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Research Paper / Araştırma Makalesi

An Optimization Study for Laboratory Scale Production of Glucose Syrup from Potato, Wheat and Maize Starch

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ABSTRACT

Glucose syrup is a valuable food ingredient produced by the hydrolysis of starch preferrably from maize. In this study, small-scale production process of glucose syrup from wheat, maize and potato starches was investigated. Two-step ezymatic hydrolysis using α–amylase and amyloglucosidase for liquefaction and saccharification, respectively, was analyzed based on the glucose content of a final product. The optimization of conditions was conducted with different initial amount of starch, different amount of enzymes and reaction time. Starch slurries at 30% were hydrolzed into smaller dextrins by 0.0002% (mL/g, v_{enzyme} /w_{starch}) α–amylase for 2 hours and further hydrolyzed into glucose by 0.0002% (mL/g, v_{enzyme} /w_{starch}) amyloglucosidase for 48 hours optimally. These process conditions yielded glucose syrups with dextrose equivalent (DE) values of 97.04, 97.27 and 95.34% and dry matter content of 84.30, 78.30 and 82.37% from wheat, maize and potato starches, respectively. It was concluded that starch from different biological origins offered promising raw materials for the enzymatic production of glucose syrup wih high DE value at optimum conditions.

Keywords: Botanical source, Enzymatic hydrolysis, Glucose syrup, Starch

Patates, Buğday ve Mısır Nişastasından Laboratuvar Ölçekli Glikoz Şrubu Üretimi İçin Optimizasyon Çalışması

ÖZ

Glikoz Şurubu tercihen mısır nişastasının hidrolizi ile üretilen değerli bir gıda bileşenidir. Bu çalışmada buğday, mısır ve patates nişastalarından küçük ölçekli glikoz şurubu üretim süreci incelenmiştir. Sırasıyla sıvılaştırma ve şekerleştirme için α–amilaz ve amiloglukosidaz kullanılarak iki aşamalı ezimatik hidroliz, nihai ürünün glikoz içeriğine bağlı olarak analiz edildi. Koşulların optimizasyonu, nişasta için farklı başlangıç miktarları, farklı enzim miktarları ve reaksiyon süreleri ile gerçekleştirildi. Başlangıç miktarı %30 olan nişasta bulamaçları, 2 saat boyunca %0.0002 (mL/g, h enzim/a nişasta) α–amilaz ile küçük dekstrinlere hidrolize edildi ve daha sonra 48 saat boyunca %0.0002 (mL/g, h enzim/a nişasta) amiloglukozidaz ile glikoza hidrolize edildi. Bu işlem koşulları ile buğday, mısır ve patates nişastalarından sırasıyla %97.04, 97.27 ve 95.34 dekstroz eşdeğerlerine (DE) ve %84.30, 78.30 ve 82.37 kuru madde değerlerine sahip glikoz şurupları elde edildi. Farklı biyolojik menşeli nişastaların, optimum koşullarda yüksek DE değerine sahip glikoz şurubunun enzimatik üretimi için umut verici hammaddeler olduğu sonucuna varıldı.

Anahtar Kelimeler: Botanik kaynak, Enzimatik hidroliz, Glikoz şurubu, Nişasta

INTRODUCTION

Starch is a glucose polymer synthesized by plants in leaves or non-photosynthetic tissues, such as seeds, stems, roots or tubers. The two glucose polymers, amylopectin and amylose, found in starch have different structure. While the amylose structure is a linear and long glucose polymer that contains 99% α-(1→4)-glucose, amylopectin is a branched polymer containing 95% α-(1→4)-glucan and 5% α-(1→6)-glucan in its structure [1]. The crystal region of starch obtained from tubers and roots contains only amylopectin and the amyloses are located in the amorphous region. In starches obtained from cereals, amylopectin is mostly found in the crystal region, and amyloses form a weak crystalline complex with fat molecules [2].

