

# Viscosity and Gel Formation of a Konjac Flour from *Amorphophallus oncophyllus*

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## Abstract

The influences of different variables on the viscosity and gel formation of the konjac flour produced from *Amorphophallus oncophyllus* have been studied. At the concentration studied, the 1.5% konjac flour yielded a viscous solution than that of 0.5% konjac flour. The viscosity of konjac flour solution were unaffected by pH (pH 2 to pH 8), salt concentration (0-10% w/v), and high acid (pH 3.5) / high temperature (70 °C) condition for 5 hr. With higher sucrose concentration, the viscosity of konjac flour solution tended to decrease. The konjac flour maintained its viscosity under sterilization process (121 °C at 15 lb/in<sup>2</sup>) for 30 min, whereas the viscosity decreased in the same condition with the presence of 2.5% NaCl. The considerable increase in viscosity were observed for the mixtures of konjac flour / rice flour, konjac flour / wheat flour, and konjac flour / corn flour. For gel formation studied, the hydrocolloids which synergistically interacted with konjac flour to form gels were xanthan gum, **k**-carrageenan, and agar. The texture of these gels were varied with konjac flour/synergistic hydrocolloids ratios.

**Keywords:** Konjac flour, *Amorphophallus oncophyllus*, viscosity, gel formation, hydrocolloids, xanthum gum, **k**-carrageenan.

## Introduction

The konjac plant is a perennial plant and a member of the family of Araceae. There are many species of konjac plants in the Far East and Southeast Asia that belong to the *Amorphophallus*, for example, *A. konjac* K. Koch, *A. rivierii*, *A. bulbifer*, *A. oncophyllus*, etc. (Takigami 2000). The *A. oncophyllus* grown in Thailand contains high glucomannan in their tubers. Glucomannan or konjac mannan is a heteropolysaccharide consisting of D-mannose and D-glucose in a ratio of 1.6:1 with  $\beta$  (1,4) linkages. There are random acetyl side group, typically one per six sugar residues (Thomas 1997).

The raw material for konjac flour or konjac gum is the konjac tuber. The konjac flour is composed of 70-90% glucomannan (Thomas 1997). This flour has been

traditionally used in Japan both as a food and a medicine (Wootton *et al.* 1993). For food applications, the konjac flour is based on basic properties including thickening agent, gelling agent and water binding, which are suitable for many food products (Ford and Chesey 1986 ; Toba *et al.* 1986 ; Tye 1991 ; Thomas 1997). It may be used to provide fat replacement properties in low-fat meat products and reduced fat cake and cookie products (Osburn and Keeton 1994 ; Akewan 1997 ; Akewan 1998). The konjac flour was approved by the USDA-FSIS in July 1996 for use in prepared meat products (Chin *et al.* 1998). For clinical studies, the konjac mannan solution has the ability to reduce cholesterol and triglycerides, to influence on glucose tolerance and glucose adsorption and to demonstrate the role of dietary fibre in weight reduction (Sugiyama and Shimahara 1974 ; Hannigan 1980).

In general, the proper applications of any hydrocolloids are depended on their functional properties such as viscosity, solubility, and gel formation. The objective of this research was to investigate the influences of variables on viscosity of a solution of the konjac flour obtained from *A. oncophyllus* which indigenous to Thailand. Furthermore, the purpose of the study was also considered the gel formation of konjac flour in combination with other hydrocolloids.

## Materials and Methods

### Materials

Konjac flour (100 mesh sieve), produced from *Amorphophallus oncophyllus* by the method of Akesowan (1997), with a moisture content of 9.52% was used. Sucrose and sodium chloride (NaCl) used were of AR grade. Hydrocolloids (food grade) including xanthan gum, K-carrageenan, agar, pectin and gelatin were obtained from the Thai Food and Chemicals, Ltd.

### Viscosity of konjac flour solution

The influences of the different factors affecting on viscosity of a solution of konjac flour have been studied in this work as following operational conditions :

**Concentration:** 0.5, 1.0 and 1.5%

**PH:** pH 2 - pH10

**Salt Concentration:** 1% konjac flour in phosphate buffer pH 7.0 with different salt concentration (0, 5 and 10%) and time (0 to 180 min).

**Sucrose Concentration:** 0.5% konjac flour in phosphate buffer pH 7.0 with different sucrose concentration (0, 25 and 50%) and times (0 to 180 min).

