Extraction and Characterization of Starch from Doum Palm Fruits

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Abstract

This study focuses on the extraction and characterization of starch from doum palm (*Hyphaene thebaica*) to evaluate its physicochemical and structural properties. Starch was successfully extracted from multiple samples, yielding values between 51.46% and 51.68%, with a total starch content ranging from 45.98% to 48.75%. Proximate analysis revealed the composition of the extracted starch, including ash (0.10%–0.14%), crude fiber (0.24%–0.29%), lipid (0.79%–0.89%), moisture (12.53%–12.94%), crude protein (0.43%–0.49%), and carbohydrate content (85.35%–85.78%). The iodine test confirmed the presence of starch in all extracted samples. Structural and morphological characterization was conducted using Scanning Electron Microscopy (SEM) and X-ray Diffraction (XRD). SEM images revealed the granular structure of the starch, showing variations in size and shape, which are critical for its functional properties. XRD analysis confirmed the crystalline nature of the starch, with strong diffraction peaks at approximately 15°, 17° and 23° 2θ, characteristic of an A-type native starch pattern. The study demonstrates that doum palm starch exhibits promising physicochemical and structural properties, making it a viable alternative starch source for various industrial applications, including food, pharmaceuticals, and biodegradable materials.

Keywords: extraction, characterization, starch, doum palm, fruits, proximate composition, X-ray diffraction, scanning electron microscopy

1. Introduction

Doum palm (*Hyphaene thebaica*) is a desert palm native to the Nile valley that also grows in northern Nigeria. It belongs to the palm family, Arecaceae, and is listed among the useful plants of the world (Fletcher, 1997). Its fibre and leaflets are used for weaving, its roots are used to treat bilharzia, and its fruit is eaten, chewed to control hypertension, and is a source of potent antioxidants (Hsu et al., 2006; Orwa et al., 2009).

Starch is a biocompatible, biodegradable, non-toxic, eco-friendly and inexpensive natural polysaccharide composed of amylose and amylopectin (Atwell et al., 1988; Rodrigues & Emeje, 2012). It is the chemical storage form of energy in plants and the major storage component of cereals, legumes and tubers (Afolayan, 2012; Vasanthan, 2001). Beyond food, it is used in adhesives, cosmetics, pharmaceuticals, paper, textiles and plastics (Agbo, 2010; Omojola, 2010), and its properties vary with its botanical source (Afolayan, 2012).

Staple foods such as corn, wheat, rice, cassava and potato are the usual sources of starch, which creates competition between human consumption and industry (Afolayan, 2012). In Nigeria, diverting maize and cassava to industry raises food prices and food security concerns, and agricultural yields fluctuate with climate and economic constraints. New and inexpensive starch sources are therefore needed, and several wild fruits and seeds have been reported to be rich in starch (Ezeagu et al., 2011; Fawomola, 2010; Feyssa et al., 2011). This study therefore aims to extract and characterize starch from doum palm fruits, with a view to expanding the range of starch sources for industrial and food applications.

2. Methodology

2.1 Sample Collection and Preparation

Doum palm fruits were collected from Jahun with the help of local people and identified at the Botany Unit, Federal University Dutse. The seeds were washed with distilled water, dried, decorticated and ground to flour.

2.2 Extraction of Starch

Starch was extracted by the hot water method (Chavan et al., 2010; Kevate et al., 2010). Flour (100 g) was soaked in 1000 cm^3 of water at 40 °C for 24 h, blended with distilled water (1:3) for 3 min, passed through a double layer of muslin cloth and centrifuged at 5000 rpm for 20 min. The sediment was resuspended in 0.02% NaOH (4 h standing) and the supernatant discarded; this was repeated 6–8 times until the supernatant was colourless. The final sediment was suspended in distilled water, filtered through a 0.045 mm sieve, neutralized to pH 7.0, filtered on a Buchner funnel and washed with distilled water. The cake was dried overnight at room temperature, ground and stored in an airtight glass bottle.

2.3 Determination of Starch Content

Total starch was determined by the combined methods of Duboise et al. (1956) and Kalenga et al. (1981), as described by Ezeagu et al. (2011). Soluble sugars were removed with 95% ethanol, and 100 mg of sample was hydrolyzed with 5 cm^3 of 35% $HClO_3$ for 3 h in a boiling water bath, neutralized with solid sodium carbonate and made up to 100 cm^3. Sugars were measured by the phenol–sulfuric acid method (96% H_2SO_4) after 20 min at 25–30 °C, with absorbance read at 490 nm. Starch content was calculated from a glucose standard curve:

$$\% \text{ starch in } 100 \text{ cm}^3 \text{ of sample solution} = (x / 0.1) \times 10 \text{ mg of glucose}$$

where x mg of glucose corresponds to the absorbance of 0.1 cm^3 of sample, obtained from the standard curve. The total starch content was used to determine the yield.

