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# Changes in Flow Behavior of Whey Protein Based Adible Coating Solutions with Concentration

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**Abstract**

The flow behavior of an edible coating solution prepared from whey protein isolate (WPI) and glycerol (G) as plasticizer was studied using a HAAKE rheometer. The parameters used were concentration (15.5, 18.0, 19.5, and 21.5°Brix WPI-G (8, 9, 10 and 11% w/w WPI, respectively)) and temperature (5, 10, 20, and 30°C). It was observed that with increasing concentration of WPI the flow behavior changed from Newtonian to pseudoplastic, to a degree retarded by temperature. For industrial applications, the use of 10% WPI solution below 30°C seemed to be quite satisfactory.

**Key Words:** whey protein isolate, flow behavior, edible coating.

## Peynir Altı Suyu Proteini Bazlı Yenilebilir Kaplama Çözeltilerinin Konsantrasyona Bağlı Akış Karakteristiği Değişimi

**Özet**

Peynir altı suyu protein izolatı (PASPI) ve plastikleştirici olarak glycerol (G) kullanılarak hazırlanan yenilebilir kaplama çözeltilerinin akış davranışı bir HAAKE rheometre ile incelendi. Parametre olarak derişim 15.5, 18.0, 19.5 ve 21.5°Brix PASPI-G (sırasıyla ağırlıkça % 8, 9, 10 ve 11 PASPI) ve sıcaklığın, 5, 10, 20 ve 30°C, etkileri çalışıldı. Artan PASPI derişimi ile çözeltinin Newtonsu davranıştan yanıltıcıplastik davranışa geçtiği ve sıcaklığın artmasının bunu biraz geciktirdiği gözlendi. Uygulama için % 10 PASPI çözeltisinin 30°C'nin altındaki sıcaklıklarda yeterli sonuç vereceği sonucuna varıldı.

**Anahtar Sözcükler:** peynir altı suyu izolatı, akış davranışı, yenilebilir kaplama.

## Introduction

WPI is a highly purified protein product (90-95% protein, dry basis) obtained by ultrafiltration and ion-exchange (Mate and Krochta, 1996). The structural and rheological properties of WPI have been reported in the literature (Katsuta et al., 1990; Kuhn and Foegeing 1991). WPI has a number of functional properties that make it suitable for use as an edible film or coating (McHugh et al., 1994). Films and coatings may be differentiated on the basis of application method. A film can be preformed and applied to a food at any time, much like a synthetic package, whereas a coating must be applied in liquid form to a food directly (Guilbert 1986). During production of the film and coating solutions, the addition of a food-grade plasticizer, like sorbitol and glycerol, is needed to improve film flexibility (McHugh and Krochta, 1994a).

There are some application techniques for preparation of edible coating solutions such as spraying, dipping, enrobing, and casting (Chen 1995). A knowledge of the flow characteristics of the concentrates is useful in quality control and engineering applications for the proper design and operation of units, as well as for the understanding of the pertinent transport processes in the operations (Rao et al., 1984). The flow behavior of the edible coating solutions needs to be studied since the viscosity of the film forming solution is key to controlling the desirable thickness of the coating (Chen 1995). The viscosity of the coating solutions is also important for decreasing the dewetting process which prevents the creation of a continuous layer around food, making in necessary that the magnitude of the viscous forces be greater than that of the interfacial ones (Mate and Krochta, 1996).

The aim of this study was to characterize the rheological behavior of WPI based edible coating solutions with glycerol as a plasticizer at various concentrations of WPI and temperatures.

## Materials and Methods

### Materials

Whey protein isolate (BiPro) with 98.1% (w/w) protein on a dry basis was supplied by Davisco International, Inc., Le Seur, MN. Glycerol was purchased from Aldrich Chemical Company, Inc., Milwaukee, WI. Distilled water was used for production of the solutions.

