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ORIGINAL ARTICLE

Parametric optimization of sweet potato-based glucose syrup production and preservation: a response surface methodology approach

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Abstract
Sweet potato is one of the largest sources of starch. Due to this fact, it can be utilized to obtain value-added products. This research aims at optimizing the operation parameters for sweet potato-based glucose syrup production and preservation. A maximum yield of starch isolated using distilled water was found to be 31.59%. The produced starch was then subjected to acidic hydrolysis to obtain glucose syrup with a dilute sulfuric acid concentration of (0.5, 1, and 1.5%) at temperatures (130, 140, and 150 °C) and time (25, 30, and 35 min). The total reducing sugar content of the hydrolysates was determined using the dinitro salicylic acid method and an optimum reducing sugar amounting to 242.3 g/L was found at 1.34% sulfuric acid concentration, 140.89 °C temperature, and 32.96 min. The moisture, dry matter, ash, density, viscosity, and pH of the product were found to be 26%, 74%, 0.26%, 1.37 g/mL, 5.63, and 4.9, respectively. Since glucose syrup has a short shelf-life during storage, potassium sorbate having concentrations of 0, 0.025, 0.05, 0.075, and 0.1% were studied for 60 days to sustain the shelf-life of glucose syrup. Potassium sorbate concentration 0.05% which is within the permitted level was identified as a suitable preservative to retain the quality and extend the shelf-life of glucose syrup at room temperature.

Keywords Sweet potato starch · Acid hydrolysis · Glucose syrup concentration · Potassium sorbate preservative · Box-Behnken design

1 Introduction

Sweet potato (SP) (*Ipomoea batatas*), which is believed to originate in tropical America, is a dicotyledonous plant that belongs to the bindweed *Convolvulaceae*. The term "sweet" emanates from its sweet-tasting roots. It is usually characterized as a plant with "large, starchy, and tuberous roots" [1]. The storage roots of SP have high amounts of carbohydrates, which often takes from 80 to 90% share of the dry matter content. Carbohydrates in SP consist mainly of starch and sugars, where they constitute over 60% of the dry matter in the storage roots [2]. This translates to at least 16–20% of the fresh weight. Fresh SP storage roots are mainly composed of sugars such as sucrose, glucose, and fructose [2], with sucrose taking the highest share.

Starch, the main component of SP tubers, accounts for around 50–80% of their dry weight [3]. It is one of the common raw materials used for the preparation of low molecular weight products including glucose and maltose, which are widely used in sugar, brewing, and in textile industries [4]. Glucose syrup (GS) is usually produced from corn, mostly used for food consumption in Ethiopia. For this reason, searching for another cheaper and abundantly available raw material such as SP is critical. Approximately 53,499 hectares of land was used to grow sweet potatoes, with a total yearly production of 1.85 million tons just during the primary growing season, according to reports from the Central Statistical Authority [5]. Thus, shifting the main raw material for GS production from a highly competitive crop like corn into a less competitive one such as SP without compromising the quality and quantity of the product is crucial for a country like Ethiopia, which is still under food insecurity problem.

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The starch component can be hydrolyzed to increase the concentration of glucose and fructose for the same unit volume of SP, hence obtaining alternative products. One such product is GS, which can be obtained through the conversion of starch by different extraction methods such as enzymatic hydrolysis and acidic hydrolysis. Investigating the process profits of the recovered reducing sugars from the starch present in cassava, the efficiency of two of the approaches were almost equal regarding the yield based on the reducing sugar recovered from the cassava, but economically, the acid hydrolysis was more beneficial. Looking at the time required for each process, acid hydrolysis was more advantageous than the enzymatic process. For a batch, the acid hydrolysis was completed in only 10 min plus the time to heat and cool the material. The enzymatic hydrolysis, in contrast, took 25 h and 20 min, plus the time to heat and cool the material for the whole process in a batch. Considering the chemicals necessary for a batch, acid hydrolysis was much less expensive than the enzymatic one [6, 7], which was the basis for the selection of the acidic hydrolysis for this study over the other.

GS has a short shelf-life during packing, necessitating the use of preservatives to extend it. Preservatives are substances added to foods to ensure safety with their guarding capability against damage caused by microbial, physico-chemical, or enzymatic reactions [8]. Several chemical preservatives have been tested, and potassium sorbate (PS) has been more accredited for different reasons such as its ability to increase shelf-life and reduces the risk of foodborne illnesses, without badly affecting the taste, color, or flavor and have the lowest allergenic potential of all food preservatives. It also has high solubility and can be used at a wide range of pH levels [9].

To the best of our knowledge, no published literature reports on the optimization of GS production from SP using BBD of the response surface methodology approach. So, this work will focus on the utilization of sweet potato as raw materials for the production of glucose syrup by acid hydrolysis using sulfuric acid followed by heating at different temperatures and time. The interactions between the parameters, sulfuric acid concentration, temperature, and time will be optimized using Box-Behnken design experiment to determine the optimum conditions for maximized GS production. The use of PS to preserve the produced GS is not also well investigated. Therefore, in the present study, the effect of PS was evaluated on the stability of GS to enhance its storage shelf-life.

