, the firmness of French fries has been attributed to low-temperature blanching and increased affinity of pectin to bind Ca2+ through activated pectin methylesterase or crosslinking of pectin molecules by calcium fertilizer application.[7]

Potato and sweet potato pulp/starch residues and peels have been reported to have some quantifiable amounts of pectin. [8–10] In the work of,[11] it was hypothesized that pectin could play a role in the texture of yam-based foods. To our knowledge and from literature, the amount of pectin in yam is unknown. Also, yam pectin has not been characterized in terms of its degree of esterification, which could have an effect on the texture of yam-based foods. Understanding the relationship pectin and its degree of esterification (DE) play in the textural characteristics of yam-based foods will give a deeper insight into the role of non-starch-determining components, particularly pectin in the texture of yam-based foods.

Pectin consists of a chain of galacturonic acid units linked by α-(1,4) glycosidic bonds with the urinate residues naturally partially esterified.[12] Work done by[13] categorized pectin into two types depending on their degree of methylation (DM) or DE. Theoretically, the DE can range from 0 to 100%. That is high methoxy pectin (DE > 50) and low methoxy pectin (DE < 50). In an acidic medium (pH 2.0–3.5) high methoxy pectins can form gels if sucrose is present at a low concentration higher than 55 weight%.[14] showed that low methoxy pectin in the presence of divalent ions, such as calcium form gels over a large pH range (2.0–6.0). In the present work, pectin was isolated from newly developed and local yam varieties in Ghana, characterized using the DE and correlated with textural parameters of boiled and pounded yam.

Materials and methods

Acquisition of raw materials and chemicals

Local yam samples were obtained from a known farmer in Mampong in the Ashanti Region. Seven (7) newly developed yam varieties, (3 *D. rotundata* Poir and 4 *D. alata*) were obtained from the Crops Research Institute (CRI), Fumesua, Ghana. Heat stable *α*-amylase (Termamyl 120 type LS) and *α*-amyloglucosidase (EC 3.2.1.3 from rhizopus mold, 11600 U/g), pectin (P. 2157 from apple) were obtained from Sigma Aldrich.

Sample preparation

Yams were peeled, washed, and sliced into small pieces, and macerated with Philips Compact Blender (HR 2027/5, United Kingdom). The slurry was filtered through cheesecloth to separate the residue from the starch milk. The residue was rinsed thoroughly with water until the water ran clear and was dried in a YK-118 vacuum freeze dryer (True Ten Industrial Co., Limited, Taiwan). The resultant dried starch residue was kept in zip-lock bags for further analysis.

Dried cell wall material (CWM) preparation

The dried starch residue was milled in a Solitaire Mixer Grinder (VTCL) and 10 g suspended in 200 ml distilled water and boiled for 5 min. Keeping the suspension at 80°C, 0.5 mL of heat-stable *α-amylase* (Termamyl 120 type LS) was added and incubated at 80°C for 30 min. The mixture was then centrifuged at 3000 rpm for 10 min and the supernatant discarded. Residue digestion was repeated with 0.5 mL *α*-amyloglucosidase (EC 3.2.1.3 from rhizopus mold, 11,600 U/g) and incubated at 55°C for 30 min at pH 4.5. Two layers of cheese cloth was used to filter the mixture and the residue washed with water, methanol, and acetone, successively, and oven-dried at 60°C for 48 h.

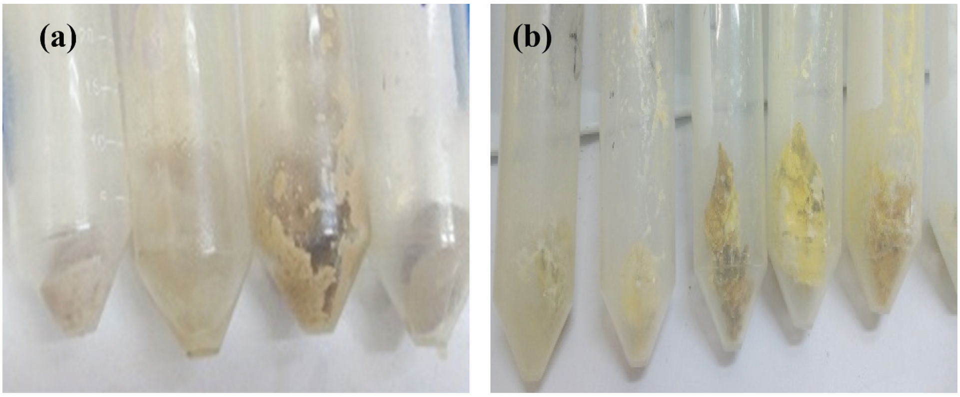

Figure 1. (a) Wet and (b) Lyophilized pectin isolates.

