Bovine Plasma as a Replacement for Egg in Cakes[1]

L. A. JOHNSON,[2,4] E. F. HAVEL,[3,4] and R. C. HOSENEY,[4] Department of Grain Science and Industry, Kansas State University, Manhattan, KS 66506

ABSTRACT

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Livestock blood plasma represents a large, under-utilized source of animal protein, and the potential of using stabilized bovine plasma as egg white and whole egg replacements in high-ratio cakes was explored. Whole bovine blood was treated with a sodium citrate anticoagulant. The plasma fraction was separated from erythrocytes by low-speed centrifugation and dried by lyophilization. Bovine albumin has heat-coagulating and foaming properties similar to those of egg white. Cake structure, specific volume, profile, and pan shrinkage of cakes made with bovine plasma were substantially the same as those made with natural egg products.

Historically, blood wastes from livestock slaughter have posed major pollution problems (Kerrigan 1971). More than 95% of the 2 billion pounds of blood produced annually[5] is used in animal feeds and fertilizers (Hirchberg 1957, Inst. of Meat Packing 1955). Blood proteins have been used as binders and extenders in comminuted meat products (Frentz and Perrin 1971, Lipner 1972) and cheeselike products.[6] There has been little use of blood proteins in other foods, although blood pudding and blood sausage are traditional foods of European and Asian cultures. Incorporating whole blood into bread for nutritional fortification has been promoted (Droste 1915, Kobert 1915), but extensive application has been rejected owing to appearance, reduced loaf volume, and poor crumb texture (Bates et al 1974). More recently a decolorized blood plasma isolate produced acceptable bread and increased its protein content 62%.[7]

Eggs are used in baked cereal products because of their nutritional and functional properties[8] (Pyler 1973). In cakes the functional properties of eggs arise from the ability of egg proteins to foam, emulsify, and coagulate with heat. Protein coagulation helps to set the cake structure. In general, high-ratio cakes (where sugar content exceeds flour content) are difficult to make without egg.

Blood plasma and egg white have similar functional properties because blood plasma protein is predominantly albumin (50–60%), which is heat-coagulable, produces a stable foam, and has good emulsification properties (Tybor 1973, Tybor et al 1971, 1973, 1975). Germans during WW II used spray-dried plasma as an egg substitute in mayonnaise, pancakes, soup, and sauces (Shenstone 1953). The only published account of using blood plasma in cakes reports that 33% of whole egg could be replaced in European low-ratio cakes (Brooks and Ratcliff 1959). Our study was done to assess the feasibility of using bovine plasma as a replacement for eggs in cakes.

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[2]Present address: Food Protein Research and Development Center, Texas A & M University, College Station, TX 77843.
[3]Present address: ConAgra, Omaha, NE 68131.
[4]Graduate research assistant, research assistant, and research cereal chemist, respectively.
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MATERIALS AND METHODS

Isolation of Protein Concentrates

Freshly shed bovine blood was mixed immediately with an equal volume of anticoagulant solution at 5°C to prevent fibrinogen-catalyzed clot formation in the blood. The anticoagulant solution contained sodium citrate at 0.25% basis total volume in physiological saline (0.85% NaCl). The solution chelates the Ca^{+2} ions necessary for blood clotting. The stabilized whole blood was centrifuged with a portable cream separator ($\approx$ 1,000 $\times$ *g*) into plasma and erythrocyte phases. The plasma phase was kept frozen (−28°C) until lyophilized. Plasma solids were evaluated as substitutes for both egg whites and whole eggs in high-ratio cake formulations. A portion of the plasma solids was dialyzed to remove salts, then centrifuged to separate the protein into two fractions, which were lyophilized. Plasma solids were also decolorized with acidified acetone, and the precipitated protein was lyophilized.

Evaluation of Protein Concentrate in White Layer Cakes

Plasma protein concentrates were substituted at equivalent protein levels for egg white and evaluated in high-ratio white layer cakes (AACC procedure 10-90) [1969]. When the protein concentrate contained salt, the salt called for in the formulation was reduced on an equivalent molar ion basis. In each case, 240 g of batter was scaled into 6-in. pans and baked at 375°F (191°C) for 25 min. Cake volume was quantified by rapeseed displacement.