2 Experimental section

2.1 Materials

The fresh sweet potatoes were purchased from Atklt Tera, Addis Ababa, Ethiopia. The reagents used during this study including hexane, anhydrous D–glucose, 3, 5-dinitrosalicyclic acid (DNS), and chemicals such as active carbon, potassium sodium tartrate (Rochelle salt), and PS ($C_6H_7KO_2$) were bought from Mollarie trading P.L.C., Cherkos sub-city Addis Ababa, Ethiopia. Other chemicals and instrumentation were obtained from Addis Ababa Institute of Technology, School of Chemical and Bio Engineering, where this research was conducted.

2.2 Proximate analysis of raw material

The methods described in [10] were applied to the proximal analysis. The moisture and ash contents of sample were determined using the gravimetric principle, the oven drying, and dry ashing methods, respectively. A Soxhlet extraction method was used to determine the crude fat content of sample. A micro-Kjeldahl method was used to determine the crude protein contents. Total carbohydrate contents of the samples were determined by subtracting the sum of the values of crude protein, crude fat, and ash contents (% wet basis) of the sample from 100 [11].

2.3 Extraction of sweet potato starch

As described by [12] with slight modification, SP starch was extracted by using distilled water. About 3.39 kg of fresh SP tubers was cleaned, peeled, and cut into small pieces and milled to a fine powder. After weighing accurately, enough water was added and was homogenized by shaking. The slurry was subsequently screened sequentially through sieve adding excess water and it was put aside for 3 h so that the starch component settles at room temperature. After 3 h, starch-free supernatant was decanted carefully. The starch was re-suspended in distilled water and filtered and then left to settle in a tray for 2 h. This last step was repeated for three times using deionized water instead of tap water for the last washings. A compact mass of starch was collected and dried in a hot air oven at 40 °C for 48 h. The final weight of isolated starch was recorded, and the starch yield was determined as

$$\text{Starch yield}(\%) = \frac{\text{Dry weight of starch recovered from extraction}}{\text{Milled mass of sweet potatoes}} \quad (1)$$

2.4 Starch hydrolysis and hydrolysate purification

In this study, the methods of [13] with minor modification were adopted to produce GS. Briefly, the dried starch was suspended in distilled water at 45 °C in the ratio 1:3 (starch to water) to gelatinize. Then, the solution was mixed with 98% H_2SO_4 in 0.5–1.5% (v/v) in the suspension at pH 1.6. Finally, the solution was heated by high-pressure autoclave at 130–150 °C for about 25–35 min.

After that, the solution was neutralized with 50 mL of 0.1 M NaOH until the pH level reached 4.9. A 250-mL beaker was used to hold the sample. The sample was then clarified and decolored after being stirred for 30 s with 0.5 g of granular activated carbon. Then after, the sample was filtered through Whatman filter paper by vacuum filtration. Finally, since the GS density was low, rotary vacuum evaporator was used to raise the solid concentration at a temperature of 70 °C for 30 min [14].

2.5 Reducing sugar determination by dinitro salicylic acid method

After applying slight modifications, the method of [15] was adopted at this stage. A solution of 3,5-dinitrosalicylic acid reagent was prepared as follows: 10 g of 3,5-dinitro salicylic acid was added to 10 g of NaOH in 200 mL in distilled water. On the other hand, Rochelle salt was prepared by adding 200 g potassium sodium tartrates in 400 mL distilled water. Finally, dinitrosalicylic reagent was prepared by mixing both solutions to a final volume of 1 L with distilled water. A standard stock solution of glucose was prepared by dissolving 100 mg of glucose in 100 mL of distilled water (Table A-1).

After replacing solutions in the labeled tubes, it was shaken well and then placed in a boiling water bath for 5 min. The tubes were cooled and 7 mL of distilled water to each tube was added (Table A-1). After that, some amount of the mixture from each test tube was taken to clear cuvettes and the absorbance was read at 540 nm using UV visible spectroscopy. Then, a standard curve was produced by plotting the absorbance versus glucose concentration data. Finally, using the already prepared standard curve, the 17 unknown glucose concentrations samples were determined using the equation:

$$\text{Glucoseconc.}\left(\frac{\text{g}}{\text{L}}\right) = \left[\frac{\text{Absorbance} - Y - \text{intercept}}{\text{Slope}}\right] \quad (2)$$

2.6 Experimental design

A 3-factor 3-level Box-Behnken design (BBD) was used for the design of the experiment. The three factors and their levels considered for this study were temperature (130, 140, and 150 °C), H_2SO_4 concentration (0.5, 1, and 1.5%), and time (25, 30, and 35 min) (Table 1). This study design of 17 experimental runs were generated and analyzed by BBD of the response surface methodology approach (Design-Expert version 11 software). Numerical optimization was then carried out to find the optimum parameters, which were applied to in the experimental investigation.

