SOME CHARACTERISTICS OF YOLK SOLIDS AFFECTING THEIR PERFORMANCE IN CAKE DOUGHNUTS

II. Variability in Commercial Yolk Solids[1]

Leo Kline, T. F. Sugihara, and Maura L. Bean

ABSTRACT

Yolk solids vary considerably in their influence on cake-doughnut performance, principally in their effect on batter fluidity. This effect has been found to be related to the extent of heat-induced processing alteration which may occur during preheating of the liquid, drying, or storage of the solids at moderate to elevated temperatures. Measures of the processing change that show promise as indicators of the effect on batter fluidity include loss of protein solubility and increase in viscosity of the reconstituted powder. Comparison of various commercially prepared yolk solids showed that those yielding the least fluid or most viscous cake-doughnut batters had the lowest protein solubilities and highest reconstituted viscosities. Similarly, laboratory-prepared, spray-dried yolk intentionally processed to reduce protein solubility also yielded more-viscous batters.

The effects of slight-to-moderate, heat-induced processing change in yolk solids on batter and doughnut characteristics could be largely corrected by increasing the water content of the batter. However, the effects of pronounced processing change, as indicated by marked loss in protein solubility, could not. These results indicate that control of processing change is necessary for producing yolk solids with uniform properties as well as permitting, where desirable, slightly higher absorptions.

It has been recognized for some time that commercial yolk powders vary considerably with respect to their effect on cake doughnut preparation and properties. The previous report (1) eliminates variations in adhering white content as a likely contributing factor. In the present study commercial yolk powders were obtained which had

[1] Manuscript received January 24, 1962. Presented in part at the 46th annual meeting, Dallas, Texas, April 1961. Contribution from Western Regional Research Laboratory, one of the laboratories of the Western Utilization Research and Development Division, Agricultural Research Service, U.S. Department of Agriculture, Albany 10, California.

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received a variable response from manufacturers of cake doughnut mixes. These powders were compared for doughnut performance, and properties that relate to their different performances were determined. Processing procedures capable of contributing to varied performance quality were identified.

Materials and Methods

Methods for appraising performance of yolk solids in cake doughnuts are described in the previous report (1).

The yolk powders were reconstituted with distilled water to 45% solids (moisture-free basis); the reconstituted yolk was permitted to stand for 1 hour with occasional stirring to implement full dispersion; and the viscosity was then measured at 75°F. with a Brookfield rotating viscometer. Preliminary tests revealed that the apparent viscosity values obtained on yolk with this instrument increased with lowered rotor speed. Accordingly, to improve precision, rotors were selected that permitted operation at the two highest rotor speeds (rotors 5, 6, and 7 and speeds 50 and 100 r.p.m. on Brookfield Model RVT).

Yolk protein solubility was estimated according to a procedure similar to that developed for whole-egg powder by Hawthorne (3). In this method 2.0 g. of yolk solids (moisture-free basis) were dispersed in 79 ml. of 10% KC1 (approximately 80 ml. total volume) by slow shaking for 1 to 1.5 hours in a manner designed to minimize frothing. The dispersion was then filtered through Whatman No. 12 folded filter paper, and the percentage of the total nitrogen (determined by the Kjeldahl method) that was filterable was reported as protein solubility. This is of course an approximation, since protein components actually account for 94% of the total nitrogen of yolk.

For estimating egg-white solids in commercial yolk powders, principal reliance was placed on the fat content as determined by a modified Roese-Gottlieb extraction procedure. A 1.25-g. sample of yolk solids was weighed into a Mojonnier extraction flask and mixed with 10 ml. of distilled water. Extraction was made using successive additions of 3.0 ml. of concentrated NH_4OH, 10.0 ml. ethyl alcohol, 25.0 ml. of diethyl ether, and 25.0 ml. of petroleum ether. The total solvent layer was decanted after centrifugation, and the extraction of the residue was repeated twice, each time with successive additions of 5 ml. of ethyl alcohol, 25 ml. of diethyl ether, and 25 ml. of petroleum ether. The combined extracts were evaporated to near dryness on a steam bath and then dried to constant weight (1.5 hours) in a forced-air oven at 105°C. By this method, yolk solids free of adhering whites yielded 68.1% fat.