Evaluation of Plasma Solids in Yellow Layer Cakes

The potential of plasma solids to replace whole egg in high-ratio yellow layer cakes was also evaluated (Table I). Fresh whole eggs were used in the control. When evaluating the plasma solids, we maintained equivalent protein, salt, and water. The plasma solids constituted 20.2% of solids. Lecithin was added to replace the phospholipid of whole eggs. The mixing procedure involved three stages of 2 min. each. In each case, 240 g of batter was scaled into 6-in. pans and baked at 375°F (190°C) for 30 min. Cake volume was evaluated by rapeseed displacement.

TABLE I
Ingredient Formulation for Yellow Layer Cakes[a]

Ingredients	Whole-Egg Control	No-Egg Control	Plasma Solids
Cake flour	100.0	100.0	100.0
Sugar	120.0	120.0	120.0
Emulsified shortening	32.5	32.5	32.5
NFDM[b]	13.0	13.0	13.0
Salt	2.0	2.0	Var.
Baking powder	5.0	5.0	5.0
Lecithin	0.0	0.0	Var.
Water	92.0	92.0	92.0

[a]%Basis flour
[b]NFDM = Nonfat dried milk.

RESULTS AND DISCUSSION

In this investigation of the feasibility of replacing egg white and whole egg with blood plasma in high-ratio cakes, the dried plasma solids were analyzed by standard AACC methods (Table II). Dried plasma solids contained 61–66% protein, traces of free fat, and a high ash content that reflected the salts used in stabilization. The remainder of the composition probably was citrate ion and bound lipid. Solids not decolorized were generally pink but not red, whereas the decolorized solids were off-white.

In the initial feasibility trial, the dried plasma solids were evaluated within 7 days of collection (Fig. 1). Control cakes contained 14% egg-white solids and 3% added salt. The corresponding experimental cake contained 18.6% plasma solids and no added salt. Those levels yielded equivalent protein and salt concentrations for the plasma and the egg-white control cakes. The cake made with plasma was at least equivalent if not greater in volume and had good structure. Control cakes made without egg white collapsed and were excessively fragile. The cakes made with plasma solids exhibited good profile and a crumb texture that appeared more open as a result of the grey crumb color. Cakes made with plasma solids shrank less than the egg-white control cake. Crust colors of cakes made with plasma solids were more golden, indicating more browning. This simple experiment demonstrated that it is indeed feasible to replace egg white solids in white layer cakes with bovine plasma solids.

The initial experiment compared only one level of egg white with a comparable level of plasma. The functional efficiencies of the two protein sources also were evaluated. A second lot of whole blood was fractionated, dried, and refrigerated for 3 mo before evaluation. The response of cake volume to protein level was quantified (Table III). Cake volume increased with protein level for both egg white and plasma. Egg white was slightly more efficient. At equivalent levels of protein, cakes made with plasma protein were about 8% smaller. They raised to equal heights but had flat profiles rather than normal crowns. The cake made with 5.6% egg white protein produced an acceptable cake with a volume of 650 cc, and 8.4% plasma protein gave nearly an equivalent cake volume. Acceptable cakes were made with plasma protein; however, results deviated slightly from those of the initial experiment.

The functionality of blood plasma improved as the water level and the mixing time were optimized in white layer cake formula-

TABLE II
Chemical and Physical Characteristics of Bovine Plasma Solids

Analysis	Response
Protein (N × 6.25)	61.8%
Moisture	4.3%
Fat (petroleum ether extract)	0.2%
Ash	25.4%
Color	Pink to tan

TABLE III
Functional Efficiency of Egg White and Bovine Plasma in White Layer Cakes

Added Protein (%)	Added Solids (%)		Cake Volume (cc)	
	Egg White	Plasma	Egg White	Plasma
0.0	0.0	0.0	430	430
2.8	3.5	4.2	550	450
5.6	7.0	8.5	650	590
8.4	10.5	12.7	690	640
11.2	14.0	17.0	720	670

