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(RESEARCH ARTICLE)

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Physicochemical and functional properties of native starch from seeds of *Pterocarpus santalinoides*

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Abstract

In order to enhance the value of the seeds of *P. santalinoides*, consumed like peanut seeds by certain populations of Côte d'Ivoire, studies on a few physicochemical and functional properties have been carried out on the starch extracted from these seeds. Indeed, the humidity rate, the percentage of amylose and amylopectin as well as the non-carbohydrate composition (proteins, lipids, ash) were evaluated. In addition to these parameters, the shape and size of the grains, the water absorption capacity, the clarity, the swelling and solubility power as well as the percentage of syneresis were investigated at -15 and 4 °C for 4 weeks. The results obtained indicate that the starch grains exhibited spherical shapes for some and polyhedral shapes with a smooth outline for others. Also, the average starch grain diameter was 10.30 µm. The rate of amyloidosis was 27.40% and 65.01% for amylopectin. The low humidity rate (6.72%) observed gave the starch long-lasting preservation. The non-carbohydrate composition for its part gave 0.87%. In addition, the *in vitro* digestibility study revealed that the starch of *P. santalinoides* was digestible. The recorded water absorption capacity was 117.34% with a percentage clarity that ranged from 5.84 to 0.62% transmittance in four weeks. The swelling ranged from 1.33 at 50 °C to 19.22 ge / gms at 90 °C. In contrast, the solubility was 0.50 at 50 °C and then intensified to reach 20.14% at 90 °C. These values for swelling and solubility reflect a possible use of this starch in food technology. The syneresis study indicated a value of 59.41% for storage at -15 °C compared to 52.72% at 4 °C.

This study, which revealed interesting properties of the native starch of the seeds of *P. santalinoides*, thus suggests some areas of use of these seeds.

Keywords: Physico-chemical; Functional; *Pterocarpus santalinoides*; Native starch.

1. Introduction

Starch is a polymer of glucose synthesized by higher plants from solar energy. It is naturally found in cereals, tubers, legumes and in certain roots. This polysaccharide is according to Laouini [1] one of the main sources of energy for human and animal food. The applications of starch are diverse and varied from one area to another. In the food sector, it is used for the production of glucose syrup, pasta, instant flours and various diet products [2]. Besides its dietary implications, industrial applications of starch are just as numerous as they are important. Especially in the manufacture of textiles, glues, adhesives, cardboard paper or as an excipient or binder in the pharmaceutical industry. In the latter area, starch is still used as a raw material in the production of biodegradable plastics as well as in the production of bioethanol, as a fuel [3]. These various uses of starches in general are a function of their properties, as well as their cost

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and availability. Indeed, a greater knowledge of the properties of the starch obtained from the seeds of *P. santalinoides* could be interesting in the sense that this legume can constitute another source of starch production besides potatoes, corn and wheat. In reality, the rational use of a starch implies prior knowledge of its properties [4]. However, these properties can only be revealed through studies on them. Therefore, a better knowledge of the starch of *P. santalinoides* would facilitate the choice of this starch for possible use in the food or non-food industry.

The objective of this study is to contribute to the valuation of the seeds of *P. santalinoides* by evaluating the physicochemical and functional properties of its starch.

2. Material and methods

2.1. Plant material

The biological material used for this study is native starch from the seeds of *P. santalinoides.*

Figure 1 Fruits of *P. santalinoides*

Figure 2 *P. Santalinoides* seeds

2.2. Methods

2.2.1. Sampling

The fruits of *P. santalinoides* were collected at random in a field in Monga, a locality located in the department of Alépé in the South East of Côte d'Ivoire and then sent the same day in mesh bags to the biocatalysis and bioprocesses laboratory (Nangui Abrogoua University).

2.2.2. Extraction and purification

Starch extraction from seeds of *P. santalinoides* was performed according to the method of Jayakody et *al.* [5] with some modifications. The collected fruits were sorted, washed and shelled. Subsequently, 1 Kg of already shelled seeds was skinned and washed twice with distilled water. The seeds without seed coats obtained were immediately ground in a Binatone brand mixer (BLG, 455) containing a sodium chloride solution (4%, w / v). The ground material obtained was filtered through a fine sieve (100 µm). The filtrate was allowed to settle for 12 hours on the bench at room temperature, then the supernatant was removed. The pellet obtained was taken up in sodium chloride solution (4%, w / v) then manually stirred from time to time for 1 h, and allowed to settle at 4 °C for 13 hours.