Starch is highly preferred carbohydrate source for both animals and humans and also it is an important industrial source for the production of low molecular weight products such as glucose, maltose, maltotriose and dextrin. The starch and starch-based products have been used widely in food (as sweetners, emulsifiying agents, film formers, texture providers, and thickeners) [3, 4] pharmaceutical (as carrier for drug delivery) [5], textile (as paper coaters) [6] and chemical industries (as raw materials of bioethanol) [7]. Although starch and starch-based products have been produced mostly from maize [8], many other tuber and cereal plants such as wheat [9], potatoes [10], rice [11], sweet potatoes [12], cassava [13], sorghum [14], and barley [15] have been searched as raw materials for starch production all over the world. The physicochemical, morphological and functional characteristics show variations among starches obtained from different biological origins of plant and these properties lead to differences in the starch-based products and their production processes [16, 17]. An industrially important starch-product, glucose syrup, is produced by an enzymatic or acid-catalyzed reaction mostly from maize, wheat, rice, cassava and potato starches and based on the raw material and hydrolization reaction; they differ in their grades, characteristics and application areas [18]. For example, liquefaction reaction in which starch polymers are partially hydrolyzed into smaller dextrins via bacterial amylase yielded digested products with dextrose equivalent (DE) value ranging from 3.4 to 20.6 for potato starch whereas percentage conversion to reducing groups were reported as 15.5%, 14.8% and 14.3% for cassava, sweet potato and maize starches, respectively. In the saccharification of smaller dextrins to glucose syrup, the percent convertion to reducing sugar ranged from 94.09% for maize starch to 98% for wheat starch [19, 20]. As their application area compared it was observed that low converted glucose syrups having dextrose equivalent (DE) value of 20-35 are preferred for the production of frozen dairy products while high converted syrups with DE 55-70 are used in soft drinks and jam production.

In the present study, wheat, maize and potato starches were used as raw materials for glucose syrup production via enzymatic reaction. The alpha amylase from *Bacillus licheniformis* and glucoamylase from *Aspergillus niger* were used sequentially, in liquefaction and saccharification process and optimization of the conditions for both processes was conducted with different amount of enzymes and reaction time. The glucose syrup produced from wheat, maize and potato starches were evaluated according to the glucose contents and DE values.

MATERIALS and METHODS

Materials

Wheat, Maize, potato starches were obtained from Konya Seker Industry and Co. (Konya, TURKEY), Cargill (İstanbul, TURKEY) and Rotel Company (İstanbul, TURKEY), respectively. Thermostable α–amylase (endo-1,4-α-D-glucan glucohydrolase, E.C.3.2.1.1) (from *B. licheniformis*) and amyloglucosidase (1,4-α-D-glucan glucohydrolase, EC 3.2.1.3) (from *A. niger*) were purchased from Sigma (St Louis, MO, USA).

Chemical Characterization of Starches

The moisture, pH, starch, lipid, protein and ash contents of starches from wheat, maize and potato were determined according to standard methods [21].

Structural and Morphological Characterization of Starches

The functional groups of wheat, maize and potato starches were identified by the Fourier Transform Infrared Spectroscopy (FTIR, Bruker Vertex 70 FTIR). The absorbance peaks corresponding to the frequencies formed by the vibration of the bonds between atoms of starch samples were measured in the frequency interval of 4000 and 400 cm^{-1}.

The crystalline structures of these starches were characterized by X-Ray Difractometer (XRD) (Bruker D8 DAVINCI)**.** The difratograms of the samples were analyzed in the range of $10°<2\theta<80°$ under a current of 40 mA using Cu-Kα radiation (λ = 1.5406 Å).

Morphological charaterization was carried out by scanning electron microscopy (SEM) using Hitachi SU-5500 SEM instrument. Starch samples were coated with thin films of gold and the micrographs of starches were taken at a magnification of 500, 1500 and 2500 using at 3 kV.

Production of Glucose Syrups

Wheat, maize and potato starch slurries were prepared at 2, 5, 20, 30 and 40% (w/w). After adjusting pH of slurries to pH 6-6.2, α–amylase (0.00025% (mL/g) was added to each sample and they were incubated at 95±5°C for 1 hour [22]. After liquefaction reaction, samples were cooled down to room temperature and their pH was adjusted to pH 4-4.2. For saccharification, 0.00025% (mL/g, v_{enzyme} /w_{starch}) amyloglucosidase was added to each sample and they were incubated at

60±5°C for 24 hours with constant shaking at 100 rpm. The glucose syrups produced from wheat, maize and potato were clarified by centrifuging at 7000 rpm and their glucose contents were analyzed via high performance liquid chromatography (HPLC).

The effects of α-amylase amount and liquefaction time on the glucose content and DE value of final product was evaluated separetly by producing glucose syrup with 0.0001, 0.0002, 0.0003% (mL/g, v_{enzyme} /w_{starch}) α–amylase at 95±5°C for 1, 1.5 and 2 hours. Also, saccharification reaction was conducted with 0.0001, 0.0002, 0.0003% amyloglucosidase at 60±5°C for 24, 48, 72 and 96 hours to obtain glucose syrup having higher amount of glucose content and thus DE value.

HPLC Analysis

The glucose syrups produced from wheat, maize and potato were analyzed according to their glucose contents via Thermo HPLC system (Thermo). Carbohydrate column (4.6 x250 mm size column filled with 5 µm particles) (Zorbax, Agilent) was used with refractive index (RI) detector for quantification of carbohydrates. Samples (20 µL) were injected through column at the flow rate of 1.0 mL/min at 40°C with mobile phase of acetonitrile: water (20:80, v:v). All HPLC analyses were replicated three times for each biological replicates and results were given as the mean of analysis±standard deviation.