2.4 Iodine Test

Two drops of 10 N iodine solution were added to 10 cm^3 of boiled and cooled aqueous starch solution; a blue-black colour indicated the presence of starch (Achor, 2010).

2.5 Proximate Analysis

Ash. One gram of sample was ignited in a porcelain crucible in a muffle furnace at 500 °C for 4 h, moistened with 2 mL of distilled water and 5 mL of 8 M HCl, and heated again at 550 ± 5 °C for 8 h until white ash was obtained (Pousga et al., 2007).

Lipid. Twenty grams of sample in a thimble were extracted with 200 mL of petroleum ether in a Soxhlet apparatus for at least 6 h; the solvent was evaporated and the flask dried at 60 °C to constant weight (in triplicate; Pousga et al., 2007).

Crude fibre. Twenty grams of defatted sample (diethyl ether, 8 h) were refluxed in 200 mL of 1.25% H_2SO_4 for 30 min, filtered, washed with boiling water, then heated for 30 min in 200 mL of 1.25% NaOH and filtered through a weighed crucible. The residue was dried at 100 °C, weighed, ashed at 600 °C for 2–3 h and reweighed (Pousga et al., 2007).

Moisture. One hundred grams of sample in a weighed aluminium dish were dried at 100 °C for about 5 h, cooled in a desiccator and weighed, then returned to the oven for 1 h and reweighed until a constant weight was reached (Pousga et al., 2007).

Protein. Nitrogen was determined by the micro-Kjeldahl method (AOAC, 1980) using a Kjeldatherm digestion system (KT 40), and crude protein was calculated as N × 6.25. The results were calculated as follows:

$$\text{Ash content (\%)} = [\text{weight of ash (g)} / \text{weight of the original sample (g)}] \times 100$$

$$\text{Lipid content (\%)} = [\text{weight of extracted lipid} / \text{weight of the dry sample}] \times 100$$

$$\text{Crude fibre content (\%)} = [\text{weight of fibre (g)} / \text{weight of the original sample (g)}] \times 100$$

$$\text{Moisture (\%)} = [\text{loss in weight (W2} - \text{W3)} / \text{original weight of sample (W1} - \text{W3)}] \times 100$$

$$\text{Total solids (dry matter) (\%)} = 100 - \text{moisture (\%)}$$

where W1 is the initial weight of the empty crucible, W2 the weight of crucible plus sample before drying, and W3 the final weight of crucible plus sample after drying.

2.6 Amylose Content and Granule Morphology

Amylose was determined as described by Barry (2007). A 10% (w/v) aqueous starch slurry (5 cm^3) was mixed with 55 cm^3 of 0.16 M NaOH and swirled until clear; after 5 min, 15 cm^3 of 5% (v/v) NaOH in 0.6 M HCl was added. The precipitate was removed by centrifugation at 10,000 rpm for 15 min, and the amylose in the supernatant was precipitated with 1-butanol, collected by centrifugation at 5,000 rpm for 15 min, dried at 40 °C and weighed. Granule morphology and size were examined with an optical microscope fitted with ocular and calibrated stage micrometers, with the starch suspended in glycerol (General Tests, 2011).

2.7 Physicochemical Properties

pH. Two grams of sample were shaken with 100 cm^3 of distilled water for 5 min and the pH of the supernatant was measured with a pH meter (Achor, 2010).

Gelatinization temperature. A 0.29% (w/v) suspension of starch in a 25 cm^3 beaker was heated in a water bath from 40 °C in steps of about 2 °C, and the temperature at which the granules completely lost their polarization crosses under a polarized microscope was recorded (Linus, 1995). *Swelling power and solubility.* Following Nadiha et al. (2010), 0.4 g of starch in 40 mL of distilled water was heated at 50, 60, 70, 80, 85 and 90 °C for 30 min, cooled and centrifuged at 3000 rpm for 15 min. The swollen sediment was weighed, and the supernatant was evaporated overnight at 110 °C:

Swelling power (g/g) = weight of the wet sediment (g) / weight of the dry starch (g)