After removing the supernatant, the pellet was taken up twice with a sodium chloride solution of the same concentration (4%, w / v) under similar conditions.

The mass of starch obtained was rinsed with distilled water for 10 minutes and then filtration followed. The filtrate obtained was allowed to settle for 12 hours on the bench, at room temperature (28 °C.) then the supernatant was separated from the pellet. In addition, three (03) rinses with distilled water were performed followed by decanting for 12 hours. The starch obtained after these successive rinses was dried in an oven (BIOBASE) at 40 °C for 48 hours and then ground. The ground material was sieved with a 100 µm mesh sieve to obtain a fine flour which was packaged in a hermetically sealed flask.

2.2.3. Physical properties of starches

Morphology and granulometry

The forms of the native starch grains were observed under a scanning electron microscope (FEG SUPRA 40 VP) with a voltage varying from 0.1 Kev to 30 Kev. The technique consists in carrying out a topographical study of the starch grains by scanning their surface with an electron beam. A thin layer of the dehydrated starch sample was placed on a metal support for microscopic observation. The distribution of the mean diameter (mean of major axis + minor axis) was made on a total of 1000 grains [6]. From the data thus obtained, the mean and the standard deviation were determined.

Frequency distribution of mean grain diameter

The distribution was performed according to Sturge's rule [7] and translated as a histogram. This rule made it possible to define the number of expected classes and the associated amplitude from the following mathematical formulas:

$$NC = 1 + (3.33 \log 10\ N)$$

$$a = \frac{Dmax - Dmin}{NC}$$

Where;
N: total number of grains counted,
a: amplitude of the classes,
NC: number of class,
Dmax: maximum average diameter,
Dmin: minimum grain diameter.

2.2.4. Chemical composition of starch

Determination of moisture content

A sample of 2 g of starch, placed in previously tared porcelain crucibles, was dried in a BIOBASE BOV-D70 brand oven at 105 ° C for 24 h. At the end of this drying time, the crucible removed from the oven was placed in the desiccator for cooling before being weighed. The humidity level was determined from the mathematical relationship proposed by AOAC [8];

$$TH\ (\%) = \frac{(M_1 - M_2)}{Me} x\ 100$$

Where;
TH: humidity rate (%);
M1: mass (g) of the crucible + the sample (before drying);
M2: mass (g) of the crucible + the sample (after drying);
Me: mass of the sample.

Amylose and amylopectin levels

The amylose content of starch was determined according to the method described by Chrastyl [9]. And that of amylopectin was deduced from that of amylopectin, based on the difference in the starch content of the samples. The determination of the amylose content of starches involved three steps, namely the extraction of lipids from the starch, the solubilization of the delipidated starch and the determination of the amylose content.

Lipid extraction

Lipid extraction consisted of introducing 10 to 20 mg of powdered starch into a test tube. 5 mL of 85% methanol prepared in distilled water was added and the mixture was placed in a water bath at 60 °C. The extraction takes 30 min with occasional shaking of the tube. The resulting solution was centrifuged at 2000 rpm for 30 min. Extraction with 85% methanol was repeated three times under the same conditions, removing the supernatant each time.

Solubilization of delipidated starch

2 mL 1M NaOH and 4 mL distilled water were added to the pellet contained in a screw cap test tube. The tube was placed in a water bath at 95 °C and kept for 30 min under stirring. The resulting solution is called "S".

Determination of amylose

0.1mL of solution "S" is introduced into a test tube, 5mL of 1% trichloroacetic acid (TCA), 0.05ml of 0.01N I2-IK solution (1.27g I2 per liter of distilled water + 3g KI) and distilled water are added. The optical densities are read at 620nm.

The amount of amylose in each test tube is determined by referring to the calibration curve and the amylose content (TA) in g/100g dry matter was calculated by the following equation:

$$TA = \frac{100 \text{ x } Q \text{ x } VT \text{ x } 100}{V \text{ x } 100 \text{ x } (100 - Hr) \text{ x } m}$$

Where;
TA: amylose content in g/100g of dry starch;
Q: amount of amylose in mg in each test tube;
VT: total volume in mL of solution (S);
V: volume of solution (S) in each test tube (0.1mL);
m: mass of the starch test portion in mg (20mg);
Hr: residual water content of the starch.