**High Acid / High Temperature:** 1.0% konjac flour in acid-phthalate buffer pH 3.5 with heating temperature at 70°C for 1 to 5 hr.

**Thermal Stability:** 0.5% and 1.0% konjac flour in distilled water compared to 0.5% and 1.0% konjac flour in 2.5% NaCl solution

(phosphate buffer pH 7.0) with sterilized in an autoclave (Hirayama Model HA-300 MII, Japan) at 121°C, pressure at 15 lb/in<sup>2</sup> for 30 min.

**Interaction with Flour:** Flour, namely, rice, wheat, corn, tapioca and glutinous flour were selected in this study. The 5% mixture of konjac flour and these flours (1:4) were heated at 80-85°C until the total volume was reduced to 2/3. After cooling at room temperature (25-27°C), the mixture was measured with a Brookfield. In addition, the konjac flour and synergistic flours were studied in Brabender viscoamylography using a viscoamylograph (C.W.Brabender Instruments, Inc., NJ).

### Viscosity Measurement

Viscosity measurements were carried out at room temperature (25-27°C) using a Brookfield viscometer (Model RVTDV II, Brookfield Engineering Laboratories, Inc, Stoughton, MA). Each sample was used at 200 ml in a 250 ml beaker. The suitable spindle was employed for each treatment, while shear rate was set up at 100 rpm. Triplicate measurements were made in each treatment.

### Gel formation of konjac flour

Hydrocolloids such as xanthan gum, K-carrageenan, agar, pectin and gelatin, were selected to study the interaction between konjac flour and these hydrocolloids to form gels. The total hydrocolloid concentration was studied at 1.0%. The combination of konjac flour and these hydrocolloids at any ratio were added in distilled water and heat at 80-85°C until the total volume was reduced to 2/3. The hot solutions of konjac flour / hydrocolloids mixtures were poured immediately into a container (4.3 cm diameter × 3 cm depth), and cooled at room temperature for 1 hr. Peak force necessary to shear each sample was measured with a Lloyd texture analyzer (Model LRX, Lloyd instruments, Hampshire, UK) with a 1000-N load cell and a crosshead speed of 250 mm/min. Triplicate measurements were made in each sample.

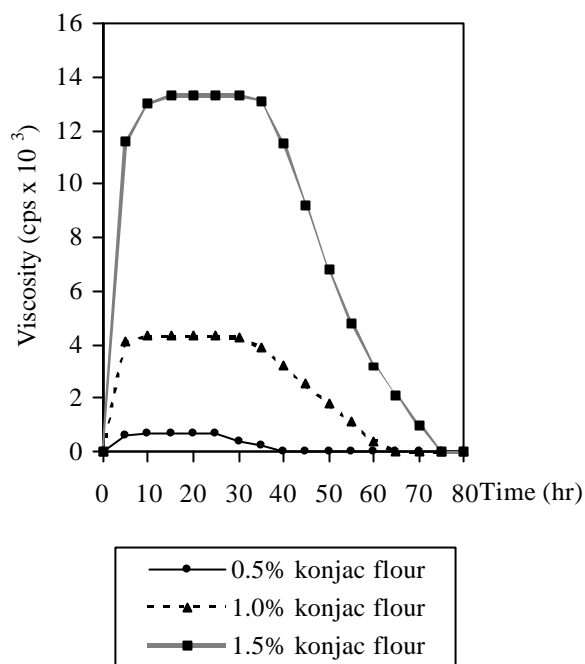
## Results and Discussion

### Viscosity of Konjac Flour

A konjac flour solution was prepared at room temperature by slowly adding konjac flour to water with stirring until the powder was completely dissolved. It was necessary to stir the solution continuously so that the powder did not lump. The viscosity of a solution of konjac flour changed with time. As shown in Fig. 1, the konjac flour (at any concentration) yielded solutions with low viscosity within the first hour after dissolving, and then they formed viscous solutions a few hours later. The viscosity of konjac flour solution increased with stirring time and reached constant values after 5, 6 and 12 hr for 0.5, 1.0, and 1.5% konjac flour, respectively. The viscosity of konjac flour solution increased with increasing concentration. The viscosity of 1.5% konjac flour solution was more than 15 times higher than that of the 0.5% solution. The konjac flour solutions maintained highest viscosity for different hours because of difference in concentration, and then the decreases in viscosity were obtained. The time for constant viscosity and declined viscosity of 0.5% konjac flour solution was less than those of 1.0 and 1.5% konjac flour.