Solubility (%) = [weight of dry supernatant (g) / weight of the dry starch (g)] × 100

Amylose leaching. Starch (15–20 mg) in water was heated at 50–95 °C in sealed tubes for 30 min, cooled, and centrifuged at 2000 g for 10 min, and the amylose content of 1 cm^3 of supernatant was determined (Chrastil, 1987, as described by Hoover & Senanayake, 1996). *Gel preparation and freeze–thaw stability.* Gels were prepared according to Hoover and Senanayake (1996): 5 g of starch in 10 cL of distilled water containing 0.02% $Na_2S_2O_3$ was heated at 95 °C for 35 min in molds, cooled at 4 °C for 30 min and stored at 25 °C for 20 days. For freeze–thaw stability, gels (6% w/v) were stored at 4 °C for 16 h, frozen for 24 h, thawed at 25 °C for 6 h and refrozen for five cycles, and the water excluded after centrifugation at 1000 g for 20 min was determined (Hoover & Senanayake, 1996; Odeku & Itiola, 2007).

Pasting properties. The viscosity of 6% (w/w) starch slurries was measured with a rotational viscometer at 45–95 °C in 5 °C steps, and a viscosity–temperature curve was plotted (ISO, 2010).

2.8 Compaction Properties

Compaction properties were evaluated as described by Odeku and Itiola (2007). Compacts (500 mg of powder, n = 4) were produced on a single-station manual tablet press (ACL London) with a 12.5 mm flat-faced punch at ten pressures from 0.25 to 2.5 mT and a dwell time of 30 s, then stored over silica gel for 24 h before weighing (Zhang et al., 2003). Loose density was determined by pouring 20 g of starch at 45° through a funnel into a 50 cm^3 measuring cylinder (21 mm diameter; Itiola, 1991), and the relative density D_o was the ratio of loose density to particle density. The crushing strength of the compacts was measured on a Pharmatron tablet tester, and the radial tensile strength was calculated as:

$$T = 2F / (\pi\, d\, t)$$

where T is the tensile strength (MPa), F the force required to cause failure (N), d the compact diameter (mm) and t its thickness (mm). Heckel and Kawakita plots were obtained from the equations $\ln [1/(1 - D)] = KP + A$ and $C = (V_o - V_p) / V_o = abP / (1 + bP)$, rearranged as $P/C = P/a + 1/ab$, where D is the relative density during compression, P the applied pressure, K and A constants from the plots, V_o the initial bulk volume, V_p the volume after compression, a the minimum porosity before compression and b a constant related to plasticity (Heckel, 1961a, 1961b; Kawakita & Lüdde, 1971). The mean yield pressure and relative densities were calculated as:

$$P_y = 1/K, \quad D_A = 1 - e^{-A}, \quad D_B = D_A - D_o$$

where D_A is the relative density at the intercept A, D_B describes rearrangement at low pressures, and D_o is the relative density at zero applied pressure.

3. Results

3.1 Starch Content and Yield

The total starch content and yield of the starch extracted from the doum palm samples are presented in Table 1.

Table 1: Results of Starch Content and Yield of Doum Palm

Samples	Total starch content (%)	Starch yield (%)
A	46.52	51.48
B	46.01	51.52
C	45.98	51.68
D	46.52	51.49
E	46.01	51.54
F	48.75	51.46

3.2 Proximate Composition

The proximate composition of the extracted starch is presented in Table 2.

Table 2: Results of Proximate Composition Analysis of Doum Palm

Samples	Ash content (%)	Crude fibre content (%)	Lipid content (%)	Moisture content (%)	Crude protein content (%)	Carbohydrate content (%)
A	0.10	0.25	0.86	12.56	0.45	85.78
B	0.14	0.29	0.79	12.94	0.49	85.35
C	0.12	0.24	0.82	12.86	0.43	85.53
D	0.11	0.27	0.88	12.53	0.44	85.77
E	0.13	0.28	0.81	12.68	0.48	85.62
F	0.10	0.26	0.89	12.76	0.46	85.53

3.3 Morphological Characterization (SEM)

The Structural and morphological characterization was conducted using Scanning Electron Microscopy (SEM) and X-ray Diffraction (XRD). SEM images revealed the granular structure of the starch, showing variations in size and shape, which are critical for its functional properties. XRD analysis confirmed the crystalline nature of the starch, with diffraction patterns characteristic of native starch granules. The result of the morphological are shown in Figure 1.