Calculation of the percentage of purity of starch

The calculation of the percentage of purity was done according to the method described by Tapia et *al*, [10]. According to this method, the percentage of purity was determined by the difference between 100% material and the percentage of moisture, protein, lipids and ash. The formula used for the calculation is as follows:

$$\text{Purity (\%)} = 100 - (\%\text{ Humidity} + \%\text{ Proteins} + \%\text{ Lipids} + \%\text{ ashes}$$

The amylopectin content is calculated by the difference between the purity of the starch and the amylose content. Either:

$$T_{Am}\ (\%) = P\ (\%) - T_A\ (\%)$$

Where;
TAm: amylopectin level
P: purity
TA: amylose rate

Determination of lipid content

The method used was that described by the French standard AFNOR [11] using Soxhlet as an extractor. This method consisted in placing fifty (50) g of starch in cellulose extraction cartridges plugged with cotton. These cartridges were introduced into the Soxhlet tank and oil extraction was performed by a solvent flux and reflux system using 300 ml of n-hexane. After two extraction cycles of 7 hours each [12], the solvent (n-hexane) was recovered using a rotary evaporator. The flask, initially tared and containing the oil, was weighed to determine the mass of oil extracted. The lipid content was expressed as a percentage by mass as follows:

$$L\ (\%) = \frac{M_2 - M_1}{Me} \text{x } 100$$

Where;
L: lipid content
Me: mass of the sample
M_1: mass of the vacuum flask
M_2: mass of the balloon + oil

Determination of protein content

Crude protein was determined from the determination of total nitrogen according to the Kjeldhal method [13]. It comprises a mineralization phase, followed by a distillation phase and a sulphuric acid titration phase:

$$\text{Total nitrogen (\%)} = \frac{V_1 - V_0 \times N_x \, M_N}{Me} \times 100$$

$$\text{Total protein (\%)} = 6.25 \times \text{Total nitrogen (\%)}$$

Where;
V0: volume (mL) of sulfuric acid (0.1N) poured for the blank test;
V1: volume (mL) of sulphuric acid (0.1N) poured for the test (sample);
N: nitrogen content;
N: normality of the sulphuric acid solution;
Me: mass of the test sample in grams (g).

Determination of ash content

The ash content of starch in P. santalinoides seeds was determined according to the AOAC method[14]. A 5 g sample (Me) was weighed into a porcelain crucible of known mass (M1). The whole (crucible + sample) was placed in a muffle furnace (Nabertherm) at 550 °C for 6 h. After calcination, the sample was left to cool in the desiccator for 30 minutes. The crucible containing the calcined sample was weighed, or M2 the new mass. The following mathematical formula was used to calculate the ash content (TC):

$$\text{TC (\%)} = \frac{M1 - M2}{Me} \times 100$$

Where;
Me: mass (g) of the sample about 5 g
M2: mass (g) of the whole (crucible + ashes) after incineration.
M1: mass (g) of the assembly (crucible + powder) before incineration.
TC: ash content

2.2.5. In vitro digestibility

Preparation of the enzyme solution

The digestive juice of the snail *Archachatina ventricosa* was collected according to the method described by Colas and Attias [15] with some modifications. The collection of the digestive juice is carried out on batches of snails kept on an empty stomach for 3 days. The shell of the mollusc was carefully broken and the brown-coloured digestive tract was isolated using forceps. The raw digestive juice containing mucus is filtered through a sterile medical compress. The filtered digestive juice was then centrifuged at 10000 g for 15 min using a refrigerated centrifuge (TGL-16M) at 4 °C to obtain the raw enzyme extract.

Preparation of starch paste

A mass of 0.1 g of starch was added to 8 mL of distilled water in an Erlenmeyer flask. The suspension obtained was homogenized while hot with stirring until the first bubbles appear. The resulting solution was made up to 10 mL with distilled water to obtain a 1% (w / v) starch paste.

Enzymatic digestibility

In a tube containing 2.5 mL sodium acetate buffer (100 mM, pH 5.0) 1.25 mL enzyme extract diluted 1:100 is added. This was pre-incubated for 10 min at 37 °C and 2.5 mL starch starch starch was added. The resulting reaction mixture was incubated at 37 °C in a water bath. At regular time intervals (5 min), 250 µL of reaction medium was sampled and 250 µL of DNS was added to stop the reaction.

The released reducing sugars were dosed according to the method of Bernfeld [16]. Enzyme-free control tubes were made under the same conditions. The amount of sugar released was determined using a calibration line obtained with a glucose solution (1 mg/mL).

