Cake-Baking (High-Ratio White Layer) Properties of Egg White, Bovine Blood Plasma, and Their Protein Fractions[1]

M. Ö RAEKER[2] and L. A. JOHNSON[2,3]

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ABSTRACT

We investigated the cake-baking properties of egg white, blood plasma, and their component proteins in a high-ratio white layer-cake formulation and describe the relationship between the functional properties of the proteins and cake quality. Egg white produced slightly larger cake volume, significantly more crowned profile, and finer crumb structure than did blood plasma. Among egg white proteins, cakes made with globulins had the highest volume, finest crumb structure, and most crowned profile compared with cakes made with other fractions. Ovalbumin produced similar volumes and profiles as egg white, but the crumb structure was coarser. Ovomucoid did not coagulate into a strong matrix during baking, and cakes made with conalbumin and lysozyme had decreased volumes and very dense crumb structures. Fibrinogen produced the smallest cake volume among the blood plasma proteins. Albumin, the major protein in blood plasma, had cake-baking properties inferior to those of whole blood plasma, whereas γ-globulin had superior properties. α-Globulin produced cakes with high volumes but coarse crumb structures. Separation of fibrinogen from blood plasma increased cake volumes and profiles. The correlation coefficient between cake volume and denaturation peak temperatures of the protein (composite data for all proteins) was significant ($r = 0.944$, $P = 0.001$). Foaming and emulsification properties did not significantly affect cake volume.

Bovine blood plasma is a significant source of high-quality proteins and exhibits functional properties of utility in food products. Spray-dried beef blood plasma protein concentrate is now commercially available in food-grade form and is a likely low-cost candidate to replace egg products in baked goods.

Brooks and Ratcliff (1959) found that 33% of whole egg could be replaced with plasma in cakes other than sponge cakes. Reportedly, cakes prepared with blood plasma were equal in volume, texture, crumb, and flavor to cakes made with whole egg. Khan et al (1979) reported that blood plasma protein isolate could replace 30% of the egg white solids in angel food cakes. Johnson et al (1979) evaluated bovine blood plasma in high-ratio layer cakes and found that cakes made with fresh lyophilized plasma were substantially the same as those made with egg products. However, functional properties and replacement efficiency of dried blood plasma solids decreased as storage time increased. In a more recent study, Lee et al (1991) achieved nearly equivalent performance when egg white protein was replaced by 1.1× as much blood plasma protein in high-ratio white layer-cakes.

In the aforementioned studies, full replacement with blood plasma did not quite produce the same volume, crumb structure, and profile as egg white. Cakes made with plasma had slightly less volume, coarser crumb structure, and a flatter profile than did those made with egg white. However, partial replacement with blood plasma did produce acceptable cakes, and there is potential for further improvement by producing fractions rich in more functional proteins.

Functional properties of egg white, blood plasma, and their component proteins were investigated by Raeker and Johnson (*in press*), and considerable differences in the heat denaturation temperatures of egg white and blood plasma proteins were noted. Blood plasma proteins denatured at lower temperatures than did both ovalbumin (the major protein in the egg white) and globulins. Differences were also observed in foam stabilities between blood plasma and egg white. The stability of blood plasma foam was lower than that of egg white (Tybor et al 1975; Khan et al 1979; Raeker and Johnson, *in press*). However among blood plasma fractions, serum albumin, fibrinogen, and Cohn fraction IV-1 (predominantly α-globulin) have good foaming capacities and stabilities (Raeker and Johnson, *in press*).

Cake-baking properties of egg white component proteins were investigated in angel food cakes (MacDonnel et al 1955, Johnson and Zabik 1981), but the baking properties of the component proteins of blood plasma have not been studied. The objectives of this study were to determine cake-baking properties of egg white, blood plasma, and their component proteins in high-ratio white layer cakes; and to determine the relationships between the functional properties of these proteins and the qualities of cakes made with these proteins.

