Supichar Wattanaprasert¹Chaleeda Borompichaichartkul²Pilane Vaithanomsat³George Szrednicki⁴

Research Article

Konjac glucomannan hydrolysate: A potential natural coating material for bioactive compounds in spray drying encapsulation

¹ Program in Biotechnology,
Faculty of Science,
Chulalongkorn University,
Bangkok, Thailand

² Department of Food
Technology, Faculty of Science,
Chulalongkorn University,
Bangkok, Thailand

³ Kasetsart Agricultural and
Agro-Industrial Improvement
Institute, Kasetsart University,
Bangkok, Thailand

⁴ Food Science and Technology,
School of Chemical Engineering,
University of New South Wales,
Sydney, NSW, Australia

This research aimed to develop a suitable coating material for encapsulating a plant bioactive compound via spray drying. A suitable process for modifying the rheological property of konjac glucomannan (KGM) solution by enzymatic treatment was developed. A plant bioactive compound, andrographolide, was selected to use as core material. Mannanase (1500 units of enzyme) was used in the treatment of KGM solution. The concentration of KGM solution was varied from 9 to 18% (w/w). It was found that 12% (w/w) was the optimum KGM concentration that could be hydrolyzed to a viscosity of <100 mPa·s. HPLC analysis of hydrolyzed solution found a fair amount of DP4–DP7 oligosaccharides (where DP is degree of polymerization) were obtained. The solution was then used as coating material in spray drying with inlet air temperature of 170°C and outlet air temperature of 85°C. It was found that 12% (w/w) konjac glucomannan hydrolysate (KGMH) was suitable for coating 2% (w/w) andrographolide. Its efficiency of encapsulation was also higher than that of KGMH combined with gamma-cyclodextrin or beta-cyclodextrin. This study revealed a great potential of using KGMH solution for pharmaceutical and food industries in the spray drying encapsulation process.

Keywords: Andrographolide / Coating materials / Konjac glucomannan / Spray drying / Viscosity

Received: January 22, 2016; revised: May 6, 2016; accepted: August 1, 2016

DOI: 10.1002/elsc.201600016

1 Introduction

Konjac glucomannan (KGM) is a natural polysaccharide isolated from the tubers of *Amorphophallus* spp. plants found in Asian countries such as China, Taiwan, Japan, and Thailand [1]. KGM is widely used in the food pharmaceutical, chemical, and biotechnology industries [2]. KGM consists of β -(1,4)-linked D-glucose and D-mannose units with a 1.0:1.6 molar ratio of glucose: mannose and a low degree of acetyl groups at the C-6 position. The molecular weight of the polymer is 10^5 – 10^6 g/mol [3]. In addition, KGM has desirable properties of good film formation, a high water solubility, edibility, and biodegradation [4]. It has a tendency to create a fine dense network upon drying [5]. In

addition, the microencapsulation using KGM as the coating material has been reported to be able to protect volatile compounds and antimicrobial compounds [6] as well as increase the encapsulation yield [7].

Andrographis paniculata Nees, also known by the name of Kalmegh or “King of Bitters,” belongs to the Acanthaceae family. From the ancient times, it has been known as a treatment for diseases of gastrointestinal tract, upper respiratory infections, herpes, fever, and sore throat. The andrographolide, extracted from *A. paniculata*, is known as the active diterpenoid lactone compound. In addition, it was recognized for the ability to prevent the proliferation of tumor cells by approaching through each different type of human cancers (colon cancer cells) and immune cells (the proliferation human peripheral blood lymphocytes [8]). However, the andrographolide was also noted for its limitations in the practice due to its bitterness and the lack of the stability in the solution. Therefore, transformation of andrographolide extract to microcapsule may be the way to solve these problems.