2.2.6. Water absorption capacity

The water absorption capacity was obtained according to the methods of Phillips et *al*. [17]. 1 gram of starch was dissolved in a centrifuge tube containing 10 mL of distilled water. This mixture was homogenized for 30 min using a mechanical stirrer (ROTATERN) and kept in a water bath at 37 °C for 30 min. After centrifugation at 4200 rpm for 15 min in a centrifuge (TGL-16M), the obtained pellet (M2) was weighed, then dried at 105 °C in a ventilated oven (BIOBASE) until a constant mass (M1) was obtained. The WAC was calculated from the following mathematical ratio:

$$\text{WAC (\%)} = \frac{M_2 - M_1}{M_1} \text{x } 100$$

Where;
WAC: Water Absorption Capacity
M1: Dry mass of the sample after drying in grams
M2: Mass of fresh pellet after centrifugation in grams

2.2.7. Clarity of starch gel

The method described by Zheng and Sosulki. [18] was used for the determination of starch gel clarity. A 1% (w/v) aqueous suspension of starch was boiled at 100 °C for 30 min with constant stirring. The initial transmittance percentage (To) was measured with the spectrophotometer (MS-A 5100) at 650 nm. After cooling of the starch starch bead to 30 °C, the tubes containing the starch gels were kept in the refrigerator at 4°C for 4 weeks and the transmittance percentage was determined weekly on three tubes.

2.2.8. Swelling and solubility

Swelling and solubility tests were carried out according to the method of Leach et *al*. [19]. Suspensions of 1% (w/v) starch were placed in a water bath at different temperatures (50 °C to 90 °C) with maximum stirring for 30 min. The suspensions contained in the tubes were centrifuged using a centrifuge (TGL-16M) at 4200 rpm for 15 min. The pellets and supernatants were collected in different crucibles and placed in an oven at 105 °C for 24 h for the supernatants and 48 h for the pellets. The supernatants were used to determine solubility and the pellets to determine the swelling index.

Swelling and solubility were determined according to the following formulas:

$$\text{Sw (gw/gdm)} = \frac{M_H - M_S}{M_S}$$

$$\text{S (\%)} = \frac{E}{M} \times 100$$

Where;
Sw (gw/gdm): Swelling (gram of water/gram of dry matter);
MH: Wet pellet mass;
Ms: Oven dried pellet mass;
S: Solubility;
E: Mass of the supernatant after steaming;
M: Mass of the sample taken for the preparation of the solution.

2.2.9. Syneresis

Starch gels were prepared according to the method described by Sahoré [20]. A 4% (w/v) aqueous suspension of starch was heated for 25 min under gentle agitation in a water bath at 100 °C. The gel thus obtained was distributed in 27 centrifuge tubes at a rate of 10 g per tube. Three tubes were conditioned at room temperature (25 °C) and allowed to stand for 20 min before being centrifuged at 2700 rpm for 30 min using a centrifuge (TGL-16M). The remaining tubes were divided into two batches, one stored in the refrigerator at 4 °C and the other in the freezer at -15 °C for 4 weeks. Each week, three tubes per batch were removed from the refrigerator and freezer and reheated to 50 °C for 90 min. These tubes were then centrifuged under the same conditions as before. The percentage of syneresis was then calculated according to Eliason and Kim [21] as follows:

$$\text{Syneresis (\%)} = \frac{Me}{Mg} \times 100$$

Where;
Me: mass of water (g) separated from the gel after centrifugation.
Mg: mass of gel (g) before refrigeration or freezing.

2.2.10. Statistical analysis of the data

All measurements were performed in triplicate. Statistical analyses of the data were performed using Statistica version 7.1 software. Comparisons of means were determined according to the Student Test and statistical significance was set at $p \leq 0.05$.

3. Results

3.1. Physico-chemical characteristics

3.1.1. Morphology and granulometry

Observation with a scanning electron microscope has shown that some native starch grains from *P. sandalinoides* seeds have spherical shapes with a smooth and regular surface. Others, on the other hand, had polyhedral shapes due to stress during extraction (Figure 3).

Frequency distribution of starch grains

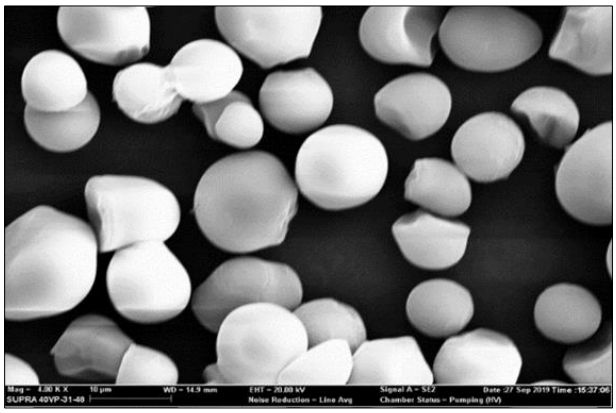

Figure 3 Morphology of native starch grains as seen by scanning electron microscope