Determination of Glucose Content and DE Value

DE values of glucose syrups produced from all three starches were determined with Lane-Eynon Method [23]. The following equation (Eq. 1) was used for the calculation of DE according to DE values of pure glucose (DE=100%) and native starch (DE=~0%).

$$\mathrm{DE} = \frac{\%\ \text{Reducing Sugar}}{\%\ \text{Dry substance}} \mathrm{x}\ 100 \quad (1)$$

Statistical Analysis

All experiments were performed in triplicate. The results in the graphs were presented as the mean± standard deviation of three replicates. Significant difference was analyzed by one-way one-way analysis of variance (ANOVA) (statistically when p≤0.05).

RESULTS and DISCUSSION

Physicochemical Differences in Starches from Wheat, Maize and Potato Origins

Biological origin and production process cause variations in the phycochemical properties of starch. In the maize starch production process, seeds are steeped in water containing low concentration of sulfur dioxide for 24 to 40 hours to increase the solubility of proteins by breaking the disulfide bonds. Also, sugar molecules are converted to lactic acid by lactic acid bacteria so that decreasing pH leads to the separation of proteins from starch molecules. After wet milling, proteins and starches are seoerated from other sugars and bacteria. By separating dietary fibers, starches are obtained by centrifugation or sedimentation [24]. Starch production process from wheat begins with grinding. Wheat flour is steeped in water and dough ball is prepared at 30-50°C. Starches and proteins are removed by centrifugation or sieving [25]. Potato starch is produced by mashing potato to make potato juice, centrifugation to separate starch granules and other polysaccharides from that juice, extraction of fibers by sieving and sepatation of starches by multi-stage reverse flow system [4, 26]. Due to the differences in the starch production process and most importantly the botanical origin, the size and content of starch granules are different among different plants.

Physical, chemical and morphological properties of wheat, corn and potato starches were determined in this study. Table 1 shows the moisture, starch, pH, protein, fiber, lipid and ash content of starched from three different botanical origins. Starch with highest lipid and protein content was maize starch whereas starch with highest ash and moisture content was potato starch because of its higher phosphorus content and B type polymorphic structure. Tuber starch was found to have lower protein and higher ash content, while cereal starches had higher protein content and lower ash content, as expected. The starch content was higher in maize as compared with wheat due to the variations in starch production and purification processes [27]. Also, lactic acid fermentation in the production process of maize starch resulted in lower pH than other starches.

Table 1. Chemical properties of starches from wheat, maize and potato sources*

Source	Moisture (%)	Starch (%)	pH	Protein (%)	Fiber (%)	Lipid (%)	Ash (%)
Wheat	11.92±0.20^{a}	86.53±0.12^{a}	6.51±0.11^{a}	0.86±0.010^{a}	1.95±0.012^{a}	0.23±0.002^{a}	0.18±0.006^{a}
Maize	11.29±0.15^{a}	88.26±0.21^{b}	4.48±0.14^{b}	1.34±0.003^{b}	1.01±0.010^{b}	0.51±0.005^{b}	0.07±0.003^{b}
Potato	13.00±0.16^{b}	86.96±0.14^{a}	7.64±0.23^{c}	0.67±0.009^{c}	0.98±0.005^{b}	0.29±0.003^{a}	0.25±0.002^{c}

*: Means with different superscript in the same column were significantly different (p≤0.05)

Structural Differences in Starches from Wheat, Maize and Potato Origins

Diffraction patterns obtained by X-ray crystallography were used to characterize the semi-crystalline structure of starch from wheat, maize and potato. In the diffraction pattern shown in Figure 1A, larger peaks represented crystalline regions which were associated with the amylopectin content, while smaller peaks showed amorphous regions of starch represented by amylose content. In the pattern of wheat and maize starches strong and weak peaks were observed at 15°, 23° and at 11°, 20°, 26° and 30°, respectively. Potato starch showed strong peaks at 17° and weaker peaks at 15°, 19.7°, 21.8° and 24°. In accordance with previous study [28], wheat and corn starches as cereal starches exhibited crystalline A-type X-ray pattern and potato starches as tuber starches showed crystalline B-type X-ray pattern.