Studies on effects of heating yolk liquid prior to drying were carried out on yolk liquid adjusted to 45% solids with egg white to simulate commercial liquid yolk. Generally, at this solids level, liquid "yolk" contains about 15% of liquid white. For these studies 100-ml. batches of yolk were placed in electrolytic beakers, 6 × 11.3 cm., containing calibrated metal dial thermometers for manual stirring. First the yolks were warmed to and held at 131°F., at which temperature little or no change in viscosity or protein solubility is observed in several hours. Then, for warming to the normal pasteurization range of 140° to 145°F., the beakers were transferred to a second constant-temperature bath at 149°F. Upon reaching the desired temperature within this pasteurization range (approximately 3 to 4 minutes were required), they were transferred to a third bath at the desired holding temperature (e.g., 144°F.). For temperatures higher than the normal pasteurization range, a fourth constant-temperature bath maintained at 152°F. was employed. Yolk temperatures were recorded every minute. Upon completion of the heating period, the beakers were transferred to an ice-water bath where they cooled to below 131°F. in less than 30 seconds. For viscosity measurements, they were cooled further to 75°F. These small batches were freeze-dried for protein solubility measurements.

An 18-lb. batch prepared for spray-drying purposes was heated to 148°F. in a 20-gal. jacketed stainless kettle by means of hot water (150° to 165°F.) passing through the jacket and held at that temperature for approximately 0.5 hour; the temperature was then brought down quickly to less than 131°F. by passing ice water through the jacket.

Results and Discussion

Variability in Commercial Yolk Solids. Four commercially prepared yolk powders were supplied by a major egg dryer with the information that they comprised two separate pairs with respect to difference in acceptability by cake doughnut mix manufacturers. The powders were all of good color and odor. They were evaluated for their effects on cake doughnut preparation and properties and compared with a laboratory-prepared powder considered of excellent quality. (This latter powder was prepared in the pilot spray dryer at minimum drying temperatures and cooled rapidly after drying; it contained no detectable off-flavor as evaluated in a sensitive custard test.) As shown in Table I, all of the powders yielded doughnuts of nearly equivalent volumes and fat absorptions. However, whereas commercial powders A and B were similar to the laboratory-prepared

TABLE I

PERFORMANCE OF COMMERCIAL YOLK SOLIDS IN CAKE DOUGHNUTS

Yolk Solids [a]	Batter Properties		Initial Air Pressure	Doughnut Properties		
	Water Level	Fluidity		Specific Volume	Height/ Diameter	Fat Absorption (Fresh Basis)
	% of dry mix	*g/lb* [c]	*psig*	*ml/g*		%
A. Usual water level in mix:						
Laboratory-prepared [b]	37.2	8.0	3.0	2.78	0.38	14.4
Commercial A	37.2	7.8	3.1	2.76	0.39	13.6
Commercial B	37.2	7.7	3.1	2.81	0.38	14.4
Commercial C	37.2	6.9	3.5	2.74	0.37	13.3
Commercial D	37.2	6.8	3.5	2.72	0.37	12.9
B. Adjusted water level:						
Commercial C	38.4	7.9	3.1	2.71	0.38	12.1
Commercial D	38.6	8.3	3.0	2.62	0.38	11.4

[a] Tested at a level of 1.5% of dry mix.
[b] Prepared in laboratory spray dryer with liquid yolk adjusted with white to contain approximately 5% white solids in the resulting powder, i.e., comparable to that usually encountered in commercial yolk solids.
[c] Average of measurements on batter weight extruded per lb. of operating air pressure; cf. reference 1.

powder in their effects on batter characteristics, powders C and D yielded batters of noticeably greater viscosity (decreased fluidity). This necessitated appreciably greater initial operating pressures to obtain the standard-weight (28-g.) doughnut. Additionally, the more viscous batters obtained with C and D resulted in flatter doughnuts (lower height/diameter ratios) with poor center star formation. The above comparisons were all made at the usual water level for this particular mix (37.2 parts per 100 parts of dry mix). Increasing the water used with C and D to levels that gave normal batter fluidities and operating pressures improved the height/diameter ratios of the doughnuts (Table I) and largely corrected the center star formation. Fat absorption was, however, slightly decreased, although not sufficiently to eliminate the possibility that these or similar yolk solids might support increased water absorption without impairment of eating quality to an important degree.

Some comparative analyses of the commercial yolk powders and two laboratory-prepared powders are shown in Table II. As reported previously (1), commercial yolk powders would generally be expected to contain about 5% white solids. This is substantiated for the present commercial powders by the fat analysis and also indicated by the pH and nitrogen values.