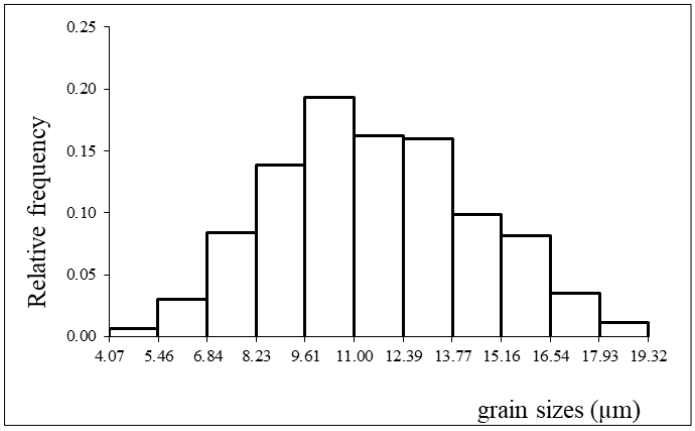

Figure 4 Frequency distribution of mean native starch grain diameters

The frequency distribution of the starch grains was performed with respect to a sample of 1000 grains. This frequency distribution was unimodal with an average diameter of 10.30 µm. The mode was reached for starch grains with sizes between 9.61 and 11.00 µm. Starch grain sizes range from 4.07 to 19.32 µm (Figure 4).

3.1.2. Chemical composition

The results obtained showed that *Pterocarpus santalinoides* starch had a moisture content of 6.72% and contains 0.87 ± 0.04% dry matter of non-starchy substances. The purity level was around 92.41% with a low ash content (0.19 ± 0.01%). The study also revealed a low lipid content of 0.20 ± 0.02% and a low protein content of 0.48 ± 0.01%. The starch extracted from the seeds contained 27.40 ± 0.35% amylose and 65.01 ± 0.15% amylopectin (Table I).

Table 1 Chemical composition of *Pterocarpus santalinoides* starch

Parameters	Starch
Humidity (%)	6.72 ± 0.15
Amylose (%)	27.40 ± 0.35
Amylopectin (%)	65.01 ± 0.15
Lipid (%)	0.20 ± 0.02
Protein (%)	0.48 ± 0.01
Ash (%)	0.19 ± 0.01
Purity (%)	92.41 ± 0.03

3.1.3. Enzymatic digestibility

The kinetic study curve of *in vitro* enzymatic digestibility is shown in Figure 5. The curve showed an increasing rate from 0 to 160 minutes followed by a stationary phase from 160 to 180 minutes. The amount of sugars produced ranged from 2.48 ± 0.02 mg at 10 minutes to 13.77 ± 0.01 mg at 180 min.

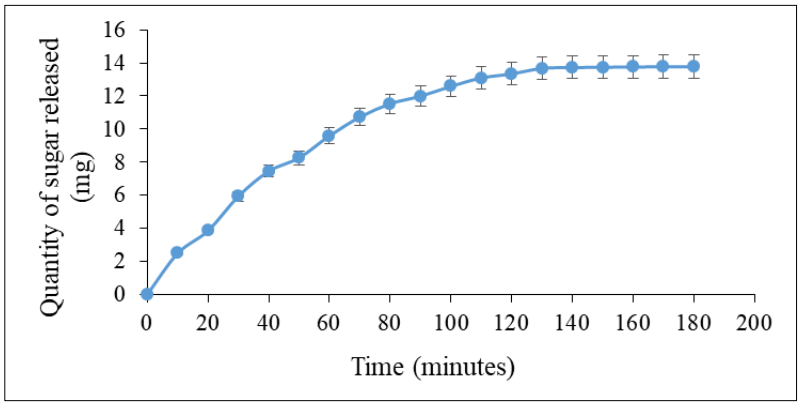

Figure 5 Evolution of the starch gel digestibility curve of *Pterocarpus santalinoides* seeds as a function of time

3.2. Functional properties

3.2.1. Water absorption capacity

The result of this functional property indicated that *Pterocarpus sandalinoides* starch had a good water absorption of 117.34 ± 0.95%.

3.2.2. Gel clarity

The starch gel clarity evolution curve is shown in Figure 6. Stored at 4 °C in the refrigerator for four weeks, the gel clarity decreased considerably with storage time in the first week and stabilized after the second week. It ranged from 5.84 ± 0.03 to 0.62 ± 0.01% transmittance.

