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Sweet Potato Peel Pectin's Potential as a Suspending Agent in Pharmaceutical Formulations: The Effect of Extraction Technique

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Abstract

Introduction: Sweet potato (*Ipomoea batatas* L. Lam) represents an essential underutilised crop globally. The ubiquitous hydrocolloid, pectin, with versatile pharmaceutical and cosmetic applications has been reported to be abundant in the peels. This study thus examined the impact of acid (citric acid) and alkaline (sodium hydroxide) extraction procedures on the suitability of pectin extracted from sweet potato peels as a biocompatible and economical alternative pharmaceutical suspending agent. **Methods**: Conventional acid and alkaline extraction procedures were utilised in sweet potato pectin extraction followed by characterisation and phytochemical evaluation. The proximate composition, FTIR spectra, secondary metabolites and degree of esterification were determined. Additionally, different concentrations (1% and 2%) of the pectins were utilised in formulating paracetamol suspensions using acacia gum as the reference and assessed for pharmaceutical quality. **Results**: Secondary metabolites were present in all pectins while the yield was 9.04±0.07 and 7.24±0.25 respectively for the acid and alkaline extraction methods. Quality and high methoxyl pectins with significant differences ($p<0.05$) in all characterisation parameters (Equivalent weight=1666.67 and 1250mg/mol; methoxyl content=16.43 and 9.57% respectively) except for ash content (3.12 and 2.95 % respectively) were obtained. FTIR highlighted characteristic functional groups in pectin. Both pectin suspensions demonstrated good however, variable significant differences ($p<0.05$) in flow rates, re-dispersibility, sedimentation rates, and volumes compared to acacia gum. The pH remained mildly acidic (<7) with no physical instabilities. **Conclusion**: The alkaline pectin exhibited a better-suspending property than the acid pectin extract. Nevertheless, they both can be utilised as an alternative to acacia gum as a suspending agent.

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Introduction

An essential albeit underused versatile crop is sweet potato (Ipomoea batatas L. Lam) (Alam, 2021). It currently ranks seventh on the global essential crops list and behind yam (Dioscorea spp.), Taro (Colocasia spp.), and cassava (Manihot esculenta Crantz) in Ghana. Its capacity to thrive in varied agro-ecologies and water-stress soils coupled with its short growth cycle and functional properties makes it increasingly attractive for commercial and industrial purposes (Ocloo et al., 2011; Sugri et al., 2017). Significant phytochemical and physicochemical attributes of sweet potato tubers such as high mineral contents (iron and calcium) and antioxidant properties have been established in literature highlighting their ubiquitous nutritional benefits and potential for industrial application (Shaari et al., 2021; Shamsudin et al., 2022). Several cultivars of sweet potato (CRI-Apomuden, CRI-Bohye, Resisto, Ukerewe) are reported in Ghana which is generally orange to pale yellow with a maximum maturity period of 4 months (Darko et al., 2020; Ofori et al., 2009; Teye & Abano, 2012). CRI-Apomuden in particular has a short maturity period (3 to 3.5 months) coupled with high beta-carotene contents and serves as an excellent input for industries making it an ideal alternative to current pectin sources (Darko et al., 2020). Commercial and industrial applications of sweet potatoes such as starch and flour production and biofuel generation produce sizable amounts of residues either employed as animal feed or disposed of as waste (Alam, 2021). Specifically, the peels of sweet potatoes account for 15-40% of the initial product mass which ends up in landfills and degrades to generate greenhouse gases. This contributes immensely to environmental pollution and the wastage of substantial resources (Oluyori et al., 2016; Torres & Domínguez, 2020).

Pectin, an abundant plant polymer in the middle lamella of the cell wall of plants, is composed of α-galacturonic acid (GalA) with varying amounts of methyl ester groups, α-L-rhamnopyranosyl backbone and neutral sugars (e.g. Arabinose, galactose) (Garna et al., 2004). Pectin has high-value applications in the pharmaceutical as well as food industries nevertheless, commercial sources are currently limited to apple pomace and citrus peels which exhibit good gelling properties but are disadvantaged by long maturity periods (Boakye-Gyasi et al., 2021). Therefore, there is a need to investigate a new pectin source with ideal molecular weight, degree of esterification, and methoxyl content (Zhang & Mu, 2011). According to Mei et al, sweet potato residues have a dry matter pectin content of 15% (Mei et al., 2010). Furthermore, rhamnogalacturonan I (the hairy section of pectin) is present in significant amounts in industrial sweet potato waste suggesting the potential of sweet potato as a viable source of pectin (Hamidon & Zaidel, 2017).

The physicochemical and functional properties such as the degree of esterification, molecular weight, and GalA content depend on the pectin product structure and are significantly dependent on the method of extraction (Wandee et al., 2019). High methoxyl pectin has been extracted using water, mineral acids, and bases however, due to the salt-bridge linkages with polyvalent metal ions, the extraction of low methoxyl pectin is difficult using similar solvents (Zhang & Mu, 2011). Citric acid is reported to be the least pectin-degrading agent and yields pectin with the best gelling properties (Hamidon et al., 2020; Kliemann et al., 2009). Furthermore, alkaline extraction processes have yielded low methoxyl, and low-molecular-weight pectin via saponification reactions and β-elimination (Hamidon et al., 2020; Wandee et al., 2019).

There are high healthcare expenditures coupled with increased out-of-pocket medicine payments in Ghana largely due to increased importation (70-90%) of drugs (Adebisi et al., 2022; Conway et al., 2019). This impedes the attainment of the World Health Organization's (WHO) Universal Health Coverage and highlights the need to increase local production while utilising indigenous raw materials such as sweet potato peels to address this problem.

Despite the extensive characterisation of sweet potato pectin, there is limited evaluation of the effect of different extraction techniques on the quality of extracted sweet potato pectin and its subsequent utilisation as a pharmaceutical suspending agent (Hamidon et al., 2020; Hamidon & Zaidel, 2017; Zaidel et al., 2015; Zhang & Mu, 2011). Furthermore, current sources of suspending agents such as acacia are plagued with significant disadvantages such as bio-incompatibility, variable viscosity and decreased stability in acidic medium (Nussinovitch, 2009). The objective of this study is therefore to investigate the effect of acid and alkaline extraction procedures on the suitability of pectin extracted from sweet potato peels as a pharmaceutical suspending agent. Suspending agents ensure that dispersed drugs are dispersed long enough for an accurate dose to be dispersed by ensuring slow sedimentation and easy redispersibility (Bamigbola et al., 2017). Previous studies have highlighted the viscosity-enhancing effects of pectin polymers in suspensions and other liquid dosage forms (Chandel et al., 2022; H. Chen et al., 2016; Owusu et al., 2022, 2024; Pacheco et al., 2019). The study has the potential to transform significant waste of sweet potato (*Ipomoea batatas* L. Lam) peels generated into considerable wealth all the while ensuring the diversification of local sweet potato use and its commodification by the pharma industry.

Materials and methods

Materials

Analytical grades of citric acid, 95% Isopropyl alcohol, 95% ethanol, benzoic acid, 0.25N HCl, 0.1N NaOH, phenol red, and NaCl were acquired from UK Chemicals in Kumasi. Paracetamol powder (99%) (Xi'an Henrikang Biotech Co., China), Acacia gum powder (Sigma-Aldrich, Darmstadt Germany). 0.1% Ferric Chloride, Fehling's Solution A and B, and 1% Lead Acetate obtained from the Department of Pharmacognosy laboratory, Kwame Nkrumah University of Science and Technology (KNUST). The Department of Pharmaceutics Laboratory, KNUST provided distilled water.

Method

Sample Collection and Preparation

Simple random sampling was utilised in acquiring ~ 40 kg of fully ripe sweet potato tubers (CRI-Apomuden) from the Ayigya market in the university community which was authenticated at the Department of Horticulture. The average linear dimensions ± standard deviations were 11.6±2.2, 5.7±1.3 and 4.9±1.1 cm respectively for the major, intermediate, and minor diameters. The tubers were thoroughly washed to remove dirt and peeled about 1 mm from the tubers. The peels were sun-dried till crisp and of constant weight for 7 days. For easier extraction, the dried peels were then ground into fine powder using a compact blender (ARMG Aardee, India) and divided into two for the alkaline and acid extraction, and stored in an airtight container.