Extraction of pectin

Pectin extraction was based on the method proposed by[15] In:[16] with slight modification in the type of acid used. In the preliminary work, hydrochloric acid (HCl) produced little amount of pectin with some varieties producing almost nothing, thus, the use of citric acid. The sample (5.0 g) of ground CWM was dispersed in 100 mL of distilled water maintained at pH 2.5 (optimum pH determined from preliminary work) using citric acid. The solution was stirred and kept at 90°C for 1 h. After incubation, the suspension was centrifuged (Sorvall, RC 5C PLUS Ultracentrifuge) at 10°C for 15 min at 10000 rpm. The liquid fraction containing extracted pectin materials was then neutralized with 32% NaOH. The same volume of 95% ethanol was added, and the mixture was stirred for 5 min and stored at 4°C for 12 h. The mixture was then centrifuged at 10000 rpm for 15 min and the pectin residue was washed successively with 70%, 80%, and 90% ethanol and freeze-dried (Figure 1 a and b).

Determination of spike recovery rate with commercial pectin

This was done by introducing 0.5 g of commercial pectin into the sample (dried CWM). The initial weight of 3.0 g of sample was weighed and another 2.5 g of the sample plus 0.5 g of commercial pectin were weighed together. The amount of pectin in grams was obtained for both samples (sample without commercial pectin (unspiked) and sample with commercial pectin (spiked). Recovery efficiency was then calculated as described by.[17]

$$\%\text{Recovery} = \frac{\text{spiked} - \text{unspiked}}{\text{known spike added}} \times 100$$

Pectin yield

The yield of pectin was calculated as:

$$\%\text{Pectin} = \frac{\text{gram of pectin extracted(dry basis)}}{\text{gram of initial cell wall material(dry basis)}} \times 100$$

Determination of degree of esterification (DE)

The DE was determined using the potentiometric titration method according to[18] with slight modification. Dried pectin (50 mg) was wetted and stirred for complete dissolution. The resultant solution was titrated with 0.1 N NaOH and a few drops of phenolphthalein. The titration volume was recorded as the initial titer (It). Subsequently, another 30 mL of 0.1 N NaOH solution was added and the mixture was stirred at room temperature for 30 min to de-esterify the pectin. Next, 0.1 N H_2SO_4 (30 mL) was added to neutralize the NaOH. The mixture was further titrated with 0.1 N NaOH in the presence of phenolphthalein. The total titration volume (Ft) of NaOH was recorded and the DE was calculated using the equation below:

$$\%DE = \frac{Ft}{Ft + It} \times 100$$

Instrumental texture profile analysis of boiled yams

The Texture Profile Analysis (TPA) of the cooked yam samples was carried out as described by[18] with slight modifications in the percentage of deformation of samples. The Stable Micro Systems texture analyzer (TA-XT plus – 13051), Surrey, UK was used in this study. A size 15 cork borer (22.5 mm outside diameter) was used to obtain cylindrical-shaped samples from the cooked yams and cut to a height of 1 mm. A two-bite compression test was performed at a test speed of 2 mm/s, force of 5 g, and 75% strain using a 75 mm compression platen probe. Parameters obtained were hardness, fractuability, adhesiveness, springiness, cohesiveness, gumminess, and chewiness with the aid of the Exponent® software.

Back extrusion test for pounded yam

The back extrusion test was done using a TA-XT plus texture analyzer (Stable Micro Systems, Surrey, UK). The A/BE probe with a 40 mm disc was used in addition to a standard size back extrusion container of height 70 mm and 50 mm diameter. The container was filled with the sample to 75% of the container's height and probe was calibrated to a starting distance of 30 mm above the top of the pot. During the test, disc penetrated to a depth of 25 mm at a 1 mm/s speed. The pretest speed was set at 1 mm/s, posttest speed at 10 mm/s and trigger force at 10 g. Data obtained were firmness, consistency, and cohesiveness using the Exponent® software. The method is as described by[19] with modifications in posttest speed and use of software.