The shelf-life was also determined using preservative PS (Table 2). Varying amounts of PSs were added to each of the GS samples and their effects on the physio-chemical properties (pH, moisture content, and viscosity) were evaluated. To do so, four different runs of experiments were performed. Samples void of PS were taken as control. The samples were left at room temperature for 60 days to see the effect of the preservative. The physiochemical properties were measured, and Microsoft Excel was applied to present data in graphical forms.

2.7 Analytical method

The moisture and ash contents of the produced GS were determined according to the method by [10]. Besides, the pH was determined by taking standard buffer solutions and samples were cooled to 25 °C while the electrode and receptacle were rinsed using a portion of the solution to be tested. The beaker was filled to a depth that would be covered by the bulb of the glass electrode. The temperature of the solution was recorded, the system was allowed to come to equilibrium, and the pH was recorded. The apparent viscosity of GS from SP starch was carried out using a Sinewave Vibro Viscometer SV-10 model measurement. Density was determined at 25 °C by weighing the sample in a 25-mL pycnometer.

Table 1 Experimental design of numerical factors

Factor	Name	Units	Type	Low actual	High actual	Low coded	High coded	Mean
A	Temp	°C	Numeric	130	150	− 1.000	1.000	140
B	H_2SO_4 conc	%	Numeric	0.5	1.5	− 1.000	1.000	1.0
C	Time	min	Numeric	25	35	− 1.000	1.000	30

Table 2 Shelf-life determination

Factor	Name	Units	Type	Levels				
A	Potassium sorbate	%	Numeric	0.0	0.025	0.05	0.075	0.1
B	Time	day	Numeric	1st	15th	30th	45th	60th

2.8 Statistical analysis

For statistical analysis of the results of the experimental design, Design-Expert software was utilized, which incorporated exceptionally helpful data and proclaimed the necessity of statistical design for the execution of experiments. The statistical validation was entrenched by assessment of statistical parameters such as model *F*-value, lack of fit *F*-value, correlation coefficient (R^2), adjusted *R*-squared (R^2_{Adj}), predicted *R*-squared (R^2_{Pred}), predicted residual error sum of squares (PRESS), and adequate precision (AP) generated by ANOVA provision available in the Design-Expert software to check sufficiency and adequacy of models. Model *F*-value with $p < 0.05$ and lack of fit *F*-value with $p > 0.05$ for response variables implied that model was significant and the lack of fit was non-significant relative to the pure error, respectively. When the difference between R^2_{Adj} and R^2_{Pred} is less than 0.2, R^2_{Pred} would be in reasonable agreement with R^2_{Adj}. PRESS statistics were used for cross-validation to provide the measure of fit. Regression model with a smaller value of PRESS statistics was preferred. Adequate precision measured signal to noise ratio (*S*/*N* ratio). AP value greater than 4 indicated adequate model discrimination. Optimization report was developed by Design-Expert software for determining optimum parameters having highest desirability function.

3 Results and discussion

3.1 Sweet potato characterization

The results showed that SP contains a moisture content of 53.66% ± 0.45 on a wet weight basis. This value was found to be lower than that of values observed by [16] who indicated that fresh SP had a moisture content of 59.3%. This variation might be due to varietal effects, stage of maturity, and gaps between harvesting time and analysis. The fat content (0.36%), however, was higher than the literature values. For instance, [17] found out a 0.17 g/100 g fat content in fresh SP. The reason for this deviation may be due to the difference in the method of hydrolysis and varieties of the crop used. The protein, ash, and the crude fiber content were also determined and found to be 2.13, 2.18, and 0.31%, respectively, which are in close agreement with the result of the literature, [18] for instance, except for crude fiber. The chemical composition of SP also varies according to genotype [19], which can be another reason for the difference. A carbohydrate content amounting to 41.36% is also reported in this study, compiling with the report by [20].

3.2 Extraction of starch

In the present study, starch was isolated by using distilled water. Hence, starch sediment was sieved, dried in a hot air oven at 40 °C for 48 h, and weighed from which the percent yield was calculated. Finally, the maximum extracted starch was calculated at 31.59% on a wet weight basis. The findings were relatively lower compared to that of sweet potato tuber studied by [21], who obtained 75.1% maximum yield starch on a dry weight basis. This was due to the difference in the moisture content of milled mass. But the increased yield of starch in the present study as compared to another researcher [22] might be due to repeated extraction with distilled water who found 28.5% maximum starch yield.

3.3 Optimum hydrolysate total reducing sugar content

The standard solutions and corresponding absorbance were recorded at a wavelength of 540 nm using a UV–visible spectrophotometer (Table A-2). The concentrations of the samples were calculated from the equation of the standard curve given as

$$X = \left[(Y - 0.0084)/0.0198\right] \tag{3}$$

where *X* and *Y* represent the concentration and absorbance, respectively.