MATERIALS AND METHODS

Materials

Fresh eggs were obtained from the Iowa State University poultry farm. The whites were separated from the yolks and blended in a Waring Blendor (New Hartford, CN) for 40 sec. The mixing speed was reduced using a variable autotransformer. The slowest speed was used for homogenization. The blended fresh egg white was freeze-dried. Frozen blood plasma (AMPC, Inc., Ames, IA) was thawed at 4°C and divided into two parts. One part was freeze-dried and the other part was centrifuged at 613 × *g* for 15 min at 4°C in a refrigerated centrifuge (Beckman J2-21 with a JA-14 rotor, Palo Alto, CA). After that, half of the supernatant was freeze-dried and the other half was spray-dried using a Pulvis mini-spray spray drier (model GA-31, Yamato Scientific, LTD, Tokyo, Japan) at an air inlet temperature of 90°C and an air outlet temperature of 50°C.

When frozen blood plasma was allowed to thaw at 5°C, fibrinogen stays in a solid phase and can be separated by centrifugation (Ware et al 1947). This fibrinogen-free plasma is called serum. Therefore, in the present work, the terms "serum" (centrifuged plasma), "spray-dried serum" and "freeze-dried serum" are used to differentiate them from blood plasma.

Commercial supplies used included: spray-dried beef blood plasma and albumin-rich and IgG-rich fractions of beef blood plasma (AMPC, Ames, IA); and spray-dried egg white (type P-110, Henningsen Food, Inc., Omaha, NE). Protein fractions of bovine blood plasma and egg white (Sigma Chemical Co., St. Louis, MO) were: bovine serum albumin (A7638, 99% purity), γ-globulins (G5009, 99% purity), Cohn fraction IV-1 (G8512,

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[2]Graduate research assistant, Department of Food Science and Human Nutrition, and professor and professor-in-charge, Department of Food Science and Human Nutrition and the Center for Crops Utilization Research, respectively, Iowa State University, Ames.

[3]Author to whom correspondence should be addressed.

60–80% α-, 15–40% β-, 0–2% γ-globulins), Cohn fraction III (G4633, 56% β- and 44% γ-globulins), fibrinogen (F4753, 95% of protein clottable), ovalbumin (A5503, 99% purity), conalbumin (C0755, iron free), ovomucoid (T2011), lysozyme (L6876), and egg white globulins (EG, substantially free of albumin).

Cake flour values (as-is basis) were: moisture 13.6%, protein 7.5%, ash 0.4% (Super Cake Flour, Mennel Milling Co., Fostoria, OH). Betrkake emulsified shortening (mono- and diglycerides) was purchased from Durkee Industrial Foods (Cleveland, OH). All other ingredients, powdered sugar 6X, nonfat dry milk solids, double-acting baking powder, and salt were local retail products.

Protein Determination

The protein contents of blood plasma, egg white, and the albumin-rich and IgG-rich fractions of blood plasma were determined using the macro-Kjeldahl method (AOAC 1984) (N × 6.25). The protein contents of fractions were calculated from the absorbance measured with a spectrophotometer. The optical factors ($A^{1\%}_{1cm}$) were: bovine serum albumin 6.67 at 279 nm (Aoki et al 1973); γ-globulin 13.5 at 275 nm (Ruegg et al 1977); ovalbumin 7.12 at 280 nm (Glazer et al 1963); conalbumin 11.3 at 280 nm (Glazer and McKenzie 1963); lysozyme 26.3 at 281 nm (Sophianopoulos et al 1962). Protein contents of ovomucoid and fibrinogen were determined by using the Biuret method (Gornall et al 1949) with bovine serum albumin as a standard. Protein contents of egg white globulins and Cohn fraction IV-1 were determined by using the Biuret method with γ-globulin as a standard. The protein content of Cohn fraction III was estimated by using the micro-Kjeldahl method (AOAC 1984).

Cake Preparation

Cakes were prepared by using the micro method for cake baking (Raeker and Johnson 1995). The cake ingredients used in the formula were: 5 g of cake flour; 7 g of sugar; 2.5 g of shortening; 0.6 g of non-fat dry milk; 0.45 g of dried egg whites; 0.15 g of salt; 0.25 g of baking powder; and 4.0, 1.4, and 1.3 g of water in mixing stages 1, 2, and 3, respectively. The dried egg white in the formula was replaced by equivalent amounts of protein from the various forms of blood plasma, egg white, and protein fractions. Cakes were baked at 191°C (375°F) for 15.5 min in a rotary electric oven. Specific gravity of the batter was determined as the ratio of the weight of a standard container filled with batter to that of the same container filled with water. Cake volume and profile (symmetry index) were determined as previously described (Raeker and Johnson 1995) and crumb structure was subjectively evaluated. Baking trials were replicated three times.