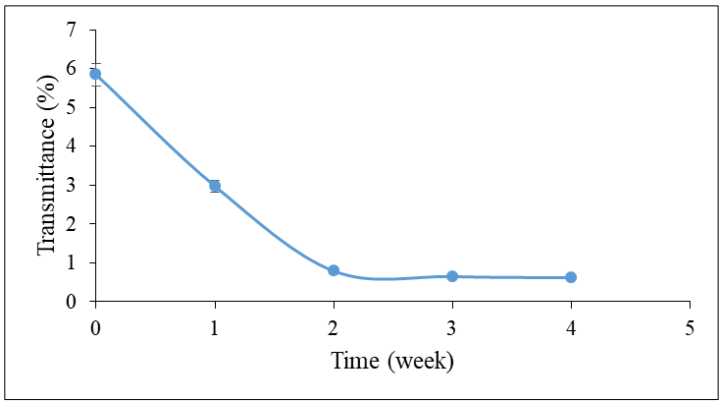

Figure 6 Evolution of the clarity of the starch gel of *Pterocarpus santalinoides* seeds at 4 °C

3.2.3. Swelling and solubility

Swelling

The swelling curve of starch in aqueous media showed an increasing rate of swelling as a function of temperature. This growth starts at 50 °C where the swelling was low (1.33 ± 0.3 gw/gdm) and then gradually intensified until it reaches 90 °C. After 50 °C, the swelling increased to 90 °C with a value of 19.22 ± 0.29 gw/gdm (Figure 7).

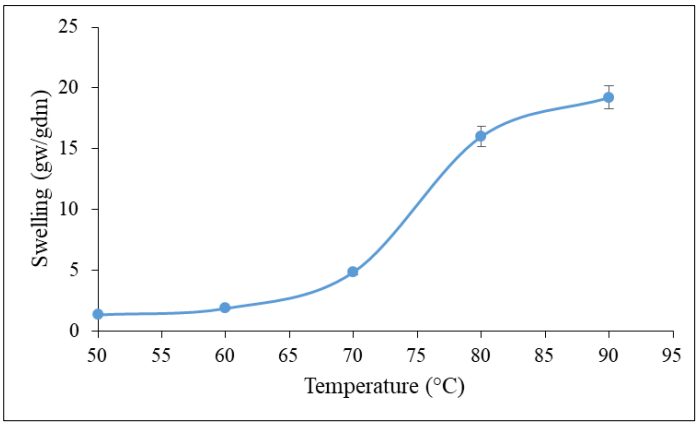

Figure 7 Variation of starch swelling of *Pterocarpus santalinoides* seeds in water as a function of temperature

Solubility

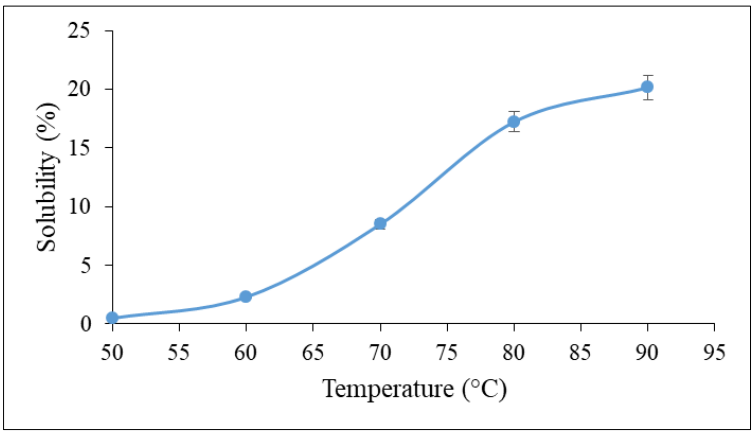

Figure 8 Variation of starch solubility of *Pterocarpus santalinoides* seeds in water as a function of temperature

The starch solubility curve showed an increasing profile as a function of temperature (Figure 8). This progression starts from 50 °C to 90 °C. The solubility percentage was 0.50 ± 0.01 at 50 °C. After 50 °C, the solubility increased to 90 °C with a value of 20.14 ± 0.01%.

3.2.4. Syneresis of starch gel at -15 °C and 4 °C

The syneresis of the starch gel stored at -15 °C gradually increased and stabilized after the second week (Figure 9). The syneresis of starch gel stored at 4 °C increased strongly over one week and equilibrated after the second week (Figure 10).