It is apparent that C and D differ markedly from the other powders in having sharply reduced protein solubilities and in exhibiting

TABLE II
ANALYSES OF COMMERCIAL YOLK SOLIDS

Yolk Solids	pH [a]	Total Nitrogen [b]	Fat [b]	Adhering Egg-White Solids [c]	Viscosity [a] of Reconstituted Yolk Solids	Protein Solubility
		%	%	%	cps	%
Laboratory-prepared (no adhering white)	6.0	5.19	68.1	0.0	2,000	97.3
Laboratory-prepared (2% white solids)	6.1	5.26	66.7	2.1	2,260	96.4
Commercial A	6.5	5.68	64.2	5.6	2,170	97.2
Commercial B	6.4	5.60	65.0	4.5	4,890	96.4
Commercial C	6.6	5.64	63.4	6.9	7,100	79.7
Commercial D	6.6	5.64	63.6	6.6	6,200	79.4

[a] Measured after reconstitution to 45% solids.
[b] Moisture-free basis.
[c] Estimated from dilution of fat content in white-free yolk.

slightly higher viscosities upon reconstitution. Viscosity values by themselves may be misleading, since increases can be brought about by freezing or freeze-drying without any apparent change in protein solubility as measured by the present method. Thus, we have found that freeze-dried yolks with no loss in protein solubilities generally have viscosities of about 6,000 centipoises upon reconstitution to 45% solids as compared with about 2,000 cps. for the best spray-dried powders (mildest drying conditions). Additionally, mechanical treatment such as colloid milling or homogenization may also influence yolk viscosity (5). However, although the apparent viscosity obtained may be complicated by the state of emulsion or other unknown factors which may not relate to protein denaturation, viscosity measurements can be useful in consideration of processing effects on powders prepared by the same drying procedure.

In the case of yolk powders C and D, both their higher viscosities and lower protein solubilities suggest heat-induced processing change. Conceivably, this may have occurred during 1) preheating of the liquid, 2) spray drying, or 3) storage of the powder at moderate to elevated temperatures after drying, or any combination of these possibilities. These alternatives are examined individually below.

Effects of Preheating Prior to Drying. Yolk is commonly heated or pasteurized prior to drying to improve either drying characteristics or bacteriological quality. The maximum heat-treatment is applied for pasteurization purposes and is generally reported to be in the range of 142° to 145°F. for not over 4 minutes (2,6,7,9). The limiting factor in the heat-treatment appears to be the build-up or film formation on the conventional plate or tubular heating equipment, rather than damage to functional properties (10). Paul *et al.* (7) reported that pasteurization of yolk prior to spray drying had little or no effect on cake doughnut characteristics. However, they did not report effects on yolk or batter properties. We have found that the conventional pasteurization treatment has little or no effect towards increasing viscosity of the liquid yolk before drying or decreasing protein solubility of the product (Fig. 1). Indeed, maintaining a tempera-

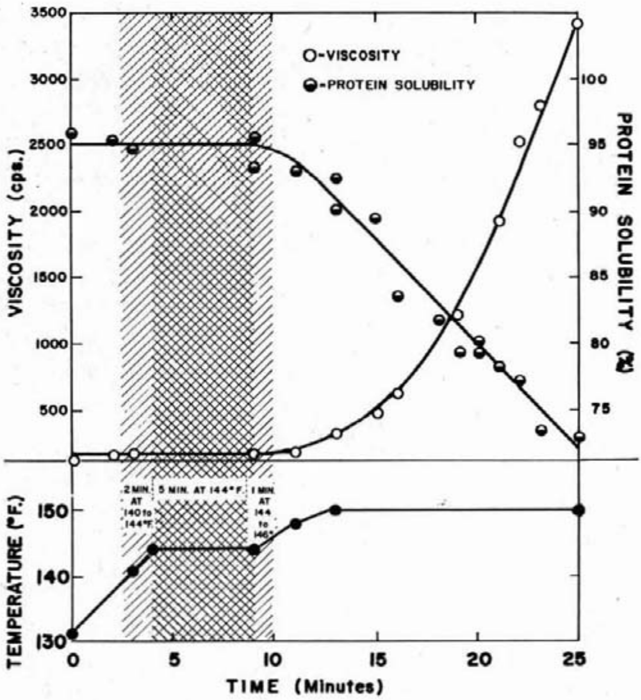

Fig. 1. Effect of time and temperature of heating on viscosity of liquid yolk and on protein solubility of resulting solids. Shaded area indicates the total time (8 minutes) in the conventional pasteurization temperature range (140° to 146°F.); 2 minutes at 140° to 144°; 5 minutes at 144°; 1 minute at 144° to 146°F.