Extraction of pectin

Pulverised sweet potato peels (150 g) were dispersed in 1000 ml of distilled water (adjusted pH to 1.5 with citric acid) and heated at 90 °C for 60 minutes. The mixture was cooled and subsequently filtered through a cheesecloth. The precipitation of pectin was carried out by adding 1000 mL of 95 % ethanol (about three times the volume of the filtrate that passed through the cheesecloth). Thorough and vigorous stirring of the filtrate was undertaken and then allowed to rest for 30 minutes followed by skimming off the pectin flocculate with a spatula. The excess flocculate was filtered again using a cheesecloth to ensure purity. The extracted acid pectin gel (ACP) was then left to dry at 40 °C in an oven and stored in an airtight zip-lock bag until further analysis. A similar extraction protocol was followed for the alkaline procedure with the initial pH of distilled water being adjusted to 7.4 with NaOH (Owusu et al., 2023).

The pectin yields of the acid (ACP) and alkaline (ALP) pectins were subsequently determined using Equation 1:

$$\%\,Yield = \frac{Weight\ of\ dried\ pectin\ (g)}{Weight\ of\ powdered\ sweet\ potato\ peels\ (g)} \times 100 \quad Eq. 1$$

Determination of moisture content, crude protein and ash content

The method described by Ismail and colleagues was used to determine the ash and moisture content. Briefly, an amount of 1 g pectin was ignited at 550 °C for 4 hours to assess the ash content. For the moisture content, 1 g pectin was oven-dried (105 °C) (Ismail et al., 2012). The Kjeldahl method was used for the crude protein analysis (Sáez-Plaza et al., 2013). Measurements were obtained on a constant dry weight basis and in triplicates.

Test for Secondary Metabolites

The presence of phenols, tannins, saponins, and glycosides was established using the standard protocols described by (Evans, 2009).

Phenols

An amount of 2 mL 2% pectin solution was treated with five drops of 0.1% ferric chloride solution and observed for a colour change.

Tannins

An amount of 0.2 g pectin was boiled in 20 mL of distilled water and allowed to cool for 2 minutes. Five drops of 1% lead acetate were added and the precipitate was observed.

Saponins

Distilled water (10 mL) was added to 0.2 g pectin and the mixture was filtered. The filtrate was vigorously shaken, and the persistence of the foam for more than 5 minutes indicated the presence of saponins.

Glycoside

Five (5) mL dilute HCl was added to pectin (0.2 g), boiled in a water bath for 5 min, and allowed to cool. 20 % NaOH (20 drops) was added to alkalise the mixture. Additionally, 1 mL of Fehling A and B solutions were added and boiled for 5 minutes. The formation of brick-red precipitates was observed.

Test for Pectin

Before being heated and cooled, a quantity of pectin (1 g) was quickly combined with 9 ml of water to form a gel. NaOH was subsequently added to 5 ml of the pectin solution and allowed to rest for 15 minutes before 1 ml HCl was added and boiled (Owusu et al., 2023).

Characterization of Ipomoea batatas Peels Pectin

Determination of Equivalent Weight

The method described by Rangana was used with minor modifications. To 500 mg pectin in a 250 mL conical flask, 5 mL of ethanol (to moisten pectin) before it was dissolved in 100 mL distilled water. 1g NaCl and 6 drops of phenol red (indicator) were added to the mixture which was then thoroughly mixed to ensure homogeneity and then titrated against 0.1 N NaOH (Ranganna, 1986). Equivalent weight was determined using Equation 2:

$$Equivalent\ weight = \frac{weight\ of\ pectin\ sample\ (g)\ \times 1000mg}{volume\ of\ alkali\ (ml) \times Normality\ of\ Alkali} \quad Eq. 2$$

Determination of Methoxyl Content (MeO)

In a stoppered flask, 25 mL of 0.25 N NaOH was added to the neutralized solution from the equivalent weight setup, thoroughly mixed and allowed to rest on the bench for 30 minutes. Subsequently, 25 mL of 0.25 N HCl was introduced into the solution which was titrated to the same endpoint as before after the addition of phenol red and NaCl (Ranganna, 1986).

Equation 3 was used in calculating MeO.

$$methoxyl\ content\ (\%) = \frac{volume\ of\ alkali\ (ml)\ \times\ Normality\ of\ Alkali\ \times\ 31\ \times\ 100}{weight\ of\ pectin\ sample\ (mg)} \quad Eq. 3$$

The molecular weight (MW) of the methoxyl group is 31.

The Determination of Anhydrouronic Acid Analysis (AUA)

The method proposed by (Twinomuhwezi et al., 2023) was used:

$$\%\ AUA = \frac{176 \times 0.1y \times 100}{w \times 1000} + \frac{176\ \times 0.1z \times 100}{w\ \times 1000}\ Eq. 4$$

Where 176 indicated the 1 unit of AUA, z and y are the volumes of NaOH used in the determination of equivalent weight and MeO respectively and w is the sample weight.

Determination of Degree of Esterification (DE)

The values of AUA and MeO obtained were substituted into Equation 5 to determine the DE (Twinomuhwezi et al., 2020):

$$\%\ DE = \frac{\%MeO\ \times 176\ \times 100}{\%\ AUA\ \times\ 31}\ Eq. 5$$

Fourier Transformed Infrared (FTIR) Spectroscopy

The spectroscopic analysis of ALP and ACP was determined using an FTIR spectrometer (UATR Spectrum 2, 941333, PerkinElmer, UK). Transmission mode scanning was done on the spectrum between 400 and 4000 cm^{-1}.

Formulation of Paracetamol suspensions using Ipomoea batatas peels pectin as a suspending agent

The method used by (Owusu et al., 2023) was replicated in the formulation of 100 mL paracetamol (5 g) suspensions. The test-suspending agents were ACP and ALP while the reference was acacia gum. Evaluations were done on two concentration levels 1% $^{w}/_{v}$ and 2% $^{w}/_{v}$ with distilled water as the vehicle and benzoic acid (0.1% $^{w}/v$) as the preservative (Table 1).

Table 1: Master Formula for Preparation of Paracetamol Suspension

Ingredient	Quantities
Paracetamol powder	5 g
Benzoic acid (0.1% w/v)	0.1 g
Purified water to	100 mL

Quality Control Tests on Suspensions

Sedimentation volume (F)

Separate portions (50 mL) of formulations were quantitatively transferred into 100 ml measuring cylinders. The sedimentation volume was measured on the first day and then every week for the following three weeks in triplicates (Owusu et al., 2023). Equation 6 was used to determine the sedimentation volume:

$$F = \frac{Ultimate\ volume}{Initial\ volume} \times 100\% \qquad Eq.6$$

Flow rate (f)

Equation 7 was used to determine the flow rate. The flow time was established by measuring the time required for 10 mL suspension to move through the entire length of a 10 ml pipette (Owusu et al., 2023).

$$f = \frac{volume\ of\ pipette\ (ml)}{flow\ time\ (s)} \qquad Eq.7$$

pH of Suspension

An amount of 20 ml of the suspensions was quantitatively transferred into beakers (100 mL) and stirred thoroughly. The pH readings were obtained in triplicates by submerging the electrodes of the pH meter in the suspension (Mettler Toledo, USA) (Owusu et al., 2023).

Ease of Re-dispersibility

A qualitative assessment of the suspension's re-dispersibility was made as described by (Owusu et al., 2023).

Sedimentation rate and volume

The method described by Owusu colleagues was followed to calculate the sedimentation rates of the formulations as described in Equation 8 (Owusu et al., 2023).

$$Sedimentation\ rate = \frac{Change\ in\ volume\ of\ sediment\ (V_1 - V_2)}{T_1 - T_2}$$

Where V1 and V2 represent the initial volume of sediment and the final volume of sediment respectively. T1 and T2 also represent the time it took for V1 to settle to V2.