At a temperature of -15 °C, syneresis reached an average value of 59.41 ± 0.8% compared to 52.72 ± 1.01% at a temperature of 4 °C.

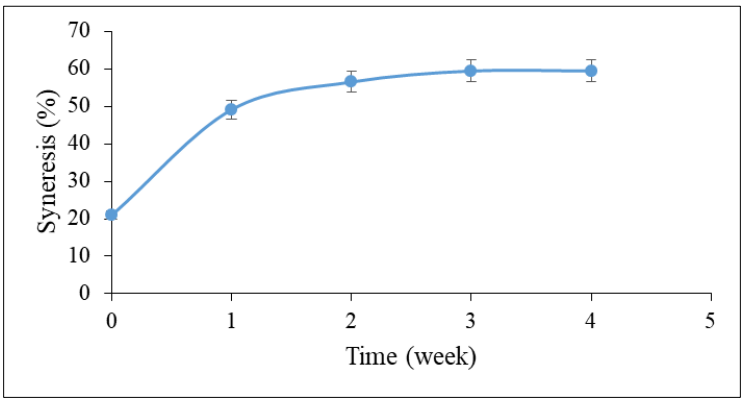

Figure 9 Evolution of the syneresis of the starch gel of *Pterocarpus sandalinoides* seeds at -15 °C

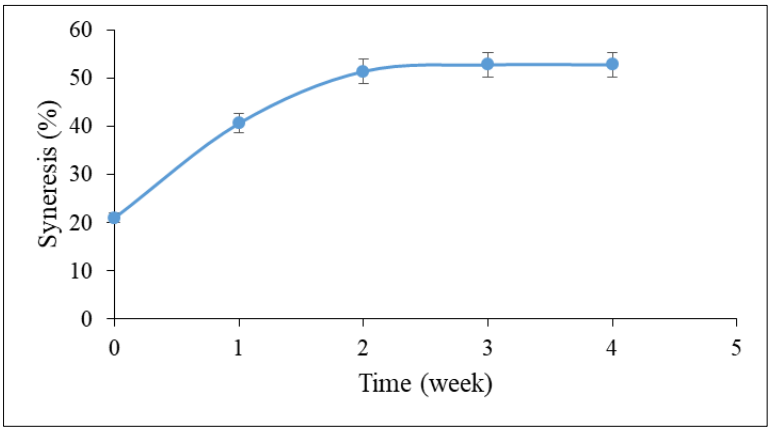

Figure 10 Evolution of the syneresis of the starch gel of *Pterocarpus santalinoides* seeds at 4 °C

4. Discussion

According to Cissé [22], the size and distribution of starch grains are parameters that depend on their botanical origin and can therefore vary within the same species. These parameters influence the properties of gelatinization, solubility and digestibility [23]. On a microscopic scale, the majority of *P. sandalinoides* starch presented spherical and polyhedral grains with smooth and regular contours. Moreover, the value of the mean diameter of these starch granules (10.30 µm) was comparable to that (10.90 µm) of the mean diameter of the Anango agba variety of cassava [2], but remained lower than those reported by Cissé et *al*. [24] for ordinary maize (white 13.27 µm; yellow 13.39 µm). Consequently, starch grains from *P. santalinoides* seeds could be used for biodegradable films, glues and cosmetic powders.

The non-starchy components of *P. santalinoides* starch were estimated to be approximately 0.87% or a purity level of 99.13%. These molecules would essentially consist of non-enzymatic proteins, enzymes bound to the surface of the granules, ash and lipids, particularly phospholipids [23]. The presence of these compounds in a starch extract is useful

because they are likely to influence certain properties such as swelling, syneresis, iodine absorption and viscosity. This is the case for lipid-amylose complexes, which are thought to promote a decrease in viscosity during dissociation [25].

The water content was 6.72%. This content was close to those (7.22 ± 0.04 to 7.82 ± 0.05%) calculated by Amoo et *al.*[26] who worked on different starches from different varieties of *Dioscorea rotundata* yam. According to these authors, the low moisture content would be the result of a long drying of the starch after extraction. Moreover, this low moisture content reflects the fact that this starch could be preserved over a relatively long period of time.

The purity level recorded (92.41%) was lower than that (98.86%) of the starches of ordinary corn varieties, calculated by Cissé [22].