The effect of pH on viscosity change for 0.5% and 1.0% konjac flour solutions was presented in Table 1, and showed that the viscosity tended to slightly change with decreasing pH values from pH 8 to pH 2. It may be stated that the viscosity of konjac flour solution was stable in this pH range. At pH 10, the konjac flour solution yielded higher viscosity and started changing to gel. The viscosity of konjac flour solution was not affected by salt concentration (10% NaCl) (Fig. 2). This can be explained that konjac flour is non-ionic, therefore, it is unaffected by the levels of salt used and is stable to below pH 3.8 (Thomas 1997).

The sucrose concentration was influenced on the konjac flour solution as evidenced by decrease in viscosity values (Fig. 3). The viscosity of 0.5% konjac flour in 50% sucrose solution was only 20 cps, which



**Fig 1.** Relationships between viscosity of konjac flour solution at different concentrations and stirring time determined using a Brookfield viscometer with the spindle no. 7 at 100 rpm.

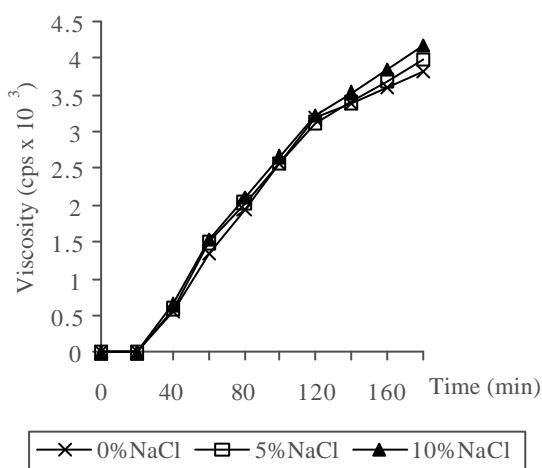
**Table 1.** Effect of pH on viscosity of 0.5% and 1.0% konjac flour solutions

Konjac flour concentration (%)	Viscosity*(cps)				
	pH 2	pH 4	pH 6	pH 8	pH 10
0.5	575	580	582	586	610
1.0	5385	5396	5395	5400	5450

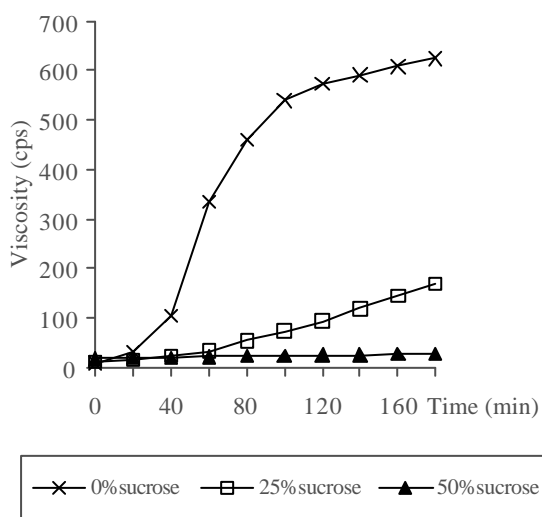
\*Determined using a Brookfield viscometer with the spindle no.7 at 100 rpm.

was constant during 180 min. It was attributed to no hydration of konjac flour. With 25% sucrose concentration, the konjac flour solution showed the slow rate of hydration, allowing lower viscosity than that of the control (0.5% konjac flour in distilled water). This phenomena may be due to the affinity of sucrose to being extremely soluble in water, resulting in decrease of free water which is necessary for hydration of konjac flour (Knecht 1990; James 1995). The dissolution of konjac flour tended to decrease as the sucrose concentration increased.

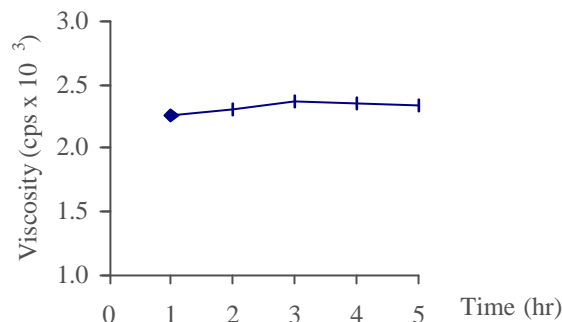
The influence of heating condition was also studied. As could be seen in Fig. 4, the viscosity of 1.0% konjac flour solution were stable in the high acid (pH 3.5) / high temperature (70°C) condition for 5 hr. The 1.0% konjac flour solution also maintained its viscosity as heating at 121°C in an autoclave (15 lb/in<sup>2</sup>) for 30 min, but reduction of the viscosity for 1.0% konjac flour in 2.5% NaCl solution was observed as heating in the same condition (Fig. 5).