TABLE I
Qualities of Cakes Made with Egg White, Bovine Blood Plasma, and Their Protein Fractions[a]

Protein	Batter Specific Gravity (g/cm^3)	Cake Volume (cm^3)	Cake Profile (mm)
Spray-dried egg white (commercial)	0.757 ± 0.011	49.0 ± 0.5	9.3 ± 0.4
Freeze-dried egg white	0.780 ± 0.008	48.4 ± 0.6	9.0 ± 0.4
Spray-dried blood plasma (commercial)	0.752 ± 0.012	47.8 ± 0.4	6.8 ± 0.5
Freeze-dried blood plasma (no centrifugation)	0.761 ± 0.006	47.7 ± 0.5	7.2 ± 0.3
Spray-dried serum (laboratory)	0.757 ± 0.009	49.8 ± 0.8	8.9 ± 0.8
Freeze-dried serum (after centrifugation)	0.750 ± 0.012	48.7 ± 1.4	8.9 ± 0.8
Egg white fractions			
Ovalbumin	0.793 ± 0.016	49.4 ± 0.6	9.4 ± 0.6
Globulins	0.774 ± 0.013	51.0 ± 0.7	10.5 ± 1.1
Conalbumin	0.798 ± 0.029	45.6 ± 0.5	8.3 ± 0.5
Lysozyme	0.786 ± 0.021	45.5 ± 0.5	7.7 ± 1.3
Ovomucoid	0.778 ± 0.014	38.6 ± 0.6	−1.8 ± 0.3
Blood plasma fractions			
Albumin	0.781 ± 0.013	46.9 ± 0.5	8.0 ± 0.3
γ-Globulin	0.788 ± 0.018	49.5 ± 0.7	9.0 ± 0.3
Cohn fraction III	0.762 ± 0.007	48.5 ± 1.0	8.7 ± 0.4
Cohn fraction IV-1	0.741 ± 0.002	49.9 ± 0.8	10.4 ± 1.1
Fibrinogen	0.929 ± 0.024	42.2 ± 1.1	3.2 ± 1.1
Least significant difference$_{(0.05)}$	0.025	1.2	1.2

[a] Values are the means of three replicates (means ± standard deviation).

Functional Properties

Heat denaturation properties of the proteins were determined using differential scanning calorimetry (DSC) as described previously (Raeker 1994; Raeker and Johnson, *in press*). Three determinations were made for each protein.

Foaming and emulsification properties of proteins were determined as described previously (Raeker 1994; Raeker and Johnson, *in press*; Pearce and Kinsella 1978) by using a 1% protein solution in 0.06*M* phosphate buffer containing 0.11*M* NaCl at pH 7. The definition of Regenstein and Regenstein (1984) for foam stability was used. Determinations were done in duplicate for foaming and in triplicate for emulsification properties.

Statistical Analysis

The data were analyzed with statistical analysis system (SAS 1990). When the *F* test was significant at the 0.05 or 0.01 level, means were compared by the least significant difference (LSD) test. Multiple linear regression analyses were run by using the stepwise procedure with forward, backward, and Max*R* options between cake volume and the functional properties of the proteins (Raeker and Johnson, *in press*).

RESULTS AND DISCUSSION

Cakes Prepared with Egg White and Blood Plasma

Volumes and crown profiles (symmetry index) of the cakes prepared with egg white, blood plasma, serum, and their constituent protein fractions are given in Table I. Spray- and freeze-dried egg whites produced cakes with similar volumes and crown profiles. Cakes made with egg whites had slightly greater volumes than cakes made with freeze- or commercial spray-dried blood plasma. However, cakes made with egg whites (Fig. 1a) produced significantly more crowning than those produced with blood plasma (Fig. 1b). Freeze-dried blood plasma produced cakes with properties similar to those of commercial spray-dried blood plasma. Removal of fibrinogen from blood plasma increased volumes and crown profiles of cakes; values were similar to those made with egg white (Table I, Fig. 2).

