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Optimization of reaction conditions for improving nutritional properties in heat moisture treated maize starch

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ABSTRACT

Impact of heat-moisture treatment (HMT) on nutritional properties of normal maize starch (NMS) under various reaction conditions was investigated. NMS was adjusted to moisture levels of 20%, 25%, 30% and 35% and heated at 80, 100, 120 and 140 °C for 4, 8, 12 and 16 h. Response surface methodology (RSM) based on Box-Behnken design (BBD) was employed to obtain the optimal combination of moisture level (X_1: 20–30%), length of heating (X_2: 4–12 h), and temperature (X_3: 100–140 °C). The optimum reaction condition decreased rapidly digestible starch (RDS) from 87.10% to 82.21%, when NMS was subjected to HMT at 23.6% moisture content and heated at 114.8 °C for 9.04 h. The ANOVA measurement and confirmation experiments were performed to verify the predictive value and the RSM model, indicating that temperature was the main factor to determine the digestion rate of HMT NMS. The results suggested that RDS was not correlated to heating length but positively correlated to temperature and moisture content. Reaction condition had no correlations with slowly digestible starch (SDS) and resistant starch (RS). This study could provide more information for producing low-glycemic index products.

1. Introduction

Starch is the main carbohydrate resource in human diets, so digestion of starch in the gastrointestinal tract is an important metabolic response. For nutritional purposes, starch is classified into rapidly digestible starch (RDS), slowly digestible starch (SDS) and resistant starch (RS). The nutritional starch fraction of RDS elevates blood glucose level rapidly after absorption. Starch based foods with a low proportion of RDS relative to SDS and RS are considered as low glycemic index (GI) foods [1,2]. The fraction of SDS could be completely digested in the gastrointestinal tract at a slower rate of glucose release, providing energy sustainably and slowly for physical activities. The health benefits of SDS has been reported as prevention of metabolic disorders including hyperlipidemia and diabetes, reduction of oxidative stress, and inhibition of postprandial circulated free fatty acids [3]. The fraction of RS cannot be digested in the small intestine, but it can be fermented by microorganisms in the colon [3,4]. RS has been extensively studied due to its beneficial effects on human health, such as prevention colon cancer and coronary heart disease, improvement of satiety, and reduction of plasma cholesterol and triacyl glycerol levels [5–7]. Therefore, improving starch based food nutritional properties with lower amount of RDS relative to SDS and RS is of interest to acedamic researchs, food industry and consumers.

The structural properties of starch determine the rate of starch digestion, such as surface porosity, the degree of channelization, crystalline perfection, the degree of crystallinity, covalent linkages of double helices, helical order, amylose/amylopectin ratio, chain length distribution and branch density of amylopectin [1,5,8]. Attempts to produce low GI foods products have been based on physical, chemical and enzymic treatments by alteration of molecular structure of starch. Song et al. [9] found that annealing treatment increased both RDS and SDS levels in granular sweet potato starches. Páramo-Calderón et al. [10] reported that the cross-linking treatment by sodium trimetaphosphate (STMP) served a better source of RS in banana starches. Sorndech et al. [11] reported a progress for making SDS products by treating cassava starch with amylomaltase and branching enzyme.

Heat moisture treatment (HMT), an environmentally friendly technique, is of interest to make the low GI foods without any chemical residue. It involves the hydrothermal treatment of starch granules at low moisture levels (<35% slurry in water, w/w) during certain time (5 min–16 h), and at relatively high temperature (80–140 °C) above the glass transition temperature but below the temperature when gelatinization occurs [8,12]. Chung, Liu, and

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Table 1
Independent parameters and levels in Box-Behnken design.

Levels	Parameters		
	Moisture content (%)	Length of heating (h)	Temperature (°C)
−1	20	4	100
0	25	8	120
+1	30	12	140

Table 2
Experimental results (with coded process factors) of response surface methodology.

Trial	X_1 (%)	X_2 (h)	X_3 (°C)	RDS level (%)	
				Experimental	Predicted
1	1	0	1	86.15	86.18
2	0	0	0	82.59	82.58
3	0	0	0	82.52	82.58
4	−1	0	−1	84.19	84.16
5	1	1	0	84.81	84.83
6	1	−1	0	83.80	83.61
7	−1	0	1	84.29	84.16
8	−1	1	0	82.77	82.95
9	0	−1	1	84.02	84.11
10	0	−1	−1	84.41	84.53
11	0	1	−1	83.17	83.07
12	−1	−1	0	83.88	83.85
13	0	0	0	82.63	82.58
14	0	1	1	86.01	85.89
15	0	0	0	82.56	82.58
16	1	0	−1	83.65	83.78
17	0	0	0	82.61	82.58

Hoover [13] found that the hydrothermal treatment decreased the RDS level in gelatinized starches through the structural reorganization and rearrangement in amorphous and crystalline regions. Sui, Shah and BeMiller [14] reported that the various derivatizations of in-kernel HMT maize starch enhanced the formation of SDS and RS. He, Liu, and Zhang [15] proposed that the HMT waxy maize starch modified by octenyl succinic anhydride esterification was an uncompetitive enzyme inhibitor to produce SDS.