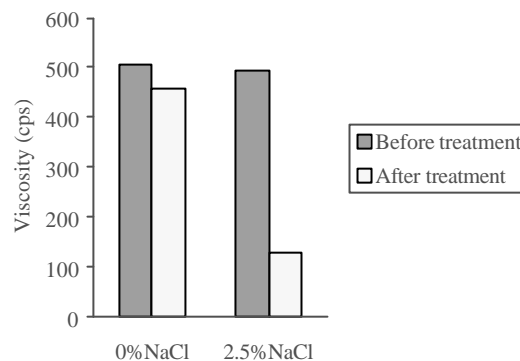
**Fig 2.** Effect of salt concentration on viscosity of 0.5% konjac flour solution determined using a Brookfield viscometer with the spindle no. 7 at 100 rpm.



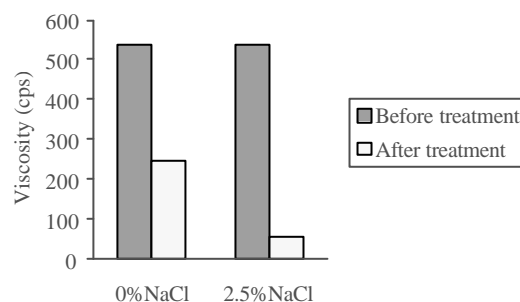
**Fig 3.** Effect of sucrose concentration on viscosity of 0.5% konjac flour solution determined using a Brookfield viscometer with the spindle no. 7 at 100 rpm.



**Fig 4.** Effect of high acid / high temperature on viscosity of 1.0% konjac flour solution determined using a Brookfield viscometer with the spindle no. 7 at 100 rpm.



(a) 1.0% konjac flour solution



(b) 0.5% konjac flour solution

**Fig 5.** Effect of salt and sterilization (121°C) on viscosity of konjac flour solution determined using a Brookfield viscometer with the spindle no. 7 at 100 rpm.

Konjac flour interacted with most flours to give a considerable increase in viscosity of the solutions of mixtures which were not achieved with flours alone or konjac flour

alone, as shown in Fig 6. The flours which interacted synergistically with konjac flour to give higher viscosity were rice, wheat and corn flour, for example, the maximum viscosity of mixed corn flour / konjac flour was  $14 \times 10^3$  cps, while viscosity of corn flour and konjac flour solution were found to have values of  $1.8 \times 10^3$  and  $10.8 \times 10^3$  cps, respectively.

The viscoamylograph is the industry-standard instrument used to control mixing, heating, and cooling during viscosity measurement (Murphy 2000). The Brabender viscoamylographs of konjac flour, rice flour, wheat flour, corn flour, and mixtures of konjac flour/these flours were presented in Table 2. The gelatinization temperature of rice flour, wheat flour, and corn flour were 85-95°C, 84-94°C, and 79-92°C, respectively, whereas the konjac flour exhibited broader gelatinization temperature (43-95°C). When these flours were mixed with the konjac flour, decreases in gelatinization temperature of each combination occurred. These combination showed higher Brabender viscosity than those of individual flour. The viscosity broke down during the holding cycle at 95°C for 15 min except for the mixture of konjac flour/wheat flour. Further study is required to elucidate this point to explain the latter.

### **Gel Formation of Konjac Flour**

The konjac flour, when heated and cooled, gave a viscous solution. The konjac flour solution did not change to a gel under heating condition. In general, polysaccharide gels are formed when long molecules in solution come together to form a network (Tye 1991). When konjac flour was combined with other hydrocolloids, the synergism to form gels was occurred. The synergistic interactions between konjac flour and three synergistic hydrocolloids including xanthan gum, K- carrageenan and agar, were obtained. As shown in Table 3, the konjac flour / xanthan gum mixtures formed gel under heating conditions for which the individual components did not gel. This behavior must be due to the intermolecular interaction between the konjac flour (glucomannan) and xanthan gum, producing a gel. Morris (1998) stated

that the exact mechanism of this interaction was really unknown. The mechanism models for gelation were suggested in many ways, namely: (1) a binding of the glucomannan backbone to the xanthan helix, (2) combination of a glucomannan backbone with the free cellulosic face of the backbone of the denatured xanthan helix, (3) deacetylation of xanthan in xanthan-konjac mannan mixtures, enhanced xanthan-konjac mannan gelation, and (4) heating disrupted aggregated xanthan chains, enabling interaction with glucomannan to occur, etc. However, the precise nature of the konjac flour/xanthan gum interaction is still very much in debate.