In general, cakes prepared with blood plasma had coarser and

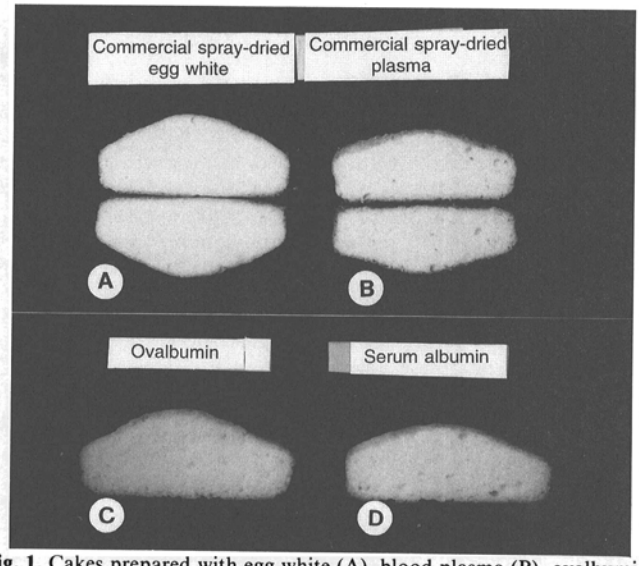

Fig. 1. Cakes prepared with egg white (A), blood plasma (B), ovalbumin (C), and serum albumin (D).

darker crumb structures than cakes made with egg white. Freeze-dried blood plasma gave the coarsest crumb structure. Commercial spray-dried blood plasma produced denser crumb structure than serum, which was fragile and crumbly. Cakes made with spray-dried egg white had smoother crumb appearances than cakes made with freeze-dried egg white.

Cakes Prepared with Protein Fractions of Egg White

Significant differences were observed in cake volumes when different protein fractions were used (Table I, Fig. 3). In agreement with Johnson and Zabik (1981), egg white globulins produced cakes with the largest volumes, followed by ovalbumin. In comparison with whole egg white, ovalbumin produced cakes with similar properties (Fig. 1c), whereas egg white globulins produced significantly higher volume and more crowned profile. Previously, Johnson and Zabik (1981) reported that angel food cakes made with lysozyme and conalbumin were smaller in volume because of less air inclusion and instabilities of the foams. However, in our study, we attributed the small cake volumes of conalbumin and lysozyme to their lower denaturation temperatures (Raeker and Johnson, *in press*). Early denaturation of these proteins at the bubble surface probably decrease film elasticity and prevent maximum cake expansion during baking.

Ovomucoid produced cakes with very small volumes, even less than cakes prepared without any protein. Cakes fell in the middle, which resulted in negative values for profile crown. Cakes made with ovomucoid expanded normally during baking, but then collapsed in the last stage of baking. This suggests that ovomucoid did not coagulate into a strong protein matrix during baking to set cake structure. Ovomucoid remains soluble in dilute solutions even when its biological activity is completely destroyed by heat (Lineweaver and Murray 1947). Our results suggest that ovomucoid also remains soluble during baking and does not coagulate into a strong matrix at baking temperatures, and therefore, by itself, cannot support cake structure. However, in egg white, ovomucoid, because of its resistance to heat coagulation during baking, may increase flexibility and viscoelasticity of the film around the gas bubbles contributing to the stability of egg white foam. The other egg white proteins coagulate into a strong matrix at baking temperatures and provide cake structure.

Foaming properties of the proteins played significant roles in determining the crumb structures of the finished cakes. Cakes prepared with lysozyme had very dense crumb structures, followed by conalbumin. The previous study of Raeker and Johnson (*in press*) showed that lysozyme did not produce foam. Conalbumin and ovomucoid had low foaming capacities and stabilities. Cakes prepared with ovomucoid had very coarse, rough crumb-cell structures. Ovalbumin and globulins possessed similar foaming capacities; however, egg white globulin foam exhibited very good stability, whereas ovalbumin foam was unstable. Consequently, ovalbumin cakes had somewhat nonuniform cell structures with bigger gas cells, whereas globulins produced cakes with good crumb structures.