The variation in glucose concentration yield for 17 of the experiments was recorded with changes in time, temperature, and acid concentration (Table A-3). The maximum reducing sugar was found to be 241 g/L at 1% sulfuric acid concentration, 140 °C temperature, and 30-min time. It was observed that the glucose concentration increased with a sulfuric acid concentration of 0.5 to 1%, temperature of 130 to 140 °C, and time 25 to 35 min and dropped as temperature, sulfuric acid concentration, and time increased further. This is because extreme cases lead to the decomposition of the sugars produced by hydrolysis of the starch. Besides, severe heating conditions (high temperature, high sulfuric acid concentration, and long heating times) result into an increase in aldehyde yields, which in turn leads to a decrease in glucose yields [23].

Previous research on SP starch showed a glucose yield of 81.09% [24] while the present study obtained 69.4%. The difference could be attributed to different reasons such as the difference in hydrolysis method followed, the range of factors considered, the difference in the efficiency and sophistication of the equipment employed, and the varieties of the raw material used. Finally, after carrying out numerical optimization by the help of the Design-Expert software, optimum glucose concentration amounting to 243.23 g/L was found at 140.898 °C temperature, 1.34 sulfuric acid

concentration, and 32.97-min time optimum parameters. These results are relatively similar to the finding of Regy Johnson and G. Padmaja [25]. An experimental investigation was then employed at these optimum parameters which gave a closer result of 242.3 g/L glucose concentration (Table 3).

3.4 Statistical analysis of experimental results

Model *F*-value, lack of fit *F*-value, correlation coefficient, adjusted *R*-squared, predicted *R*-squared, predicted residual error, sum of squares, and adequate precision generated by analysis of variance (ANOVA) provision available in the Design-Expert software were assessed to check sufficiency and adequacy of models. ANOVA was used to analyze the data (Table 4). The goodness fit of the model was checked by the coefficient of determination (*R*-squared), which was found to be 0.9968. The present *R*-squared value reflected a very good fit between the observed and predicted responses and implied that the model is reliable for GS production in the present study. The model *F*-value of 315.38 implies that the model is significant. There is only a 0.01% chance that an *F*-value this large could occur due to disturbance.

The factors A, B, C, AB, AC, A^2, B^2, and C^2 are significant model terms since their *p*-values are lower than 0.05. But the interaction effect between B and C (BC) is not significant for its *p*-value is greater than 0.1. The *p*-values denote the significance of the coefficients and are also important in understanding the pattern of the mutual interactions between the variables. The above coefficients of variables show that variables named temperature, time, and sulfuric acid concentration positively affect GS production. The interaction between sulfuric acid concentration and time is not significant, which is an indication that there is no significant correlation between each of the two variables, and they did not help much in increasing the production of GS. The lack of fit *F*-value of 1.34 implies that the lack of fit is not significant relative to the pure error. There is a 39.20% chance that a lack of fit *F*-value this large could occur due to noise. Non-significant lack of fit indicated a good fit of the model.

Table 3 Model validation

Temp. (°C)	H_2SO_4 (%)	Time (min)	Glucose conc. (g/L)	
			Predicted	Experimental
140.898	1.34	32.97	243.23	242.3

3.4.1 The regression model equation

The ANOVA result showed that glucose concentration was affected by temperature, time, and sulfuric acid concentration in the experiment. Therefore, the estimated model can be used for the response of glucose yield. The quadratic equation describing the relationship between predicted response (glucose concentration) in terms of coded factors of temperature, time, and sulfuric acid concentration is given as

$$\begin{aligned}\text{Glucose concentration} = {} & +10.75 \times A + 6.88 \times B + 21.63 \\ & \times C - 5.00 \times AB - 5.00 \times AC - 10.92 \times A^2 - \\ & 15.17 \times B^2 - 17.18 \times C^2 + 238.60\end{aligned} \tag{4}$$

where A is the temperature (°C), B is the sulfuric acid concentration (%), and C is the time (min).

3.4.2 Effect of individual factors on product yield

Figure 1a shows the change in the product yield in the temperature range 130 to 150 °C. From the regression model equation (Eq. (4)), the coefficients of A and A^2 are positive and negative, respectively, which indicate that yield is increased with increasing temperature and decreases eventually at a very high temperature level. This is also reflected in Fig. 1a where the maximum glucose yield amounting to around 241 g/L was observed at 140 °C and

Table 4 Statistical analysis of variance

Source	Sum of squares	df	Mean square	*F*-value	*p*-Value	
Model	8262.86	8	1032.86	315.38	< 0.0001	Significant
A—temp	924.50	1	924.50	282.29	< 0.0001	
B—H_2SO_4	378.12	1	378.12	115.46	< 0.0001	
C—time	3741.13	1	3741.13	1142.33	< 0.0001	
AB	100.00	1	100.00	30.53	0.0006	
AC	100.00	1	100.00	30.53	0.0006	
A^2	502.55	1	502.55	153.45	< 0.0001	
B^2	969.60	1	969.60	296.06	< 0.0001	
C^2	1242.02	1	1242.02	379.24	< 0.0001	
Residual	26.20	8	3.28			
Lack of fit	15.00	4	3.75	1.34	0.3920	Not significant
Pure error	11.20	4	2.80			

