OPTIMIZATION OF YELLOW DEXTRIN FOR THE PRODUCTION OF STARCH BASED ADHESIVE

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Abstract

This study investigates the optimization of yellow dextrin for the production of starch based adhesive using cassava starch. It involves the optimization of process variables namely, roasting temperature, roasting time and concentration of acid using Minitab 17 software in order to achieve the optimum combination of the variables that will give the best solubility for yellow dextrin. In the dextrinization process, a temperature range of 80 to 100ºC was adopted while acid concentration range of 0.25 to 0.3 M and time range of 60 to 120 minutes were used. The results obtained shows that roasting temperature of 100ºC and roasting time of 120 minutes with concentration of 0.25 M gave a yellow dextrin with the highest solubility of 42.8 %. The individual and combined (interaction) effects of the process parameters were determined using factorial analysis. An empirical model was also developed for the factorial analysis. The analysis showed that the process variables (roasting temperature, roasting time and concentration of acid) have significant effects on the solubility of the yellow dextrin produced. It also suggested that the best of yellow dextrin was produced at a roasting temperature of 100ºC, concentration of 0.3 M and roasting time of 120 minutes and the model equation for the predicted value of yellow dextrin solubility as 42.55%. Yellow dextrin of the highest solubility was consequently used to prepare adhesive. The viscosity, drying time and the pH of the adhesive produced are 1.5 Pas, 4.13 minutes and 7.54 respectively.

Keywords: Adhesive, Starch, dextrin, solubility, design.

Introduction

Adhesives as defined by Akpa (2012) are polymer substances that can join materials together by a process of adhesion. It is a semi-synthetic low molecular weight carbohydrate formed by the hydrolysis of starch that can be obtained from any of cassava, potatoes, rice and corn. it can also be produced by pyrolysis or roasting after mixing starch with quantified amount of hydrochloric acid (HCl) or nitric acid (HNO_3). An adhesive is said to be effective if it is able to bind materials together properly and it is able to show resistance to moisture (Ubadike, 2015). As reported by Baumann and Conner (1994), adhesive may be classified according to their origin which maybe semi synthetic, natural or synthetic. Dextrin usually exists in white, yellow or brown colour which may be fully or partially soluble in water. Even though, various types of adhesives available in the market nowadays, adhesives made from cassava starch is normally desirable for domestic use because of its smooth texture, non-poisonous and non-staining nature (Ubadike, 2015).

Starch is a very important food crop to man and it has been observed that approximately 60-70 % of calories taken by man is derived from starch (Lawton, 2004). Apart from been suitable for consumption, it is also used as raw material in food, pharmaceutical, paper, and construction industries. It is also applicable in non-food industries such as packaging, paper industry, match header in explosives, pill coating and dispersing agent in pharmaceuticals (Burrell, 2003). The uses highlighted depend on the functional properties like pasting, gelatinization and solubility which normally vary from one botanical source to another with variety and environmental condition (Yuan *et al.,* 2007). As reported by Vaclavik and

Christian, (2008), the use of starch in food and non-food industries needs a good understanding of their functional, physicochemical and structural properties. Buba and Kabiru (2014) reported that cassava has also become a food crop of high potential and industrial value. The aforementioned therefore suggest the need to encourage farmers to do more in production of cassava to be able to meet up with these competing demands to avert possible food crisis.

Montgomery (2005) stated that essential method to process and product design and development which include design of experiment involves three phases namely characterization, control and optimization. It is therefore important to employ design of experiment in a process where optimization of variables is been sought.

This research seeks to optimize the production of yellow dextrin before using the dextrin to produce adhesive. The adhesive produced will then be characterized. Design of experiment was used for the optimization of dextrin through the use of Minitab.

Materials and Methods

Materials, Chemicals and Equipment

Cassava starch used for this experiment was gotten from Minna, Niger State in Nigeria. The equipments used for the experiment includes Stop watch, viscometer, electric oven, plastic funnel, thermometer, mesh sieve (250 µm), spatula, hot plate with magnetic stirrer, centrifuge, pH meter, digital weighing balance, 250 ml volumetric flask, 50 and 100 ml measuring cylinders and 250 ml beakers. All the chemicals used in this study are of analytical grade with high level of purity. The chemical reagents used include distilled water, hydrochloric acid (HCl), sodium hydroxide (NaOH), borax ($Na_2B_4O_7.10H_20$) and formaldehyde (CH_2O).