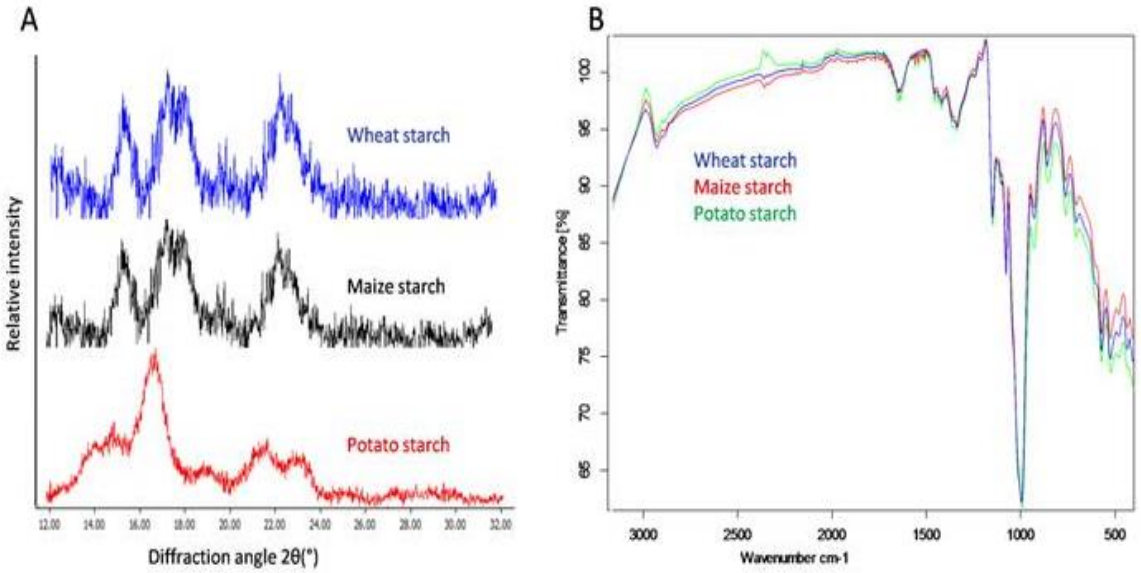

Figure 1. Structural characterization: A) X-Ray Diffraction patterns; B) FTIR spectra of wheat, maize and potato starches

The structure of three different starches were further determined with their FT-IR spectra. As shown in Figure 1B the broad band at 3393 cm^{-1} represented the stretching mode of OH groups. The bands at 1649 cm^{-1}, 1148 cm^{-1} and 2931 cm^{-1} were assigned to the hydrogen bonds of carboxyl groups, the C-O stretching and C-H stretching, respectively. It was also determined that the bands below 800 cm^{-1} showed the vibration of glucose pyranose rings and that seen at 932 cm^{-1} belonged to the skeletal structure of starch showing the α-1,4 bond between glucose molecules in amylose. The bands occurring at the spectra between 1700 and 1200 cm^{-1} belonged to the minor components such as protein and fat in starches. In accordance with previous studies, typical FTIR spectra of starches from three different plant sources were shown as bands between 2900-3000 cm^{-1} for C-H stretching, between 1100-1150 cm^{-1} for C-O, C-C and C-O-C stretching, and between 1100-900 cm^{-1} for C-O-H bending [29, 30].

Morphological Differences in Starches from Wheat, Maize and Potato Origins

Morphological properties of starches from different plant origins vary with size and shape. These variations originate from the biological origin, chloroplast biochemistry and physiology of plant [31]. Even sharing same biological origin, many studies showed that there were differences between granule size and shapes of starches among species. Potato cultivars, for example, have 1 to 20 µm and 20 to 110 µm of granule sizes for small and large starch granules, respectively. In literature, the size of small and large maize starch granules was shown within the range of 1 to 7 µM and 15 to 20 µM, while A and B type of wheat granules were 10-35 µm with disk shape and 1-10 µm with spherical shape, respectively [32]. In this study, as shown in Figure 2, wheat starches showed lenticular shape with lenghts between 12 and 20 µm and while maize starch granulles had irregular shapes with sharp edges. Potato starch granules had llipsoidal shape having lenghts between 22 and 30 µm with smooth surface. When the granular size was compared, it was observed that maize starches had the smallest granular size than others. Having average 25.4 µm lenght, potato starch granules had the largest size. The morphological characteristics of wheat, maize and potato starches shown in this study were similar with those reported in other study [33]. As mentioned, the different morphology of starch granules was attributed to chloroplast biochemistry, physiology and biological origin of plant. Also, it has been observed that environmental factors such as temperature and storage conditions have affected the size and shape of starches [34]. The effect of granule size on the physicochemical properties and starch content of starches from wheat, maize and potato were discussed further in the glucose syrup production process in this study.