### Coating solution preparation

Aqueous solutions of 8, 9, 10 and 11% whey protein isolate (WPI) were prepared as described by McHugh et al. (1994) and were heated with stirring to 90°C for 15 min (total heating time was 30 min) over a hot plate. The solution was then cooled to room temperature. Glycerol, as plasticizer, was added in equal weight to WPI originally dissolved in water for each concentration to yield 50% WPI/ 50% G. Dissolved air was removed by vacuum. The soluble solids content of the WPI-based edible coating solutions (WPI-G) was determined by an OPTON model Refractometer (F.G. Bode & Co., Hamburg) before each viscosity measurement and expressed as °Brix. The same amount of WPI concentration was prepared as described above without the addition of glycerol to control the effect of glycerol on WPI solutions.

### Viscosity measurement

The steady shear flow data of WPI-G edible film solutions with concentrations of 15.5, 18.0, 19.5 and 21.5°Brix (8, 9, 10 and 11% WPI, respectively) were generated using a rheometer HAAKE RheoStress RS1 coupled with a Peltier/Plate TCP/P temperature control unit (HAAKE GmbH, Karlsruhe) using a cone and plate system (d:35 mm, $\alpha$:2°). Circulator DC10 was used to control working temperature within the range of 5-30°C. The shear stress and viscosity as a function of shear rate were obtained as output of the controlled shear rate program in which the shear rate was gradually increased from 0.08 to 600 $s^{-1}$ in 6 min. Shear rate, shear stress and viscosity values were analyzed using a RheoWin Data Manager (RheWin Pro V. 2.64). Fresh samples were used in the measurements at each temperature, in triplicate. Statistical analysis of the data was done using SigmaPlot for Windows (SPSS Inc., Version 4).

## Results and Discussion

WPI concentrations (8 to 11% ) used in this study were selected to represent the concentration range corresponding to the coating characteristics. Below 8% concentration, WPI intact films cannot be formed, and at concentrations above 11% , solutions tend to gel (Kaya, and Kaya 2000). The temperature range was chosen to cover the possible storage temperature (5°C) and the coating application temperatures (10-30°C).

Flow curves of WPI-G solutions (Figures 1-4) were used for the flow behavior determination. These clearly indicate either a Newtonian (Eq. 1) or a shear thinning character with $n < 1$ (Eq. 2)

$$\tau = \eta * \gamma \tag{1}$$

$$\tau = K * \gamma^n \tag{2}$$

where $\tau$ is the shear stress (Pa), $\eta$ is the viscosity (Pa.s), $\gamma$ is the shear rate ($s^{-1}$), K is the consistency index and n is the flow behavior index.

Newtonian behavior was observed for the 15.5 °Brix of WPI-G solutions at all temperatures, 18.0°Brix WPI-G solution at 20 and 30°C; and, 19.5°Brix WPI-G solution at 30°C. The others were found to be non-Newtonian, shear-thinning fluids.

These results are in accordance with the findings of Alizadehfard and Wiley (1996), who also observed Newtonian flow behavior at concentrations below 12% whey protein concentrate (WPC) and non-Newtonian behavior in the range of 40-54% WPC solutions.