ture between 140° and 146°F. for 8 minutes, or roughly 2 times a maximum pasteurization treatment, is also without important effect on these properties. Payawal *et al.* (8) also have reported that viscosity increases are slight in holding yolk at 62.5°C. (145°F.) but marked at 65°C. (149°F.). However, these results were obtained with white-free yolk. To achieve a decrease in protein solubility to less than 80%, or comparable to those exhibited by commercial powders C and D, requires preheating treatments far in excess of those employed for pasteurization purposes. To accomplish this change, heat-treatment equivalent to holding the yolk for 10 minutes at approximately 150°F. appears to be necessary (Fig. 1). The increase in viscosity of the liquid yolk during the heating period may be a useful indicator of the extent of solubility change. In the present example a viscosity increase (as measured after cooling to 75°F.) to approximately 2,000 cps. was indicated as that necessary to accomplish a protein solubility decrease to below 80%.

Viscosity measurement was used successfully as an indicator in the preparation of an 18-lb. (liquid) batch of yolks to obtain a spray-dried product with protein solubility comparable to that of C and D, or about 79%. The batch was heated until the viscosity exceeded 2,000 cps. This required holding the liquid yolk for approximately 0.5 hour at 148°F. (higher temperatures were not feasible with our equipment), after which it was rapidly cooled to below 131°F. and spray-dried. The powder obtained after this treatment (63C) exhibited a decrease in protein solubility to approximately 81% and an increase in viscosity upon reconstitution to 11,000 cps. (Tables III-A and III-B). As compared with the control powder (63A), which had virtually no preheating treatment but which was spray-dried under identical con-

TABLE III-A

EFFECT OF HEATING LIQUID YOLK PRIOR TO DRYING ON YOLK SOLIDS PROPERTIES[a]

PREHEATING TREATMENT	VISCOSITY OF LIQUID YOLK PRIOR TO SPRAY DRYING	VISCOSITY OF RECONSTITUTED YOLK SOLIDS	PROTEIN SOLUBILITY
	cps	*cps*	%
<1 minute at 125°F. (63A)	200	2,000	96.5
30 minutes at 148°F. (63C)	2,600	11,000	80.8

[a] Liquid yolk adjusted with egg white to 45% solids before processing (equivalent to approximately 15% adhering liquid white or 5% white solids in final powder).

TABLE III-B

EFFECT OF HEATING LIQUID YOLK PRIOR TO DRYING ON YOLK-SOLIDS PERFORMANCE IN CAKE DOUGHNUTS[a]

YOLK SOLIDS		BATTER FLUIDITY	INITIAL AIR PRESSURE	DOUGHNUT PROPERTIES	
Designation	Level			Specific Volume	Fat Absorption (Fresh Basis)
	% of dry mix	*g/lb*	*psig*	*ml/g*	%
63A	1.5	7.7	3.2	2.80	13.9
63C	1.5	7.1	3.4	2.86	13.4
63A	3.0	9.3	2.5	3.07	17.0
63C	3.0	7.9	2.9	2.96	16.3

[a] Liquid yolk adjusted with egg white to 45% solids before processing (equivalent to approximately 15% adhering liquid white or 5% white solids in final powder).

ditions, 63C caused more-viscous or less-fluid batters and, accordingly, required higher initial operating pressures. Effects on volume and fat absorption were slight. The treatment did not cause any noticeable visual discolorations or loss of color in the final powder. It would appear, therefore, that the preheating treatment effected changes in the properties of the final yolk powder similar to those exhibited by commercial powders C and D, although, as shown below, other processing stages may effect similar changes.