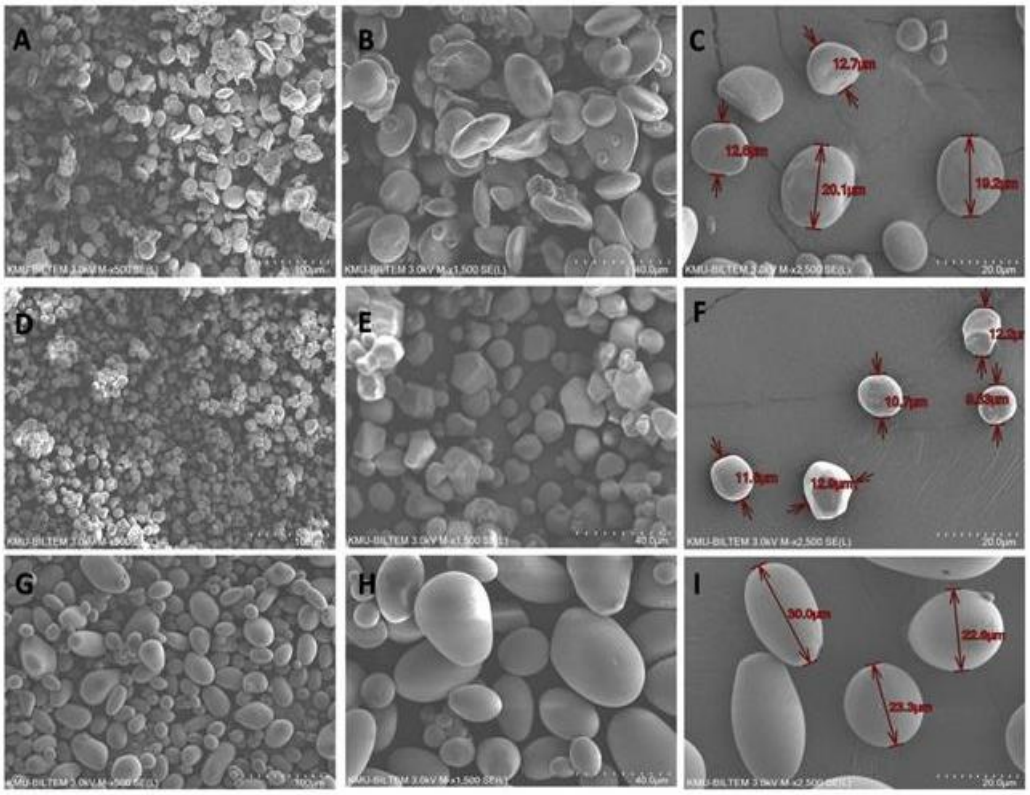

Figure 2. Scanning electron micrographs of starches from; A, B and C) wheat; D, E and F) maize; G, H and I) potato.

Glucose Syrup Production using Starches from Different Plant Origins

Enzymatic production of glucose syrup from wheat, maize and potato starches in this study was shown in Figure 3A. The first enzyme α–amylase (endo-1,4-α-D-glucan glucohydrolase, E.C.3.2.1.1) hydrolyses large polysaccharides into glucose and maltose by breaking α-(1→4)-glucan bonds at high temperature and acidic environment (pH 6 optimally). Amyloglucosidase (1,4-α-D-glucan glucohydrolase, EC 3.2.1.3) further hydrolyses α-(1→4) and α-(1→6) bonds from non reducing ends of shorther dextrin and maltodextrin molecules at lower temperature and more acidic environment (pH 4-4.2). It has been known that the biological origin of plant, the ratio of amylose to amylopectin, the crystalinity and the size of starches have impact on the efficiency of enzymatic hydrolysis of starches and percent glucose content of final product [35]. Within the scope of this study, the effect of biological origin of plant on the glucose syrup production was shown with the use of wheat, maize and potato starches as a source. Also, initial starch amount, incubation time and amount of α-amylase for liquefaction, incubation time and amount of amyloglycosidase for saccharification were optimized for laboratory scale production of glucose syrup with high DE.

Effect of Initial Amount of Starch on Two-Step Enzymatic Production of Glucose Syrup

The effect of initial starch amount on final product was evaluated by measuring the glucose content of glucose syrup produced from maize starch initially at 2, 5, 10, 20, 30 and 40%. As shown in Figure 3B, the increase in the starch amount in initial slurry leaded to the increase in the percent amount of glucose and maltose in final product, as expected. The starch slurry with 2% starch content yielded approximately 0.22 and 88% glucose and maltose, respectively, while that of 40% starch content yielded 20 times higher sugar content in the syrup. In addition to its effect on the glucose content, initial starch amount also improved the stability of enzyme in the reaction solution. De Cordt et al. [36] reported a study showing that the increase in starch content from 9 to 37% in slurry improved the stability of α–amylase from *Bacillus licheniformis* by decreasing its inactivation rate constant (*k*). With the increase in initial starch concentration moisture content in slurry is reduced so that the activity of enzyme is prolonged in the slurry.