Experimental procedure

The processed cassava starch was sieved using a 250 µm mesh sieve. The dextrinization process was developed using a 2^3 experimental design. The variables considered are concentration of acid, roasting time and roasting temperature. Minitab 17 software was chosen for the factorial design and sixteen experiments were run as shown in Table 1.

The method used by Gumus and Udezue (2011) with slight modification was employed for the preparation of dextrin. In this study, 25 g of the sieved dried cassava starch was mixed with 200 ml of 0.30 M HCl (gelatinization enhancer) and aged for 24 hours. This mixture was then heated at a temperature of 100 ºC using a heater with magnetic stirrer for 60 minutes. This step was repeated for all other experiments but with changes in the variables as shown in Table 1.

The solubility of the produced dextrin was determined by method similar to those of previous researchers (Aytunga *et al.,* 2010; Leach *et al*. 1959). 2.5 g of the prepared dextrin was measured out and dissolved in 30ml of distilled water and heated for 15 minutes using hot plate with magnetic stirrer maintained at 50 ºC. It was allowed to cool and then centrifuged at 2000 rpm for 10 minutes. The supernatant was separated and heated for 15 minutes after which the percentage solubility was determined.

In preparing adhesive for sealing carton, 106.7 g of yellow dextrin having 42.3 % solubility in water was mixed with 16 g borax, 2.7 formaldehyde and 0.2 g of liquid paraffin the mixture was heated at 85ºC for 30minute and cooled to 50ºC and 0.2 g of 50 % NaOH was added to the mixture. The pH of the adhesive produced was determined using a digital pH meter. 20 ml of the sample was put into a sample bottle and the pH meter electrode was inserted into it. The value was gotten from the display of the pH meter. The viscosity was determined using Brookfield viscometer at room temperature. It was set at a speed of 60 rpm with spindle number 29 and expressed in pa.s. The drying time which is the time required for the adhesive to set after it is covered with substrate was determined manually, using a stop watch.

Results and Discussions

The solubility of dextrin as described by Peroni *et al.,* (2006) is the evidence of interaction between water molecules and starch chain. It increases with increase in temperature since water penetrates more into the amorphous region of the starch granules. Temperature increase therefore results to more hydration and dissolution due to the swelling of the starch granules. Table 1 shows the temperature (80 to 100ºC), acid concentration (0.25 to 0.3 M) and roasting time (60 to 120 minutes) range that were employed in the production of yellow dextrin. Yellow dextrin gave solubility values ranging from 25.7 to 42.8 %.The highest solubility which is 42.8 % was gotten at temperature of 100ºC, roasting time of 120 minute and concentration of 0.25 M.

Table 1: Solubility (response) at different roasting temperatures, time and concentrations for yellow dextrin

Run order	Temperature (ºC)	Roasting Time (min.)	Acid Concentration (M)	Solubility (%)
1	100	60	0.30	40.4
2	100	120	0.25	42.3
3	80	120	0.25	36.8
4	80	60	0.30	36.3
5	100	60	0.30	40.7
6	80	120	0.30	39.0
7	80	120	0.25	37.4
8	80	120	0.30	39.6
9	80	60	0.25	25.7
10	100	120	0.25	42.8
11	100	60	0.25	37.7
12	100	120	0.30	31.8
13	80	60	0.25	26.3
14	100	120	0.30	32.6
15	80	60	0.30	36.7
16	100	60	0.25	37.0

This is an improvement on the highest solubility of 32 % obtained by Azeez (2005) for yellow dextrin where 50 g of starch diluted with 0.3M HCl (acid) was heated at 90^{o}C for 180 minutes. The highest solubility obtained in this research is in line with the observation of Peroni et al. (2006) since the temperature at which the highest solubility is obtained in this research is higher than that of Azeez (2005).