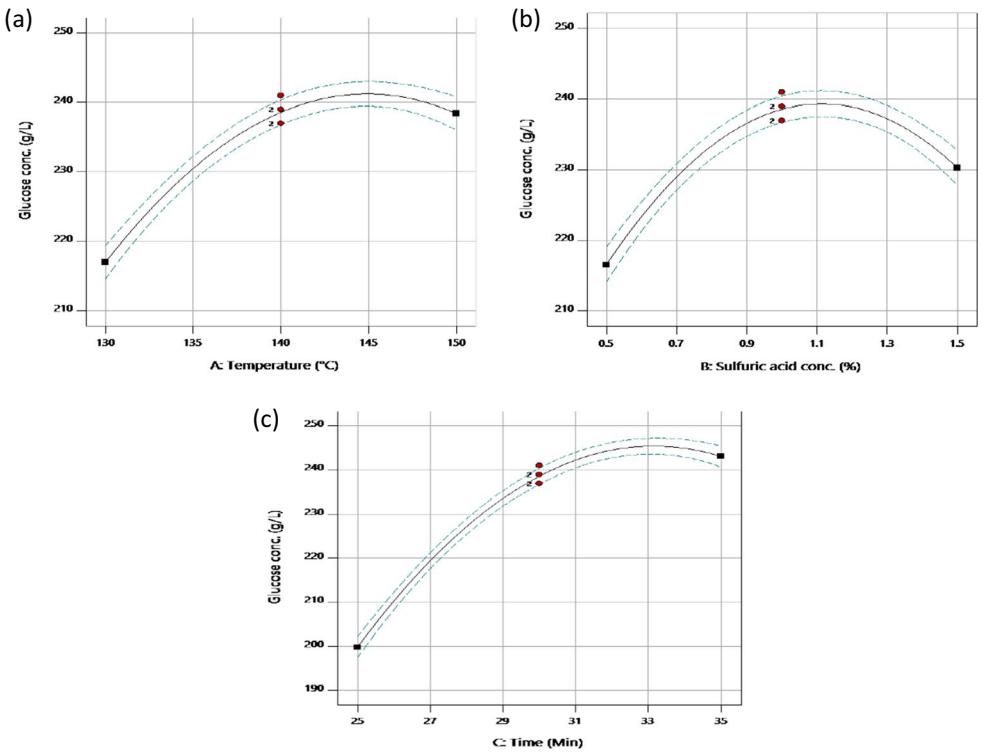

Fig. 1 Effect of individual factors on product yield. (**a**) Temperature. (**b**) Sulfuric acid concentration. (**c**) Time

then significantly decreased with increasing temperature. This compiled with the findings of [23], which observed that heating increases in glucose yield until it reaches its optimum temperature.

The regression model equation also shows that the coefficients of B and B^2 are positive and negative, respectively, showing that yield is increased with increasing H_2SO_4 concentration and decreases eventually at extensive H_2SO_4 concentration. This can be seen in Fig. 1b, illustrating that the production of glucose was significantly affected by the concentration of H_2SO_4. The result showed that the 1% concentration of H_2SO_4 in starch hydrolysis leads to the maximum concentration of glucose released since at this range the desirability function was at the maximum value.

The positive and negative coefficients of C and C^2 are also shown by the regression model which shows that yield is increased at the glance with increasing time of hydrolysis and decreases eventually with a further increase in time. This can also be confirmed by Fig. 1c, which shows that glucose yield increased with time up to 30 min, reaching a maximum value of 241 g/L, the yield decreasing thereafter, corresponding to the decrease of total organic carbon values. A report by [26] showed that as time increased the major products were monosaccharaides and decomposition products such as 5-hydroxymethylfurfural and furfural, while polymers having a high degree of polymerization were no longer present. Generally, this could be due to the increase in aldehyde yield proportionally with glucose yield up to the maximum glucose yield and increased significantly with decreasing glucose yield. This implies that the aldehyde was formed as a by-product, together with the production of glucose from the degradation of starch polymers. After the glucose yields reached the maximum value, heating conditions became too severe, leading to a further decomposition of the sugars such as glucose, maltose, and fructose to produce aldehydes [26].

3.4.3 Interaction effect of factors on GS product

The p-values denote the significance of the coefficients and are also important in understanding the pattern of the mutual interactions between the variables. Moreover, as it can be observed from H_2SO_4 concentration and time coefficient that their interactions were not significant, an indication that there was no significant correlation between each of the two variables, and they did not help much in increasing the production of GS. However, there was a significant interaction between temperature and sulfuric acid concentration ($p = 0.0006$), and between temperature and time ($p = 0.0006$).