Numerous studies have found that HMT under various conditions could improve structural properties of starch granules, leading to a decrease in RDS level but an increase in SDS and RS level [8,13–15]. However, it is difficult to determine the starch digestibility of HMT starches in a consistent way since the combination of HMT parameters are diverse, i.e., the botanical source, moisture content, temperature range, treatment length [8]. Besides, there is limited information on relationship between HMT reaction condition and nutritional properties of starch.

Response surface methodology (RSM) is a statistical technique to efficiently evaluate the significance of interactions among various parameters and determine the optimal combination based on an empirical model [16]. RSM was widely used in food science field, especially in extraction of functional substances in foods [17–19]. The objective of the study was to optimize the HMT reaction condition for normal maize starch (NMS) using response surface methodology (RSM), employing a Box-Behnken design (BBD) to study the effects of moisture content, length of heating and reaction temperature on the nutritional properties of normal maize starch.

2. Materials and methods

2.1. Materials

Normal maize starch (NMS) was obtained from Gaofeng starch technology Co., Ltd. (Suzhou, China). The amylose, moisture, lipid and protein contents were 18.4%, 12.2%, 0.13% and 0.35%, respectively. Amyloglucosidase (EC 3.2.1.3, 330AGU/mg), pancreatin from porcine pancreas (EC 232.468.9, 228 USP/mg) were obtained from Sigma Chemical Co., Ltd. (MO, USA). Glucose oxidase-peroxidase (GOPOD) was obtained from Megazyme International Ireland Ltd. (Bray, Ireland). All chemicals and solvents were analytical grade.

Table 3
Estimated regression model for relationship between response variables (RDS content) and independent variables (X_1, X_2, X_3).

Source	SS[a]	DF[b]	MS[c]	F value	P-value
Model	20.98	9	2.33	104.90	<0.0001
X_1	1.35	1	1.35	60.89	0.0001
X_2	0.05	1	0.05	2.30	0.1728
X_3	3.19	1	3.19	143.45	<0.0001
X_1X_2	1.11	1	1.11	50.09	0.0002
X_1X_3	1.44	1	1.44	64.80	<0.0001
X_2X_3	2.61	1	2.61	117.37	<0.0001
X_1^2	2.07	1	2.07	93.24	<0.0001
X_2^2	1.20	1	1.20	54.03	0.0002
X_3^2	6.97	1	6.97	313.60	<0.0001
Lack of Fit	0.15	3	0.05	26.39	0.0043
Adjusted R^2				0.9832	
Predicted R^2				0.8873	
Adequate Precision				31.754	
C.V. (%)				0.18	

[a] Sum of squares.
[b] Degree of freedom.
[c] Mean square.

2.2. Heat-moisture treatment

Heat-moisture treatment (HMT) was performed according to a laboratory protocol [20]. Starches (22 g, dry base) were weighed and placed into screw-capped glass containers. Small amount of distilled water was added slowly with frequent stirring until moisture levels (w/w) of the total mixture reached 20%, 25%, 30% and 35% respectively. After mixing thoroughly, the glass containers were sealed and equilibrated at 4 °C for at least three days. Samples were heated at 80, 100, 120 and 140 °C for 4, 8, 12 and 16 h in a hot-air oven. After HMT, the samples were dried at 40 °C overnight to a constant weight. All samples were ground in a mortar and pestle, and passed through a 0.4 mm sieve.

2.3. Determination of levels of starch nutritional fractions

Starch nutritional fractions of RDS, SDS and RS were determined according to the method of Ye and Sui [3] with minor modifications. Starch samples (550 mg, db) were placed in screw-capped tubes and heated in 10 mL distilled water for 20 min with frequent mixing. After cooling, 10 mL of sodium acetate buffer (0.5 M, pH 5.2), 50 mg guar gum and 15 glass beads were added to each screw-capped tube with frequent mixing by vortexing. The tubes with starch were then incubated with pancreatin from porcine pancreas (50 units) and amyloglucosidase (35 units) in a shaking water bath (37 °C). After 20 min and 120 min of incubation, the hydrolyzate (0.1 mL) was removed and mixed with 20 mL of 80% ethanol to stop the reaction. The amount of released glucose was determined using glucose oxidase assay [21]. Starch fractions were calculated as $RDS(\%) = SD_{20}(\%)$; $SDS = SD_{120}(\%) - SD_{20}(\%)$; $RS(\%) = 100 - SD_{120}(\%)$, where $SD_{20}(\%)$ represents the percentage of RDS and $SD_{120}(\%)$ represents the percentage of RDS and SDS.

2.4. Experimental design for optimization

2.4.1. Single factor experiments

The moisture content (20%, 25%, 30% and 35%), length of heating (4, 8, 12 and 16 h) and temperature (80, 100, 120 and 140 °C) were selected as three independent parameters. Single factor experi-