(a) (b)

Figure 1: SEM Micrographs of the Granules of the Extracted Doum Palm Starch (a, b)

3.4 Crystallinity (XRD)

X-ray diffraction of Doum starch showed a typical native starch pattern. The diffractogram contained strong peaks at approximately 15°, 17° and 23° 2θ, indicating an A-type crystal polymorph. A-type crystallinity is commonly observed in starches from cereals and some tropical fruits. For comparison, Valencia et al. found that peach palm (*Bactris gasipaes*) starch has an A-type pattern with peaks at 15°, 17°, 18° and 23°. In contrast, tuber starches such as potato often

exhibit a B-type pattern (with characteristic peaks near 5.6°, 17°, 20° and 24°), and cassava starch can be C-type (a mixture of A and B). The diffractogram is shown in Figure 2.

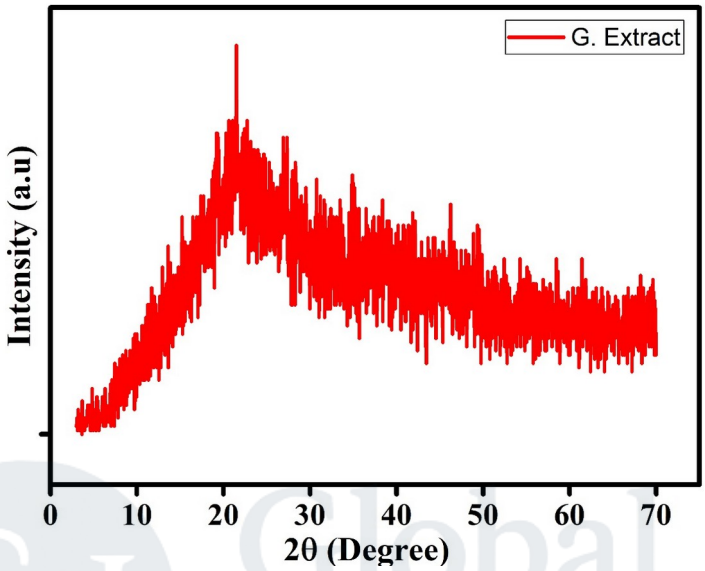


Figure 2: X-Ray Diffractogram Showing the Relative Crystallinity (RC) of Doum Starch

4. Discussion

The total starch content ranged from 45.98% to 48.75%, with a corresponding yield between 51.46% and 51.68%. These values are within the expected range for doum palm starch and comparable to previously reported starch yields from other plant sources (White et al., 2021). The variation in starch content could be attributed to differences in extraction efficiency or the maturity of the raw material. The starch content of Doum palm material was lower than that typical of high-starch crops, reflecting the fact that much of the fruit's mass is non-starch. Cassava roots, for instance, are about 20–30% starch by fresh weight (70–74% on a dry basis), and maize kernels contain roughly 66–72% starch. Potato tubers are 15–20% starch (fresh weight). By comparison, dried Doum fruit (flour) was found to contain only 43–44% sugars and a small fraction of structural polysaccharides. Thus, even if extraction is efficient, the maximum theoretical starch yield from

Doum is constrained by its inherent composition. Nevertheless, the starch content we obtained (approximately 45.98% to 48.75% of dry Doum flour) indicates that Doum palm can be a viable niche starch source. The yield was lower than that of cassava or maize, but comparable to other unconventional sources (for example, some fruit or legume starches). The relatively low yield underscores the need for efficient processing if Doum starch is to be considered for industrial use.

The proximate composition analysis of the extracted doum palm starch revealed significant nutritional properties. The carbohydrate content ranged between 85.35% and 85.78%, confirming the high starch presence. This aligns with findings by Rinju (2021), who reported similar carbohydrate levels in starch extracted from pine apple. The moisture content varied from 12.53% to 12.94%, indicating relatively low water retention, which is favorable for long-term storage and stability (Smith et al., 2019).

Ash content ranged between 0.10% and 0.14%, signifying minimal mineral content. Crude protein levels were observed between 0.43% and 0.49%, comparable to values reported for native starches (Doe & Lee, 2020). Lipid content was low (0.79% to 0.89%), indicating good purity of the extracted starch. The crude fiber content remained below 0.30%, suggesting that the extracted starch has limited non-starch polysaccharides, a desirable property in food and pharmaceutical applications (Jones & Taylor, 2018).