Statistical analysis

Statistical analysis was performed using Statistical Package for Social Scientists (SPSS, Version 20). The data were subjected to analysis of variance (ANOVA). Duncan's multiple range test was used for the mean comparisons at $p < .05$ and Pearson correlation used to determine the effect of pectin on textural characteristics of boiled and pounded yam.

Results and discussion

Cell wall materials (CWM)

The dried CWM prepared was light, loose, and non-sticky in texture for all the *D. rotundata* (Poir) varieties while the *D. alata* was sticky and hard. From Table 1, low CWM was recorded for all the *D. rotundata* (Poir) varieties from CRI, which varied from 11.88 to 18.95%. *D. alata* varieties had relatively high CWM contents of 27.60 to 32.79%. The local varieties had CWM ranging from 21.82, 25.44, 25.76, and 28.10% for *akaba, matches, pona*, and *serwaa* respectively. The CWM of *D. alata* local varieties (21.82% and 25.44%) were slightly lower than counterpart CRI *D. alata* varieties (27.6%-32.79%). However, *D. rotundata* (Poir) local varieties had high CWM (25.44% and 25.76%) compared to CRI varieties (11.88%, 17.23%, and 18.95%). The differences could be due to genetic variations/ modifications during breeding. The content of CWM from different sweet potato varieties reported by[20] varied from 35 to 52%.[21] also reported CWM of 19.9, 7.3, and 30.1% respectively for sweet

Table 1. Cell wall material content, pectin yield, and degree of esterification (DE) of pectin.

Sample	Species	CWM (%)	Pectin yield (%)	DE (%)
Pona (L)	*D. rotundata*	25.76 ± 0.40^{e}	15.88 ± 0.01^{h}	51.37 ± 0.04^{k}
Serwaa (L)	*D. rotundata*	28.10 ± 0.45^{f}	7.64 ± 1.30^{e}	40.00 ± 2.12^{f}
Akaba (L)	*D. alata*	21.82 ± 0.04^{d}	5.91 ± 0.14^{c}	38.03 ± 0.10^{e}
Matches (L)	*D. alata*	25.44 ± 0.06^{e}	4.32 ± 0.03^{a}	30.51 ± 0.08^{a}
Afase ahodenfo CRI)	*D. alata*	32.05 ± 0.50^{g}	8.75 ± 0.29^{f}	31.94 ± 0.23^{b}
Mankrong pona CRI)	*D. rotundata*	17.23 ± 0.04^{b}	5.27 ± 0.30^{c}	43.59 ± 1.15^{h}
Afase pa (CRI)	*D. alata*	28.40 ± 0.28^{f}	11.35 ± 0.00^{g}	35.27 ± 0.23^{c}
Pona (CRI)	*D. rotundata*	11.88 ± 0.23^{a}	5.50 ± 0.28^{bc}	48.01 ± 0.014^{j}
Kurupa (CRI)	*D. rotundata*	18.95 ± 0.08^{c}	5.18 ± 0.17^{b}	42.54 ± 0.47^{g}
Afase soanyinto(CRI)	*D. alata*	27.60 ± 0.12^{f}	7.05 ± 0.30^{d}	47.63 ± 0.10^{i}
Afase biri (RI)	*D. alata*	32.79 ± 0.30^{h}	4.47 ± 0.13^{a}	37.16 ± 0.24^{d}

Mean ± *SD* (standard deviation). Mean values in the same column with different letters are significantly different ($p < .05$). L-local variety; CRI-Crops Research Institute released variety

potato, cassava, and potato starch residues. The obtained results for yam compare well with these values for other root and tuber crops. Work done by[22,23] shows that, within the cell wall matrix, pectin, hemicelluloses, and small amounts of phenolic acids, glycoproteins and minerals are usually present. The presence of these substances could affect the quantities of extracted CWM. The CWM is important for determining the digestibility of foods. Higher CWM is implicative of high dietary fiber which contributes to a healthy diet by lowering bad cholesterol.[24] The high CWM content of *D. alata* varieties therefore, makes them suitable for the preparation of high fiber diets.

