Hydrolysis of starches and flours by sorghum malt amylases for dextrins production

Khady Ba1, 3\*, Mario Aguedo2, Emmanuel Tine3, Michel Paquot2, Jacqueline Destain1, Philippe Thonart1

1 University of Liege - Gembloux Agro-Bio Tech, department of Bio-Industry, Passage des Déportés, 2, 5030 Gembloux, Belgium.

2 University of Liege - Gembloux Agro-Bio Tech, department of Industrial Biological Chemistry, Passage des Déportés, 2, 5030 Gembloux, Belgium

3 University Cheikh Anta Diop of Dakar, High School Polytechnic of Dakar, Laboratory of Applied Microbiology and Industrial Engineering, BP 5085 Dakar Fann, Senegal.

\* Corresponding author. Tel.: +32 81622305; Fax: +32 81614222

E-mail: k.ba@doct.ulg.ac.be or basy.khady@gmail.com, or bioindus.gembloux@ulg.ac.be

.

**Abstract**

Corn and wheat starches as well as wheat and cassava flours were hydrolyzed using sorghum malt at 65 °C for 6 hours. During these reactions, dextrose equivalent (DE) values were followed under 3 concentrations of sorghum malt and of calcium chloride. Wheat flour presented the highest DE values and cassava flour had the highest hydrolysis yield. Thus, different dextrins were produced in a pilot plant and were analyzed by HPSEC and HPAEC-PAD for their molecular weight distribution and oligosaccharides composition respectively. The results indicated that oligosaccharides with broad molecular weight distributions were present in the dextrins produced and that the proportion of maltose was very high.

**Keywords**: Sorghum malt; hydrolysis; dextrose equivalent; dextrins; cassava flour; oligosaccharides

**1. Introduction**

Starch is composed of two polysaccharides: amylose, composed of linear chains of glucose linked by α-1,4 bonds, and amylopectin (α-1,6 bonds) which is the major macromolecular component and responsible for the architecture of the starch granules [1]. The physical properties of starch are influenced by the molecular structures of both amylose and amylopectin [2]. Starches from various botanical origins differ in amylose and amylopectin content, chain length distribution and molecular weight. Starch hydrolysis products are widely used in food industry for their functional properties; moreover practical applications have been found in pharmaceutics, cosmetics, detergents, textiles, paper and paints [3]. Starch hydrolysates with dextrose equivalent (DE) below 20 are referred to as maltodextrins, while those with DE above 20 are referred to as maltose syrup or glucose syrups [4]. Starch hydrolysates with the same DE can have different properties and molecular compositions depending on the starch and how it is digested [5].

The hydrolysis of starch can be done enzymatically or through acid-mediated processes. Amylases are digestive enzymes which hydrolyze glycosidic bonds of starch to glucose, maltose, maltotriose and dextrin. There are various amylases with different properties. -Amylase (E.C. 3.2.1.1) catalyzes the cleavage of internal α-1,4 bonds of starch, releasing oligosaccharides as main products. β-Amylase (E.C. 3.2.1.2) releases low molar mass sugars, i.e. glucose and maltose. Pullulanase (E.C. 3.2.1.41) is a debranching amylase which catalyzes the hydrolysis of α-1,6 bonds present in amylopectin. Other amylases are also important in starch hydrolysis, such as α-glucosidase (E.C. 3.2.1.20) and glucoamylase (E.C. 3.2.1.3). Amylases act synergistically in the hydrolysis of starch [6]. Amylases can be produced by a wide variety of organisms, bacteria, fungi, animals and plants. Starch hydrolysis products can be produced industrially with the use of enzymes from microorganisms; however, malted cereals can also be sources of amylases. To our knowledge the hydrolysis of starch has not yet been done with sorghum malt (SM) amylases.

Ayernor et al. [7] have produced glucose syrup from cassava flour by combining rice malt and amyloglucosidase from *Aspergillus niger.* The depolymerisation of starch was performed in two steps (liquefaction and saccharification). During the liquefaction process, α-amylases convert starch into dextrins and small amounts of oligosaccharides. Some sorghum varieties exhibit good amylase activities especially α-amylase activity [8,9] . The hydrolytic process and the use of efficient low-cost amylolytic enzymes are important factors to be considered for the production of dextrins. The objectives of the present work were to study the possibility of producing dextrins by using SM on starches and flours and to characterize the oligosaccharides obtained.

**2. Materials and methods**

**2.1. Materials**

Corn (*Zea mays*) starch was obtained from Roquettes Frère (Lestream, France); wheat (*Triticum aestivum*) starch was provided by THT s.a. (Gembloux, Belgium); wheat flour was kindly donated by Belourthe (Hamoir, Belgium) and cassava (*Mannihot esculenta*) flour was purchased from the Senegalese market. All chemicals used were analytical grade.