Statistical Analysis

All the analyses were carried out using GraphPad Prism version 8.0.1. Standard deviations and mean were used to present data while the unpaired student t-test and two-way analysis of variance (ANOVA) were used to determine the p-values where appropriate. Significance was denoted as $p \leq 0.05$.

Results and discussion

The pectin yield and phytochemical constituents of sweet potato peels pectin

Percentage yield of pectin

The pectin yields obtained were 9.04±0.07 and 7.24±0.25 for the acid and alkaline extraction methods respectively as shown in Figure 1. The ACP yield has a significantly higher yield ($p<0.05$) than the ALP which could be accounted for by β-elimination reactions as well as saponification reactions resulting in the galacturonic acid backbone degradation (Wandee et al., 2019). Acid extraction conversely loosens the cell wall matrix resulting in increased pectin extraction and high levels of galacturonic acid (Zaidel et al., 2015). The yield of sweet potato pectin from cell wall materials under varied conditions has been reported to range from 7.2 and 29.3% indicating the results obtained were comparable (Zaidel et al., 2015). Compared to other pectin sources extracted using similar procedures such as watermelon (yield = 14.1%) and plantain (10.01%-46.55%), the yields were however lower which could be accounted for the variation in plant sources (Otu et al., 2024; Owusu et al., 2022).

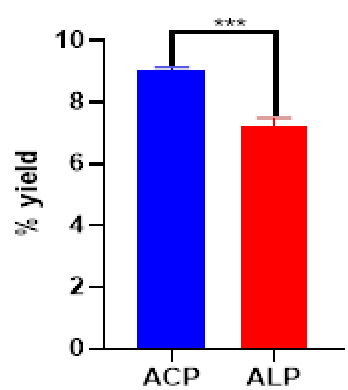


Fig. 1: Statistical analysis on % Yield of pectin extracted by Acid (ACP) and Alkaline (ALP) extraction methods ***P < 0.001 significant difference between ACP and ALP using unpaired student's two-tailed t-test.

Phytochemical constituents of pectin

The phytochemical analysis indicated that the secondary metabolites; tannins, glycosides, saponins, and phenols were present in both ACP and ALP (Table 2). These metabolites particularly phenols and tannins have been implicated in the antioxidant, antineoplastic, and antimicrobial activity of plants. Saponins also exhibit emulsifying properties (Edeoga et al., 2006; Schieber et al., 2003). The pectin identification test concluded the presence of pectin as per the requirements prescribed in the USP (The United States Pharmacopeial Convention, 2021).

Table 2: Phytochemical components in extracted Ipomea batatas peel pectin

Phytochemical Parameters	Observation	Inference
Glycosides	The appearance of a brick-red precipitate was observed for both ACP and ALP	Presence of glycosides
Saponins	The persistence of a froth for 5 minutes for both ACP and ALP	Presence of saponins
Tannins	A greenish-coloured precipitate and a light brown precipitate were formed for both ACP and ALP respectively which remained after the introduction of 5 drops of a solution of 1% ferric chloride	Presence of tannins
Phenols	The appearance of bluish-black colouration for both ACP and ALP	Presence of Phenols

Proximate content and characterisation of Ipomoea batatas peels pectin

Moisture content

In the pharmaceutical sector, moisture content is crucial since it affects powders' flow characteristics and susceptibility to microbial degradation (Ismail et al., 2012; Joel et al., 2018). For ACP and ALP, respectively, the moisture contents were significantly different ($p<0.05$); 16.05%±0.05 and 14.23±0.25 (Table 3). Nevertheless, when stored for an extended duration, ACP shows a higher propensity for microbial growth and poor flow characteristics since it is above the recommended British Pharmacopoeia acceptable moisture content (<15%$^{w}/_{w}$) (British Pharmacopoeia, 2018). Storage in air-tight containers is consequently recommended to prevent early-onset degradation.

Ash content

The ash content is a measure of pectin purity. Decreased ash values translate into higher pectin purity (Ismail et al., 2012). The ash contents of ACP (3.12%±0.1) and ALP (2.95±0.05%) (Table 3), were below recommended standards in literature (<10%), pointing to high-quality pectin in the extracted materials. The values were also non-significant further highlighting that both the alkaline and acid extraction techniques yield high-quality pectin

(British Pharmacopoeia, 2018).

Crude protein content

The crude protein content in Table 3 was significantly different ($p < 0.05$) for ACP and ALP; 5.78%±0.03 and 8.26%±0.05 respectively. Pectin's activating and stabilising qualities, notably in dispersed systems, are directly influenced by the proteinaceous components connected to the pectin polymer chains (Funami et al., 2007; Mada et al., 2022). The high protein content in ALP may be secondary to the increased covalent bonds between the proteins and pectin that caused co-precipitation by the ethanol (Li et al., 2015; Yapo et al., 2007). This supports the AUA content results indicating ACP was significantly purer. The lower crude protein concentrations in ACP can be attributed to protein hydrolysis by the acidic medium (Yapo et al., 2007).

Equivalent weight

The equivalent weight determines the quantity of free galacturonic acid in the pectin. In addition to affecting the gelling properties, the equivalent weight is also a measure of the purity of the pectin. It is reported to be dependent on the plant source, the quality of raw material, and the extraction technique (Ismail et al., 2012; Twinomuhwezi et al., 2020). The equivalent weights were 16667.67±0.00 and 1250.00±0.00 mg/mol for ACP and ALP respectively and as shown in Table 3, were significantly different ($p<0.05$). This confirms the impact of alkaline conditions on the amount of galacturonic acid as discussed earlier. Moreover, because the gel-forming properties of pectin correlate positively with the equivalent weight, the greater values obtained by ACP may translate to enhanced gelling capabilities (Ismail et al., 2012; Twinomuhwezi et al., 2020).

Methoxyl content

The methoxyl content of pectin affects their ability to gel and their set times (Azad et al., 2014). According to Aina *et al.*, values ≥7% are high methoxyl pectins, and this classification depends on the source of the pectin and the extraction method used (Aina et al., 2012). The methoxyl contents of ACP and ALP were 16.43%±0.31 and 9.57%±0.25, respectively, suggesting that both pectins can easily disperse in aqueous conditions and generate high-sugar gels despite the significant difference between them ($p < 0.05$) as shown in Table 3. They may accordingly be utilised as binders, suspending agents, or gelling agents in pharmaceutical formulations (Ismail et al., 2012; Twinomuhwezi et al., 2020).

Anhydrouronic acid content

Anhydrouronic acid (AUA) content affects the pectin structure and the texture of the gel produced. The quality of pectin is also influenced by the AUA (Chan and Choo, 2013). Levels of < 65% are indicative of high concentrations of proteins, starch, and sugars (Ismail et al., 2012; Twinomuhwezi et al., 2020). Despite the AUA values of ACP and ALP being significantly different ($p<0.05$); 103.80%±1.76 and 68.41%±1.42 respectively (as shown in Table 3), they were all > 65%. This suggests that both extracted pectin may have low contents of proteins and other cell wall constituents, however, ACP may be purer than ALP in comparison corroborating the findings in the ash and moisture contents.

Degree of esterification

The extracted pectins had a high degree of esterification (DE) 89.83%±0.17 and 79.41%±0.43 for ACP and ALP respectively as shown in Table 3. The results were comparable to the results of the work by Hamidon and colleagues (58.5%) (Hamidon et al., 2020). The high DE demonstrates that pectin from sweet potato peels can convert into gel at a pH range between 2.9 and 3.5 when sugar is present in concentrations of more than 55%. Additionally, as the ester content rises to 75%, the gel strength of high methoxyl pectin increases (Chen et al., 2014). The pectins' strong gelation and emulsification characteristics are further established by the high degree of esterification. This supports their prospective use as emulsifying agents, gelling agents, and suspending agents in pharmaceutical formulations (Willats et al., 2006).

