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Concentration of Soymilk

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SUMMARY

A logarithmic relationship was observed between the apparent viscosity of soymilk and the solids content. When soymilk was concentrated to 27% solids, it was a thick, resilient gel. The addition of 0.5% sodium sulfite had the effect of reducing the apparent viscosity of concentrated soymilk at solids contents below 20%. Sodium sulfite at concentrations of 0.05% was found to be relatively ineffective in reducing the viscosity of concentrated soymilk. Addition of sucrose to the soymilk before concentration had the effect of increasing the viscosity of soymilk. A sweetened condensed soymilk evaporated at a temperature of 82°C showed better redispersibility of the protein than soymilk evaporated at lower or higher temperatures.

INTRODUCTION

The marketing advantages of concentrated cow's milk would also be applicable to soymilk, if the latter could be concentrated to a solids level of 30% or above and still retain an acceptable viscosity.

The problems in the concentration of soymilk, one of which is the viscosity behavior of soymilk during concentration, have been investigated by very few workers. Tan (1958) investigated the effect of solids content on the viscosity of soymilk. He reported an abrupt increase in the viscosity of soymilk as the solids content approached the 30% level. The term "viscosity-barrier" was used to describe this phenomenon.

Preliminary observations in this laboratory showed that, when soymilk was concentrated to a high solids level, a gel-like structure was formed, thus confirming Tan's finding.

Pre-heating of cow's milk for various times and temperatures (forewarming) has been found to be effective in controlling the viscosity of both evaporated milk and sweetened condensed milk, Deysher *et al.* (1929, 1944), Curran *et al.* (1944), Webb *et al.* (1943a), and Webb *et al.* (1943b). This forewarming effect applied to soymilk before concentration was also investigated by Tan (1958). He concluded that both the temperature and the duration of heating soymilk before concentration increased the viscosity of the concentrated soymilk. Forewarming resulted in the establishment of a "viscosity-barrier" at a lower solids level than was encountered in the absence of a forewarming procedure.

Ferry (1948) postulated that the formation of gel structure in protein was generally caused by the denaturing and unfolding of the polymers, allowing a maximum exposure of the reactive sites as well as the non-polar groups, making them less hydrophilic. During the gel formation, cross-linkages were formed between the active sites along the chains, while the hydrophobic groups tended to repel water molecules, effecting a dehydrating process.

Circle *et al.* (1964) attributed the formation of gel-like structures in soy proteins as well as the increases of viscosity in the water-dispersion of soy proteins, partly to the formations of disulfide bonds between cysteines in the proteins. They also reported that sodium sulfite, a disulfide bond disruptor, had the effect of reducing the viscosity of the aqueous dispersions of isolated soy proteinates.

Since the use of sulfite compounds to control color in food products is not an uncommon practice, for example, in the spray drying of egg white, the effect of this compound in the concentration of soymilk was studied.

The viscosity of soymilk was studied before and after concentration. The effect of the temperature of evaporation on the ability of the concentrated soymilk to be redispersed was investigated.

EXPERIMENTAL METHODS

Method of concentration of soymilk. Non-dehulled soybeans of Harasoy variety were used. Soymilks of 5, 7, or 9% solids content were prepared from non-soaked beans ground with water at 90°C using a ratio of 1:10 (beans:water) w/w. Grinding was done in a Waring blendor for 7 min and filtered through a Buchner funnel under 15-in. vacuum equipped with 7-in. standard Agway-GLF milk filtering pads with one layer of coarse pad on top of a fine pad.

A sample size of 600 ml of soymilk was used for each concentration, which was done in a 3-L, round-bottom wide-mouth evaporating flask. The flask was attached to a rotary vacuum evaporator. The temperature of each evaporation was controlled by partly immersing the flask under the water surface in a temperature-controlled water bath. The internal temperature of the soymilk was measured with a thermocouple and a potentiometer. An internal temperature of between 65 to 75°C and a vacuum of 15-in. U. S. gauge were used for each evaporation.

The condensate was recovered in

two suction flasks, hooked in series in an ice bath. The volume of the condensate collected was used as an indication of the extent of each evaporation. The exact solids content of each sample, however, was determined on a Cenco moisture balance. A sample size of 5 g and a drying period of 30 min were given for each moisture measurement on the Cenco balance.

Sodium sulfite or sugar to be added to the soymilk samples was incorporated before concentration. The additives were mixed with the soymilk for 30 min on a magnetic stirrer before evaporation was started. The time of each evaporation, depending upon the required solids level, varied from 3 to 5 hr.

Viscosity determinations on soymilk. Viscosity of samples was measured on a Brookfield viscometer. The RV and RVT spindles were employed to cover, respectively, the low and high viscosity ranges of the samples. Rotation speeds of 100 and 5 rpm were used for measurements with the RV and RVT spindles respectively. The speed of rotation was generally kept constant for each spindle, while different spindles were used to cover various viscosity ranges.

The apparent viscosity was expressed in centipoises by referring to Brookfield conversion charts.

Color of the samples was measured in a Hunter color difference meter (Model 25). The "small-area" of illumination was employed to measure the reflected color.