**2.2. Amylases production and assay**

Amylases were produced by malting sorghum seeds in our laboratory [10].The activity of three amylases was measured in the malt. Amylases activities were determined using specific kits: AMYLAZYME (Azurin-crosslinked amylose = AZCL-Amylose) (Megazyme, Ireland) was used for α-amylase (312.6 U/g), BETAMYL (Megazyme, Ireland) for β-amylase (62.7 U/g) and LIMIT-DEXTRIZYME (Megazyme, Ireland) for pullulanase (1.3 U/g). The activities of α- and β-amylases were expressed in units Ceralpha corresponding to the amount of enzyme required to liberate one micromole of p-nitrophenol per minute per gram of dry matter at 40 °C. For pullulanase, a unit of activity is defined as the amount of enzyme required to liberate one micromole of glucose from pullulan per minute per gram of dry matter at 40 °C.

**2.3. Chemical composition of starches and flours**

Moisture and ash contents were determined by AOAC Methods 934.01 and 942.05, respectively [11]. Starch content in flours was estimated by Ewers’ polarimetric method using hydrochloric acid [12]. The total nitrogen (TN) content of starch was determined by the Kjeldahl method and the protein contents were calculated by TN × 6.25.

**2.4. Enzyme hydrolysis**

Solutions with 30 % of corn starch, or wheat starch and flour and a solution at 10 % of cassava flour were hydrolysed using different concentrations of SM. The hydrolyses were done in a thermoregulated bath with stirring at 65 °C and pH 5.5 ; chloride calcium was added in amounts of 60, 80 and 100 ppm as α-amylase activator. The pH was adjusted with lactic acid or potassium hydroxide. The hydrolysis was carried out for 6 hours. The yields of released sugar were measured as reducing sugars by Miller’s method [13]. Every 30 min, one fraction was removed from the water bath, centrifuged during 20 min at 10000 rpm and analysed.

**2.6. Soluble solids**

The yield of hydrolysis was determined by soluble solids determination (°BRIX) with an ATAGO® refractometer (Tokyo, Japan).

**2.7. Determination of dextrose equivalent**

The dextrose equivalent (DE) during hydrolysis was determined by the ratio of reducing sugar in the final product and the total soluble solids.

$$DE=\frac{Reducing sugar in starch hydrolysate (expressed as glucose) }{Total solids content of starch hydrolysate} ×100$$

Based on the results obtained in the thermoregulated bath, the process was accomplished on a pilot plant scale and three different DE values were produced and analyzed for each substrate.

**2.8. Chromatography**

High Performance Size-Exclusion Chromatography (HPSEC) was performed with a Waters 2690 Alliance chromatograph coupled to a Waters 2410 RI detector. The column used was a TSK GPWxl (300 × 7.8 mm I.D.) (Tosoh, Tokyo, Japan). The column temperature was maintained at 30 °C and the RI detector was held at 40 °C. The mobile phase was an aqueous solution of 50 mmol/L sodium nitrate (NaNO3) and 0.05 % sodium azide (NaN3). The flow rate was 0.7 mL/min and the injection volume was 100 µL. Dextran standards of 1,270, 5,220, 11,600, 23,800 and 48,600 Da (Sigma-Aldrich, Bornem, Belgium) were used. Samples solutions were diluted in distilled water to 2 mg/mL and filtered through 0.45 µm syringe filters prior to injection. The curves were processed and the peaks were integrated using Millennium®32 software (Waters)

High-Performance Anion-Exchange Chromatography with Pulsed Amperometric Detection (HPAEC-PAD) was performed with a Dionex ICS-3000 (Sunnyvale, CA, USA) equipped with an ED 3000 pulsed amperometric detector. The column used was a CarboPac PA 100 ICF-3000 model (250 × 4 mm I.D.) (Sunnyvale, CA, USA) equipped with a guard column CarboPac PA 100 (40 × 4 mm I.D.). The mobile phases consisted of 100 mmol/L sodium hydroxide (eluent A), 100 mmol/L sodium hydroxide containing 600 mmol/L sodium acetate (eluent B) and 500 mmol/L sodium hydroxide (eluent C). The elution program was run at 35 °C as follows: 100 % eluent A during 10 min, then a progressive gradient during 50 min to reach 25 % eluent B/75 % eluent A, then a 10 min gradient until 50 % A/50 % B, then 100 % eluent C during 8 min and finally 100 % A during 12 min. The flow rate was 1 mL/min and the injection volume was 25 µL. Sugars with degree of polymerization (DP) from 1 to 5 (glucose DP1; maltose DP2; isomaltose DP2; maltotriose DP3; maltotetraose DP4 and maltopentaose DP5) (Sigma-Aldrich, Bornem, Belgium) were used to identify the chromatographic peaks. A standard solution containing all the compounds at 2 mg/mL was prepared in distilled water and this solution was then diluted from 100 to 10 ppm. 100 ppm solutions of dextrin samples were prepared and analyzed.