As KGM is viewed as a suitable material for the encapsulation of bioactive compounds via spray drying process from

Correspondence: Dr. Chaleeda Borompichaichartkul (chaleedab@hotmail.com), Department of Food Technology, Faculty of Science, Chulalongkorn University, Phayathai Road, Patumwan, Bangkok 10330, Thailand

Abbreviations: β CD, beta-cyclodextrin; CD, cyclodextrin; DP, degree of polymerization; FT-IR, FT infrared spectroscopy; γ CD, gamma-cyclodextrin; KGM, konjac glucomannan; KGMH, konjac glucomannan hydrolysate; SEM, scanning electron microscopy

its above-mentioned characteristics; however, the use of KGM is limited by the fact that it has a very high apparent viscosity when dissolved in water even at low concentration ($>2\%$ (w/w)). Therefore, its viscosity needs to be reduced to an appropriate level (<100 mPa·s) before using it in the spray drying and encapsulation process. There is a study on using β -mannanase to hydrolyze the β -(1,4)-D-mannopyranosyl linkages of glucomannans. β -Mannanases obtained from *Bacillus* sp. under the optimal conditions were capable to hydrolyze KGM at 50°C (pH 5.5) for 24 h, and hydrolysate more than 90% of polysaccharides into oligosaccharides and some monosaccharides [9]. However, there is no research that studies the optimization of KGM concentration that would be used in mannanase enzymatic degradation for lowering viscosity of KGM solution suitable for microencapsulation via spray drying.

The microencapsulation efficiency depends on the composition of the coating wall material. The coating material can be selected from natural and synthetic polymers, such as gum arabic, gelatin, and maltodextrins [10]. Among these substances, cyclodextrin (CD) are well known for their toroidal shape and dominated by rigid cyclic oligosaccharides including the D-glucopyranose units, linked by α -(1,4)-glycosidic bonds. Furthermore, the known common types of CD are beta-cyclodextrin (β CD) and gamma-cyclodextrin (γ CD), which comprise seven and eight glucose units, respectively [11]. The hydrophobic interior cavity of CD is due to the presence of nonpolar molecules creating the complexity, while the exterior of CD is hydrophilic. There was an attempt to encapsulate andrographolide by using CD [12]. The study found that the mixture of andrographolide- β CD and andrographolide- γ CD at a molar ratio of 1:1 had the best performance in the dissolution process and was more effective than the pure drug. Furthermore, the stabilizing effect of andrographolide- β CD on degradation at 1:1 molar ratio spray dried proved to be more effective than andrographolide- γ CD compared to other CD [13]. Nevertheless, the price of β CD and γ CD is very high.

Therefore, the aims of this research are to (1) find a suitable concentration of KGM solution combined with units of enzyme in the appropriate ratio to reduce the viscosity of a KGM solution for encapsulating andrographolide via spray drying and (2) compare microencapsulation efficiency of konjac glucomannan hydrolysate (KGMH) to KGMH combined with β CD or γ CD based on encapsulation efficiency and product yield, which would improve the quality of the andrographolide microcapsules.

2 Materials and methods

2.1 Optimization of KGM concentration for enzymatic hydrolysis

2.1.1 Enzymatic reaction

Mannanase is used for hydrolysis reaction. It is produced from *Bacillus* sp. and has an activity of 30 000 IU/g (Food grade, Bosar Biotechnology, China). It was prepared as described in refs. [14, 15] but using 1500 units of mannanase dissolving in 90.95% (w/w), 87.95% (w/w), 84.95% (w/w), and 81.95% (w/w) solution of 0.05 M Na_2HPO_4 -citric acid buffer (pH 7.1), respec-

tively. After that, KGM powder was added to the mannanase solution prepared as per above-mentioned concentration to make up concentrations of KGM at 9%, 12%, 15%, and 18% (w/w), respectively. The reaction took place at $40 \pm 1^\circ\text{C}$, with stirring at 200 rpm for 4 h, as reported in ref. [14]. KGM was fully dissolved in all hydrolysis. The viscosity of the sample was measured throughout the experiment using a rheometer (C-VOR Bohlin Rheometer, UK) with a cone-plate geometry (40 mm of diameter, 4° cone angle, and $150\ \mu\text{m}$ gap) at a fixed shear rate of $100\ \text{s}^{-1}$ and temperature of 21°C , the latter measured with a Peltier device.