Effects of High-Heat Spray Drying. In an experiment aimed at inducing processing change during the spray-drying step, inlet air temperatures were arbitrarily raised by 100°F. The changes effected were extreme (Tables IV-A and IV-B); protein solubility of the powder was reduced to approximately 39% and the reconstituted viscosity increased to 80,000 cps. Both figures indicate change well beyond that observed in any of the commercial powders tested. The powder exhibited slight but obvious visible browning. At least part of this discoloration can be attributed to glucose-induced reactions, according to a previous report showing loss of glucose under average spray-drying conditions (4). Use of the high-heat powder resulted in extremely viscous batters that necessitated much higher initial operating

TABLE IV-A

EFFECT OF HIGH-HEAT SPRAY DRYING ON YOLK SOLIDS PROPERTIES[a]

	Spray-Drying Conditions		Viscosity of Reconstituted Yolk Solids	Protein Solubility
	Inlet Air Temp.	Outlet Air Temp.		
	°F	*°F*	*cps*	*%*
Low heat (43AB)	250	140	2,500	96.4
High heat (45A)	350	215	80,000	39.4

[a] Liquid yolk contained 10% adhering liquid white equivalent to about 2.5% white solids in final powder.

TABLE IV-B

EFFECT OF HIGH-HEAT SPRAY DRYING ON YOLK SOLIDS PERFORMANCE IN CAKE DOUGHNUTS[a]

Yolk Solids		Batter Properties		Initial Air Pressure	Doughnut Properties		
Designation	Level	Water Level	Fluidity		Specific Volume	Height/ Diameter	Fat Absorption (Fresh Basis)
	% of dry mix	*% of dry mix*	*g/lb*	*psig*	*ml/g*		*%*
43AB	1.5	37.2	7.8	3.1	2.81	0.38	14.7
45A	1.5	37.2	5.7	4.0	2.74	0.36	14.2
45A	1.5	40.1	8.6	3.0	2.71	0.37	10.9
43AB	3.0	37.2	9.3	2.5	3.02	0.39	18.8
45A	3.0	37.2	5.0	4.5	2.99	0.38	19.6

[a] Liquid yolk contained 10% adhering liquid white equivalent to about 2.5% white solids in final powder.

pressures (Tables IV-A and IV-B). Volume and fat absorption were not noticeably affected. However, the fat absorption of doughnuts containing high-heat solids at the 3.0% level may be misleading, because numerous large surface cracks developed during frying which appeared to implement fat absorption. Other defects were also apparent in doughnuts prepared from the high-heat powders, such as irregular shapes and little or no center star formation. Increasing the water level of the batter containing 1.5% yolk solids to the extent that normal operating pressure could be used did not correct the defects. The resulting doughnuts had a heavy, soggy texture and showed a sharply decreased fat absorption. It is obvious that heat-induced change in yolk properties can occur during spray drying and also have the net effect of increased batter viscosities. However, the change would have to be of a milder nature than that observed in the present study in order to yield yolk powders capable of making satisfactory doughnuts. While this was not further explored, there does not appear to be any reason why it could not be accomplished.

Effects of Storage at Elevated Temperatures. Previous work (4) shows that glucose-containing yolk solids (not desugared or "stabilized") exposed to storage at elevated temperatures will, in time, suffer browning and loss in protein solubility. These changes can be almost entirely attributable to glucose-induced reactions. In the present study, commercial yolk powder A, which showed no evidence of heat-induced processing or storage change (Tables I, II), was stored at 86° and at 100°F. for 2 months in a nitrogen atmosphere (Table V). The sample stored at 100°F. exhibited marked browning, extreme loss of protein solubility, and a tremendous increase in reconstituted viscosity. As might be expected from results above, it yielded very

TABLE V

EFFECT OF STORAGE OF YOLK SOLIDS[a] AT ELEVATED TEMPERATURES ON THEIR PROPERTIES AND PERFORMANCE IN CAKE DOUGHNUTS

Storage Temperature[b]	Batter Properties		Initial Air Pressure	Doughnut Properties		Yolk Solids Properties	
	Water Level	Fluidity		Spec. Vol.	Fat Absorption (Fresh Basis)	Viscosity of Reconstituted Yolk Solids	Protein Solubility
°F	*% of dry mix*	*g/lb*	*psig*	*ml/g*	*%*	*cps*	*%*
Control 34	37.2	7.8	3.1	2.76	13.6	2,170	97.2
86	37.2	7.5	3.3	2.78	12.4	21,500	90.3
100	37.2	5.8	4.2	2.84	11.0	>600,000	38.9
86	38.2	8.5	3.0	2.77	12.5		
100	39.4	8.0	3.2	2.72	10.3		

[a] Commercial yolk powder A used throughout (moisture content = 3.90%); all evaluated at a level of 1.5% dry mix.
[b] All storage (including control) for 8 weeks under N_2.

viscous batters. In agreement with the report of Paul *et al.* (6), the doughnuts prepared from it showed decreased fat absorption. As with the powders dried at high heat, the doughnuts were irregular with poor center star formation, and increasing the amount of water used with the mix to achieve normal batter fluidities (i.e., comparable to those obtained with control powders) did not yield satisfactory doughnuts.