**3. Results and discussion**

**3.1. Composition of the starches and flours**

The chemical composition of the starches and flours are presented in Table 1. The moisture contents of corn starch (13.8 %), wheat starch (12.5 %), wheat flour (11.5 %) and cassava flour (10.4 %) were in line with published values [14,15,16,17,18]. Corn and wheat starches had similar protein contents (0.05 %) and low ash contents. Cassava flour contained noticeably higher amounts of starch (81.4 %) and ash (1.3 %) than wheat flour, however the protein content was higher in wheat flour. These values were comparable to those reported by Naguleswaran et al.[19]in wheat, Charoenkul et al. [20 in cassava, Charles et al*.* [21](2007) in wheat and cassava and Aryee et al.[22] in 31 varieties of cassava.

**3.2. Effect of sorghum malt (SM) and CaCl2 concentrations on hydrolysis**

Corn and wheat starches, as well as wheat and cassava flours were hydrolyzed by sorghum amylases at 65 °C for 6 h and the degree of hydrolysis was followed by measuring the DE. The effect of SM and CaCl2 concentrations on the reactions is presented in Fig. 1 to 4. Corn and wheat starches (30 % w/v) were hydrolyzed with 0.17 %, 0.25 % and 0.33 % (w/w) SM and 0, 60, 80 and 100 ppm of CaCl2. As it can be seen in Fig. 1,after one hour of hydrolysis, corn starch without Ca2+ produced DE of 4.2, 7.9 and 8.6 at 0.17, 0.25 and 0.33 % SM respectively and a progressive increase in DE was observed with time (Fig. 1). At the end of the hydrolysis, maximum DE of 15.1, 25.0, and 18.2 were obtained. These values can be compared to those obtained by Sadeghi et al. [23] by hydrolyzing corn starch with α-amylase Termamyl 2-x® (180-240 KNU/g): after 5 h of hydrolysis at 65 °C with enzyme concentrations of 0.2, 0.25 and 0.3 ml per kg of starch, DE varies from 10.9 to 16.15 and 26.7 respectively. The addition of Ca2+ at concentrations of 0.17 and 0.25 % SM did not give DE values higher than those obtained without Ca2+ except for 0.33 % SM concentration, for which the DE values were higher. After one hour of hydrolysis of wheat starch (Fig. 2), DE values were 2.7, 3.7 and 7.6 with the three increasing concentrations of SM respectively. Thereafter, DE increased to 17.3, 12.2 and 20.2 at 6 h reaction time. However, at 0.25 % malt concentration, wheat starch gave low DE values compared to those obtained at 0.17 and 0.33 % SM. The effect of Ca2+ on the reaction was not significant. At a concentration of 30 % (w/v), wheat flour was hydrolyzed with 0.03, 0.05 and 0.07 % (w/w) of SM. The products obtained after one hour of reaction had DE values of 10.6, 17.3 and 17.9 respectively for the three concentrations of SM and without Ca2+ (Fig. 3**)**. When Ca2+ was added at 60, 80 and 100 ppm, DE values of the products increased and the highest values were obtained with 80 ppm of Ca2+. At 0.05 and 0.07 % of SM, wheat flour yielded after three hours syrup with DE values higher than 20 (Fig. 3b and 3c). For reasons of viscosity, cassava flour was hydrolyzed only at a concentration of 15 % with three concentrations of SM (0.13, 0.23 and 0.33 % (w/w)). This hydrolysis yielded DE values of 4.8, 9.4 and 6.2 after one hour of reaction (Fig. 4). DE values increased progressively with reaction time and reached 15.0, 14.9 and 20.1 respectively at 0.13, 0.23 and 0.33 % of malt and without Ca2+. High DE values were also obtained in the presence of Ca2+. Ayernor et al. [7] reported that cassava flour has advantages compared to other flours such as a complete and easier hydrolysis. They found that cassava flour (10 % w/v) hydrolyzed with rice malt extract gives sugar syrup within 2 h (with DE equal to 43.6). According to Chen et al. [24]most cassava granules are in truncated form and that truncatures are weak points in the granule structure that lead to increased susceptibility to enzymatic attack.

Different calcium concentrations were added to determine the impact of calcium ions on amylase activity. The role of calcium in maintaining catalytic activity and structural of α-amylase is not new and in majority of cases they are largely influenced by variation of calcium level. However, there are certain α-amylases which catalyze the reaction independent of calcium ion concentration [25]. In this study a lower impact of calcium on the process was observed.