Cakes Prepared with Protein Fractions of Blood Plasma

Fibrinogen, the most heat-sensitive protein in blood plasma (Raeker and Johnson, *in press*), produced cakes with very small volumes and flat profiles (Table I, Fig. 3). The early denaturation of the protein films surrounding the air cells prevent them from expanding as the temperature increased during baking.

Albumin, the major protein in blood plasma, produced cakes with slightly less volume than did whole blood plasma (Fig. 1d), whereas globulin fractions of plasma produced larger cake volumes with more crowned profiles than did whole blood plasma. Among the globulins, Cohn fraction IV-1 (primarily α-globulins) produced the largest cake volume followed by γ-globulins and Cohn fraction III (mixture of β- and γ-globulins). In previous research, γ-globulins were the most heat-stable proteins, followed by Cohn fraction

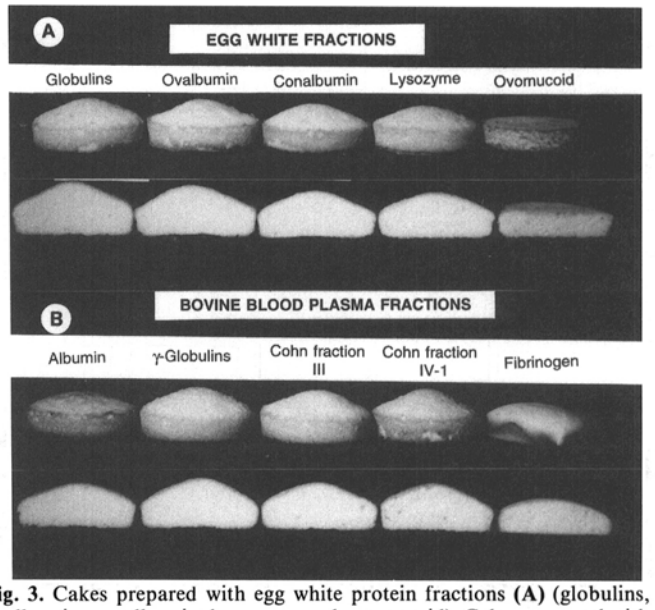

Fig. 3. Cakes prepared with egg white protein fractions **(A)** (globulins, ovalbumin, conalbumin, lysozyme, and ovomucoid). Cakes prepared with bovine blood plasma protein fractions **(B)** (albumin, γ-globulins, Cohn fraction III [56% β- and 44% γ-globulins], Cohn fraction IV-1 [predominantly α-globulins], and fibrinogen).

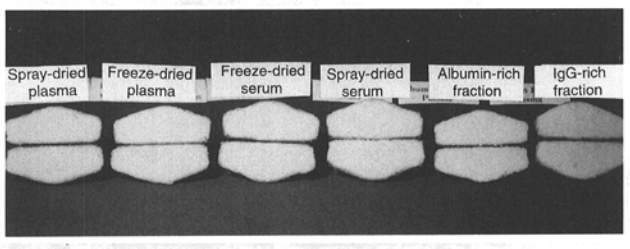

Fig. 2. Cakes prepared with commercial spray-dried blood plasma, freeze-dried blood plasma, freeze-dried serum, spray-dried serum, albumin-rich fraction, and IgG-rich fraction.