FTIR Spectra

FTIR was used to characterise ACP and ALP. The peaks corresponding to various functional groups were assigned. Compared to those reported, similar pectin pecks were obtained (Arachchige et al., 2020;

Ogutu & Mu, 2017; Sato et al., 2011).

The FTIR profiles for ACP and ALP are presented in Figures 2a and 2b respectively. The principal bands observed for ACP were 3295.72, 2929.69, 1717.82, and 1626.36 cm^{-1}. These corresponded to O–H stretching vibrations, C–H stretching of the CH_2 group, esters (COOR), and free carboxylic acid moieties (COO^-) respectively. The bands at 1145.33 and 1022.11 cm^{-1} represented rhamnogalacturonan, while the bands at 935.11 cm^{-1} corresponded to the monopyranose component. The CH deformation vibration associated with the primary amide groups ($CO–NH_2$), the carboxylic acid (COO^-), and the methyl ester ($COOCH_3$) were highlighted by the higher peak between 1210.66 and 1398.12 cm^{-1}. The C–C, C–O–C, and C–OH vibration modes of the carbohydrate ring coupled to the glycosidic linkage vibrations of the fingerprint region were identified below the 1500 cm^{-1} range. In similitude, ALP showed corresponding principal bands at 3287.60, 2902.65, 1789.87, and 1618.76, 1307.37 with similar fingerprint regions. The intense peaks in 1000-115 cm^{-1} can be assigned to the rich homogalacturonan content in pectin. The C–O–C vibrations of glycosidic bonds were assigned to the less intense peak around 1146 cm^{-1}. The bands below 1000 cm^{-1} are associated with the neutral sugars, xylose, galactose, and arabinose. The number of ester groups in ALP was relatively higher compared to ACP which could be attributed to the hydrolysis of the ester groups by the acid employed in its extraction (Arachchige et al., 2020; Ogutu & Mu, 2017).

For both ALP and ACP, higher absorbance at 1717.82 cm^{-1} (COOR) was observed compared to 1626.36 cm^{-1} (COO^-). This suggests that the pectins were high methoxyl pectins (DE > 50%) as indicated by the titration method.

Table 3: Proximate content and characterization of *Ipomoea batatas* peels pectin

Parameter	ACP	ALP
Equivalent Weight (mg/mol)	1666.67±0.00[a]	1250.00±0.00[b]
Methoxyl Content (%)	16.43±0.31[c]	9.57±0.25[d]
Anhydrouronic Acid Content, AUA (%)	103.80±1.76[e]	68.41±1.42[f]
Degree of Esterification, DE (%)	89.83±0.17[g]	79.41±0.43[h]
Moisture Content (%)	16.05±0.05[i]	14.23±0.25[j]
Ash Content (%)	3.12±0.1	2.95±0.05
Crude Protein (%)	5.78±0.03[k]	8.26±0.05[l]

The results are presented as a mean ± SD (n=3). Different superscript letters denote statistical significance ($p < 0.05$) using students' two-tailed t-test.

Evaluation of quality control parameters of extracted pectin

pH of suspensions

To assess the stability of suspension dosage forms, pH analysis is crucial (Owusu et al., 2022). Throughout the evaluation period, a reasonably constant weakly acidic pH was observed for all formulations (Table 4). This suggests that pH stability issues may not be a problem during extended storage periods. The lack of any undesirable physical modifications, such as crystal growth development and caking, was further evidence. Moreover, the growth of microbes which can culminate in degradation and stability issues is circumvented by the acidic pH and, therefore, can increase stability throughout the shelf-life (Ayesu et al., 2022; Oppong et al., 2016). At all the concentrations and weeks, the pH of ACP was significantly lower than the standard which could be accounted for by the acid utilised in the extraction.

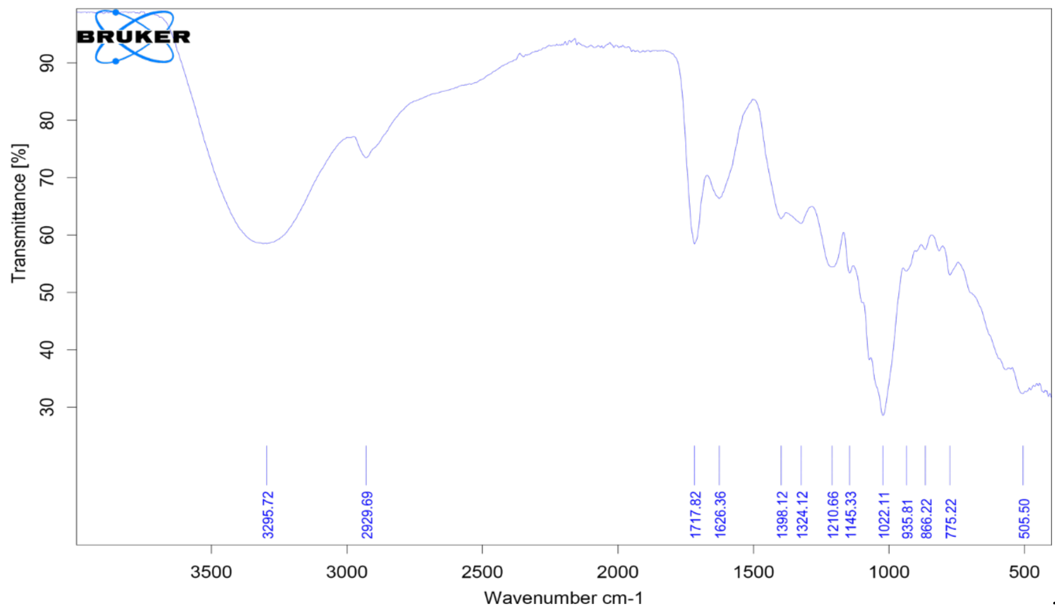
Table 4: pH determination of ACP, ALP, and Acacia as suspending agents

WEEK	1% ACACIA	1% ACP	1% ALP	2% ACACIA	2% ACP	2% AI
Week 1	3.58±0.03	3.05±0.02[a]	3.54±0.04	3.70±0.03	2.86±0.02[a]	3.56±0.
week 2	2.67±0.04	2.27±0.03[a]	2.89±0.02[b]	2.91±0.03	2.33±0.03[a]	3.02±0.
week 3	3.06±0.01	2.61±0.02[a]	3.46±0.03[a]	3.22±0.02	2.46±0.01[a]	3.21±0.
week 4	3.14±0.01	2.83±0.01[a]	3.42±0.01[a]	3.39±0.02	2.75±0.03[a]	3.14±0.

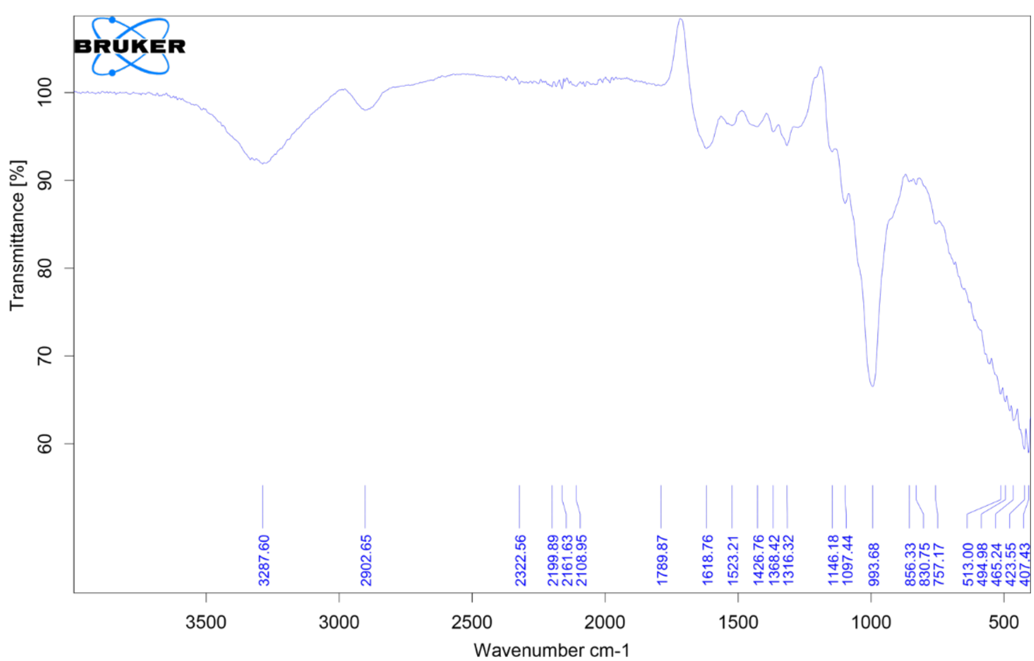
The results are presented as a mean ± SD (n=3). ****$P < 0.0001$ (a), **$P \leq 0.01$ (b), and *$p < 0.05$ (c), statistical difference between pH of acacia and pectin suspensions using two-way Analysis of variance (ANOVA) followed by Turkey's multiple comparisons.