 The hydrolysis yield can be expressed by DE and by soluble solids determination [26,27]. Table 2 shows the hydrolysis yield by measurement of the soluble solids suspension by refractometry. During hydrolysis, cassava flour gave the highest yields with 69.3 % after one hour and 76 % at the end of the reaction; whereas the lowest yields were obtained with corn starch. Moore et al. [27] reported final yields of 76.3 % for cassava starch and 74.8 % for corn starch after 120 min of hydrolysis with α-amylase Termamyl-120L®. They explained the higher yield obtained with cassava starch by its high swelling power.

**3.3. Characterization of the hydrolyzed products**

***3.3.1 Molecular weight distribution***

Molecular weight distributions of dextrins were determined by HPSEC/RI detection in order to determine the impact of sorghum amylases on the tested substrates. The profiles of the hydrolyzed products are displayed in Fig. 5 to 8: HPSEC separates compounds according to size with larger polymers eluting first. The elution profiles were divided into four fractions (F1 to F4) and the proportion of each one was determined (Table 3). In Fraction 1 (F1), DP ranged from 704 to 1433 for corn dextrins, from 694 to 1380 for wheat dextrins, from 694 to 1412 for wheat flour dextrins, and from 724 to 1476 for cassava dextrins. F2 had DP values lower than in F1, ranging from 108 to 245 for corn dextrins, from 120 to 203 for wheat dextrins, from 91 to 342 for wheat flour dextrins and from 114 to 330 for cassava dextrins. DP values in F3 were almost the same in samples and ranged from 7 to 12 for corn dextrins, from 7 to 13 for wheat dextrins and cassava dextrins, except for wheat flour in which they were slightly higher 7 to 17. However, in F4, DP values were the same and be around 3. The proportions of each fraction in the samples changed according to DE value and type of substrate. The amount of high molecular weight compounds decreased with the hydrolysis in all dextrins and the mean DP decreased with increasing DE. The profiles observed here differ from those observed by Sun et al. [3], who found that dextrins produced by enzymatic hydrolysis of corn starch by two α-amylases (the common neutral α-amylase and a thermostable α-amylase) showed two fractions.

***3.3.2. Oligosaccharides composition***

The composition in oligosaccharides of the dextrins produced was characterized by HPAEC-PAD. Table 4 shows the amounts of oligosaccharides in dextrins produced from the different substrates. In the dextrins from corn and wheat starches, the content of maltose was higher than that of glucose and isomaltose and the content of maltopentaose was higher than that of maltotetraose. Wheat flour hydrolyzed with the lowest concentration of SM exhibited dextrins with the highest DE values and composed mainly of maltose. This can be explained by the presence of amylases in wheat flour which in combination with amylases of SM resulted in rapid hydrolysis of the gelatinized starch. Cassava flour (15 % w/v in solution) was hydrolyzed with the same SM concentration that corn and wheat starches. The dextrins produced contained more maltose, maltotetraose and maltopentaose than glucose and isomaltose (Table 4). It is well known that cereal malts are rich in enzymes involved in starch hydrolysis [7]. The largest proportion of maltose in all samples may result from the action of α-amylase, β-amylase and pullulanase. Pullulanase is capable of hydrolyzing α-1🡪6 glycoside bonds, releasing small linear chains from branched starch and the synergetic action of pullulanase and other amylases can effectively produce small saccharides [28]. The isomaltose detected in the samples can result from the reaction of reversion. Indeed, when the concentration of glucose in the medium is more than 30 to 35 %, glucoamylase catalyses the reverse reaction to form primarily maltose and isomaltose [29]. Maltotriose was not detected in any of the dextrin samples. The same phenomenon was described by Khatoon et al. [16] analyzing maltodextrins obtained by corn starch hydrolysis with a thermostable α-amylase from *Bacillus licheniformis*. However, they detected maltotriose in dextrins from cassava starch and not maltotetraose. Wang and Wang [30] found maltotriose in corn, potato and rice maltodextrins. Sun et al. [3] reported also a larger proportion of maltotriose and maltotetraose in corn dextrins. In this study we assumed that maltotriose could be cleaved into maltose and glucose by sorghum malt amylases such as α-amylase or glucoamylase. However this assumption should be investigated.

**4. Conclusion**

Amylases of malted sorghum were able to hydrolyze starches and flours at variable degrees with relatively high rates. Dextrins with low and high DE could be obtained depending on the concentration of SM used and the addition of calcium had no significant impact on the efficiency of hydrolysis. The highest DE values were observed in dextrins from wheat flour. Oligosaccharides with broad molecular weight distributions were present in dextrins. Glucose, maltose, isomaltose, maltotetrose and maltopentaose were detected, with a high proportion of maltose and an absence of maltotriose in all dextrins. Such dextrins should be suitable to be used for instance as fillers in production of spray dried foods, freeze-control agents or anti-caking agents. However their physicochemical properties will be further studied.