Table 2 shows the estimated coefficient and effects for the solubility of yellow dextrin. It shows that the model contains three main effect which are significant since there p value is less than 0.05. The p-value result from Table 2 shows some important information regarding the effect of a single process variable and combination of process variables on yellow dextrin solubility. It indicates that there is a significant interaction between roasting temperature and roasting time (0.000) roasting temperature and concentration of acid (0.000) and also between roasting time and concentration of acid (0.000) as they have p-value less than

0.05. Table 2 also shows that the interaction between time and concentration has the greatest effect (-5.462) on yellow dextrin solubility. The interaction between roasting temperature and concentration of acid has the second greatest effect (-4.962). In addition, setting the roasting temperature high and concentration of acid low will produce yellow dextrin of high solubility. The interaction between the three variables roasting temperature, roasting time and concentration of acid has the smallest effect (-1.312) on the solubility.

Table 2: Estimated effects and coefficients for yellow dextrin solubility response

Term	Effect	Coef	SE Coef	T-Value	p-Value
Constant		36.444	0.103	354.21	0.000
Temperature	3.437	1.719	0.103	16.71	0.000
Time	2.687	1.344	0.103	13.06	0.000
Concentration	1.388	0.694	0.103	6.74	0.000
Temperature*Time	-4.263	-2.131	0.103	-20.71	0.000
Temperature*Concentration	-4.962	-2.481	0.103	-24.12	0.000
Time*Concentration	-5.462	-2.731	0.103	-26.55	0.000
Temperature*Time*Concentration	-1.312	-0.656	0.103	-6.38	0.000

Pareto chart of the standardized effect for yellow dextrin solubility response shown in Figure 1 shows that there are also three significant effects effect (α=0.05), which are roasting temperature (A) roasting time (B) and concentration of acid (C). It is also observed that Pareto plot shows the largest effect to be the interaction between time (B) and concentration (C) because it extends the farthest and that the smallest effect is the interaction between the three variables roasting temperature (A) roasting time (B) and concentration of acid (C). The plot shows that all the variables are significant including their interaction with each other.

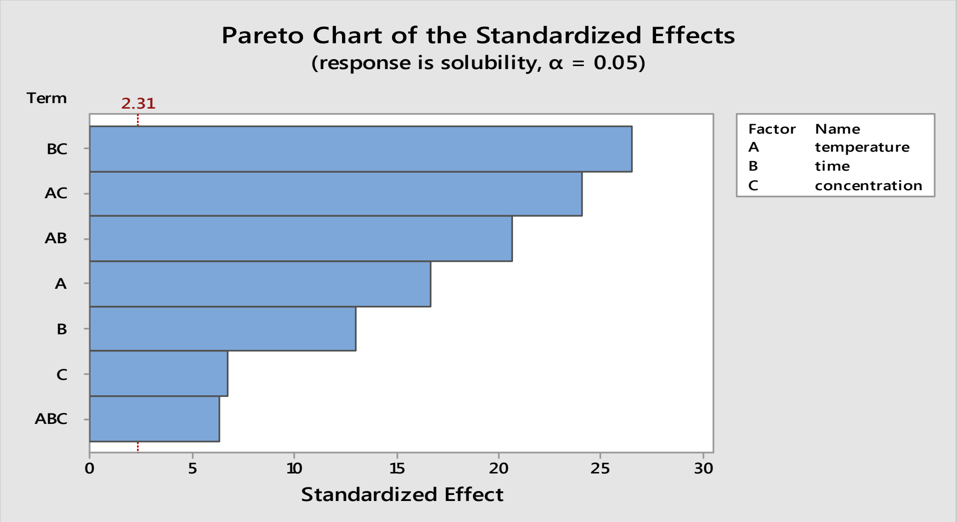

Figure 1: Pareto chart of the standardized effect for yellow dextrin solubility

Normal plot of the standardized effect for yellow dextrin solubility response of Figure 2 indicates that there are three significant effect (α= 0.05) and these effect include all the three main effects roasting temperature (A) roasting time (B) and concentration of acid (C). Roasting temperature has the highest effect because it lies furthest from the line. In addition it indicate the concentration of acid and roasting time has a positive effect since they reside to the right of the line. This means that if the roasting time changes level from low to high the solubility increases. The combined effect of temperature time and concentration all have negative effect since they reside to the left of the line meaning when the process variables change level from low to high the solubility decreases. Also the significant of the process factor and their ranking is in agreement with the result of the estimated effects and the coefficients for the solubility of yellow dextrin in Table 2.