Ease of Re-dispersibility of Suspensions

The number of cycles necessary to rotate the sediment through 180^o and achieve homogenous



(a)



(b)

Fig. 2: FTIR spectra of ACP (a) and ALP (b).

suspension determines how easily it can be redispersed. The quality of suspension and ease of redispersion are improved with fewer cycles (Allen & Ansel, 2013; Owusu et al., 2021). During the 4 week evaluation period, both ACP and ALP demonstrated significant differences ($p<0.05$) compared to acacia at all concentrations except for ALP 2% during the 3rd week (figure 3). This implies that the pectin requires less agitation to re-disperse and ensure that uniform doses are obtained.

A comparison of the re-dispersibility of ALP and the ACP suspensions alone demonstrated non-significant differences generally except for the 2% concentrations during the second week. It may be concluded that the extraction technique has no impact on the transformation of sediments into a homogeneous suspension (Figure 4).

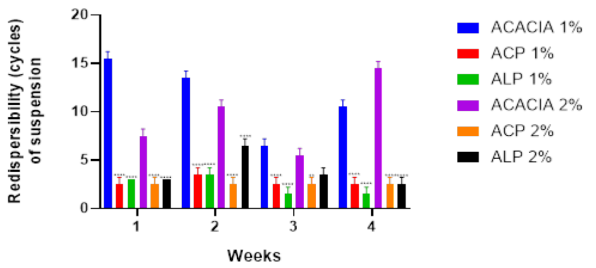


Fig. 3: Redispersibility of acacia and pectin suspensions; ****p <0.0001, **p ≤ 0.01, statistical difference between redispersibility of acacia (standard) and pectin suspensions using two-way ANOVA followed by Turkey's multiple comparisons.

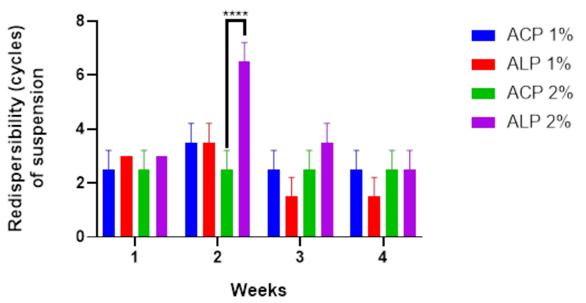


Fig. 4: Redispersibility of ALP and ACP suspensions; ****P <0.0001 statistical difference between redispersibility pectin suspensions using two-way ANOVA followed by Turkey's multiple comparisons.

Flow rate of suspensions

Apparent viscosity is an essential property of suspensions as it impacts stability and ensures that the dispersed phase in suspensions settles slowly for a sufficient time to guarantee correct dosing. This occurs as a result of the breakdown of the flocculated structure, which must be restored to create a good suspension (thixotropic suspensions) and avoid the product's long-term caking (Asantewaa et al., 2011; Ayesu et al., 2022). The apparent viscosity relates directly to the concentration and inversely to the flow rate which was observed for all suspending agents when the concentration increased from 1% to 2% as shown in Figures 5 and 6 (Bamigbola et al., 2017).

According to Ngwuluka *et al.,* autocatalytic hydrolysis accounts for the natural tendency of natural polymers such as gums and pectin to decline in flow rates with time as was observed during the 4-week evaluation period (Figure 5) (Ngwuluka et al., 2012). Nevertheless, the phenomenon had no detrimental effect on the formulation stability.

Furthermore, the flow rates of both ALP and ACP were significantly higher ($P \leq 0.01$) than the acacia during the 2nd week at 1% concentration; however, only 1% ACP demonstrated significantly higher flow rates compared to 1% acacia during the 1st and 3rd weeks (Figure 5). This supposes that both ALP and ACP were comparable to acacia gum, particularly at higher concentrations and extended storage periods. Similar observations were made when ALP and ACP were compared suggesting a non-significant impact of extraction methodology on flow rates of pectin suspensions (Figure 6).

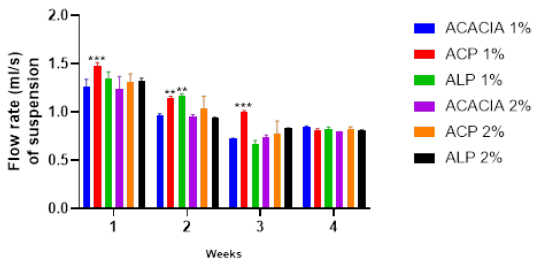


Fig. 5: Flow rate of Acacia and pectin suspensions; ****P <0.0001, ***P < 0.001, and **P ≤ 0.01, statistical difference between the flow rate of acacia (standard) and pectin suspensions using two-way ANOVA followed by Turkey's multiple comparisons.

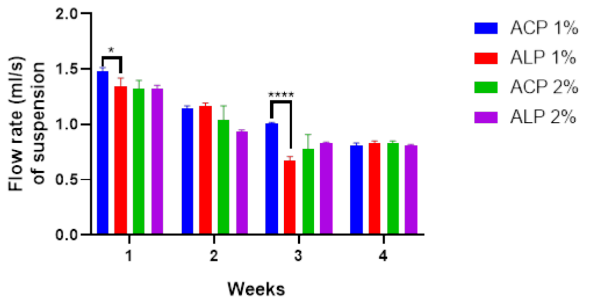


Fig. 6: Flow rate of ALP and ACP suspensions; ****P <0.0001, and *P ≤ 0.05, statistical difference between the flow rate of pectin suspensions using two-way ANOVA followed by Turkey's multiple comparisons.

Sedimentation Volume (SV) and Sedimentation Rate of Suspensions

The SV values typically range between 0 and 1 with values closer to 1 being associated with superior suspending qualities (Larsson et al., 2011; Owusu et al., 2021). Generally, except for the 2nd week, the ALP and ACP demonstrated a variable significance difference ($p<0.05$) between the pectin and Acacia (Figure 7). It can be inferred that pectin demonstrates better suspending properties when compared to acacia at 1% and 2% concentrations. This has been reported by Owusu et al. (2024) to be accounted for by the branching, monosaccharide compositions and molecular weights of the polymers which impacts the gelling properties.

A further comparison of the SV of ALP and ACP highlights variations in significant differences across the weeks. For instance, during the 1st week, there was a non-significance difference at 2% and a significant difference was observed at 1%. The opposite was observed during the 2nd week (Figure 8). The sedimentation volume only provides a qualitative appreciation of how the suspension sediments, however, lacks any practical reference point, therefore, the sedimentation rate is a more significant parameter to analyse (Ayesu et al., 2022).