**Acknowledgements**

This work was supported by Wallonia-Brussels International. The authors would like to express their thanks to Catherine Chemotti for her technical assistance on HPLC.

**References**

1. Vásquez M, Delgado R, Castro AJ (2009) Modeling of the enzymatic hydrolysis of potato (*Solanum tuberosum*) using response surface methodology. Starch/Stärke61:601–609

2. Lin, AHM, ChangYH, Chou WB, Lu TJ (2011) Interference prevention in size-exclusion chromatographic analysis of debranched starch glucans by aqueous system. J. Agri. Food Chem. 59:5890-5898

3. Sun J, Zhao R, Zeng J, Li G, Li X (2010) Characterization of dextrins with different dextrose equivalents. Molecules 15:5162-5173

4. White DR, Hudson P, Adamson JT (2003) Dextrins characterization by high-performance anion-exchange chromatography-pulsed amperometric detection and size-exclusion chromatography-multi-angle light scattering-refractive index detection. J. Chromatogr. A 997:79-85

5. Marchal LM, Beeftink HH, Tramper J (1999) Towards a rational design of commercial maltodextrins. Trends Food Sci. Technol. 10:345-355

6. Castro AM, Castilho LR, Freire DMG (2011) An overview on advances of amylases production and their use in the production of bioethanol by conventional and non conventional processes. Biomass Conv.Bioref*.* 1:245-255

7. Ayernor GS, Hammond TK, Graffham A (2002) The combination of rice malt and amyloglucosidase for the production of sugar syrup from cassava flour. Afri. J. Sci. Technol. 3:11-18

8. Traoré T, Mouquet C, Icard-Vernière C, Traoré AS, Trêche S (2004) Change in nutrient composition, phytate and cyanide contents and α-amylase activity during cereal malting in small production units in Ouagadougou (Burkina Faso). Food Chem. 88:105-114

9. Dicko MH, Gruppen H, Zouzouho OC, Traoré AS, van Berkel WJH, Voragen AGJ (2006) Effects of germination on the activities of amylases and phenolic enzymes in sorghum varieties grouped according to food end-use properties. J. Sci. Food Agri. 86:953-963

10. Ba K, Tine E, Cissé N, Destain J, Thonart P (2010) Étude comparative des composés phénoliques, du pouvoir antioxydant de différentes variétés de sorgho sénégalais et des enzymes amylolytiques de leur malt. Biotechnol. Agron. Soc. Environ.214:131-139

11. Association of Official Analytical Chemists (AOAC) (1990) Official methods of the association of official analytical chemists. 15th edition Washington DC, USA.

12. Ewers E (1965) Determination of starch by extraction and dispersion with hydrochloric acid. International Organization for Standardization, ISO/TC 93/WGL.

13. Miller GL (1959) Use of dinitrosalycilic acid reagent for the determination of reducing sugars. Anal. Chem. 31:426-428

14. Chiang SH, Chen CS, Chang CY (2006) Effect of wheat flour protein compositions on the quality of deep-fried gluten balls. Food Chem. 97:666-673

15. Maache-Rezzoug Z, Zarguili I, Loisel C, Queveau D, BuléonA (2008) Structural modifications and thermal transitions of standard maize starch after DIC hydrothermal treatment. Carbohyd. Polym. 74:802-812

16. Khatoon S, Sreerama YN, Raghavendra D, Bhattacharya S, Bhat KK (2009). Properties of enzymes modified corn, rice and tapioca starches. Food Res. Int. 42:1426-1433

17. Saeleaw M, Schleining G (2010) Effect of blending cassava starch; rice, waxy rice and wheat flour on physic-chemical properties of flour mixtures and mechanical and sound emission properties of cassava crackers*.* J. Food Eng*.*100:12-24

18. Zhou X, Baik BK, Wang R, Lim ST (2010) Retrogradation of waxy and normal corn starch gels by temperature cycling. J. Cereal Sci. 51:57-65

19. Naguleswaran S, Li J, Vasanthan T, Bressler D, HooverR (2012) Amylolysis of large and small granules of native triticale, wheat and corn starches using a mixture of α-amylase and glucoamylase. Carbohyd. Polym. 88:864-874

20. Charoenkul N, Uttapap D, Pathipanawat W, Takeda Y (2011) Physicochemical characteristics of starches and flours from cassava varieties having different cooked root textures.Food Sci. Technol.-LEB. 44:1774-1781.