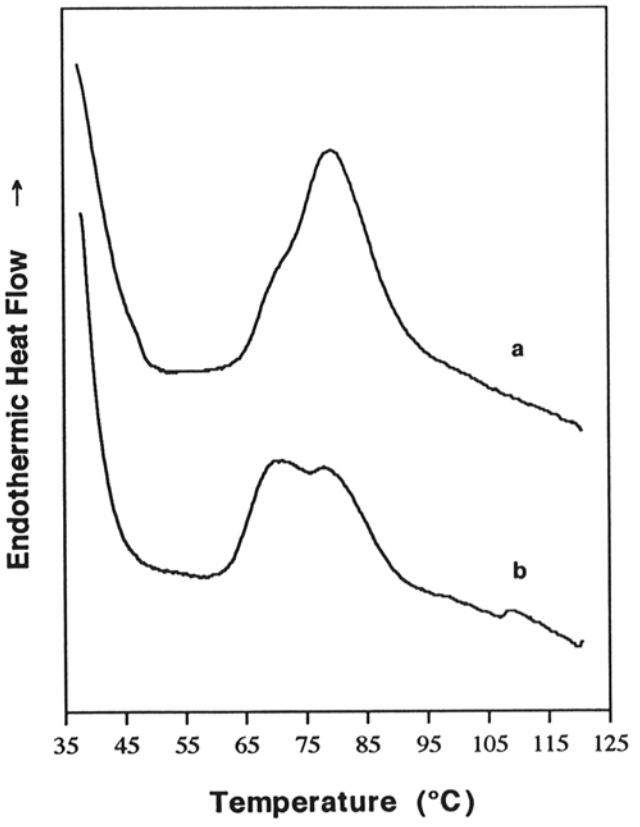

Fig. 4. Differential scanning calorimetric thermograms of (a) IgG-rich and (b) albumin-rich spray-dried blood plasma fractions.

TABLE II
Emulsification, Foaming, and Cake Properties of Bovine Blood Plasma, and Albumin-Rich and IgG-Rich Fractions[a]

Protein[b]	Emulsification Capacity (ml oil/g protein)	Foaming Capacity and Stability			Cake Properties	
		Initial Volume (ml)	Remaining Foam (%)		Volume (cm^3)	Profile (mm)
			15 min	30 min		
Albumin-rich	1,173 ± 55 b	41.8 ± 0.4 a	86.7 ± 1.1 a	85.9 ± 1.6 a	45.3 ± 0.6 c	8.1 ± 0.8 ab
IgG-rich	1,317 ± 25 a	39.5 ± 0.7 b	88.0 ± 1.0 a	87.1 ± 0.5 a	49.1 ± 0.2 a	8.5 ± 0.8 a
Blood plasma	1,035 ± 33 c	41.7 ± 0.6 a	86.6 ± 3.6 a	38.6 ± 14.3 b	47.9 ± 0.4 b	6.8 ± 0.5 b

[a]Means ± standard deviation. Values with the same letter in a column are not significantly different at $P = 0.05$.
[b]Products provided by AMPC, Inc., Ames, IA.

TABLE III
Relationships Between Cake Volume and Functional Properties of Proteins[a]

Independent Variables[b]	R^2	Model	F Value[c]
Step 1			
T_p	0.891	Volume = 29.9 + 0.223 T_p	40.94**
Step 2a			
T_p	0.916	Volume = 29.0 + 0.222 T_p + 0.0314 FC	42.23**
FC			1.20
Step 2b			
T_p	0.901	Volume = 29.7 + 0.221 T_p + 1.45 EA	34.86**
EA			0.40

[a]Values and description in Raeker and Johnson (1994).
[b]T_p = denaturation peak temperature; FC = foaming capacity; EA = emulsification activity.
[c]** = $P \leq 0.01$.

III (Raeker and Johnson, *in press*). However, α-globulins are a group of 20 glycoproteins, and the amount of carbohydrate varies from protein to protein. For example, α_1- acid glycoproteins contain 42% carbohydrate, and such a high carbohydrate content may increase resistance of the protein to heat denaturation and, in turn, increase the elasticity of the film around the gas bubbles. α-Globulins (Cohn fraction IV-1) also had very good foaming capacity and stability. Batter prepared with Cohn fraction IV-1 had the lowest specific gravity among all proteins showing that more air was entrapped during mixing. Since cake volume and crumb structure are at least partly the result of air incorporation during mixing, greater air entrainment may explain why Cohn fraction IV-1 produced a large volume cake despite having a relatively low denaturation temperature.

Albumin produced cakes with almost the same crumb structure as did whole blood plasma, but the crumb was less crumbly and denser. In general, cakes prepared with blood plasma globulins were crumbly and had crumb structures with open cells. γ-Globulins produced better crumb structure than did albumen, Cohn fraction III, and Cohn fraction IV-1. Cohn fraction IV-1 produced cakes with the coarsest, the most crumbly, and the most irregular crumb structures. This was an unexpected result because this protein had very good foaming capacity and stability. Cakes prepared with fibrinogen had very elastic and smooth crumb structures. No blood plasma protein fraction produced crumb structures as fine as did egg white globulins.