The quality of suspension formulation is inversely related to the rate of sedimentation; as such, a decreased rate of sedimentation implies a better-suspending quality (Ayesu et al., 2022). A general decrease in sedimentation rate was observed when the concentration increased from 1% to 2% for all the suspensions. This supports the hypothesis that sedimentation is concentration-dependent (Owusu et al., 2022). ALP and ACP at all concentrations significantly had slower sedimentation rates when compared to acacia ($P < 0.05$) except for the 4th week where only ALP 2% showed a significant difference ($P < 0.0001$). This confirms the earlier results that the pectin exhibited better-suspending activity than the acacia.

When ACP and ALP were compared, at all concentration levels, significant differences were observed between ALP except for the 1% concentrations in the 4th week (Figure 10). This unambiguously suggests that though ALP and ACP are better than Acacia, the alkaline extraction technique yields pectin with superior suspending properties. This may be accounted for by the significant variations observed in the equivalent weight, degree of esterification and anhydrouronic acid contents. These parameters have been reported to impact the rheological behaviour and gelling properties of pectins (Chan et al., 2017; Nascimento et al., 2016).

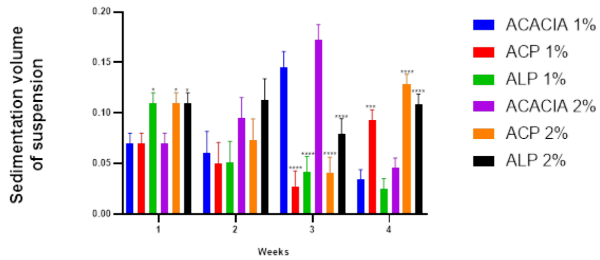


Fig. 7: Sedimentation volume of Acacia and pectin suspensions; ****P <0.0001, ***P < 0.001 and *P ≤ 0.05, statistical difference between sedimentation volume of acacia (standard) and pectin suspensions using two-way ANOVA followed by Turkey's multiple comparisons.

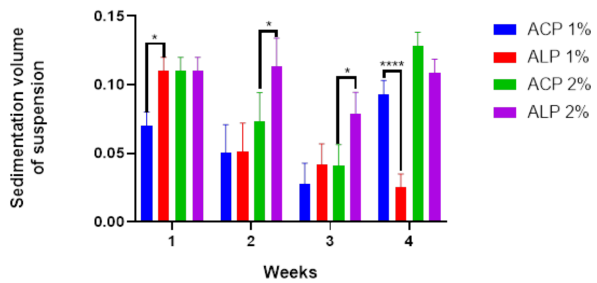


Fig. 8: Sedimentation volume of ALP and ACP suspensions; ****P <0.0001, and *P ≤ 0.05, statistical difference between sedimentation volume of pectin suspensions using two-way ANOVA followed by Turkey's multiple comparisons.

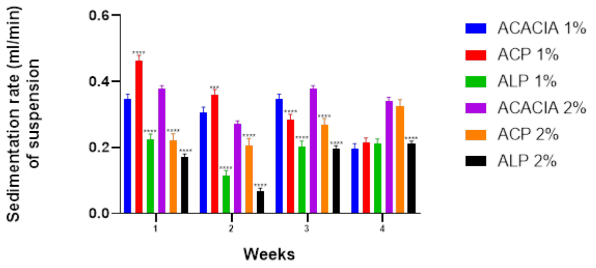


Fig. 9: Sedimentation rate of Acacia and pectin suspensions; ****P <0.0001, and ***P ≤ 0.001, statistical difference between sedimentation rate of acacia (standard) and pectin suspensions using two-way ANOVA followed by Turkey's multiple comparisons using two-way ANOVA followed by Turkey's multiple comparisons.

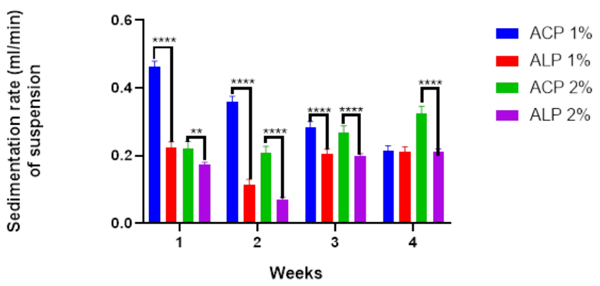


Fig. 10: Sedimentation rate of ALP and ACP suspensions; ****P <0.0001, and **P < 0.01, statistical difference between sedimentation rate of pectin suspensions using two-way ANOVA followed by Turkey's multiple comparisons. two-way ANOVA followed by Turkey's multiple comparisons.

Conclusion

This study highlights that both alkaline and acid extraction techniques yield high-quality pectins. Furthermore, at concentrations of 1% and 2%, Ipomoea batatas pectin extracted via alkaline or acid extraction possesses suspending properties that were comparable to Acacia gum which was evidenced by the significant differences for all quality control parameters during the evaluation period. Moreover, alkaline-extracted pectins produce suspensions with better sedimentation rates when compared to acid-extracted pectins.

Authors contributions

"Conceptualization, F.W.A.O. and M.E.B.G.; methodology, P.G.J.A, D.A.B.O, S.N, and P.O.A.; formal analysis, R.J, F.W.A.O, and P.G.J.A.; writing—original draft preparation, P.G.J.A, D.A.B.O, S.N, and P.O.A; writing—review and editing, F.W.A.O., M.E.B.G., M.T.B., S.N., D.A.B.O.; visualization, R.J, F.W.A.O, and P.G.J.A.; supervision, R.J., M.T.B., M.E.B.G. All authors have read and agreed to the published version of the manuscript.

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Conflict of interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

Declaration of generative AI and AI-assisted technologies in the writing process

Grammarly was used to enhance the readability and language of the work.

References

Adebisi, Y. A., Nwogu, I. B., Alaran, A. J., Badmos, A. O., Bamgboye, A. O., Rufai, B. O., Okonji, O. C., Malik, M. O., Teibo, J. O., Abdalla, S. F., Lucero-Prisno, D. E., Samai, M., & Akande-Sholabi, W. (2022). Revisiting the issue of access to medicines in Africa: Challenges and recommendations. *Public Health Challenges*, *1*(2), e9. https://doi.org/10.1002/puh2.9

Aina, V. O., Barau, M. M., Mamman, O. A., Zakari, A., Haruna, H., Umar, M. S. H., & Abba, Y. B. (2012). Extraction and characterization of pectin from peels of lemon (Citrus limon), grape fruit (Citrus paradisi) and sweet orange (Citrus sinensis). *British Journal of Pharmacology and Toxicology*, *3*(6), 259–262.

Alam, M. K. (2021). A comprehensive review of sweet potato (Ipomoea batatas [L.] Lam): Revisiting the associated health benefits. *Trends in Food Science & Technology*, *115*(April), 512–529. https://doi.org/10.1016/j.tifs.2021.07.001

Allen, L., & Ansel, H. C. (2013). *Ansel's pharmaceutical dosage forms and drug delivery systems*. Lippincott Williams & Wilkins.

Arachchige, M. P. M., Mu, T., & Ma, M. (2020). Structural, physicochemical and emulsifying properties of sweet potato pectin treated by high hydrostatic pressure and/or pectinase: a comparative study. *Journal of the Science of Food and Agriculture*, *100*(13), 4911–4920.

Asantewaa, Y., Ofori-Kwakye, K., Kipo, S. L., Boamah, V. E., & Johnson, R. (2011). Investigation of the emulsifying and suspending potential of cashew tree gum in pharmaceutical formulations. *International Journal of Pharmacy and Pharmaceutical Sciences*, *3*(4), 215–219.

Ayesu, H. D., Kuntworbe, N., Sekyere, M., Johnson, R., Owusu, W. A. F., Entsie, P., Amankwah, F., & Ofori-Kwakye, K. (2022). Investigation of the physicochemical properties of freeze-dried fruit pulp of Telfairia occidentalis and its potential use as suspending agent. *Heliyon*, *8*(7), e09997. https://doi.org/10.1016/j.heliyon.2022.e09997

Azad, A. K. M., Ali, M. A., Akter, M. S., Rahman, M. J., & Ahmed, M. (2014). Isolation and characterization of pectin extracted from lemon pomace during ripening. *Journal of Food and Nutrition Sciences*, *2*(2), 30–35. https://www.researchgate.net/publication/325859830_Isolation_and_characterization_of_pectin_extracted_from_lemon_pomace_during_ripening

Bamigbola, E. A., Olorode, O. A., & Uzim, D. A. (2017). Evaluation Of The Suspending Properties Of Cola Acuminata Gum On Calamine Suspension. *Journal of Phytomedicine and Therapeutics*, *16*(2), 96–113.