Algal polysaccharide such as agar and K-carrageenan, can form gels alone under certain conditions. When mixed with konjac flour or glucomannan (which can not form a gel), they interacted synergistically to produce a more elastic gel. The early model for gelation of algal polysaccharide-glucomannan mixtures was based on observations of self-association of glucomannan, plus evidence taken to suggest intermolecular binding between the two polysaccharides. In recent studies, the model which appeared to be becoming accepted was that the glucomannan adsorbed to the surface of the aggregated or crystalline junction zone formed by the algal polysaccharide, thus consolidating this network (Morris 1998). Williams and Phillips (1995) stated that on cooling the carrageenan chains undergo a conformational transition from random coil to (double) helices, thus lowering the overall interfacial energy. The helices can either self-aggregate or associate with mannan chains. Mannan-carrageenan association may be preferred to carrageenan-carrageenan association because the konjac mannan molecules are uncharged.

The peak force (N) of the gels of these mixtures was higher than the peak force shown by the hydrocolloids separately (Table 3). The force needed to shear the gel depended on the konjac flour / synergistic hydrocolloids ratio for 1% total hydrocolloid concentration, for example, the forces of gels of konjac flour / K-carrageenan for 20:80 and 40:60 were 5.2 N and 13.0 N, respectively. The greatest peak forces were obtained similarly for 0.6:0.4 ratio

of all mixed konjac flour/synergistic hydrocolloids gels, as could be seen in Table 3. The difference in values of peak force at the same 0.6:0.4 ratio for mixed gels were attributed to different types of hydrocolloids. In fact, the agar exhibits more brittle gel than that of the K-carrageenan, therefore, it is easy to break the gel (Glicksman 1969). When the increase of konjac flour was applied, the peak forces of these mixed gels tended to increase. This may be due to mixed gels were less brittle but more elastic, thus requiring higher force to break the gels. However, at the 0.8:0.2 ratio, the decreases in peak forces of mixed gels were obtained.

## Conclusion

This study showed that the viscosity and gel formation of konjac flour produced from *Amorphophallus oncophyllus* were influenced by different variables. The viscosity of konjac flour solution changed with operational conditions such as total concentration, absence or presence of salt or sucrose, and heating condition. The synergistic behavior in viscosity was observed when the konjac flour was mixed with rice, wheat, and corn flour. For gel formation, the highest peak force was achieved for ratio of 0.6:0.4 konjac flour and synergistic hydrocolloids including xanthan gum, κ-carrageenan, and agar.