Pectin yield

For the CRI *D. alata* varieties, pectin content ranged from 4.47, 7.05, 8.75, and 11.35% for *afase biri, afase soanyinto, afase ahodenfo*, and *afase pa* respectively. Local *D. alata* varieties had 4.32 and 5.91%. Significant differences existed among all the CRI *D. alata* varieties at p < .05. The CRI *D. rotundata* (Poir) varieties also had 5.18, 5.27, and 5.50% for *kukrupa, Mankrong pona*, and *pona* respectively. Comparatively, low pectin content was recorded for CRI *D. rotundata* (Poir) varieties compared to the *D. alata* varieties. This could be due to varietal differences. In terms of pectin yield,[25] used disodium phosphate solution for pectin extraction optimization from sweet potato starch residue and found a yield of 10.24%. Also,[26] reported a pectin yield of 14.34% from potato starch residue when citric acid was used. These results compare favorably with the obtained values in this work (4.32–15.88%). Further, the alkaline extraction method employed in pectin extraction from sweet potato peels by[16] also yielded 16.78% at 0.25 M NaOH. The species, peculiar characteristics of the tubers or roots used and geographical locations could be the reason for the variations.

Degree of esterification (DE)

The esterification of galacturonic acid residues with methanol or acetic acid is a very important factor characterizing pectin chains. The degree of substitution is known as the degree of esterification (DE). Due to variations in species, tissue, and maturity, there can be a wide range of DEs.[27] These may explain the range of values observed in Table 3 for DE. According to,[29] pectin extracted under acidic conditions contains about 60% methyl ester groups. The positive effect of citric acid-producing highly esterified pectin has been noticed in various works.[30,31] The DE reported in this study ranged from 22.54 to 51.37%. The DE reported by[20] for sweet potato was found traceable −57.0% using NMR spectra calculations.[32] also calculated a low degree of methyl-esterification from absorbance intensities for 1630 and 1745 cm-1 (FTIR) and showed that sweet potatoes had a low degree of methyl-esterification.[33] found a very low DE of 1.4% for sweet potatoes using NMR while[25] had a DE of 11.2% for sweet potatoes while[15] also had a DE of 17.4–29.5%. The obtained values (22.54 to 51.37%)

Table 2. Spike recovery of pectin from *D. rotundata* and *D. alata* yam varieties.

Sample code	Spike recovery (%)
D. rotundata	66.50 ± 0.01[a]
D. rotundata	66.70 ± 0.03[a]
D. alata	66.83 ± 0.00[a]
D. alata	66.95 ± 0.10[a]
Average	66.75

Mean ± *SEM*. Mean values in the same column with different letters are significantly different ($p < .05$)

Table 3. Qualitative test for identification of pectin.

	Yam pectin		Commercial pectin	
Test	Description	Results	Description	Results
Pectin solution + ethanol	Yellow gelatinous precipitate	Yellow, slightly gelatinous precipitate	Sandy color gelatinous precipitate	+
Pectin solution + NaOH 2 N	Yellow gel	Yellow, weak gel formed	Sandy color gel	+
Precipitated gel + HCl 3 N	Colorless gelatinous precipitate	Colorless precipitate, not gelatinous	Colorless gelatinous precipitate	+

Method adapted from Ayora-Talavera *et al.* (2017)[28]

are in the range of values reported by these authors. The differences observed among the varieties may be attributed to the different species or varieties.[29] Generally, the DEs reported in this study show that yam pectin is low methoxy.

Pectin recovery rate and yield

The recovery rate was determined to know the accuracy of the extraction method. The recovery rate of a substance is the amount of a compound that is present in the extract compared to the total amount of the compound in both the extract and the raffinate expressed as a percentage.[34] Replacing HCl with citric acid increased the yield. HCl, being a strong acid easily releases bound pectin from the cell matrix[35] but could lead to pectin degradation. Citric acid however, has less effect on chain degradation[36] and it is known to extract significantly higher than strong acids.[14]

The recoveries were calculated, and the average recovery and standard error of means (SEM) are presented in Table 2. The relative SEM from triplicate analysis ensured the precision of the method. Factors that may significantly influence the liquid-solid extraction include solvent concentration, pH, temperature, extraction time and particle size,[37] and the effect of the sample matrix.[38,39] While all these variables were kept constant, the matrix effect could be the only factor affecting pectin recovery. The average percent recovery (66.75%) shows that citric acid could not release all the protopectin into the solution. A combination of enzymatic and acid-thermal methods may improve on recovery.[8]