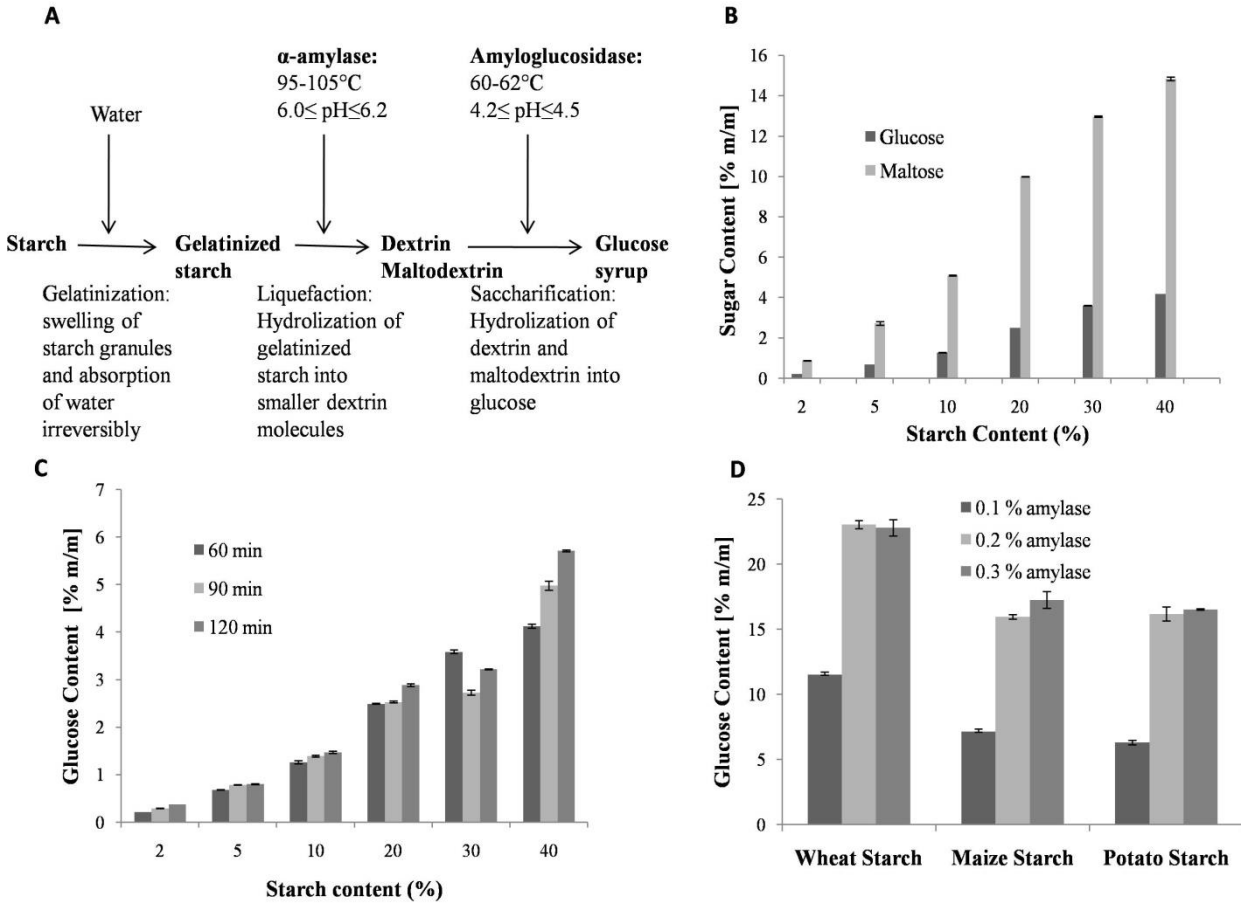

Figure 3. A) The process steps of a two-step enzymatic production of glucose syrup from starch; The effects of B) initial starch content; C) liquefaction time; and D) amylase amount on glucose content of glucose syrups produced from wheat, maize and potato starches (Each experiment was performed three times in triplicate, and standard deviations were indicated as error bars)

Effect of Incubation Time and Amylase Amount on Two-Step Enzymatic Production of Glucose Syrup