RESULTS AND DISCUSSION

Viscosity of soymilk at various levels of concentration. A logarithmic relation was observed between the apparent viscosity of soymilk (Fig. 1, control sample) and the solids content. The initial apparent viscosity of a 5% solids soymilk was 19 cps, while that of a 21 and 27% solids soymilk were 1.4×10^4 and 1.8×10^5 cps, respectively. The concentrated soymilk of 27% solids was a thick, resilient gel.

Using a soymilk of 5% solids content, the apparent viscosity of the soymilk sample increased from 8 to 19 cps as the speed of rotation of the spindle increased from 20 to 100 rpm (Table 1).

It was also found that a change in the size of the spindle from the No. 1 to No. 2 resulted in a smaller variation in the apparent viscosity than changes in the speed of rotation of the same spindle. Therefore, changes in the speed of rotation were avoided as much as possible, when samples of various viscosity were measured.

Table 1. Viscosity measurements of soymilk containing 5% solids.[1]

Speed of spindle rotation rpm	Converted apparent viscosity in cps[2]	
	Measured by Spindl. No. 1	Measured by Spindle No. 2
20	8.0	10.0
50	12.8	12.8
100	19.4	18.4

[1] Viscosity measurements done at 25°C.
[2] Viscosity measurements made in a Brookfield RV-Viscometer.

This indicates that soymilk is a non-Newtonian fluid, since its viscosity depends upon the force of shear which is directly related to the speed of rotation of the spindle.

Concentrated soymilk of 20% solids indicated properties of a thixotropic material, in which the apparent viscosity decreased with increasing time of shearing. The Brookfield viscometer showed a decrease in viscosity of a 20% solids soymilk with increasing time of measurements (Fig. 2).

The above characteristic of concentrated soymilk required that its viscosity be determined by using the Brookfield RVT spindles and the Helipath stand which lowered the inverted T-shaped spindle into the material as it was rotated. In this manner the spindle traced the locus of a helix, and only new materials were sheared throughout a measurement. The shear thinning effect also required that each sample be measured only once, as second measurements on the same sample gave unreliable results (Figure 2).

The addition of 0.5% of sodium sulfite had the effect of reducing the apparent viscosity of concentrated soymilk at solids content of below 20%, beyond which the apparent viscosity of soymilk increased abruptly in a logarithmic manner. The apparent viscosity of concentrated soymilk containing 0.5% sodium sulfite at a soymilk solids level of 24% was 8.4×10^3 cps and that of 39% solids was 6.2×10^3 cps (Fig. 1). In the latter case, the material had a resilient property and was too thick to be poured from a container.

The residual sulfite taste of a 0.5% sodium sulfite soymilk was objectionable; therefore, a lower level of 0.05% (500 ppm) was tested. A sulfite concentration of 0.05% sodium sulfite was found to be relatively ineffective in reducing the viscosity of the concentrated soymilk (Fig. 1). The logarithmic relation was resumed at the 12% solids level, giving an apparent viscosity of 6×10^3 and 1×10^5 cps at the 20 and 26% solids level.

Following is the theoretical estimation of a minimum level of sodium sulfite required to prevent the formation of disulfide bonds between cysteine groups in soymilk during evaporation.

The level of cystine in soymilk protein was estimated to be at a level of 1.7 g per 16 g of nitrogen, Hackler *et al.* (1967). The average nitrogen content in soymilk solids was 8% on a moisture-free basis; therefore, 100 g of soymilk solids contain 0.85 g of cysteine. Therefore, 600 ml (per sample of soymilk concentrated) of 7% solids soymilk has 42 g of solids and contains 0.36 g of cystine.

Since 2 moles of sodium sulfite are

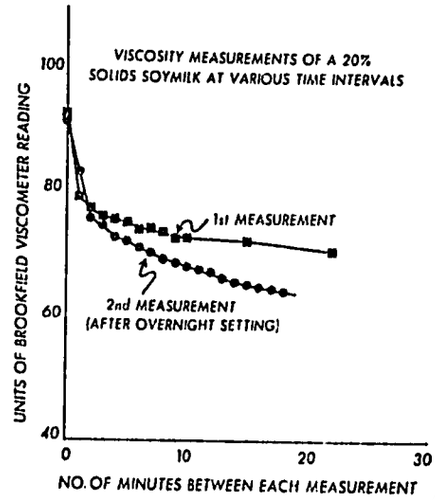

Fig. 1. Apparent viscosity of soymilk at various % solids content.