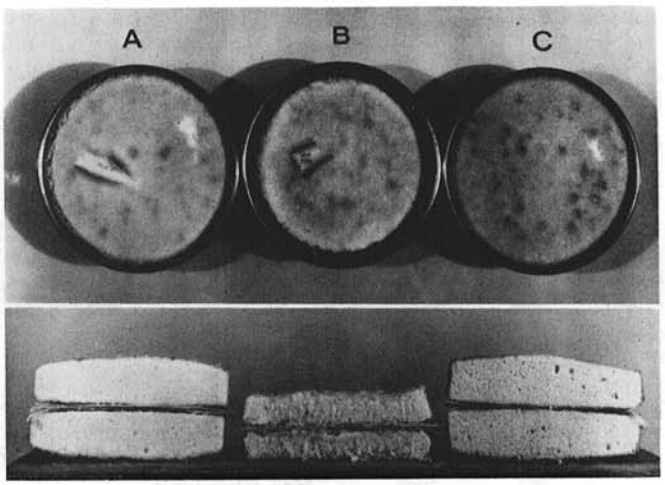

Fig. 1. Effect of plasma solids in white layer cakes. **A,** Egg-white control. **B,** No-egg-white control. **C,** Plasma solids.

TABLE IV
Effect of Water in White Layer Cakes Made With Bovine Plasma Solids

Plasma Protein (%)	Water (%)	Cake Profile	Cake Volume
11.2	127	Flat	Normal
11.2	137	Flat	Normal
11.2	147	Crown	Normal
11.2	157	Slight Crown	Normal
11.2	167	Slight Crown	Reduced

TABLE V
Effect of Mixing Time on White Layer Cakes

Protein Source	Protein (%)	Water (%)	Mix Time (min)	Cake Volume (cc)
Egg white	7.2	137	0.5	570
Egg white	7.2	137	1.0	600
Egg white	7.2	137	2.0	600
Plasma	11.2	157	0.5	600
Plasma	11.2	157	1.0	590
Plasma	11.2	157	2.0	575

TABLE VI
Effect of Dialyzing Bovine Plasma on Its Functionality in White Layer Cakes

Treatment	Protein (%)	Cake Volume (cc)
Egg white control	5.6	610
Bovine plasma control	11.2	605
Dialyzed bovine plasma	11.2	570
Soluble fraction of dialyzed bovine plasma	11.2	615

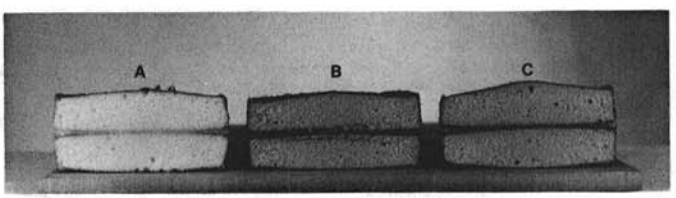

Fig. 2. Effect of dialysis on functionality of plasma solids in white layer cakes. **A,** Egg-white control. **B,** Undialyzed plasma solids. **C,** Dialyzed plasma solids.

tions. The water level was varied from 127 to 167% basis flour. The normal water level for white layer cakes made with egg white was 137%. With the plasma substitute, increasing the water level to 157% improved the cake profile while maintaining cake volume (Table IV). Mixing time was also optimized. The standard AACC method uses a three-stage mixing procedure. The third-stage mixing time was varied to determine optimum mixing time (Table V). Two-minute mixing was optimum for the egg-white control. When plasma solids were substituted for egg white, cake volume decreased at longer mixing times. Optimum third-stage mixing time was 0.5 min.

The effect on cake-making of dialyzing away the salt was evaluated (Table VI). An egg-white control produced a cake with a volume of 610 cc. The plasma solids, evaluated at twice the protein level, produced a cake at 605 cc. The dialysate, which contained some precipitated protein but little salt, produced a cake volume of 570 cc. Therefore, the salts used to prevent blood clot formation did not detrimentally affect functionality. Use of soluble dialyzed protein only improved cake volume 10 cc and also improved cake profile (Fig. 2), indicating that some plasma proteins may have been detrimental to cake volume.