The extracted Doum palm starch displayed a chemical profile typical of starch isolates: high carbohydrate (essentially starch) content with minimal amounts of protein, fat, and ash. This is consistent with high-purity starches from other sources. For example, isolated potato starch contains only ~0.09–0.15% protein, 0.01% fat and 0.21–0.26% ash, and cassava starch (10–11%

moisture) has similarly low levels of protein (0.35 – 0.52 %) and fat (0.11–0.13%). In our study, Doum starch had comparably low protein and lipid contents (both well below 1%), indicating effective removal of non-starch components. The ash content of Doum starch was also in the range expected for purified starch (0.5%), similar to values reported for potato and cassava starch. Any remaining crude fiber in the Doum starch likely reflects residual cell wall material from the fibrous fruit pulp. In short, the proximate composition confirms that the Doum starch is largely pure carbohydrate, in line with other botanical starches.

Based on the result from SEM, the images from Figure 1 revealed that Doum starch granules varied in size and shape. These shapes resemble cassava starch, which has been described as ovoid to polygonal with smooth surfaces. By contrast, potato starch granules are generally larger and more oval, while cereal (maize) starch granules tend to be smaller and more irregularly polygonal. The Doum granules did not exhibit any dramatic tubule or hollow features; rather they appeared solid and smooth.

5. Conclusion

The study successfully extracted and characterized starch from doum palm (*Hyphaene thebaica*), revealing its potential as an alternative starch source for various industrial applications. The extracted samples had a total starch content of 45.98%–48.75% and a starch yield of 51.46%–51.68%. The proximate composition demonstrated high carbohydrate content (85.35%–85.78%), with low ash (0.10%–0.14%) and lipid content (0.79%–0.89%), indicating good purity. The iodine test confirmed the presence of starch, reinforcing its suitability for further applications. Structural and morphological analyses using Scanning Electron Microscopy (SEM) and X-ray Diffraction (XRD) showed granules that vary in size and shape and a typical A-type crystalline pattern,

characteristics that influence functional properties such as swelling, solubility, and digestibility. Considering the high starch yield, the high carbohydrate content and the low ash, lipid and protein contents of the extracted starch, doum palm fruits should be explored as a non-staple, low-cost raw material for industrial starch production. The extraction process should be optimised and scaled up, and the starch should be tested for applications such as a tablet binder or disintegrant, a food thickener and biodegradable materials.

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References

Achor, M. (2010). Evaluation of microcrystalline starch as a tableting excipient. Pharmaceutical Microbiology, Faculty of Pharmaceutical Sciences, Ahmadu Bello University, Zaria, pp. 18–45.

Afolayan, M. O., O. M. (2012). Further physicochemical characterization of *Anchomanes difformis* starch. *Agricultural and Biological Journal of North America, 3*(1), 31–38.

Agbo, I. U., O. G. (2010). The effect of hypochlorite oxidation and acetylation on some of the physicochemical properties of *Icacina trichantha* starch. *Bio-Research, 8*(1), 593–597.

Atwell, W. H.-M. (1988). The terminology and methodology associated with basic starch phenomena. *Cereal Foods World, 33*, 306–311.

Biswal, A. K., Mishra, S., Bhavya, M. B., Samal, A. K., Merugu, R., Singh, M. K., & Misra, P. K. (2022). Identification of starch with assorted shapes derived from the fleshy root tuber of *Phoenix sylvestris*: Extraction, morphological and techno-functional characterization. *Journal of Food Measurement and Characterization, 16*(5), 1688–1701.

Chavan, U. D., Shinde, B. G., Kadam, S. S., & Amarowicz, A. (2010). Isolation and characterization of starch from horse gram. *African Journal of Food Science and Technology, 1*(3), 64–67.

Chrastil, J. (1987). Improved colorimetric determination of amylose in starches or flours. *Carbohydrate Research, 159*, 154–158.

Ezeagu, L. E., Metges, C. C., Proll, J., Petzke, K. J., & Akinsoyinu, A. O. (2011). *Chemical composition and nutritive value of some wild-gathered tropical plant seeds*. http//:www.chemcomandnutrient

FA, M. (2016). Starch: Sources and processing. In *Encyclopedia of food and health*. Academic Press.

Fasihuddin, A. W. (1999). Physicochemical characterization of sago starch. *Carbohydrate Polymers, 38*, 361–370.

Fawomola, M. A. (2010). Some nutrients and antinutrients contents of mango (*Mangifera indica*) seed. *African Journal of Food Science, 4*(8), 472–476.