Qualitative test for pectin identification

Though pectin characteristics depend principally on the source, solubility in water is a basic property, which all the extracts exhibit. However, clump formation occurred due to the tendency of hydrating quickly in water,[40] causing a delay in dissolution but dissolving quickly in hot water. From Table 3, slight gel formation of pectin extract with ethanol and weak gel formation with

NaOH could be due to the low concentration of pectin in the solution. It also implies extracts have the low gelling ability and probably with acetylated galacturonic acids as found in potatoes, sugar beet, and okra pectin.[41–43] This property prevents gel-formation but increases the stabilizing and emulsifying effects of pectin.

Textural profile characteristics of boiled yam

The texture profile analysis of boiled yam showed significant variations among the different species and varieties. As shown in Tables 4, 5, the *D. rotundata* (Poir) local varieties had higher values for hardness, cohesiveness and chewiness. *Matches* (*D. alata*) was the least cohesive and was significantly different (p < .05) from *akaba* (*D. alata*) and *D. rotundata* (Poir) varieties, *pona and serwaa*. These local varieties are known and utilized in various forms in Ghana. In yam growing communities, people use both species for boiling (*ampesi*) and pounding (*fufu*), but *akaba* is the most preferred *D. alata* variety for *ampesi*. In the cities however, many people prefer *D. rotundata* (Poir) varieties[44] for both *ampesi* and *fufu* as taste and moldability are associated with this variety.[45]

Hardness is the maximum force required to compress a food between the molar teeth. Among CRI varieties, the most hard was *kukrupa* (14.47 N) followed by *afase biri* and *mankrong pona* (13.74 N, 13.61 N) respectively. *Afase biri* (13.74 N) and *soanyinto* (12.26 N) are *D. alata* varieties whose hardness compared closely with the *D. rotundata* (Poir) varieties although significantly different (p < .05). *Afase pa* and *afase ahodenfo* were the least hard varieties with 7.460 N and 6.564 N respectively (Table 5).

The cohesiveness is the ability of the boiled yam to hold together. The cohesiveness of all CRI varieties ranged from 0.11 to 0.16. *Afase pa* and *ahodenfo* (*D. alata*) were least cohessive (0.11) with *mankrong pona* (*D. rotundata*) having the highest (0.16) but not significantly different (p < .05) from the other *D. rotundata* varieties (0.15). Higher values imply samples have high ability to withstand external force.

Fracturability is the ability of the boiled yam sample to crumble upon slight application of force. The most fracturable was *afase ahodenfo* (2.39 N) which is *D. alata* variety. The *D. rotundata (poir)* varieties were least fracturable and ranged from 7.33 N-8.07 N. In terms of chewiness, the chewiest *D. alata* variety was *afase biri* (71.6) and af*ase ahodenfo* had least value of 15.5. *D. rotundata* (Poir) varieties ranged from 68.9 N-76.3 N. Generally, all the varieties with higher values for chewiness corresponded with high values for gumminess (Tables 4, 5). CRI *D. alata* varieties, *afase biri* and *soanyinto*, had values that are more closely related to all the *D. rotundata* (Poir) varieties. *Afase soanyinto* having closely related textural values with CRI *pona* would be the best *D. alata* variety for *ampesi* or *fufu*.

The closeness in textural characteristics of some *D. alata* varieties to *D. rotundata* could be due to improvement in breeding as similar observations were made by[46] and.[47] The very low hardness[48] chewiness, consistency, and firmness values of CRI *afase ahodenfo* and *afase pa* would make them more suitable for pudding.

Textural profile parameters for pounded yam

From Tables 4, 5, the firmness of CRI *D. alata, afase biri* (63.58) and *afase soanyinto* (64.41), were high and comparable to *D. rotundata (poir)* varieties (42.18–60.67). The least firm was *afase ahodenfo* (36.04). Cohesiveness was high in *kukrupa* and *afase soanyinto* but *afase biri* had the least value. All the CRI *D. rotundata* (Poir) varieties were good for pounding, with *kukrupa* being best considering its textural characteristics. Also, CRI *D. alata* varieties, *afase soayinto* and *afase biri* with high firmness and consistency had better textural characteristics (Table 5) than the counterpart *D. alata* local varieties (*akaba* and *matches*). They can therefore be promoted for use in the preparation of pounded yam. CRI *pona* and *mankrong pona* compare very well with the most preferred yam in Ghana, *pona*. The link between pectin content and its DE on the textural parameters was analyzed as discussed in the following section.