A sample of plasma solids was decolorized with acidified acetone, but cakes made with decolorized plasma were totally unacceptable. Decolorizing with acidified acetone reduces emulsification and foaming properties of plasma concentrates (Tybor 1973).

Plasma solids also were evaluated as a replacement for whole eggs in yellow layer cakes. An initial bake indicated nearly equivalent functionality at equal protein levels. Because the temperature of protein denaturation may differ between whole egg and plasma, the effects of baking temperatures on cake volume were studied (Table VII). Typical baking temperatures for yellow layer cakes made with whole egg ranged from 375 to 385°F (191–196°C), although our own data indicate that 360°F (182°C) may produce more volume. Plasma solids were dissolved in water and used at levels that gave protein and water equivalent to those in the whole egg counterpart. Lecithin, 1.3%, was added to the plasma cakes to replace the natural phospholipid content of whole egg. Optimum baking temperature for cakes made with plasma substitute was 375°F (191°C).

The 1.3% lecithin is equivalent to the amount of natural phospholipid in the normal whole egg formulation. The optimum level of lecithin in yellow layer cakes made with plasma solids was determined (Table VIII). One percent lecithin significantly improved cake volume, but more than 1.0% lecithin decreased volume.

The effect of protein level in yellow layer cakes was studied for both whole egg and plasma (Table IX). Whole egg in yellow layer cakes is normally 40% basis flour. Volumes of cakes made with 0, 20, 30, 40, and 50% whole egg were evaluated. The cakes made with plasma solids had from 7 to 15% less volume at equivalent protein levels. At the 40% level of fresh whole eggs, the control measured 780 cc and the plasma substitute 700 cc. Dried plasma solids were compared with fresh whole eggs, not dried whole eggs, which produce much less volume. Plasma solids efficiently replaced 100% of whole egg in yellow layer cakes (Fig. 3). Cakes made without whole egg or plasma solids totally collapsed. The cake made with plasma solids compared favorably in volume, profile, and pan shrinkage with the fresh-egg control.

TABLE VII
Effect of Baking Temperature on Volume of Yellow Layer Cakes

Baking Temperature	Cake Volume (cc)	
	Whole Egg	Plasma
360°F (182°C)	750	670
375°F (191°C)	710	680
385°F (196°C)	700	680
405°F (207°C)	690	660

TABLE VIII
Effect of Lecithin on Functionality of Plasma Solids in Yellow Layer Cakes

Protein Source	Lecithin (%)	Cake Volume (cc)
Whole egg	0.0	715
Plasma solids	0.0	650
Plasma solids	1.0	685
Plasma solids	1.3	640
Plasma solids	1.6	620

TABLE IX
Functional Efficiency of Egg White and Bovine Plasma in Yellow Layer Cakes

Egg Equivalent (%)	Cake Volume (cc)	
	Whole Egg	Plasma
0	480	480
20	785	685
30	770	695
40	780	700
50	750	700

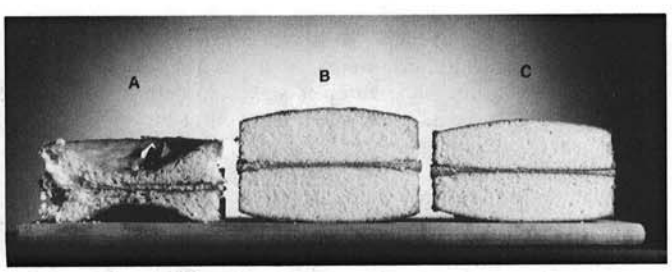

Fig. 3. Effect of plasma solids in yellow layer cakes. **A,** No-whole egg control. **B,** Fresh-whole egg control. **C,** Dried plasma solids.

CONCLUSIONS

The functional efficiency of dried plasma solids decreased as storage time increased, but freshly processed bovine blood plasma was effective in replacing all the egg white or whole egg in high-ratio layer cakes. Optimum white layer cakes made with plasma solids require less mixing and more water than the egg-white counterparts. Lecithin (1.0%) is required with plasma solids to replace the natural phospholipid content of whole eggs. The baking results reported here and the potential low cost of plasma solids suggest that they have a significant potential for use by the baking industry.

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