21. Charles AL, Huang TC, Lai PY, Chen CC, Lee PP, Chang YH (2007) Study of wheat flour–cassava starch composite mix and the function of cassava mucilage in Chinese noodles. Food Hydrocolloids 21:368-378

22. Aryee FNA, Oduro I, Ellis WO, Afuakwa JJ (2006) The physicochemical properties of flour samples from the roots of 31 varieties of cassava. Food Control. 17:916–922

23. Sadeghi A, Shahidi F, Mortazavi SA, Mahalati MN (2008) Evaluation of different parameters effect on maltodextrin production by α-amylase Termamyl 2-x. [World Appl Sci. J.](http://www.google.be/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&cad=rja&ved=0CCEQFjAA&url=http%3A%2F%2Fidosi.org%2Fwasj%2Fwasj.htm&ei=JPpaUJuvNYbTtAbss4DABQ&usg=AFQjCNGyubkEuGmXCqOgDJzwzYlx0By_-w&sig2=CBjEEWw-M3kNmrHtCU8hUg) 3:34-39

24. Chen Y, Huang S, Tang Z, Chen X, ZhangZ (2011) Structural changes of cassava starch granules hydrolyzed by a mixture of α-amylase and glucoamylase. Carbohyd. Polym.85:272-275

25. Yadav JK (2012) A differential behavior of α-amylase, in terms of catalytic activity and thermal stability, in response to higher concentration CaCl2. Int. J. Biol. Macromol. 51:146-152

26. Slomiska L, Wisniewska D, Grzeskowiak A (2003) Liquefaction of starch by thermostable α-amylase. ACTA Technologia Alimentaria, 2:17-26

27. Moore GRP, Canto LR, Amante ER (2005) Cassava and corn starch in maltodextrin production. Quim. Nova28:596-600

28. Ma Y, Cai C, Wang J, Sun DW (2006) Enzymatic hydrolysis of corn starch producing fat mimetics. J. Food Eng.73:297-303

29. Sine JP (2010) Applications agroalimentaires et industrielles In: Enzymologie et applications. Ellipses Edition, p.289-295

30. Wang YJ, Wang L (2000) Structure and properties of commercial maltodextrins from corm, potato and rice starches. Starch/ Stärke 52:296-304

**Figure 1.** Dextrose equivalent (DE) of corn starch hydrolyzed with SM, in presence of 0, 60, 80 and 100 ppm CaCl2 and malt concentrations of 0.17 % (A), 0.25 % (B) and 0.33 % (C)

**Figure 2.** Dextrose equivalent (DE) of wheat starch hydrolyzed with SM, in presence of 0, 60, 80 and 100 ppm CaCl2 and malt concentrations of 0.17 % (A), 0.25 % (B) and 0.33 % (C).

**Figure 3.** Dextrose equivalent (DE) of wheat flour hydrolyzed with SM, in presence of 0, 60, 80 and 100 ppm CaCl2 and malt concentrations of 0.03 % (A), 0.05 % (B) and 0.07 % (C)

**Figure 4.** Dextrose equivalent (DE) of cassava flour hydrolyzed with SM, in presence of 0, 60, 80 and 100 ppm CaCl2 and malt concentrations of 0.13 % (A), 0.23 % (B) and 0.33% (C)

**Figure 5.** Molecular weight distribution of corn dextrins: DE8 (A), DE15 (B) and DE26 (C)

**Figure 6.** Molecular weight distribution of wheat dextrins: DE15 (A), DE18 (B) and DE29 (C)

**Figure 7**. Molecular weight distribution of wheat flour dextrins: DE26 (A), DE31 (B) and DE45 (C)

**Figure 8.** Molecular weight distribution of cassava flour dextrins: DE10 (A), DE15 (B) and DE28 (C)

**Table 1.** Composition of starches (corn and wheat) and flours (wheat and cassava) (% dry weight)

**Table 2.** Hydrolysis yieldsin presence of three different SM contents at different hydrolysis times.

Table 3. Retention time, area and calculated molecular weight for the four peaks determined in the different dextrins by HPSEC/RI analysis. F = Number of peak; Area = peak surface; Mw = peak average molecular weight calculated from the dextran standards curves; DP = degree of polymerization (DP = Mw/162)

**Table 4.** Oligosaccharides identified and quantified in dextrins (% dry weight). DP1 to DP5 were quantified by standard curves and DP >5 were equal to 100 - ∑DP1-5.



**A**



**C**

**B**



**A**



**C**

**B**

**Figure 2.** Dextrose equivalent (DE) of wheat starch hydrolyzed with SM, in presence of 0, 60, 80 and 100 ppm CaCl2 and malt concentrations of 0.17 % (A), 0.25 % (B) and 0.33 % (C).