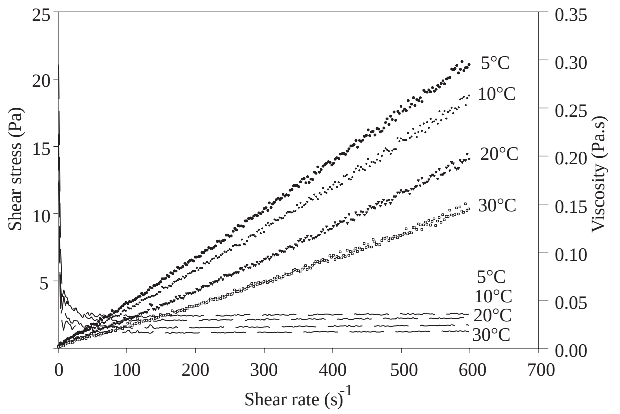


**Figure 1.** Viscosity (lines) and shear stress (symbols) of 15.5°Brix WPI-G solution at different temperatures.

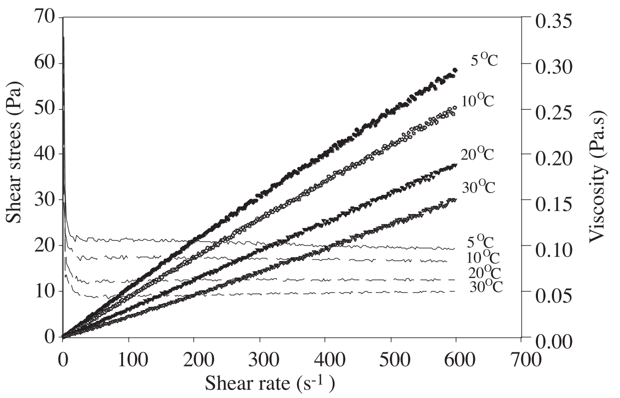


**Figure 2.** Viscosity (lines) and shear stress (symbols) of 18.0°Brix WPI-G solution at different temperatures.

The difference in the observed limiting values of the concentration might be the consequence of the heat treatment (90°C for 15 min) in this study. Such a treatment is likely to alter the structure of WPI in the solutions, hence the shape and size of proteins together with unfolding or uncoiling of the molecules, thus influencing the rheological characteristics of the protein solutions (Rha., 1978; McHugh and Krochta, 1994b; Mate et al., 1996). In order to the values of the parameters in the assigned models, the data was subjected to regression analysis. The results for the Newtonian and the Power law model parameters together with the correlation coefficients for the trends in Figs 1-4 are tabulated in Table 1. Correlation coefficients for the Newtonian and the non-Newtonian models above 0.990 indicate the acceptability of the fit. The Power law index value, n, indicates an increasing pseudoplasticity as the concentration of WPI-G increased. Furthermore, for 19.5 and 21.5°Brix solutions at 30°C, the transition from Newtonian to shear-thinning behavior caused the viscosity values to exceed the values at 20°C, beyond a specific shear rate.

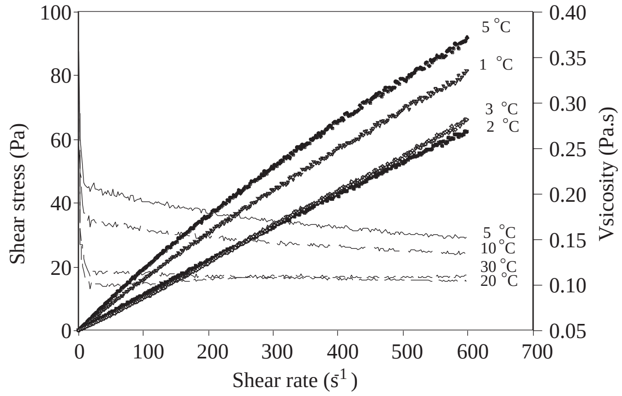


**Figure 3.** Viscosity (lines) and shear stress (symbols) of 19.5°Brix WPI-G solution at different temperatures.

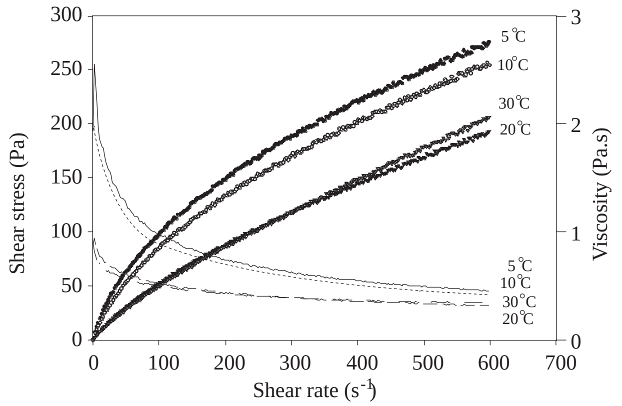


**Figure 4.** Viscosity (lines) and shear stress (symbols) of 21.5°Brix WPI-G solution at different temperatures.

The effect of concentration on the apparent viscosity of the WPI-G solutions at 20°C and at shear rates ranging from 50 to 400 $s^{-1}$ is shown in Figure

5. The same trend was observed at all concentrations and temperatures studied. At each shear rate the relationship between concentration and apparent viscosity over the concentration range employed can be described ($r^2$ >0.994) by an equation of the form