2.1.2 Determination of sugar and oligosaccharides

The analysis of mono-, di-, tri-, and oligosaccharides produced in the hydrolysate was evaluated using HPLC (Alltech Associates, Inc., Deer Field, IL, USA). After enzymatic reaction, mannanase was deactivated by heating at 70°C for 20 min. Then, the hydrolysate was centrifuged at $7000 \times g$ at 15°C for 20 min. The supernatant was harvested, diluted 10-fold, and filtered through $0.45\ \mu\text{m}$ filter prior to injecting a sample volume of $100\ \mu\text{L}$ into the HPLC column (Prevail carbohydrate ES180 column $250 \times 4.6\ \text{mm}$). The column was eluted for 20 min at a room temperature with a 65:35 (v/v) acetonitrile-water mobile phase at a flow rate of 1 mL/min. Eluates were detected using an ELSD 200 ES detector (Alltech Associates, USA). Calibration standards for representative oligosaccharides, with an average degree of polymerization (DP) of one (monosaccharide; DP1) to seven (heptosaccharide; DP7) based upon their retention time, were run as above at 2 mg/mL for the monosaccharides (DP1) glucose (Merck, Germany) and mannose (Sigma-Aldrich Chemical, St. Louis, USA), disaccharide (DP2) maltose (Sigma-Aldrich Chemical), trisaccharide (DP3) maltotriose (Sigma-Aldrich Chemical), tetrasaccharide (DP4) maltotetraose (Hayashibra Biochemical, Japan), pentasaccharide (DP5) maltopentaose (Wako Chemical, Japan), hexasaccharide (DP6) maltohexaose (Hayashibra Biochemical), and heptasaccharide (DP7) maltoheptaose (Hayashibra Biochemical).

2.2 Comparison of microencapsulation efficiency of different coating materials for andrographolide microcapsule via spray drying technique

As the suitable mixture of solution was obtained from the result of section 2.1, the suitable size of units of enzyme mannanase for KGMH can be determined. The solid content of coating material, in this section, will be fixed at optimum concentration of KGM that is obtained from section 2.1. This section aimed at comparing the microencapsulation efficiency of different coating materials by using KGMH and KGMH combined with β CD or γ CD based on encapsulation efficiency (%) and product yield (%). The concentration of core material, namely, andrographolide, was maintained at 2% (w/w) as well as concentration of β CD or γ CD was fixed at 2% (w/w) [12] in combination with KGMH in all experiment for encapsulation. Once the mixture solution was ready, it was fed to the spray dryer where the inlet air temperature was controlled at 170°C and outlet air temperature was controlled to be 85°C [6]. The appropriate type

of coating material was considered for the analysis of encapsulation efficiency (%) and product yield (%), which is described in the following section.

2.2.1 Drying experiments

The spray drying experiments were carried out in a cocurrent Spray Dryer SD-01 (Food processing Co., Thailand) characterized by the maximum evaporation capacity of 350/90°C and 10 L of water/h. The spraying system regulated during experiments was set at inlet air temperature of 170°C with outlet air temperature of $85 \pm 3^\circ\text{C}$. Microcapsules in the form of dried powder were collected from each drying experiment to determine andrographolide encapsulation efficiency (%) and product yield (%) as shown in Eqs. (1) and (2), respectively.

$$\text{Encapsulation efficiency(\%)} = \frac{\text{Andrographolide in microcapsules (g)} \times 100}{\text{Andrographolide in the solution before spray drying (g)}} \quad (1)$$

$$\text{Product yield(\%)} = \frac{\text{Weight of collected microcapsules g dried basis} \times 100}{\text{Weight of total solid content before spray drying (g)}} \quad (2)$$

$$\begin{aligned} (\text{Total solid content} = & \text{KGM (g)} + \text{mannanase (g)} \\ & + \text{andrographolide (g)}) \end{aligned}$$