Spray-dried albumin- and IgG-rich fractions of blood plasma were better emulsifiers than spray-dried whole blood plasma (Table II). The IgG-rich fraction emulsified more oil than did the albumin-rich fraction. Foaming capacities of the IgG-rich fraction were less than those prepared with the albumin-rich fraction and whole blood plasma (Table II). Albumin- and IgG-rich fractions had very good foam stabilities. They maintained more than 85% of their original foam, even after 30 min; whole blood plasma was unable to maintain more than 40% of its original volume.

The DSC thermograms show that these spray-dried fractions were not pure, and there were at least two proteins in each fraction (Fig. 4). IgG-rich plasma fraction exhibited a shoulder around 70°C and a peak at 78.2°C. As shown in Fig. 4, the albumen-rich fraction exhibited one major peak at 71.1°C and one minor peak at 78.8°C. These denaturation peak temperatures were lower than those obtained with lyophilized pure albumin and γ-globulins (Raeker and Johnson, *in press*).

The spray-dried albumin-rich fraction produced cakes with significantly less volumes than did freeze-dried albumin and whole blood plasma (Table II, Fig. 2). Crumb structures of the cakes made with albumin-rich protein were denser and more crumbly than were cakes made with whole blood plasma. The spray-dried IgG-rich fraction produced cakes with volumes and textures similar to those made with freeze-dried γ-globulin, and cakes made with the former protein had finer crumb structures than cakes made with whole blood plasma.

Relationships Between Cake Volume and Protein Functionality

From the previous study (Raeker and Johnson, *in press*), the proteins that gave only one denaturation peak were chosen to determine the relationship between cake volume and protein functionality. These proteins were bovine serum albumin, γ-globulin, Cohn fraction III, conalbumin, lysozyme, and ovalbumin. Although fibrinogen exhibited one very low major and one very high minor denaturation peak, we assumed that the protein with the lower denaturation temperature would govern the cake properties. Therefore, we also included this protein in this part of the study. Multiple linear regression equations were determined for relating cake volumes to denaturation peak temperatures, foaming properties (capacity and stability), and emulsification activities of the proteins (Table III).

There was a highly significant correlation coefficient between cake volumes and denaturation peak temperatures of proteins ($r = 0.944$, $P = 0.001$). The Max$R$ procedure used in the analysis began by finding the one-variable model that produced the highest R^2. Then another variable that yields the greatest increase in R^2 is found, and so on. This analysis showed that the protein denaturation peak temperature produced the highest R^2, the square of the correlation between the actual volumes and the predicted volumes by the model (0.891). When foaming capacity was entered into the model (Table III, step 2a), R^2 was improved by only 2% to 0.916 and contribution to the model from foaming capacity was not significant. When emulsification activity instead of foaming capacity was used in the multiple regression analysis (Table III, step 2b), the contribution from emulsification activity to the model was also not significant. These results suggest that the denaturation temperature of the protein is the only important functional property in determining the volume of the finished cake.

CONCLUSIONS

Various proteins used in this study demonstrated that the temperature at which a protein denatures during baking is the determining factor for cake volume. The higher the denaturation temperature of a protein, the larger the cake volume and the more crowned profile. This high correlation between protein denaturation temperature and volume indicates that protein denaturation temperature determined by DSC is a reliable pre-

dictor of cake volume. Since γ-globulin had the highest denaturation temperature and produced cakes with larger volumes and better crumb structures than did whole blood plasma, the use of blood plasma as an egg white substitute in cakes can be improved by fractionating it into its γ-globulin- or γ-globulin-rich fractions. Another solution is to separate fibrinogen from blood plasma because fibrinogen was responsible for low cake volumes and flat profiles of blood plasma cakes. This would be a more practical solution because separation of this component from blood plasma by centrifugation would be low in cost. However, additional research is necessary to investigate crumb structures and sensory properties of cakes prepared with fibrinogen-free plasma (serum) because cakes prepared with serum were fragile had fragile crumb structure. In general, spray-dried proteins produced better crumb structures than did their freeze-dried forms. This was attributed to the better foam stability of spray-dried samples as was shown in the previous study of Raeker and Johnson (*in press*).