**A**



**C**

**B**

**Figure 3.** Dextrose equivalent (DE) of wheat flour hydrolyzed with SM, in presence of 0, 60, 80 and 100 ppm CaCl2 and malt concentrations of 0.03 % (A), 0.05 % (B) and 0.07 % (C)



**A**



**B**



**C**

**Figure 4.** Dextrose equivalent (DE) of cassava flour hydrolyzed with SM, in presence of 0, 60, 80 and 100 ppm CaCl2 and malt concentrations of 0.13 % (A), 0.23 % (B) and 0.33 % (C)

****

 Minutes

**A**

****

Minutes

**B**

****

Minutes

**C**

**Figure 5.** Molecular weight distribution of corn dextrins: DE8 (A), DE15 (B) and DE26 (C)

****

Minutes

**A**

****

Minutes

**B**

****

Minutes

**C**

**Figure 6.** Molecular weight distribution of wheat dextrins: DE15 (A), DE18 (B) and DE29 (C)

****

 Minutes

**A**

****

 Minutes

**B**

****

Minutes

**C**

**Figure 7**. Molecular weight distribution of wheat flour dextrins: DE26 (A), DE31 (B) and DE45 (C)

****

Minutes

**A**

****

Minutes

**B**

****

Minutes

**C**

**Figure 8.** Molecular weight distribution of cassava flour dextrins: DE10 (A), DE15 (B) and DE28 (C)

**Table 1.** Composition of starches (corn and wheat) and flours (wheat and cassava) (% dry weight)

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Substrates** | **Moisture** | **Starch** | **Protein** | **Ash** |
| Corn starch | 13.79 ± 0.04 | ND | 0.05 ± 0.014 | 0.05 ± 0.003 |
| Wheat starch | 12.45 ± 0.03 | ND | 0.05 ± 0.007 | 0.15 ± 0.036 |
| Wheat flour | 11.49 ± 0.01 | 74.65 ± 0.42 | 3.14 ± 0.092 | 0.64 ± 0.033 |
| Cassava flour | 10.35 ± 0.05 | 81.36 ± 0.10 | 0.96 ± 0.021 | 1.33 ± 0.017 |

Values are percentages of mean ± standard deviation in dry weight basis

ND: not determined

**Table 2.** Hydrolysis yieldsin presence of three different SM contents at different hydrolysis times.

|  |  |  |
| --- | --- | --- |
| Substrates | SM contents | Hydrolysis time (hours) |
| 1 | 2 | 3 | 4 | 5 | 6 |
| Corn starch (30% w/v) | 0.17 % | 40.66 | 44.00 | 46.00 | 46.00 | 48.66 | 50.66 |
| 0.25 % | 54.66 | 56.66 | 58.00 | 60.00 | 61.66 | 64.00 |
| 0.33 % | 46.66 | 50.66 | 56.66 | 58.00 | 60.00 | 59.33 |
| Wheat starch (30% w/v) | 0.17 % | 55.33 | 61.33 | 60,66 | 62.66 | 64.00 | 66.00 |
| 0.25 % | 61.33 | 65.33 | 66.00 | 66.66 | 68.00 | 68.66 |
| 0.33 % | 60.00 | 65.33 | 66.00 | 66.66 | 68.00 | 65.33 |
| Wheat flour (30% w/v) | 0.03 % | 50.66 | 56.00 | 54.00 | 54.66 | 53.33 | 54.66 |
| 0.05 % | 59.33 | 62.00 | 63.00 | 63.33 | 65.33 | 66.66 |
| 0.07 % | 57.33 | 60.00 | 60.66 | 62.66 | 65.33 | 66.00 |
| Cassava flour (15% w/v) | 0.13 % | 69.33 | 73.33 | 74.66 | 74.66 | 76.00 | 76.00 |
| 0.23 % | 65.33 | 66.66 | 66.66 | 73.33 | 76.00 | 72.00 |
| 0.33 % | 66.66 | 68.00 | 72.00 | 73.33 | 73.33 | 76.00 |

Table 3. Retention time, area and calculated molecular weight for the four peaks determined in the different dextrins by HPSEC/RI analysis. F = Number of peak; Area = peak surface; Mw = peak average molecular weight calculated from the dextran standards curves; DP = degree of polymerization (DP = Mw/162)