The shape of the enzymatic digestibility curve would be justified by the susceptibility of starch to digestion. This susceptibility would be due to the presence of micropores on the surface of the granules, the size of the granules as well as their shape. The result is an increase in the amount of reducing sugars over time. Sauvant [27] and Brou et *al*. [28] also report that digestibility evolves as a function of particle size, the smaller the particle size, the higher the digestibility. According to Daouda et *al.* [29] good digestibility is caused by easy hydrolysis of native starch, which makes it interesting to use this type of starch in the manufacture of tablets because once swallowed, the starch coating the molecules is subject to enzymes in the digestive tract. The hydrolysis curve was similar to those observed by Cissé et *al.* [24] in their work.

The water absorption capacity value obtained in this study was 117.34 ± 0.95%. This rate was lower than those reported by Amoo et *al*. [26] (176.47 to 182.69%) for *Dioscorea rotundata* yam starch but close (103%) to that of cassava starch [30]. The water absorption capacity is a property related to the amorphous character of the starch and therefore to its amylopectin content. According to Sanni et *al.* [31], a high water absorption capacity would be attributed to the loss of structure of starch polymers while the low value would indicate the compactness of the molecular structure.

Gel clarity is a complex functional property based on many factors. The clarity of this starch decreased when stored at a temperature of 4°C. Jacobson et *al*. [32] explained this decrease by the acceleration of the retrogradation of amylose during the cold storage of starch gels. This leads to an opacity of the gels. The transmittance percentage (5.84%) of the starch studied was lower than that of regular maize (14.5%) as determined by Tetchi [33]. This low percentage of transmittance would be the consequence of a slower and less important solubilization of the granular material (amylose, intermediate material) obtained by heating the starch solution at 100 °C for 30 min [34]. Nevertheless, the low clarity of starch gels could be used in the preparation of sauces and thickened foods where transparency is not a quality criterion.

The swelling of the starch is linked to its hydrophilic character and therefore to its content of amylopectin responsible for the amorphous network. It reflects the capacity of the starch to absorb water and justifies the observed variation. The amylose-amylopectin ratio, chain length and molecular weight distribution are the factors determining the swelling rate [35]. In this study, the swelling was low at temperatures between 50 and 60 °C. For temperatures between 60 and 90°C, the starch swells strongly. The high hydration rate for temperatures between 60 and 90 °C would be justified by the disturbance of the molecular organization within the starch granules during gelatinization, hence the increase in water-starch interactions [36]. On the other hand, swelling was low for temperatures between 50 and 60 °C because starch granules only react to thermal shock from 65°C onwards [33]. The hydration rate and percentage of solubilized starch (19.22 gw/gdm and 20.14%) were close to those (22 gw/gdm and 22%) determined by Singh et *al*. [37] for ordinary maize starch but remain higher than those (6.2 gw/gdm and 11.9%; 15.3 gw/gdm and 11%) of different sorghum cultivars grown in India [38]. According to Amani et *al*. [39], the study of the evolution of solubility as a function of swelling generally shows the existence of a linear relationship between the two phenomena, whereby an increase in swelling is accompanied by a high degree of solubility. The swelling potential of *P. santalinoides* starch could be exploited in the pharmaceutical industry for coating the active ingredients of tablets and also in the food industry as a thickening agent [40].

Syneresis is a result of retrogradation, a phenomenon during which the starch tends to return to its native configuration. Although linked to many factors, retrogradation is a phenomenon caused initially by the reorganization of amylose, but also to the reversible crystallization of the short external chains of amylopectin over the long term [2]. The stabilization of the latter reflects the maximum retrogradation and therefore the end of the reorganization of amylose and amylopectin polymers. Thus, retrogradation remains influenced by the interaction of storage temperature and the proportion of water in the gel, the composition of the starch grains, the amount of amylose solubilized and the degree of polymerization of the amylopectin A and amylose chains [41]. Storage in the refrigerator (4 °C) results in a low water release compared to that of the freezer (-15 °C). The increase in syneresis during storage results in the release of water

from the gel due to the interaction of leached amylopectin A and amylopectin A amylose chains. The syneresis curves showed the same evolution as those for corn starches [22].

5. Conclusion

From the study of *P. santalinoides* starch, it appears that the starch granules have a medium size with spherical shapes with smooth and regular contours. Therefore, the starch has a low water content which would be favourable for long-term storage. In addition, enzyme digestibility analysis has indicated a susceptibility of the starch to digestion. It also appears a good water absorption capacity, a medium swelling followed by a high solubility and a slow syneresis whatever the type of conservation. Clarity, on the other hand, indicated a low percentage due to the slower and less important solubilization of the granular material. Thus, all these characteristics determined, make it possible to use these seeds for both food and non-food purposes.

Compliance with ethical standards

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Disclosure of conflict of interest

The authors did not declare any conflict of interest.

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