The analysis of the andrographolide that was encapsulated was performed by using HPLC. The extraction of andrographolide in microcapsules was done in following steps; 0.2 g of microcapsules were extracted by methanol and sonicated for 15 min so that it was totally dissolved. The supernatant was collected, filtered through 0.2 μm nylon membrane filter prior to injecting an aliquot of 20 μL into HPLC ultra column (C18 microns, 5 μm ; 250 $\times$ 4.6 mm; LC-10A, Shimadzu, Japan). The column was eluted for approximately 10 min at room temperature with a 70:30 (v/v) acetonitrile–water mobile phase at a flow rate of 1.0 mL/min. Eluates were detected using a PDA (λ 230 nm) detector. Standard calibration curve was constructed using standard andrographolide (99%) from Sigma-Aldrich.

2.2.2 Determination of microcapsule characteristics

The particle morphology of microcapsule was studied using scanning electron microscopy (SEM) (JSM-5800 LV, JEOL, and Tokyo, Japan) at 15 kV acceleration voltages. Moisture content determination was followed by AOAC [16]. The water activity was determined by using a water activity analyzer (SPRINT-TH500, NOVASINA; Axair Ltd., Pfäffikon, Switzerland). FT infrared spectroscopy (FT-IR) was used to study the chemical characterization of microcapsule. The microcapsule was mixed and ground with potassium bromide thoroughly. The samples, KBr pellets, were obtained by compressing the mixture of fine powder under pressure of 15 000 psi for 2 min. The pellets were scanned for 16 times at a resolution of 4 cm^{-1} from 4000 to 400 cm^{-1} .

2.3 Statistical analysis

All data were acquired in triplicate. The data are shown as mean values with standard deviation. Differences between mean values were established using Duncan's multiple range tests with a level of significance of $p \leq 0.05$ (SPSS 17.0 software; IBM SPSS).

3 Results and discussion

3.1 Optimization of KGM concentration for enzymatic hydrolysis

The target viscosity of <100 mPa·s is required because this viscosity is related to ability of the spray dryer process. In a range of concentration of KGM from 9 to 18% (w/w), it was found that 12% (w/w) is the best suitable concentration as shown in Table 1. At higher concentrations of KGM >12% (w/w), the hydrolysate viscosity remained above 100 mPa·s. The hydrolysis of the 9% (w/w) KGM gave a lower viscosity than the required value; therefore, the ability to protect ingredients from heat during drying would have been reduced [6]. Thus, 12% (w/w) was the optimum to be used in the spray drying process. Beyond this concentration, the viscosity was too high (>150 mPa·s) for solutions undergoing spray drying process. If the viscosity is too high, it could block the atomization of the feed in drying chamber and lead to inadequate drying of the encapsulating material [17]. If the viscosity is too low, the coating performance will reduce the content of coated ingredients, hence it would not be protected from the heat during the drying process.

The determination of the mono-, di-, tri-, and oligosaccharides produced in the hydrolysate by using HPLC is performed to know whether KGM has been fully hydrolyzed to all sugar. However, HPLC result revealed oligosaccharides that were released from the different concentrations of KGM solution during mannanase hydrolysis (Table 1) were up to 11 distinct peaks during the elution time of 6–13 min (data not shown). By comparing with eight standards such as glucose and mannose (DP1), maltose (DP2) maltotriose (DP3), maltotetraose (DP4), maltopentaose (DP5), maltohexaose (DP6), and maltoheptaose ((DP7), elution times of sugar and oligosaccharides from KGMH with those of the standards were found to be matched and amount of the released sugar and oligosaccharides (DP1–DP7) could be calculated. Sugar (DP1–DP3) is obtained from the hydrolysis of KGMH hydrolysate was around 0.47–0.61 mg, whereas the oligosaccharides, DP4–DP7, were between 0.10 and 0.12 mg. These data confirmed that KGM is not fully hydrolyzed by mannanase to all sugar (DP1–DP3) but there are some of oligosaccharides, particularly DP4–DP7, which were of interest. This is because oligosaccharides from DP4 up to DP7 have been reported to have ability to protect bioactive compounds during microencapsulation in the spray drying process [18]. However, there is also long chain oligosaccharides (>DP7) that were not determined here but found in HPLC chromatogram. Therefore, the obtained KGMH could have ability to encapsulate small compounds in its matrix provided that it contains enough oligosaccharides. Mannanase could hydrolyze β -mannose with β -(1,4)-mannosidic linkages and the release of short β -(1–4)-manno-oligosaccharides. Accordingly, it has been reported that