In order to evaluate the effect of incubation time of α-amylase for the hydrolization of gelatinized starch, maize starch slurries of 2, 5, 10, 20, 30 and 40% were incubated with 0.0002% thermostable α-amylase for 1, 1.5 and 2 hours. As shown in Figure 3C, glucose content of final product increased as the hyrolization time increased from 60 to 120 mins up for all starch content. The glucose content of glucose syrup prepared from maize starch slurry with initially 2% starch content was 0.22% after one hour of liquefaction while at the end of second hour it increased to 0.38%. The increase in initial starch amount together with the liquefaction time showed strong tendency to improve the glucose content. By increasing initial starch content 20 times, the glucose content of final product was increased approximately by 20 times after two liquefaction hours. The enzyme used in this liquefaction step was α-amylase from *B. licheniformis*. In a study [22], it was shown that the activity for α- amylase from *B. licheniformis* at 20−40°C was only 20−40% whereas it reached its maximum activity at a temperature of about 90°C. Further increase in temperature to 100°C did not show any effect on its catalytic activity athough the source bacteria were mesophilic bacteria. Moreover, the relative enzymatic activity at 90°C remained higher for several hours which made it preferable for industrial starch processing. Other previous studies reported different stability results for α- amylase from different bacteria. For example, Mitsuiki et al. [37] showed that two enzymes with different molecular weight isolated from *B. subtilis* gave quite different liquefaction yields. The one with higher molecular weight hydrolized <20% and 50% of maize starch at the end of the first and fifth day of incubation respectively, while low molecular weight enzyme was able to hydrolyze only 10% of starch at the end of the fifth day. In another study, α-amylase from *Heliodiaptomus viduus* had 90% hydrolization yield after 180 mins [38]. The results obtained in the present study concluded that increasing the incubation time of α-amylase and starch increased the amount of glucose obtained in the final product as long as enzyme activity was preserved.

Beside incubation time, the amount of α-amylase was also evaluated for liquefaction yields. The initial 30% of wheat, maize and potato starches were hydrolyzed separately with 0.0001, 0.0002 and 0.0003% enzyme for two hours. The glucose contents of glucose syrups from all three starch sources were shown in Figure 3D. The highest glucose amount was obtained at 30% wheat starch and 0.0002% α-amylase. The hydrolization step for 30% maize starch slurry yielded 7.2% glucose with

0.1% α-amylase and 16% glucose with 0.0002% enzyme. Increasing the enzyme amount from 0.0001 to 0.0002% caused increase in glucose contents from approximately 11.6% and 6.3% to 23.1% and 16.2%, for wheat and potato starch slurries, respectively, at the same initial starch content. However, the use of higher amount of α-amylase did not show a significant effect on glucose content for wheat and potato starches.

Effect of Amyloglucocidase Amount and İncubation Time on Two-Step Enzymatic Production of Glucose Syrup

The second and final enzymatic step in the glucose syrup production was saccharification by amyloglucosidase (Figure 3A). The amount of enzyme and saccharification time was evaluated based on the glucose content of final product. Wheat maize and potato starch slurry with initial starch content of 30% were hydrolized by 0.0002% α-amylase for 2 hours and upon liquefaction smaller dextrin molecules were further hydrolyzed by 0.0001, 0.0002, 0.0003% amyloglucocidase at lower temperature for 24, 48, 72 and 96 hours. Figure 4 showed the glucose contents of each sample of each plant source as measures of saccharification degree. In glucose syrup production process from wheat starch, saccharification time did not show a significant effect on the saccharification degree. There was a slight increase in the glucose content with the increase in amyloglucocidase amount from 0.0001% to 0.0002% however; this increase was also not significant to state the obvious effect of time on saccharification reaction. In fact, for maize and potato starches, the glucose contents decreased significantly ($P<0.05$) for saccharfication reaction by 0.0003% and 0.0002% amyloglucocidase amount after 96 hours, respectively. Zainep et al. [39] reported 17.15 mg/mL, 15.79 mg/mL and 11.32 mg/mL of reducing sugar yields from yellow maize, millet and sorghum starches, respectively, after 10 min of reaction by pure amyloglucosidase from *Rhizopus* mold (0.001%). In a study [40], the use of a mixture of granular starch hydrolyzing α-amylase from *A. kawachi* and glucoamylase from *A.niger* at a single saccharification step at 65°C yielded approximately 40% glucose whereas two-step saccharification at 65°C-70°C had approximately 50% glucose content after 120 min. In the present study, the glucose concentrations of final product higher than 95% were obtained from all three starch sources regardless of time and enyzme amount.