The interaction effects and optimal levels of the variables were determined by plotting the three-dimensional response surface curves (Fig. 2) where one of the variables was fixed at an optimum value and the other two varied. Figure 2a represents the effect of varying sulfuric acid concentration and temperature on GS production when the time was held constant at 30 min. The increase of glucose yield occurred with an increase of sulfuric acid concentration at a temperature from 130 to 140 °C. Further increase in temperature would decrease the glucose yield. According to these interaction effects, the

maximum yield of glucose concentration activity was around 241 g/L at a sulfuric acid concentration of 1.0% and a temperature of 140 °C. Figure 2b shows, on the other hand, the interactive effect of time and temperature at constant sulfuric acid concentration. As time and temperature increased from 25 to 30 min, and 130–140 °C, respectively, glucose yield also increased reaching a maximum value of 241 g/L.

3.5 Glucose syrup characterization

The proximate composition of the product must be within the optimum range to find different industrial applications. This requires knowledge of the chemical and physical characteristics of the GS. Thus, knowledge of moisture, ash, viscosity, density, pH, and total solid contents of the food is fundamental to the assessment of its nutritive quality. These contents were calculated, and each value was an average of three runs.

3.5.1 Moisture and dry matter content

Moisture content affects the ability of syrup to flow, storage stability, processing behavior, quality, and appearance of syrups [27]. The moisture content was determined, and the dry matter was calculated as the difference from 100. Thus, the level of moisture content obtained in this research was 26% ± 0.53 and dry matter 74% ± 0.33. This is relatively different from earlier studies by [28], who found 71% of dry matter. This may be due to the difference in evaporation time. The lower moisture content of the GS is an indication of better shelf-life [29]. Because the high moisture content is an indication that the food product is prone to microbial attack during storage and as such may not be stored favorably over a long time [30].

3.5.2 Ash content

Ash content in GS is defined as the amount of mineral and other inorganic contents in the dry matter form. Determining the ash content is one means of checking GS quality, and the lowest its value, the better the quality [31]. Data on the present study shows that the ash content of GS was 0.26% ± 0.67. The results obtained were lower than that of [32], who reported ash content of 4.17%.

3.5.3 Viscosity

The viscosity of GS in relation to its solids content and temperature is another important parameter that should be determined. In the present study, a viscosity of 5.63 Pa·s was obtained. This agrees with the results by [33], who found an almost equal amount of viscosity at the same temperature. The main factors affecting the viscosity of the solutions are the nature of the continuous and the dispersed phases, 289 particle–particle interactions, and particle solvent, concentration, shape, particle size, and temperature [34]. The viscosity of GS is directly related to its moisture content and its molecular weight. An association occurs through hydrogen bonding between them that leads to an effect of highly branched polymer that increases the resistance of the syrup to flow freely, and therefore, increases the viscosity of the system [34]. Temperature is also very important in relation to viscosity and viscosity decreases as temperature increases. A high viscosity was believed to be essential at one time, but for fast freezing (rapid whipping) in modern equipment, a lower viscosity seems desirable. In general, as the viscosity increases, the resistance to melting and the smoothness of texture increases, but the rate of whipping decreases [35].

3.5.4 Density

The determined density value was 1.37 g/mL. Density is routinely used to determine the carbohydrate concentration in syrups, juice, and beverages in the food industry [36]. It is generally known that syrup density decreases with increasing water content, and to a lesser extent temperature.

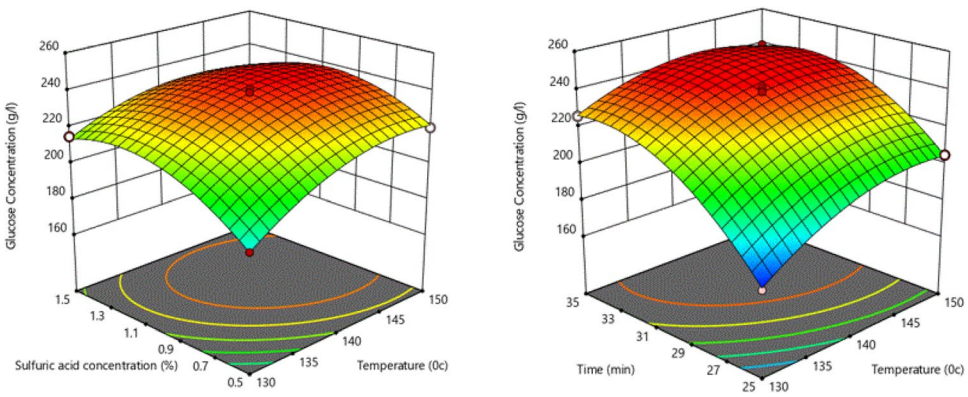

Fig. 2 The 3D plot showing the interaction effect of parameters on product yield. (**a**) Sulfuric acid concentration and temperature at constant time and (**b**) time and temperature at constant sulfuric acid concentration

3.5.5 pH

A widely used preservation method consists of increasing the acidity of foods either through fermentation processes or the addition of weak acids. pH is the negative log of hydrogen ion concentration [37], which is a measure of the product acidity and is a function of the hydrogen ion concentration in the food product. In the present study, the pH of the sample was 4.9, indicating acidity which explains that food at pH 4.4–5.0 is medium acidic food and it lasts better than food above this range which favors microbial activity [38].