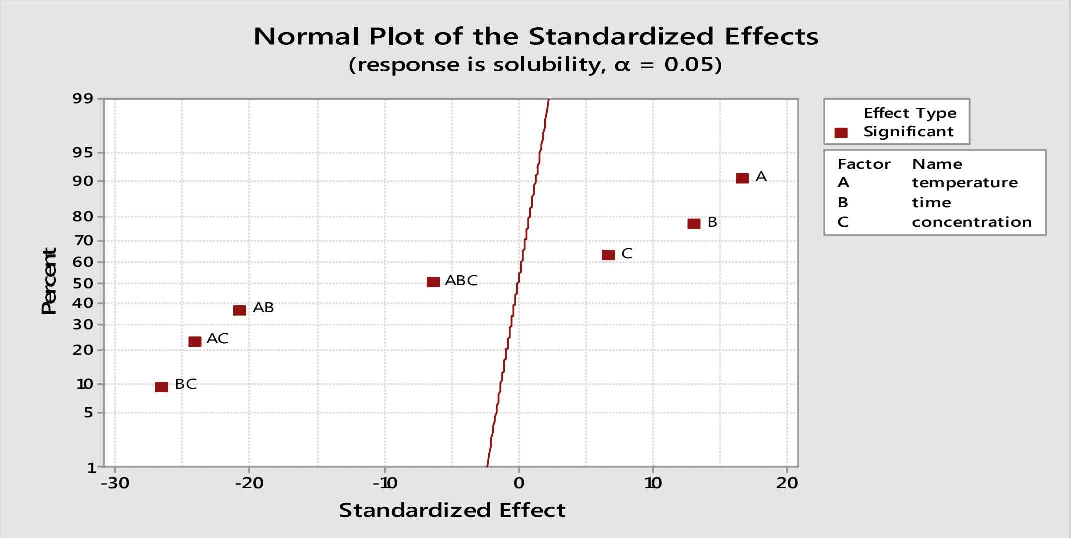

Figure 2: Normal plot of the standardized effect for yellow dextrin solubility

Half normal plot of the standardized effect for yellow dextrin solubility of Figure 3 shows that there are also three significant effect (α= 0.05). All the three main effects roasting temperature (A) roasting time (B) and concentration of acid (C) are significant. The interaction between roasting time and concentration of acid has the largest effect because it lies furthest from the line.

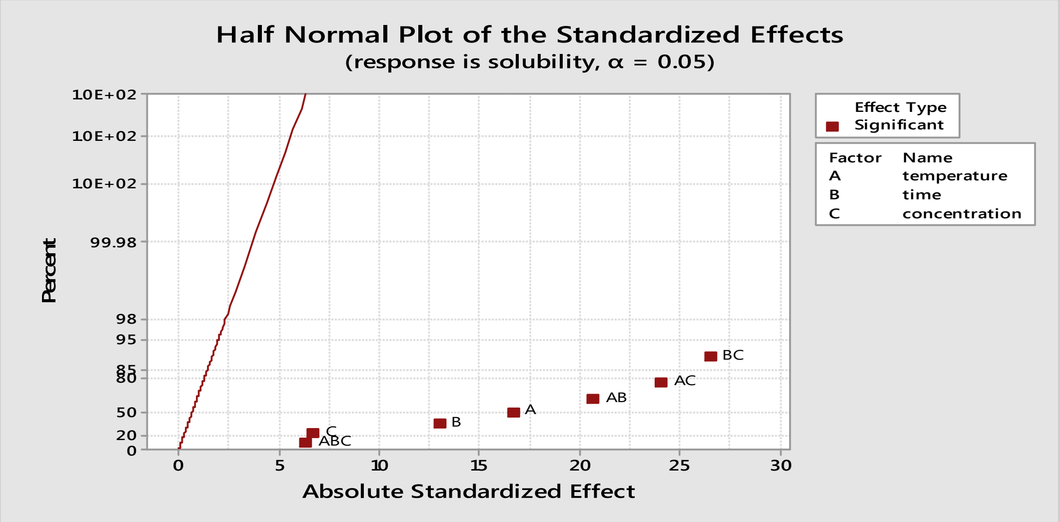

Figure 3: Half normal plot of the standardized effect for yellow dextrin solubility

The cube plot of Figure 4 shows that when acid concentration of 0.25 M, roasting temperature of 100°C and roasting time of 120 minutes is used the quality of the dextrin solubility is 42.55 %.