Table 4. Textural profile parameters of boiled and pounded yam (*D. rotundata*).

Boiled yam						Pounded yam			
Variety	Hardness (N)	Fractura-bility (N)	Cohesive-ness	Chewiness	Gumminess (N)	Consistency	Firmness	Cohesiveness	Adhessiveness
Pona (L)	11.17 ± 0.21^{a}	7.14 ± 0.14^{a}	0.15 ± 0.06^{a}	62.6 ± 0.20^{a}	16.97 ± 0.40^{b}	114.43 ± 0.15^{c}	72.79 ± 0.01^{e}	−82.07 ± 0.90^{a}	−4.09 ± 0.35^{c}
Serwaa (L)	13.39 ± 0.02^{d}	9.12 ± 0.51^{c}	0.15 ± 0.02^{a}	80.3 ± 0.09^{e}	2.03 ± 0.13^{a}	105.19 ± 0.07^{b}	53.15 ± 0.11^{b}	−78.03 ± 0.23^{b}	−4.39 ± 0.55^{b}
Kukrupa (CRI)	14.47 ± 0.20^{e}	8.07 ± 0.10^{b}	0.15 ± 0.03^{a}	76.3 ± 0.33^{d}	22.19 ± 0.24^{e}	119.89 ± 0.21^{d}	60.67 ± 0.03^{d}	−37.53 ± 0.06^{d}	−4.18 ± 0.07^{c}
Mankrong pona (CRI)	13.61 ± 0.25^{c}	7.76 ± 0.14^{b}	0.16 ± 0.02^{a}	68.9 ± 0.08^{b}	21.53 ± 0.04^{d}	111.56 ± 0.03^{c}	56.65 ± 0.05^{c}	−83.11 ± 0.01^{a}	−4.84 ± 0.04^{a}
CRI pona(CRI)	12.45 ± 0.09^{b}	7.33 ± 0.20^{a}	0.15 ± 0.43^{a}	70.1 ± 0.50^{c}	18.28 ± 0.06^{c}	84.61 ± 0.45^{a}	42.18 ± 0.03^{a}	−67.33 ± 0.92^{c}	−4.29 ± 0.50^{a,b}

Mean values in the same column with different letters are significantly different ($p < .05$) L-local variety; CRI-Crops Research Institute released variety

Table 5. Textural profile parameter of boiled and pounded yam (D. alata).

Boiled yam						Pounded yam			
Variety	Hardness (N)	Fracturability (N)	Cohesiveness	Chewiness	Gumminess (N)	Consistency	Firmness	Cohesiveness	Adhessiveness
Matches (L)	6.10 ± 0.41^{b}	3.40 ± 0.03^{b}	0.11 ± 0.01^{a}	10.3 ± 0.11^{a}	6.11 ± 0.04^{b}	123.22 ± 0.12^{d}	59.19 ± 0.06^{d}	−60.14 ± 0.10^{d}	−12.150.08 ±^{c}
Akaba (L)	13.6 ± 0.05^{a}	5.40 ± 0.12^{d}	0.14 ± 0.01^{a}	35.4 ± 0.40^{c}	15.50 ± 0.13^{e}	80.47 ± 0.14^{b}	41.23 ± 0.05^{b}	−83.73 ± 0.46^{b}	−7.05 ± 0.10^{d}
Ahodenfo (CRI)	6.56 ± 0.09^{c}	2.39 ± 0.41^{a}	0.11 ± 0.06^{a}	15.5 ± 0.01^{b}	7.47 ± 0.08^{c}	75.93 ± 0.40^{a}	36.04 ± 0.37^{a}	−37.67 ± 0.33^{e}	−22.70 ± 0.05^{a}
Afase Biri (CRI)	13.74 ± 0.64^{f}	8.28 ± 0.09^{f}	0.15 ± 0.35^{a}	71.6 ± 0.50^{e}	20.41 ± 0.43^{f}	134.06 ± 0.22^{f}	63.58 ± 0.34^{e}	−84.93 ± 0.18^{a}	−3.80 ± 0.11^{f}
Soanyinto (CRI)	12.26 ± 0.16^{e}	6.18 ± 0.22^{e}	0.13 ± 0.44^{a}	48.1 ± 0.30^{d}	1.55 ± 0.08^{a}	126.97 ± 0.01^{e}	64.41 ± 0.25^{f}	−32.13 ± 0.50^{f}	−4.93 ± 0.42^{e}
Afase Pa (CRI)	7.460 ± 0.38^{d}	4.044 ± 0.62^{c}	0.11 ± 0.02^{a}	16.0 ± 0.05^{b}	8.11 ± 0.43^{d}	97.02 ± 0.55^{c}	46.50 ± 0.08^{c}	−67.62 ± 0.39^{c}	−13.79 ± 0.05^{b}