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Fraction |  | Corn dextrins | Wheat dextrins | Wheat flour dextrins | Cassava flour dextrins |
| DE | 8 | 14 | 26 | 15 | 18 | 29 | 26 | 31 | 45 | 10 | 15 | 28 |
| F1 | RT (min) | 7.46 | 7.96 | 8.05 | 7.49 | 7.99 | 8.06 | 7.47 | 7.93 | 7.87 | 7.43 | 8.03 | 7.37 |
| Area (%) | 6.41 | 15.81 | 1.05 | 3.90 | 6.61 | 2.62 | 5.31 | 1.22 | 1.14 | 12.50 | 4.74 | 0.27 |
| Mw (Da) | 232152 | 127311 | 114199 | 223713 | 122244 | 112574 | 228848 | 131483 | 112574 | 239188 | 117380 | 202008 |
| DP | 1433.04 | 785.87 | 704.94 | 1380.95 | 754.60 | 694.91 | 1412.65 | 811.63 | 694.91 | 1476.47 | 724.57 | 1246.97 |
| F2 | RT (min) | 8.93 | 9.28 | 9.48 | 9.09 | 9.43 | 9.53 | 8.66 | 9.76 | 9.79 | 8.68 | 9.57 | 10.03 |
| Area (%) | 48.72 | 40.74 | 42.87 | 53.93 | 45.52 | 44.72 | 38.89 | 29.40 | 29.64 | 50.72 | 50.03 | 37.73 |
| Mw (Da) | 39779 | 26157 | 17573 | 32938 | 21971 | 19497 | 55443 | 14814 | 19497 | 53556 | 18566 | 33091 |
| DP | 245.55 | 161.46 | 108.48 | 203.32 | 135.63 | 120.36 | 342.24 | 91.45 | 120.36 | 330.59 | 114.61 | 204.27 |
| F3 | RT (min) | 11.42 | 11.87 | 11.86 | 11.38 | 11.85 | 11.88 | 11.15 | 11.48 | 11.49 | 11.39 | 11.85 | 11.91 |
| Area (%) | 27.94 | 38.91 | 44.58 | 27.56 | 39.06 | 36.74 | 4.15 | 5.27 | 5.34 | 24.73 | 31.67 | 34.29 |
| Mw (Da) | 2030 | 1190 | 1170 | 2139 | 1225 | 1172 | 2813 | 1901 | 1172 | 2106 | 1223 | 1147 |
| DP | 12.53 | 7,35 | 7.32 | 13.21 | 7.56 | 7.24 | 17.36 | 11.74 | 7.24 | 13.01 | 7.55 | 7.08 |
| F4 | RT (min) | 12.41 | 12.83 | 12.84 | 12.45 | 12.84 | 12.84 | 12.43 | 12.84 | 12.84 | 12.42 | 12.86 | 12.84 |
| Area (%) | 16.92 | 4.55 | 11.49 | 14.61 | 7.50 | 15.91 | 51.64 | 64.11 | 63.87 | 12.05 | 13.56 | 27.71 |
| Mw (Da) | 622 | 375 | 375 | 595 | 375 | 375 | 614 | 372 | 375 | 620 | 364 | 373 |
| DP | 3.84 | 2.32 | 2.32 | 3.68 | 2.32 | 2.32 | 3.79 | 2.30 | 2.32 | 3.83 | 2.25 | 2.31 |

**Table 4.** Oligosaccharides identified and quantified in dextrins (% dry weight). DP1 to DP5 were quantified by standard curves and DP >5 were equal to 100 - ∑DP1-5.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | Corn dextrins | Wheat dextrins | Wheat flour dextrins | Cassava flour dextrins |
| DE | 8 | 14 | 26 | 15 | 18 | 29 | 26 | 31 | 45 | 10 | 15 | 28 |
| Glucose (DP1) | 1.20 | 2.05 | 3.13 | 0.99 | 1.61 | 2.50 | 0.37 | 1.01 | 1.46 | 1.45 | 3.53 | 5.92 |
| Maltose (DP2) | 3.51 | 11.85 | 19.26 | 11.60 | 17.43 | 21.54 | 29.03 | 59.74 | 83.85 | 7.20 | 22.05 | 47.77 |
| Isomaltose (DP2) | 0.83 | 1.58 | 2.08 | 1.64 | 2.13 | 2.52 | 2.06 | 6.31 | 9.36 | 2.20 | 5.54 | 6.28 |
| Maltotetraose (DP4 | 1.83 | 4.82 | 6.30 | 2.22 | 5.28 | 6.53 | 0.34 | 1.41 | 2.57 | 1.40 | 5.32 | 14.20 |
| Maltopentaose (DP5) | 3.24 | 7.10 | 9.61 | 4.58 | 8.98 | 9.44 | 0.23 | 0.37 | 0.81 | 2.60 | 7.51 | 17.38 |
| DP > 5 | 89.39 | 72.65 | 59.62 | 78.97 | 64.59 | 57.47 | 67.97 | 31.16 | 1.95 | 85.32 | 56.05 | 8.55 |