Table 1. The viscosity and hydrolyzed products in the supernatant from mannanase (1500 units) hydrolysis at different concentrations of konjac glucomannan solution

The viscosity of solution and types of sugar	9% (w/w) KGMH	12% (w/w) KGMH	15% (w/w) KGMH	18% (w/w) KGMH
Viscosity (mPa·s)	11.82 ± 0.76 ^d	49.48 ± 6.83 ^c	167.60 ± 7.03 ^b	285.08 ± 9.20 ^a
DP1–DP3 ^{ns} (mg)	0.61 ± 0.06	0.55 ± 0.06	0.61 ± 0.09	0.47 ± 0.09
DP4–DP7 ^{ns} (mg)	0.12 ± 0.03	0.12 ± 0.03	0.12 ± 0.03	0.10 ± 0.01

Values in a row followed by different letters are significantly different ($p < 0.05$).

^{ns}Nonsignificant.

A Molecular structure of KGM

B Mannanase hydrolysis of KGM

C KGMH

D Andrographolide

E KGMH

F KGMH + β CD

G KGMH + γ CD

Figure 1. The overview process of enzymatic hydrolysis of KGM and microencapsulation via spray drying (A) molecular structure of KGM, (B) mannanase hydrolysis of KGM, (C) KGMH, (D) andrographolide and proposed structure of microcapsule from coating material, (E) KGMH, (F) KGMH + β CD, and (G) KGMH + γ CD.

mannanase hydrolysis was a suitable method to produce manno-oligosaccharides at a large scale [19,20]. Therefore, the total solid content of coating material at 12% (w/w) is selected to use in the spray drying process. Since using β CD or γ CD to encapsulate andrographolide is costly, KGM is selected to combine with β CD or γ CD to reduce the cost and enhance its encapsulation efficiency. The results are reported and discussed in section 3.2.

3.2 Comparison of microencapsulation efficiency of different coating materials for andrographolide microcapsule via spray drying technique

The suitable condition that was obtained from the result of section 2.1 is the use of 125 units of mannanase/g of KGM (1500 units of mannanase per 12 g of KGM). The section was conducted in order to increase efficiency of microencapsulation

of andrographolide by using KGMH combined with β CD or γ CD in the following concentrations; 10% (w/w) KGMH + 2% (w/w) β CD and 10% (w/w) KGMH + 2% γ CD and 12% (w/w) KGMH as the control. The overall process of enzymatic hydrolysis and encapsulation is shown in Fig. 1. In this section, the concentration of the core material was maintained at 2% (w/w) andrographolide and using the spray drying process at the inlet air temperature of 170°C and the outlet air temperature of 85 $\pm$ 3°C.