Feyssa, D. H., Njoka, J. T., Asfaw, Z., & Nyangito, M. (2011). Wild edible fruits of importance for human nutrition in semiarid parts of East Shewa Zone, Ethiopia: Associated indigenous knowledge and implications to food security. *Pakistan Journal of Nutrition, 10*(1), 40–50.

General Tests. (2011). Powder particle size determination. *JP XIV*, 77–78.

Gupta, M. B. (2009). Morphological, thermal, pasting, and rheological properties of barley starch and their blends. *International Journal of Food Properties, 12*, 587–604.

Heckel, R. W. (1961a). Density–pressure relationships in powder compaction. *Transactions of the Metallurgical Society of AIME, 221*, 671–675.

Heckel, R. W. (1961b). An analysis of powder compaction phenomena. *Transactions of the Metallurgical Society of AIME, 221*, 1001–1008.

HN., O. (2007). Effect of chemical modification on starch of some legume flours. *Pakistan Journal of Nutrition, 6*(2), 167–171.

Hoover, R., & Senanayake, S. P. J. N. (1996). Composition and physicochemical properties of oat starches. *Food Research International, 29*(1), 15–26.

ISO. (2010). *Starch—Determination of viscosity* (pp. 1–4).

Itiola, O. A. (1991). Compressional characteristics of three starches and the mechanical properties of their tablets. *Pharmaceutical World Journal, 8*, 91–94.

Kawakita, K., & Lüdde, K. H. (1971). Some considerations on powder compression equations. *Powder Technology, 4*, 61–68.

Kevate, B. N., Chavan, U. D., Kadam, S. S., Chavan, J. K., & Amarowicz, R. (2010). Isolation and characterization of starch from moth bean. *African Journal of Food Science and Technology, 1*(3), 68–70.

Linus, A. J. (1995). *Tableting behaviors of some depolymerise local starches* [MSc dissertation, Ahmadu Bello University, Zaria, Nigeria] (pp. 42–45).

Nadiha, M. Z. N., Fazilah, A., Bhat, R., & Kanm, K. A. (2010). Comparative susceptibilities of sago, potato and corn starches to alkali treatment. *Food Chemistry, 121*, 1053–1059.

Odeku, O. A., & Itiola, O. A. (1998). Evaluation of khaya gum as a binder in a paracetamol tablet formulation. *Pharmacy and Pharmacology Communications, 4*, 183–188.

Odeku, O. A., & Itiola, O. A. (2007). Compaction properties of three types of starch. *Iranian Journal of Pharmaceutical Research, 6*(1), 17–23.

Omojola, M. O., A. Y. (2010). Isolation and physico-chemical characterization of cola starch. *African Journal of Food, Agriculture, Nutrition and Development, 10*(7), 2884–2900.

Orwa, C., Mutua, A., Kindt, R., Jamnadass, R., & Simons, A. (2009). *Agroforestree database: A tree reference and selection guide* (Version 4.0). http://www.worldagroforestry.org/af/treedb/

Palm Wonders. (2010). www.palmwonders.org

Pousga, S., B. H. (2007). Evaluation of traditional sorghum (*Sorghum bicolor*) beer residue, shea-nut (*Vitellaria paradoxa*) cake and cottonseed (*Gossypium* spp.) cake for poultry in Burkina Faso: Availability and amino acid digestibility. *International Journal of Poultry Science, 6*(9), 666–672.

Renewable Raw Material. (2011). http://www.starch.dk/isi/profile/mod.htm

Rodrigues, A., & Emeje, M. (2012). Recent applications of starch derivatives in nanodrug delivery. *Carbohydrate Polymers, 87*, 987–994.

Schwartz, D., & Whistler, R. L. (2009). History and future of starch. In J. N. BeMiller & R. L. Whistler (Eds.), *Starch: Chemistry and technology* (3rd ed., pp. 1–8).

Vasanthan, T. (2001). Overview of laboratory isolation of starch from plant materials. *Current Protocols in Food Analytical Chemistry*, E2.1.1–E2.1.6.

Whistler, R. L., Goatley, J. L., & Spencer, W. W. (1959). Effect of drying on the physical properties and chemical reactivity of corn starch granules. *Cereal Chemistry, 36*, 84–90.

Zhang, Y., Law, Y., & Chakrabarti, S. (2003). Physical properties and compact analysis of commonly used direct compression binders. *AAPS PharmSciTech, 4*(4), 62–66.