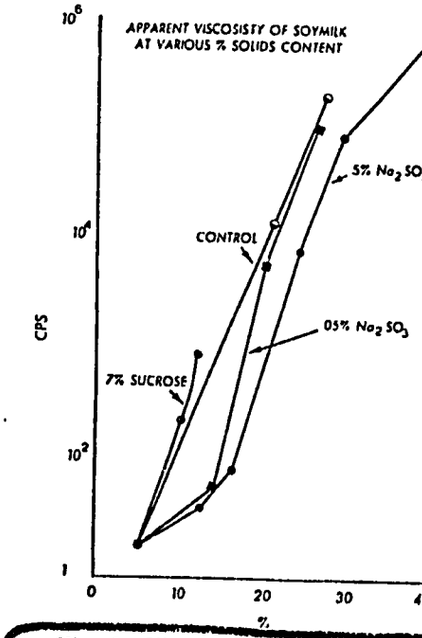

Fig. 2. Viscosity measurements of a 20% solids soymilk at various time intervals.

required to sulfonate 1 mole of cysteine, the weight of sodium sulfite required to react with 600 ml of soymilk is:

$$\frac{0.36\ g}{240\ g\ (\text{mol wt})} \times \frac{\text{mole of cystine}}{252\ g\ (\text{mol wt})} \times \text{moles of } Na_2SO_3 = 0.38\ g$$

or *630 ppm* of sodium sulfite is required per 600 ml of soymilk.

Calculations showed that the minimum effective level of sodium sulfite required to prevent the formation of disulfide bonds between the cysteines in soy protein was approximately 630 ppm. This calculated level and the experimental data seem to substantiate the hypothesis of Circle *et al.* (1964), who attributed the gel formation and the thickening effect of soy protein partly to the formation of disulfide cross-linkages between cysteines.

An alternate mechanism that may be involved is that described by Swan in Benesch *et al.* (1959) in which the disulfide bond is cleaved by sulfite through an oxidation-reduction reaction with half of the disulfide appearing as a thiol and the other half as an S-alkylthiosulfate, representing oxidation of the sulfite ion:

$$RSST + SO_3^{--} \leftrightarrows RS^- + RSSO_3^-$$

Further study will be necessary to determine whether the effect of sulfite on retarding the thickening effect during concentration of soy protein is due to breaking of disulfide bonds through sulfonation or through formation of S-alkylthiosulfates.

The addition of 7% sucrose to soymilk before concentration had the effect of increasing the viscosity of soymilks having solids contents of 10 and 11% solids to 2.5×10^3 and 9.8×10^3 cps, respectively (Fig. 1).

Relationship of the temperature redispersibility. A sweetened condensed soymilk which was evaporated at a temperature of 82°C showed better redispersibility of the protein than soymilk evaporated at lower and higher temperatures. At this temperature of evaporation, 92% of the original protein in the initial soymilk remained in suspension (Table 2).

However, stability of the protein to remain redispersed decreased during the concentration process, since only 92% of the initial protein remained in suspension after centrifugation, whereas in the control sample, 98% of the initial protein remained suspended.

A substantial decrease in the stability and the redispersibility of the protein was found in the sample which had been evaporated at a temperature of 93°C (Table 2). This could be attributed to the effect of heat denaturation of the protein, when a substantial amount of dehydration had taken place in the colloidal suspension during the concentration process. The proteins in soymilk were heat-stable under the normal conditions of extraction and heat treatments; hence, the effects of dehydration enhanced the heat denaturation of proteins. Sodium sulfite also reduced the formation of yellow color in the reconstituted soymilk (Table 3).

Table 2. Dispersibility of sweetened condensed soymilk evaporated at various temperatures.[1]

Evaporation temperature °C	Original nitrogen % remaining in suspension after centrifugation[2]
Control	98
50	—
70	74.5
76	84.5
82	92.4
93	85.3

[1] Samples contained 9% of soy solids and 9% of sucrose before being concentrated to a total solids of 50%.
[2] Samples reconstituted to their initial solids level before being centrifuged at 3500 rpm for 10 min.

CONCLUSION

At the present state of our understanding of the thickening effect and gel formation in concentrated soymilk at high solids content, it is unlikely that a satisfactory sweetened condensed product with a reasonably acceptable consistency can be produced. Since added sucrose increased the viscosity of concentrated soymilk, it would be difficult to produce a sweetened soymilk containing enough sucrose to preserve the final product. Heat sterilization is still required to prevent microbial spoilage.

However, the possibility of producing an evaporated soymilk with 12 or 15% solids can be considered. Although sodium sulfite at levels below 630 ppm was not effective in reducing the viscosity of concentrated soymilk for high solids content, it did have the effect of reducing the viscosity of soymilk at the 12 to 15% solids level. The incorporation of a small amount of sodium sulfite into soymilk before evaporation may reduce the heat-thickening effect that takes place after heat treatment in soymilk, Tan (1958).

Table 3. Hunter color difference measurements of soymilk with and without sodium sulfite treatment.

Samples	Reflected color values				
	L[2]	a	b	a/b[3]	$\sqrt{a^2+b^2}$[4]
Control	74.3	0.4	15.0	0.03	15.0
Na_2SO_3,[1] 0.50%	76.1	−1.5	15.5	0.10	15.6

[1] Sample was initially treated with 0.05% of sulfite and the solids content was concentrated to 15%; measurements were made after the re-addition of water to give a final solids content of 7%.
[2] L value —the higher the value the lighter the color.
[3] a/b —hue measurement.
[4] $\sqrt{a^2+b^2}$—measurement of saturation.

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