The encapsulation efficiency (%) and product yield (%) of each treatment are presented in Table 2. Among all coating materials, the product yield (%) of microcapsule, KGMH alone showed no different value of product yield (%) in comparison with KGMH- γ CD and KGMH- β CD that was 56.05 $\pm$ 2.52, 51.16 $\pm$ 3.40, and 50.54 $\pm$ 2.27%, respectively. But, by using the KGMH as a single coating material, it could maintain the encapsulation efficiency (%) better than using the KGMH- γ CD and KGMH- β CD as its efficiency was 46.63 $\pm$ 0.18% compared to 37.38 $\pm$ 0.88% and 10.82 $\pm$ 0.09% of KGMH- γ CD and KGMH- β CD, respectively. FT-IR spectra of microcapsule that encapsulated andrographolide at different treatment compared with FT-IR spectra of control sample are shown in Fig. 2A–G. Andrographolide crystals showed the stretching band at 1727 cm^{-1} , which was assigned to C=O [21]. The characteristic stretching bands of andrographolide showed in its physical mixtures with all three samples. In Fig. 2, the presence of C=O in these systems that include KGMH + andrographolide showed the stretching band at 1727.99 cm^{-1} , KGMH + β CD + andrographolide showed the stretching band at 1728.07 cm^{-1} , and KGMH + γ CD + andrographolide showed the stretching band at 1729.60 cm^{-1} , respectively. On the other hand, C=O was not found

Table 2. Encapsulation efficiency (%) and product yield (%) of different coating materials

Type of coating material	Encapsulation efficiency (%)	Product yield (%) ^{ns}
KGMH	46.63 $\pm$ 0.18a	56.05 $\pm$ 2.52
KGMH + γ CD	37.38 $\pm$ 0.88b	51.16 $\pm$ 3.40
KGMH + β CD	10.82 $\pm$ 0.09c	50.54 $\pm$ 2.27

Values in a column followed by different letters are significantly different ($p < 0.05$).

^{ns}Nonsignificant.

in FT-IR spectrum of pure control of three coating materials (Fig. 2E–G). KGMH alone showed the most effective coating capacity due to the intermolecular force between oligosaccharides that were mixed with the andrographolide, as shown in Fig. 1. After mixing the KGMH solution with the andrographolide solution, the dehydration process took place. During the drying process, the binding force between the molecules of the oligosaccharides was created, resulting in enclosing the particles and coating the andrographolide in the particles (see the SEM in Fig. 3A1 and B1), between KGMH and andrographolide [22, 23]. Moreover, the particle was also found to have a round shape due the continuous phase of the oligosaccharides that coated the bioactive compound without breaking of the particle. In the case of CD (γ CD and β CD), it was placed into hydrophobic cavity of pocket shape that would coat the andrographolide from inside. On the other side of CD that had the open in space, it contains primary hydroxyl groups and secondary hydroxyl groups, which contain numbers of OH groups. Once the CD +

Figure 2. The FT-IR spectra of (A) andrographolide control, (B) andrographolide + KGMH, (C) andrographolide + KGMH + β CD, (D) andrographolide + KGMH + γ CD, (E) KGMH control, (F) β CD control, and (G) γ CD control.

Figure 3. SEM of (A: 100×) andrographolide control, (A1: 500×, B1: 2000×) andrographolide + KGMH, (A2: 500×, B2: 2000×) andrographolide + KGMH + β CD, and (A3: 500×, B3: 2000×) andrographolide + KGMH + γ CD spray dried at inlet air temperature of 170°C and outlet air temperature of 85 ± 3°C.

andrographolide solution was mixed with the KGMH and went to the process of dehydration, it led to the steric attraction, producing the interruption on the intermolecular forces between the KGMH oligosaccharides and CD [24]. This phenomenon created the strain that resulted in discontinuous phase of the KGMH oligosaccharide [25]. This can be seen under SEM, as shown in Fig. 3A2, A3, B2, and B3). The particle came out as an oval shape with the cracks on the surface of the particle. The outcome of this phenomenon led to the loss of andrographolide during the encapsulation process. Therefore, only KGMH could encapsulate the andrographolide inside its microcapsule better than using the coating material of KGMH–CD, whereas other characteristics, such as the moisture content and the water activity, were not statistically different ($p > 0.05$) (Table 3). Furthermore, when using the KGMH alone as a coating material also

Table 3. Water activity and moisture content (% (w.b.)) of microcapsules from different coating materials

Type of coating material	Water activity (a_w) ^{ns}	Moisture content (% (w.b.)) ^{ns}
KGMH	0.25	5.11 ± 0.07
KGMH + γ CD	0.26	5.03 ± 0.63
KGMH + β CD	0.27	6.06 ± 0.84

^{ns}Nonsignificant.

have lower production costs than the KGMH– γ CD and KGMH– β CD. Therefore, the development of the KGMH as a coating material, as shown in this study, can provide an alternative for the

industry to use andrographolide in various applications. However, the encapsulation efficiency and product yield of andrographolide microcapsules should be improved in further study.