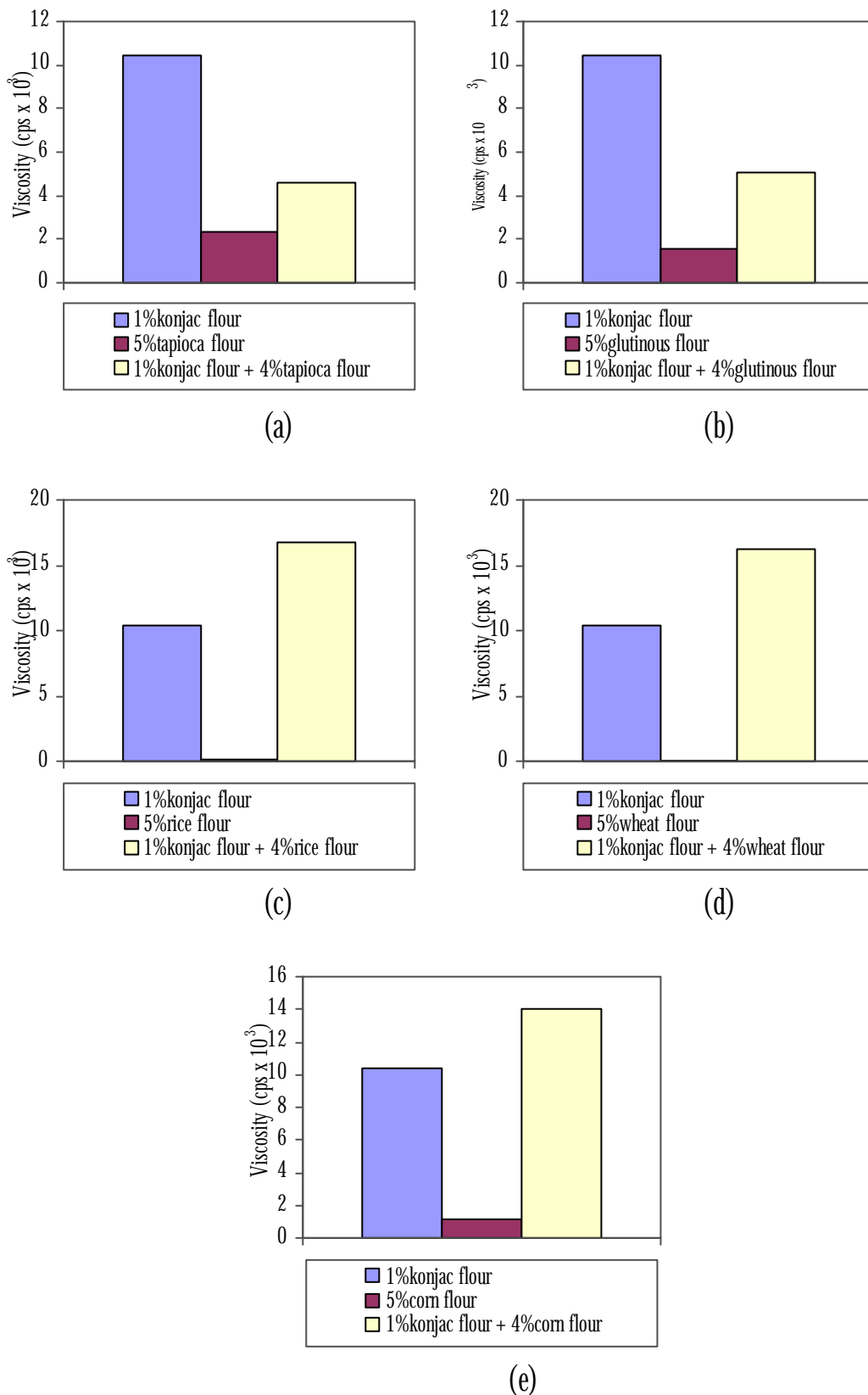
## Acknowledgement

This work has been carried out with financial support from The University of the Thai Chamber of Commerce (UTCC). The author wishes to thank Mrs. Pensiri Kiatkittigul for assistance in obtaining the Brabender viscoamylographs analysis.

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- (References continued on p. 149)



**Fig 6.** Viscosity of 5% mixture of konjac flour / other flours (1:4) determined using a Brookfield viscometer with the spindle no. 7 at 100 rpm. These mixtures as following : (a) konjac flour/tapioca flour (b) konjac flour/glutinous flour (c) konjac flour/rice flour (d) konjac flour/wheat flour and (e) konjac flour/corn flour

**Table 2.** Brabender viscoamylographs of 1% konjac flour, 5% flours and 5% the mixtures of konjac flour and other flours (1:4)

Type	Gelatinization temp (°C)	Brabender viscosity (Bu)			
		at peak	95°C	95°C 15 min	50°C
Rice flour	85-95	95	95	90	275
Wheat flour	84-94	18	18	20	55
Corn flour	79-92	165	165	140	300
Konjac flour	43-95	870	870	940	1,480
Konjac flour: rice flour (1:4)	38-88	2,400	1,980	1,620	2,270
Konjac flour : wheat flour (1:4)	36-89	1,390	1,350	1,390	2,340
Konjac flour : corn flour (1:4)	38-85	2,440	1,620	1,130	1,650

**Table 3.** Peak force of mixtures of konjac flour and other hydrocolloids with various compositions. Total concentration of the mixtures was 1%

Konjac flour concentration (%)	Other hydrocolloids concentration (%)	Peak force (N)				
		Xanthan gum	K-carrageenan	Agar	Pectin	Gelatin
0.0	1.0	-	2.0	1.2	-	-
0.2	0.8	5.7	5.2	1.4	-	-
0.4	0.6	14.2	13.0	2.0	-	-
0.6	0.4	15.3	15.2	3.1	-	-
0.8	0.2	7.8	8.0	1.5	-	-
1.0	0.0	-	-	-	-	-

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