**Table 1.** Newton and Power Law model parameters and correlation coefficients ($r^2$) for WPI-G solutions

| WPI | °Brix[a] | Temperature (°C) | $\eta$ (Pa.s) | $r^{2(b)}$ | K (Pa.s) | n | $r^{2(c)}$ |
|---|---|---|---|---|---|---|---|
| 8% | 15.5 | 5 | 0.034 | 0.9984 | - | - | - |
| | | 10 | 0.030 | 0.9976 | - | - | - |
| | | 20 | 0.023 | 0.9962 | - | - | - |
| | | 30 | 0.017 | 0.9958 | - | - | - |
| 9% | 18.0 | 5 | - | - | 0.150 | 0.932 | 0.9996 |
| | | 10 | 0.085 | 0.9990 | - | - | - |
| | | 20 | 0.063 | 0.9996 | - | - | - |
| | | 30 | 0.049 | 0.9976 | - | - | - |
| 10% | 19.5 | 5 | - | - | 0.383 | 0.857 | 0.9994 |
| | | 10 | - | - | 0.271 | 0.891 | 0.9996 |
| | | 20 | - | - | 0.141 | 0.953 | 0.9998 |
| | | 30 | 0.109 | 0.9994 | - | - | - |
| 11% | 21.5 | 5 | - | - | 6.999 | 0.576 | 0.9988 |
| | | 10 | - | - | 5.124 | 0.613 | 0.9990 |
| | | 20 | - | - | 1.931 | 0.720 | 0.9990 |
| | | 30 | - | - | 1.288 | 0.793 | 0.9998 |

[a]shows concentration of WPI-G solution. (b)and (c) show $r^2$ for Newton and Power Law model, respectively. Errors in $\eta$, K and n were ±0.01, ±0.02 and ±0.01% respectively.

$$\eta = A * e^{BC} \tag{3}$$

where C is the concentration in terms of °Brix, and A and B are the constants. For shear rates from 50 to 400 $s^{-1}$ the value of A varied from 5.3x$10^{-8}$ to 1.0×$10^{-6}$, and B from 0.59 to 0.77.

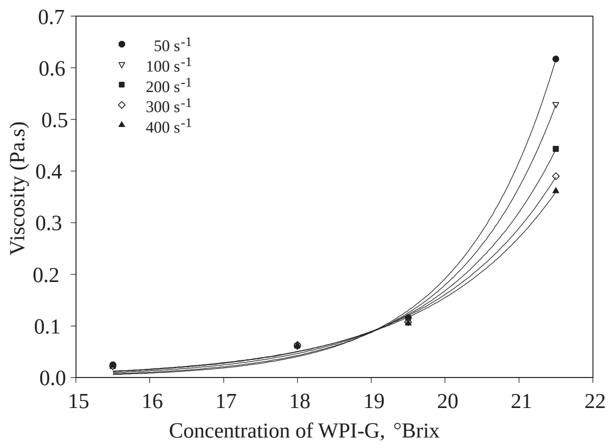


**Figure 5.** Effect of concentration (°Brix) on apparent viscosity of WPI-G solutions at 20°C and different shear rates.

The effect of solid content on the apparent viscosity for a shear rate ranging from 0.08 to 600 $s^{-1}$ was validated by the t-test. It was found that the apparent viscosities of each solution were significantly different (p<0.05) at all temperatures and concentrations studied.

For the preparation of WPI based edible films, plasticizers are required to obtain the desired chemical and physical properties. Accordingly, the viscosity of edible coatings is one of the key factors in the applicability for foods (Mate and Krochta 1996). With regard to this fact, an 11% WPI solution with the same glycerol amount used in this study was considered to have a viscosity too high for satisfactory coating (Mate and Krocta, 1996). In addition it was reported that increasing WPI concentration increased the water vapor permeability properties (McHugh and Krocta, 1994b), which is undesirable for edible films and coatings. In the light of these findings, the use of 10% WPI solution at temperatures below 30°C seems to be a good alternative.

## Conclusion

It can be concluded that the flow curve of WPI solutions follows both Newtonian and Power law models depending on concentration and temperature. The transition from Newtonian to shear thinning is strongly influenced by increasing WPI concentration, for which temperature shows a retarding effect. Considering the properties expected from food coatings, one of which is the consistency of the properties over a wide temperature range, the use of 10% WPI solution below 30°C appears to be an alternative for suitable processes.

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