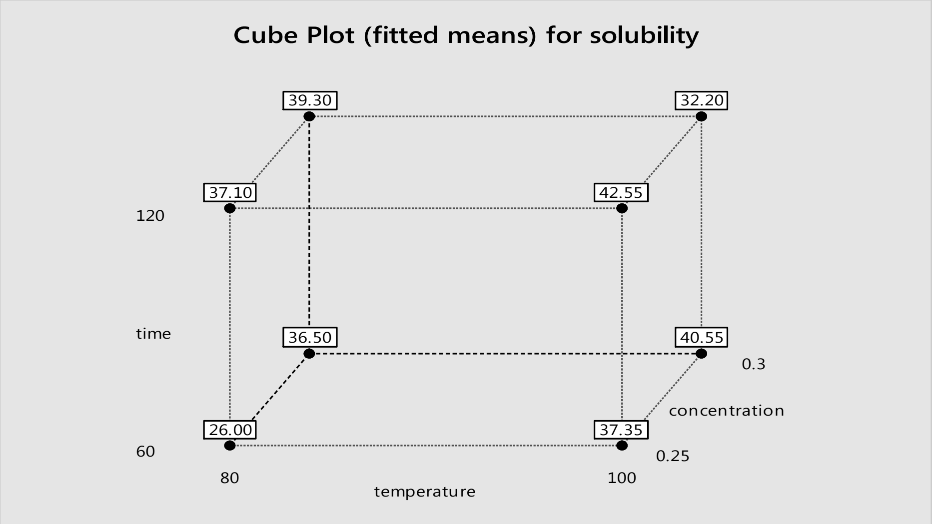

Figure 4: Cube Plot for Yellow Dextrin Solubility

The linear regression model equation for yellow dextrin can be built up from the estimated coefficients for yellow dextrin solubility in Table 2 and it's shown in Equation 1.

$$Y = \quad 36.444 \quad 1.719 \quad 1.344 \quad 0.694 \quad - 2.131 \quad - 2.481 \quad - 2.731 \quad - 0.656 \qquad (1)$$

Y : The predicted value of yellow dextrin solubility

X_1: The roasting temperature which has two levels coded 1 and -1

X_2: The roasting time which has two levels coded 1 and -1

X_3: The concentration of acid which has two levels coded 1 and -1

The model equation via the combination of the main effect shown above and the interaction plot can be shown as:

$$Y \quad 36.444 \quad 1.719\ 1 \quad 1.344\ 1 \quad 0.694\ -1 \ - 2.131\ 1\ \ 1\ - 2.481\ 1\ \ -1$$
$$- \quad 2.731\ 1\ \ -1\ - 0.656\ 1\ \ 1\ \ -1$$

Y = 42.55% which is the percentage solubility.

The characterization of the sealing carton adhesive produced shows that the viscosity of the adhesive produced is 1.5 Pa.s as indicated in Brookfield viscometer. The drying time and the pH of the adhesive are 4.13 minutes and 7.54 respectively.

Conclusions

Based on the results obtained from various analyses conducted in this study, the following conclusions can be drawn:

(i) The optimum condition for yellow dextrin was obtained at temperature of 100ºC, roasting time of 120minutes and concentration of 0.25 M and gave a solubility of 42.8 %.

(ii) From the factorial analysis carried out roasting temperature, roasting time and concentration has significant effect on the solubility of dextrin. It also suggested that there are significant interactions between the individual variables in other to produce dextrin with high solubility.

(iii) Yellow dextrin was used in the production of sealing carton adhesive which has a viscosity of 1.5 pa.s, drying time of 4.13 minutes and pH of 7.54.

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