3.6 Shelf-life determination

In this study, PS was used as a preservative. For the following parameters, the best and most economic quantity of the PS that can be used as a preservative was also determined. A higher concentration of preservatives increases the shelf-life, but the higher concentration does not only lead to high production cost but can lead to serious health hazards [39].

3.6.1 pH

Figure 3 shows the result obtained from the evaluation shelf-life using PS with time on the pH of GS. During storage, pH lowering was observed from 0.0 up to 0.05% of PS concentration. This variation on the control sample or at low concentration of the PS can be explained by the fact that carbon dioxide released during the process is converted to carbonic acid-producing carbonate ions and protons, which increases acidity and decreases the pH of the syrup [40].

The variation gradually reduces to stability as the concentration of PS reaches 0.05%. When PS dissolved in water, it ionizes to form sorbic acid which is effective against yeasts, molds, and selected bacteria but the addition of PS to a GS raises the pH depending on the amount or type of product [41]. So, the slight increase in pH from 0.05 to 0.1% could be due to this reason (Table A-4).

3.6.2 Moisture content

Figure 4 shows the result obtained from the evaluation shelf-life using PS with time on the moisture content of GS. During storage, moisture content variation was observed from 0.0 up to 0.05% of PS concentration while variation gradually reduces to stability as the concentration of the PS increases from 0.05 up to 0.1% (Table A-5). The slow decrease in moisture content with time can be explained by the rate of moisture migration or relative humidity of the sample and the surrounding. A product stored at elevated humidity accelerates moisture migration through the package whereas storage at dry conditions promotes drying of the syrup [42].

3.6.3 Viscosity

The coefficient of viscosity of fluids decreases as the temperature increases. This is because as the average speed of the molecules in a liquid increase, the amount of time they spend in contact with their nearest neighbors decreases [43].

At low concentration of the preservative, there is a decrease in viscosity (Fig. 5). This is due to a slow breakdown in the polysaccharide mixture as the product ages [44]. Variation reduced as the concentration of potassium sorbate reached 0.05% and was able to maintain steady viscosity during the experiment because of the moderate amount of the preservative. However, the viscosity is strongly affected