LITERATURE CITED

AOAC. 1984. Official Methods of Analysis of the Association of Official Analytical Chemists, 14th ed. The Association: Arlington, VA.

AOKI, K., SATO, K., NAGAOKA, S., KAMADA, M., and HIRAMATSU, K. 1973. Heat denaturation of bovine serum albumin in alkaline pH region. Biochim. Biophys. Acta 328:323.

BROOKS, J., and RATCLIFF, P. W. 1959. Dried bovine plasma. I. Storage of spray-dried plasma and the freeze-concentration of liquid plasma. J. Sci. Food Agric. 10:486.

GLAZER, A. N., MacKENZIE, H. A., and WAKE, R. G. 1963. The denaturation of proteins II. Ultraviolet absorption spectra of bovine serum albumin and ovalbumin in urea and in acid solution. Biochim. Biophys. Acta 69:240.

GLAZER, A. N., and MacKENZIE, H. A. 1963. The denaturation of proteins IV. Conalbumin and iron(III)-conalbumin in urea solution. Biochim. Biophys. Acta 71:109.

GORNALL, A. G., BARDAWILL, C. S., and DAVID, M. M. 1949. Determination of serum proteins by means of biuret reaction. J. Biol. Chem. 177:751.

JOHNSON, L. A., HAVEL, E. F., and HOSENEY, R. C. 1979. Bovine plasma as a replacement for egg in cakes. Cereal Chem. 56:339.

JOHNSON, T. M., and ZABIK, M. E. 1981. Egg albumen proteins interactions in an angel food cake system. J. Food Sci. 46:1231.

KHAN, M. N., ROONEY, L. W., and DILL, C. W. 1979. Baking properties of plasma protein isolate. J. Food Sci. 44:274.

LEE, C. C., JOHNSON, L. A., LOVE, J. A., and JOHNSON, S. 1991. Effects of processing and usage level on performance of bovine plasma as an egg white substitute in cakes. Cereal Chem. 68:100.

LINEWEAVER, H., and MURRAY, C. W. 1947. Identification of the trypsin inhibitor of egg white with ovomucoid. J. Biol. Chem. 171:565.

MacDONNELL, L. R., FEENEY, R. E., HANSON, H. L., CAMPBELL, A., and SUGIHARA, T. F. 1955. The functional properties of the egg white proteins. Food Technol. 9:49.

PEARCE, K. N., and KINSELLA, J. E. 1978. Emulsifying properties of proteins. Pages 291-338 in: Developments in Food Proteins, Vol. 4. B. J. F. Hudson, ed. Elsevier Applied Science: New York.

RAEKER, M. Ö. 1994. Functional and cake-baking properties of egg white, bovine blood plasma and their protein fractions. PhD dissertation, Iowa State University: Ames, IA.

RAEKER, M. Ö., and JOHNSON, L. A. In press. Functional properties of bovine blood plasma and egg white proteins. J. Food Sci.

RAEKER, M. Ö., and JOHNSON, L. A. 1995. A micro method for cake baking (high ratio, white layer). Cereal Chem. 72:167-172.

REGENTSTEIN, J. M., and REGENSTEIN, C. E. 1984. Protein functionality for the food scientist. Pages 285, 332-334 in: Food Protein Chemistry. Academic Press: New York.

RUEGG, M., MOOR, U., and BLANC, B. 1977. A calorimetric study of the thermal denaturation of whey proteins in simulated milk ultrafiltrate. J. Dairy Res. 44:509.

SAS 1990. SAS User's Guide: Statistics. The Institute: Cary, NC.

SOPHIANOPOULOS, A. J., RHODES, C. K., HOLCOMB, D. N., and VAN HOLDE, K. E. 1962. Physical studies of lysozyme I. Characterization. J. Biol. Chem. 237:1107.

TYBOR, P. T., DILL, C. W., and LANDMANN, W. A. 1975. Functional properties of proteins isolated from bovine blood by a continuous pilot process. J. Food Sci. 40:155.

WARE, A. G., GUEST, M. M., and SEEGERS, W. H. 1947. Fibrinogen: With special reference to its preparation and certain properties of the product. Arch. Biochem. 13:231.

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