Boakye-Gyasi, M. El, Owusu, F. W. A., Entsie, P., Agbenorhevi, J. K., Banful, B. K. B., & Bayor, M. T. (2021). Pectin from Okra (Abelmoschus esculentus L.) Has Potential as a Drug Release Modifier in Matrix Tablets. *The Scientific World Journal*, *2021*(1), 1–10. https://doi.org/10.1155/2021/6672277

British Pharmacopoeia. (2018). *General Monographs*. The Stationary Office.

Chan, S. Y., Choo, W. S., Young, D. J., & Loh, X. J. (2017). Pectin as a rheology modifier: Origin, structure, commercial production and rheology. *Carbohydrate Polymers*, *161*, 118–139. https://doi.org/10.1016/j.carbpol.2016.12.033

Chandel, V., Biswas, D., Roy, S., Vaidya, D., Verma, A., & Gupta, A. (2022). Current Advancements in Pectin: Extraction, Properties and Multifunctional Applications. *Foods*, *11*(17), 2683. https://doi.org/10.3390/foods11172683

Chen, H., Qiu, S., Gan, J., Liu, Y., Zhu, Q., & Yin, L. (2016). New insights into the functionality of protein to the emulsifying properties of sugar beet pectin. *Food Hydrocolloids*, *57*, 262–270. https://doi.org/10.1016/j.foodhyd.2016.02.005

Chen, Y., Zhang, J. G., Sun, H. J., & Wei, Z. J. (2014). Pectin from Abelmoschus esculentus: Optimization of extraction and rheological properties. *International Journal of Biological Macromolecules*, *70*, 498–505. https://doi.org/10.1016/j.ijbiomac.2014.07.024

Conway, M., Holt, T., Sabow, A., & Sun, I. Y. (2019). *Should sub-Saharan Africa make its own drugs*. McKinsey and Company. https://www.mckinsey.com/industries/public-sector/our-insights/should-sub-saharan-africa-make-its-own-drugs

Darko, C., Yeboah, S., Amoah, A., Opoku, A., & Berchie, J. N. (2020). Productivity of sweet potato (Ipomoea batatas (L) Lam) as influenced by fertilizer application in different agro-ecologies in Ghana. *Scientific African*, *10*, e00560.

Edeoga, H. O., Omosun, G., & Uche, L. C. (2006). Chemical composition of Hyptis suaveolens and Ocimum gratissimum hybrids from Nigeria. *African Journal of Biotechnology*, *5*(10), 892–895.

Evans, W. C. (2009). Trease and Evans' pharmacognosy. In *Elsevier Health Sciences.* https://doi.org/10.4103/0970-4388.180371

Funami, T., Zhang, G., Hiroe, M., Noda, S., Nakauma, M., Asai, I., Cowman, M. K., Al-Assaf, S., & Phillips, G. O. (2007). Effects of the proteinaceous moiety on the emulsifying properties of sugar beet pectin. *Food Hydrocolloids*, *21*(8), 1319–1329. https://doi.org/10.1016/j.foodhyd.2006.10.009

Garna, H., Mabon, N., Wathelet, B., & Paquot, M. (2004). New method for a two-step hydrolysis and chromatographic analysis of pectin neutral sugar chains. *Journal of Agricultural and Food Chemistry*, *52*(15), 4652–4659. https://doi.org/10.1021/jf049647j

Hamidon, N. H., Abang Zaidel, D. N., & Mohd Jusoh, Y. M. (2020). Optimization of Pectin Extraction from Sweet Potato Peels Using Citric Acid and its Emulsifying Properties. *Recent Patents on Food, Nutrition & Agriculture*, *11*(3), 202–210. https://doi.org/10.2174/2212798411666200207102051

Hamidon, N. H., & Zaidel, D. N. A. (2017). Effect of extraction conditions on pectin yield extracted from sweet potato peels residues using hydrochloric acid. *Chemical Engineering Transactions*, *56*, 979–984. https://doi.org/https://doi.org/10.3303/CET1756164

Ismail, N. S. M., Ramli, N., Hani, N. M., & Meon, Z. (2012). Extraction and characterization of pectin from dragon fruit ([i]Hylocereus polyrhizus[/i]) using various extraction conditions. *Sains Malaysiana*, *41*(1), 41–45.

Joel, J. M., Barminas, J. T., Riki, E. Y., Yelwa, J. M., & Edeh, F. (2018). Extraction and characterization of hydrocolloid pectin from goron tula (Azanza garckeana) fruit. *World Scientific News*, *101*, 157–171. https://www.researchgate.net/publication/327883731_Extraction_and_Characterization_of_Hydrocolloid_Pectin_from_Goron_Tula_Azanza_garckeana_fruit#:~:text=This study

Kliemann, E., De Simas, K. N., Amante, E. R., Prudêncio, E. S., Teófilo, R. F., Ferreira, M. M. C., & Amboni, R. D. M. C. (2009). Optimisation of pectin acid extraction from passion fruit peel (Passiflora edulis flavicarpa) using response surface methodology. *International Journal of Food Science and Technology*, *44*(3), 476–483. https://doi.org/10.1111/j.1365-2621.2008.01753.x

Larsson, M., Hill, A., & Duffy, J. (2011). Suspension Stability; Why Particle Size, Zeta Potential and Rheology are Important. *Annual Transactions of the Nordic Rheology Society*, *20*, 1–35.

Li, D. Q., Du, G. M., Jing, W. W., Li, J. F., Yan, J. Y., & Liu, Z. Y. (2015). Combined effects of independent variables on yield and protein content of pectin extracted from sugar beet pulp by citric acid. *Carbohydrate Polymers*, *129*, 108–114. https://doi.org/10.1016/j.carbpol.2015.04.058

Mada, T., Duraisamy, R., & Guesh, F. (2022). Optimization and characterization of pectin extracted from banana and papaya mixed peels using response surface methodology. *Food Science and Nutrition*, *10*(4), 1222–1238. https://doi.org/10.1002/fsn3.2754

Mei, X., Mu, T. H., & Han, J. J. (2010). Composition and physicochemical properties of dietary fiber extracted from residues of 10 varieties of sweet potato by a sieving method. *Journal of Agricultural and Food Chemistry*, *58*(12), 7305–7310. https://doi.org/10.1021/jf101021s

Nascimento, G. E. do, Simas-Tosin, F. F., Iacomini, M., Gorin, P. A. J., & Cordeiro, L. M. C. (2016). Rheological behavior of high methoxyl pectin from the pulp of tamarillo fruit (Solanum betaceum). *Carbohydrate Polymers*, *139*, 125–130. https://doi.org/10.1016/j.carbpol.2015.11.067

Ngwuluka, N. C., Akanbi, M., Agboyo, I., & Uwaezuoke, O. J. (2012). Characterization of gum from Sesamum indicum leaves as a suspending agent in a pediatric pharmaceutical suspension. *World Journal of Pharmaceutical Research*, *1*(4), 909–924.

Nussinovitch, A. (2009). *Plant Gum Exudates of the World*. CRC Press. https://doi.org/10.1201/9781420052244

Ocloo, F., Otoo, G., & Nkansah, R. (2011). Functional and Physicochemical Characteristics of Starch Obtained from Gamma-Irradiated Sweet Potato (Ipomea batatas L.). *Journal of Agriculture …*, *1*(7), 116–122.

Ofori, G., Oduro, I., Ellis, W. O., & Dapaah, K. H. (2009). Assessment of vitamin A content and sensory attributes of new sweet potato (Ipomoea batatas) genotypes in Ghana. *African Journal of Food Science*, *3*(7), 184–192.