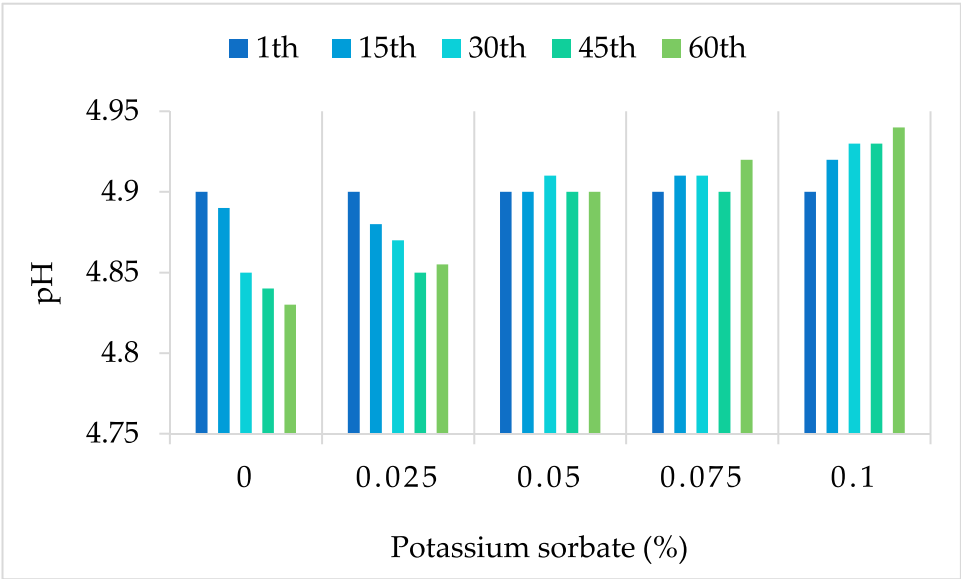

Fig. 3 Effect of potassium sorbate with time on pH of glucose syrup

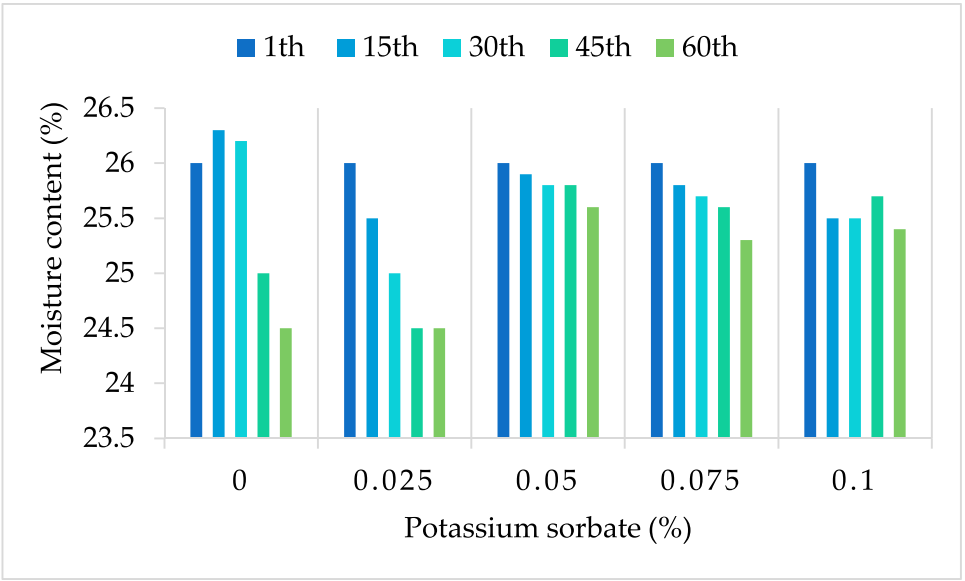

Fig. 4 Effect of potassium sorbate with time on the moisture of glucose syrup

by water content (lower viscosity for higher water contents) and temperature (lower viscosity for higher temperatures) [45]. Hence, the slow increase in viscosity content or development of more viscous skin syrup surface with time can be due to loss of water to the surrounding air with the preservative ability of the PS (Table A-6).

4 Conclusions

The results of this research showed that SP starch is a potential candidate to produce GS by acid hydrolysis. The proximate composition of SP tuber was determined before the extraction of starch. The study revealed that GS production is significantly influenced by time, temperature, and sulfuric acid concentration. Design-Expert software using Box-Behnken design was used for statistical assessment to identify the important parameters for GS production. Results showed that the hydrolysis time, sulfuric acid concentration, and temperature had a significant positive effect on GS yield. However, the interaction effect between temperature and sulfuric acid concentration and temperature and time had an antagonistic effect. The interaction between sulfuric acid concentration and time was not significant, which means that they did not help much in increasing the production of GS. The results observed in the present study also demonstrated that PS plays a positive role in extending the shelf-life of GS within the accepted concentration range. On the other hand, the control GS sample without added preservatives showed a

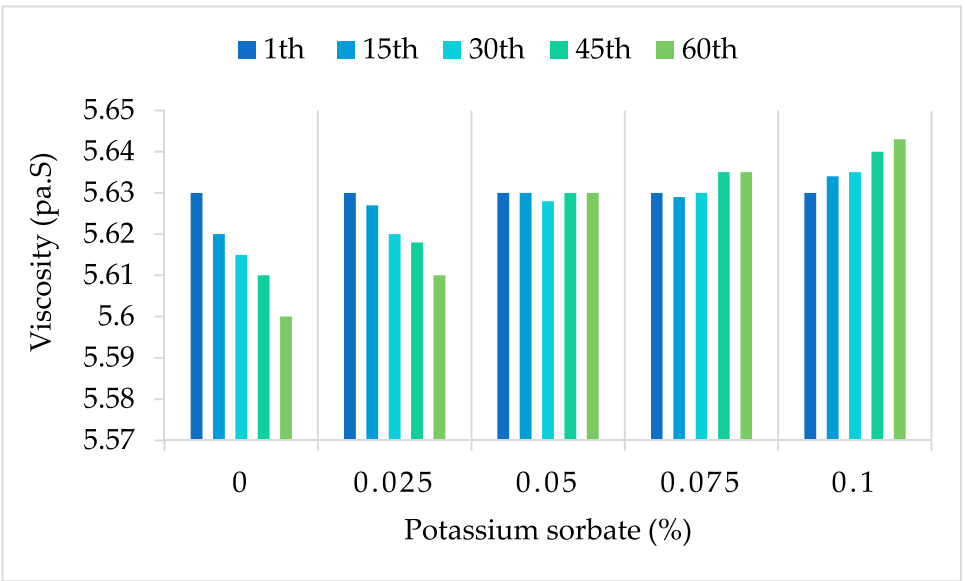

Fig. 5 Effect of potassium sorbate with time on the viscosity of glucose syrup

variation on pH, moisture content, and in viscosity. But the addition of PS to a GS raises the pH necessitating additional adjustment to keep the pH at a safer level.

To conclude, controlling hydrolysis parameters during the production of GS from acidic hydrolysis SP starch is a good choice in view of increasing yields of glucose concentration and decreasing dose and cost of chemicals, and minimizing waste generation. The analysis of the chemical composition of SP proves that it is a principal source of carbohydrates for consumers. Furthermore, PS could be an alternative packaging material to improve GS quality during storage.

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Author contribution Mr. Gebreselassie Gebregziabiher: conceptualization, methodology, writing—original draft preparation, and writing—review and editing; Mr. Hagos Kalu: data curation and visualization; and Mr. Abraha Gebremeskel: conceptualization, project supervision, and administration. All authors commented on previous versions of the manuscript and approved the final manuscript.

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Data availability All data analyzed during this study are included in this research article.

Declarations

Ethics approval Not applicable.

Conflict of interest The authors declare no competing interests.

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