4 Concluding remarks

The optimum concentration of 12% (w/w) KGM per 1500 units of mannanase (125 units mannanase per gram of KGM) was suitable for hydrolysis of KGM solution to the required viscosity within 4 h. HPLC analysis of KGMH solution found a fair amount (0.10–0.12 mg) of oligosaccharides (DP4–DP7), which means that KGMH hydrolysate contains oligosaccharides and can be used for encapsulation. To develop suitable condition for encapsulation andrographolide, KGMH encapsulation performance was compared with KGMH combined with γ CD or β CD and spray dried at an inlet temperature of 170°C and outlet air temperature of 85°C. However, 12% (w/w) of KGMH provides the highest percentage of encapsulation efficiency in comparison with KGMH- γ CD and KGMH- β CD with significant difference ($p < 0.05$). The chemical properties of the microcapsule were not different ($p > 0.05$) in terms of water activity and moisture content. As a result, it appears that KGMH is capable to produce useful microcapsule of bioactive substance for the pharmaceutical industry.

Practical application

The outcome of this study is a process that is capable to produce useful encapsulated coating material for the food and pharmaceutical industry.

The authors would like to thank the 90th Anniversary of Chulalongkorn University Fund (Ratchadaphiseksomphot Endowment Fund), Chulalongkorn University Special Task Force for Activating Research (STAR), and Dehydration of Food and Biomaterials for research funds.

The authors have declared no conflict of interest.