Mean values in the same column with different letters are significantly different ($p < .05$). L-local variety; CRI-Crops Research Institute released variety

Table 6. Correlation of pectin and DE with the textural parameters of boiled yam.

	D. alata				*D. rotundata*			
	Pectin		Degree of esterification		Pectin		Degree of esterification	
	Coefficient	p-value	Coefficient	p-value	Coefficient	p-value	Coefficient	p-value
Hardness	0.832	0.113	0.799	0.135	0.086	0.824	0.059	0.863
Fracturability	0.363	0.456	0.831	0.113	0.555	0.357	0.034	0.907
Cohesiveness	0.261	0.547	0.810	0.127	0.599	0.320	0.765	0.186
Gumminess	0.462	0.377	0.136	0.681	0.278	0.606	0.034	0.907

Table 7. Correlation of pectin and DE with the textural parameters of pounded yam.

	D. alata				*D. rotundata*			
	Pectin		Degree of esterification		Pectin		Degree of esterification	
	Coefficient	p-value	Coefficient	p-value	Coefficient	p-value	Coefficient	p-value
Firmness	0.564	0.196	0.521	0.217	0.143	0.752	0.589	0.329
Cohesiveness	0.745	0.111	0.773	0.099	0.454	0.444	0.671	0.262
Adhesiveness	0.646	0.156	0.174	0.442	0.327	0.517	0.464	0.436
Consistency	0.637	0.161	0.768	0.101	0.666	0.266	0.749	0.198

The results(Tables 6 and 7)revealed a positive correlation between pectin content and all the textural attributes of boiled and pounded yam with no significance ($p > .05$). Pectin polysaccharides are highly susceptible to modification during processing.[49] Some processing modifications include the removal of divalent cations and hydrolysis or β–elimination degradation, which could result in tissue softening.[50] The activation of pectin methyl esterases and the cross linking of the de-esterified pectic polysaccharides by divalent cations could also occur.[51,52] Further, during cooking, high methoxy pectin in the flesh of spaghetti break down while low methoxy pectin glued cells of strands together.[52] The specific transformations that pectin undergoes during processing of yam into '*ampesi*' or '*fufu*' is unknown and requires further work.

Conclusion

Citric acid achieved pectin precipitation at pH 2.5 and 90°C with a spike recovery of 66.75%. This prompts for further research as it suggests that some pectin remained bound. Further investigations could be done on an appropriate extraction solvent or method for yam pectin extraction. The textural characteristics of boiled and pounded yam from local and CRI newly developed varieties are comparable. The CWM of both local varieties and CRI *D. alata* compare well but CRI *D. rotundata* (Poir) varieties have lower CWM than counterpart local varieties. The low methoxy yam pectin positively correlated with all the textural parameters of boiled and pounded yam but were not significant at $p < .05$.

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Disclosure statement

No potential conflict of interest was reported by the author(s).

ORCID

Liticia Effah-Manu http://orcid.org/0000-0003-2896-9916
Bussie Maziya-Dixon http://orcid.org/0000-0003-2014-2201
Faustina D. Wireko-Manu http://orcid.org/0000-0002-5020-6299
Jacob K. Agbenorhevi http://orcid.org/0000-0002-8516-7656
Ibok Oduro http://orcid.org/0000-0003-3731-2684

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