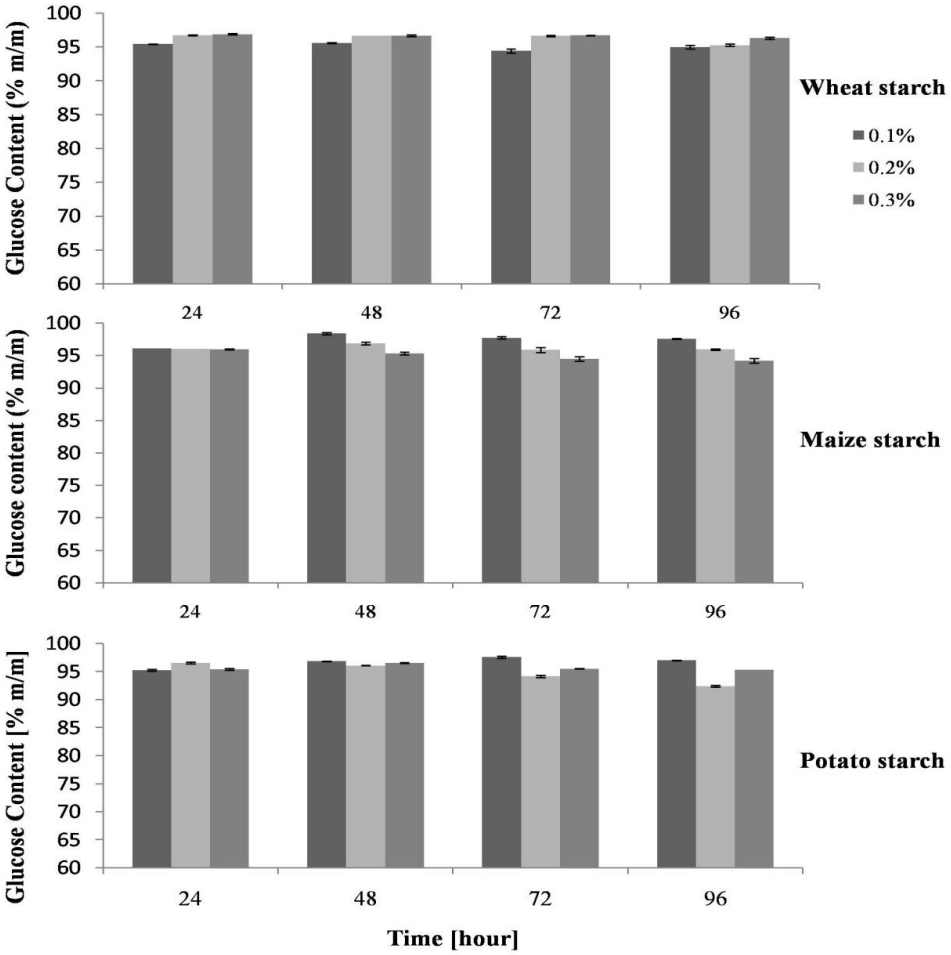

Figure 4. The effect of amyloglucosidase amount and saccarification time on glucose content of glucose syrups produced from wheat, maize and potato starches (Each experiment was performed three times in triplicate, and standard deviations were indicated as error bars)

Physicochemical Analysis of Final Product

The physicochemical properties of glucose syrups obtained from three starch sources were specified in Table 2. It was observed that glucose syrup with the highest glucose content and thus DE% value was obtained from maize starch. DE% value represents the percentage hydrolyses of the glycosidic linkages present and as compared with DE of 100 for pure glucose it should be >20% to meet the requirements of glucose syrup for its applications [18]. For example, there are glucose syrups with DE values of 35, 42 and 63% regarded as low, regular and high DE, respectively. While glucose syrups with high DE generally are used for food products having lower viscosity and tender consistency, the ones with lower DE are used in products with tough texture and moisture resistance. During the syrup production process, acidic or enzymatic hydrolization and the time for hydrolysis of starch significantly affect the DE value obtained from final product. The syrups produced by acid hydrolysis have DE values between 30 and 50 whereas glucose syrups produced enzymatically show higher DE values. As shown in Table 2, all three glucose syrups were found to have a dry substance higher than 70% and a DE higher than 20%.

Table 2. Physicochemical properties of glucose syrups produced from wheat, maize and potato starches in this study*

Glucose syrup sources	Total solids (g)	Moisture (%)	pH	Glucose (%)	Maltose (%)	DE (%)	Color (L*a*b)	Dry matter (%)
Wheat starch	91±0.14^{a}	15.80±0.35^{a}	3.98±0.011^{a}	98.08±0.13^{a}	1.92±0.021^{a}	97.04±0.31^{a}	14.11±0.25^{a}	84.30±0.30^{a}
Maize starch	110±0.50^{b}	21.69±0.26^{b}	4.02±0.024^{a}	98.35±0.18^{a}	1.65±0.062^{b}	97.27±0.12^{a}	8.99±0.45^{b}	78.30±0.54^{b}
Potato starch	94±0.21^{c}	17.64±0.18^{c}	4.54±0.022^{b}	97.58±0.21^{b}	2.42±0.032^{c}	95.34±0.09^{b}	14.33±0.31^{a}	82.37±0.28^{a}

*: Means with different superscript in the same column were significantly different (p≤0.05)

CONCLUSIONS

In this study, laboratory scale glucose syrup production from wheat, mazieand potato was investigated. Optimized process parameters improved the two-enzymatic step process and final products with high DE values were obtained from starches of three plant sources. This study showed that wheat and potato starches were also potential raw materials for glucose syrup production as well as maize starch. Scaling up the parameters from lab-scale process to industrial process would provide useful information to the sugar industries about alternative sources for glusoe syrup production.

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