5 References

- [1] Tatirat, O., Charoenrein, S., Physicochemical properties of konjac glucomannan extracted from konjac flour by a simple centrifugation process. *Food Sci. Technol.* 2011, 44, 2059–2063.
- [2] Zhang, Y. G., Xie, B. J., Gan, X., Advance in the applications of konjac glucomannan and its derivatives. *Carbohydr. Polym.* 2005, 60, 27–31.
- [3] Cescutti, P., Campa, C., Delben, F., Structure of the oligomers obtained by enzymatic hydrolysis of the glucomannan produced by the plant *Amorphophallus konjac*. *Carbohydr. Res.* 2002, 337, 2205–2511.
- [4] Tobin, J. T., Fitzsimons, S. M., Chaurin, V., Kelly, A. L. et al., Thermodynamic incompatibility between denature whey protein and konjac glucomannan. *Food Hydrocoll.* 2012, 27, 201–207.
- [5] Zhang, Y. G., Xie, B. J., Gan, X., Advance in the applications of konjac glucomannan and its derivatives. *Carbohydr. Polym.* 2005, 60, 27–31.
- [6] Adamiec, J., Borompichaichartkul, C., Srzednicki, G., Panket, W. et al., Microencapsulation of kaffir lime and its functional properties. *Drying Technol.* 2012, 30, 914–920.
- [7] Yang, J., Xiao, J. X., Ding, L. Z., An investigation into the application of konjac glucomannan as a flavor encapsulant. *Eur. Food Res. Technol.* 2009, 229, 467–474.
- [8] Kumar, A. R., Sridevi, K., Vijaya, V. N., Nanduri, S. et al., Anticancer and immune stimulatory compounds from *Andrographis paniculata*. *J. Ethnopharmacol.* 2004, 92, 291–295.
- [9] He, Z., Zhang, J., Huang, D.A., Kinetic correlation for konjac powder hydrolysis by β -mannanase from *Bacillus licheniformis*. *Biotechnol. Lett.* 2001, 23, 389–393.
- [10] Rajabi, H., Ghorbani, M., Jafari, S. M., Mahoonak, A. S. et al., Retention of saffron bioactive components by spray drying encapsulation using maltodextrin, gum Arabic and gelatin as wall materials. *Food Hydrocoll.* 2015, 51, 327–337.
- [11] Astray, G., Gonzalez-Barreiro, C., Mejuto, J. C., Rial-Otero, R. et al., A review on the use of cyclodextrins in food. *Food Hydrocoll.* 2009, 23, 1631–1640.
- [12] Zhu, Y. P., *Chinese Material Medical: Chemistry, Pharmacology, and Applications*. Harwood Academic Publishers, Amsterdam 1998, pp. 189–193.
- [13] Dinh, S. M., DeNuzzio, J. D., Comfort, A. R., Intelligent materials for controlled release. *J. Am. Chem. Soc.* 1999, 119, 113–127.
- [14] Wattanaprasert, S., Borompichaichartkul, C., Srzednicki, G., Vaithanomsat, P., Process modification of potential Thai economical tuber crop to be used in microencapsulation for nutraceutical products. *Proceedings of 2nd Asia Pacific Symposium on Postharvest Research, Education and Extension*, Yogyakarta, Indonesia, September 18–20, 2012.
- [15] Chen, J., Liu, D., Shi, B., Wang, H. et al., Optimization of hydrolysis conditions for the production of glucomannan-oligosaccharides from konjac using β -mannanase by response surface methodology. *Carbohydr. Polym.* 2012, 93, 81–88.
- [16] AOAC, *Official Methods of Analysis of AOAC International*, 17th ed., AOAC International, Rockville, MD 2000.
- [17] Rosenberg, M., Kopelman, I. J., Talmon, Y., Factors affecting retention in spray-drying microencapsulation of volatile materials. *J. Agric. Food Chem.* 1990, 38, 1288–1294.
- [18] Inglett, G. E., Gelbman, P., Reineccius, G. A., Encapsulation of orange oil-use of oligosaccharides from α -amylase modified starches of maize, rice, cassava, and potato, in: Risch, S. J., Reineccius, G. A. (Eds.), *Flavor Encapsulation: ACS Symposium Series* 1988, vol. 370, pp. 29–36.
- [19] Van-Zyl, W. H., Rose, S. H., Trollope, K., Görgens, J. F., Fungal β -mannanase: Mannan hydrolysis, heterologous production and biotechnological applications. *Process Biochem.* 2010, 45, 1203–1213.
- [20] Akino, T., Nakamura, N., Horikoshi, K., Characterization of three β -mannanase of an alkalophilic *Bacillus* sp. *Appl. Microbiol. Biotechnol.* 1988, 52, 773–779.
- [21] Ribeiro, L. S. S., Ferreira, D., Veiga, F. J. B., Hydroxypropyl methylcellulose microspheres with piroxicam and

- piroxicam-hydroxypropyl- β -cyclodextrin inclusion complex. *Eur. J. Pharm. Sci.* 2003, 20, 253–266.
- [22] Chao, W., Mei, X., Wen-ping, L. V., Pei, Q. I. U. et al., Study on rheological behavior of konjac glucomannan. *Phys. Procedia* 2012, 33, 25–30.
- [23] Alonso-Sande, M., Teijeiro-Osorio, D., Remuñán-López, C., Alonso, M. J., Glucomannan, a promising polysaccharide for biopharmaceutical purposes. *Eur. J. Pharm. Biopharm.* 2009, 18, 453–462.
- [24] Zhou, H., Lai, W. P., Zhang, Z., Li, W. K. et al., Computational study on the molecular inclusion of andrographolide by cyclodextrin. *J. Comput. Aid. Mol. Des.* 2009, 23, 153–162.
- [25] Pranker, R. J., Stone, H. W., Sloan, K. B., Perrin, J. H., Degradation of aspartame in acidic aqueous media and its stabilization by complexation with cyclodextrins or modified cyclodextrin. *J. Clin. Pharm. Ther.* 1992, 29, 37–45.