Ogutu, F. O., & Mu, T.-H. (2017). Ultrasonic degradation of sweet potato pectin and its antioxidant activity. *Ultrasonics Sonochemistry*, *38*, 726–734.

Oluyori, A. P., Shaw, A. K., Olatunji, G. A., Rastogi, P., Meena, S., Datta, D., Arora, A., Reddy, S., & Puli, S. (2016). Sweet Potato Peels and Cancer Prevention. *Nutrition and Cancer*, *68*(8), 1330–1337. https://doi.org/10.1080/01635581.2016.1225107

Oppong, E. E., Osei-Asare, C., & Klu, M. W. (2016). Evaluation of the suspending properties of shea tree gum. *International Journal of Pharmacy and Pharmaceutical Sciences*, *8*(7), 409–413.

Otu, D. A. B., Owusu, F. W. A., Acquah, P. G. J., Boakye-Gyasi, M. El, Edzor-Agbo, Y., Johnson, R., Bayor, M. T., & Archer, M.-A. (2024). Effect of Ripening and Extraction Method on the Physicochemical Properties of Pectin Extracted from Peels of Apem and Apantu Plantain Cultivars in Ghana. *Journal of Chemistry*, *2024*(1), 1–19. https://doi.org/10.1155/2024/6677179

Owusu, F. W. A., Acquah, P. G. J., Boakye-Gyasi, M. E. L., Johnson, R., Yeboah, G. N., Archer, M.-A., Antwi, M. B., & Asare, S. O. (2023). Pharmaceutical Assessment of the Impact of the Method of Extraction on the Suitability of Pectin from Plantain (Musa paradisiaca) Peels as a Suspending Agent in Oral Liquid Formulations. *The Scientific World Journal*, *2023*(1), 1–11. https://doi.org/10.1155/2023/8898045

Owusu, F. W. A., Asare, C. O., Enstie, P., Adi-Dako, O., Yeboah, G. N., Kumadoh, D., Tetteh-Annor, A., Amenuke, E. M., & Karen, M. (2021). Formulation and in Vitro Evaluation of Oral Capsules and Suspension from the Ethanolic Extract of [i]Cola nitida[/i] Seeds for the Treatment of Diarrhea. *BioMed Research International*, *2021*. https://doi.org/10.1155/2021/6630449

Owusu, F. W. A., El Boakye-Gyasi, M., Bayor, M. T., Ofori-Kwakye, K., Acquah, P. G. J., Quarcoo, E. A., Asare, J., Anokye, B. A., & Tandoh, P. K. (2024). Evaluation of Okra Pectin from Different Genotypes as Effective Suspending Agents in Pharmaceutical Formulations. *Journal of Pharmacy*, *4*(1), 33–50. https://doi.org/https://doi.org/10.31436/jop.v4i1.251

Owusu, F. W. A., El Boakye-Gyasi, M., Bayor, M. T., Osei-Asare, C., Johnson, R., Osei, Y. A., Asare, V. A., Mensah, K. A., Acquah, P. G., Otu, D. A. B., & Asante, R. (2022). Pharmaceutical Assessment of Watermelon Rind Pectin as a Suspending Agent in Oral Liquid Dosage Forms. *BioMed Research International*, *2022*(1), 1–9. https://doi.org/10.1155/2022/9526404

Pacheco, M. T., Villamiel, M., Moreno, R., & Moreno, F. J. (2019). Structural and Rheological Properties of Pectins Extracted from Industrial Sugar Beet By-Products. *Molecules*, *24*(3), 392. https://doi.org/10.3390/molecules24030392

Ranganna, S. (1986). *Handbook of analysis and quality control for fruit and vegetable products*. Tata McGraw-Hill Education.

Sáez-Plaza, P., Navas, M. J., Wybraniec, S., Michałowski, T., & Asuero, A. G. (2013). An Overview of the Kjeldahl Method of Nitrogen Determination. Part II. Sample Preparation, Working Scale, Instrumental

Finish, and Quality Control. *Critical Reviews in Analytical Chemistry*, *43*(4), 224–272. https://doi.org/10.1080/10408347.2012.751787

Sato, M. de F., Rigoni, D. C., Canteri, M. H. G., Petkowicz, C. L. de O., Nogueira, A., & Wosiacki, G. (2011). Caracterização química e instrumental de pectinas isoladas de bagaço de 11 cultivares de maçã. *Acta Scientiarum - Agronomy*, *33*(3), 383–389. https://doi.org/10.4025/actasciagron.v33i3.7125

Schieber, A., Hilt, P., Endreß, H. U., Rentschler, C., & Carle, R. (2003). A new process for the combined recovery of pectin and phenolic compounds from apple pomace. *Innovative Food Science and Emerging Technologies*, *4*(1), 99–107. https://doi.org/10.1016/S1466-8564(02)00087-5

Shaari, N., Shamsudin, R., Nor, M. Z. M., & Hashim, N. (2021). Quality attributes of Malaysia purple-fleshed sweet potato at different peel condition. *Agronomy*, *11*(5), 5. https://doi.org/10.3390/agronomy11050872

Shamsudin, R., Shaari, N., Mohd Noor, M. Z., Azmi, N. S., & Hashim, N. (2022). Evaluation of Phytochemical and Mineral Composition of Malaysia's Purple-Flesh Sweet Potato. *Pertanika Journal of Science & Technology*, *30*(4).

Sugri, I., Maalekuu, B. K., Gaveh, E., & Kusi, F. (2017). Sweet potato value chain analysis reveals opportunities for increased income and food security in Northern Ghana. *Advances in Agriculture*, *2017*.

Teye, E., & Abano, E. E. (2012). Physical properties of two varieties of sweet potato grown in the coastal savannah zone of Ghana. *International Journal of Science and Nature*, *3*(1), 105–109.

The United States Pharmacopeial Convention. (2021). *United States Pharmacopeia 44-NF 39 : General Chapter Identification of Articles of Botanical Origin*.

Torres, M. D., & Domínguez, H. (2020). Valorisation of potato wastes. *International Journal of Food Science and Technology*, *55*(6), 2296–2304. https://doi.org/10.1111/ijfs.14228

Twinomuhwezi, H., Godswill, A. C., & Kahunde, D. (2020). Extraction and Characterization of Pectin from Orange (Citrus sinensis), Lemon (Citrus limon) and Tangerine (Citrus tangerina). *American Journal of Physical Sciences*, *1*(1), 17–30. https://doi.org/10.47604/ajps.1049

Wandee, Y., Uttapap, D., & Mischnick, P. (2019). Yield and structural composition of pomelo peel pectins extracted under acidic and alkaline conditions. *Food Hydrocolloids*, *87*, 237–244. https://doi.org/10.1016/j.foodhyd.2018.08.017

Willats, W. G. T., Knox, J. P., & Mikkelsen, J. D. (2006). Pectin: New insights into an old polymer are starting to gel. *Trends in Food Science and Technology*, *17*(3), 97–104. https://doi.org/10.1016/j.tifs.2005.10.008

Yapo, B. M., Robert, C., Etienne, I., Wathelet, B., & Paquot, M. (2007). Effect of extraction conditions on the yield, purity and surface properties of sugar beet pulp pectin extracts. *Food Chemistry*, *100*(4), 1356–1364. https://doi.org/10.1016/j.foodchem.2005.12.012

Zaidel, D., Zainudin, N., Jusoh, Y., & Muhamad, I. (2015). Extraction and characterisation of pectin from sweet potato (Ipomoea batatas) pulp. *Journal of Engineering Science and Technology Special Issue on SOMCHE*, 22–29.

Zhang, C., & Mu, T. (2011). Optimisation of pectin extraction from sweet potato (Ipomoea batatas, Convolvulaceae) residues with disodium phosphate solution by response surface method. *International Journal of Food Science and Technology*, *46*(11), 2274–2280. https://doi.org/10.1111/j.1365-2621.2011.02746.x