The yolk powder stored at 86°F. exhibited slight browning, noticeable principally in side-by-side comparisons with the control. The batter prepared from it was slightly more viscous than the control batter, and the doughnuts were not entirely satisfactory in that they had lower fat absorption and only fair center star formation. The latter improved, however, when the water content of the batter was increased and this improvement was obtained without causing a further decrease in fat absorption. It is apparent that moderately high storage temperature (86°F.), conceivably encountered by some powders during commercial handling, can result in changes in yolk properties that affect doughnut batters.

Relating Yolk-Solids Properties to Their Effects on Cake Doughnuts. It is clear that either conditions of the drying process or exposure to elevated temperatures after drying can induce changes in properties of yolk solids. Further, application of preheating treatment over and above conventional pasteurization can also effect changes. These changes all lead to thicker doughnut batters which, in the extreme, yield unsatisfactory doughnuts.

Criteria are needed that will supplement present procurement specifications in correlating yolk-solids properties with their effect on batter and cake doughnut properties. The protein solubility method used in the present work is one technique that appears useful in this respect. However, there are many methods for measuring protein solubility or denaturation, and doubtless other techniques more specific could be applied. The present method and its applicability are summarized in Fig. 2. Normally, as reported earlier (1), batter fluidity increases (i.e., viscosity decreases) with increasing yolk level. Liquid yolks yield more-fluid batters than even the best-quality dried yolks, and this difference is unrelated to protein solubility, since both liquid and spray-dried yolks may exhibit maximum solubilities (> 95%). Probably this difference may be attributable to changes in the state of the emulsion or, more specifically, the lipoproteins during drying.

However, as far as spray-dried yolks are concerned, the following generalizations can be made: 1) Yolk solids with little or no processing

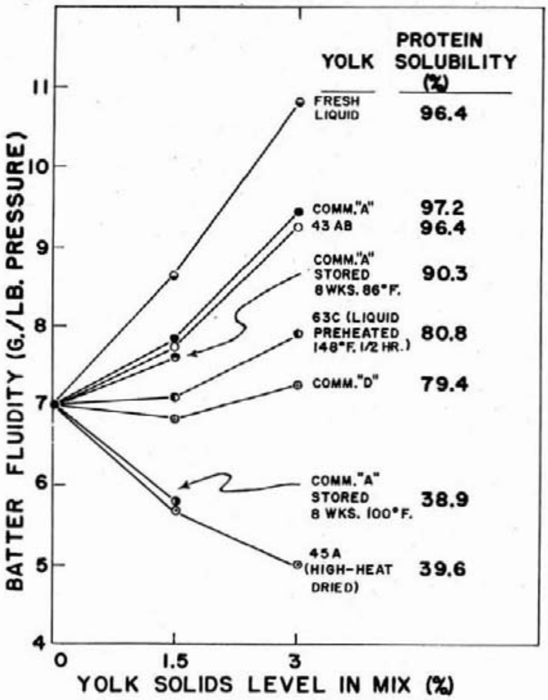

Fig. 2. Summary of effects of various yolks on cake doughnut batter fluidities (cf. tables for descriptions of powder designations).

change (e.g., commercial A or laboratory-prepared 43AB) exhibit or yield maximum protein solubility, the most fluid batters, maximum fat absorption, excellent cake doughnuts, and minimum water level in the batter for normal operating pressure. 2) Yolk solids with some processing change (commercial D, laboratory-prepared 63C, and commercial A stored 8 weeks at 86°F.) may still yield satisfactory to excellent doughnuts, particularly if the water level used with the mix is increased. While the data in Fig. 2 are illustrative in this respect for samples having protein solubility between 79 and 90%, other data (not shown, obtained co-operatively in a commercial doughnut mix laboratory) suggest that yolk solids having protein solubilities as low as 60% may fit into this second category. It is noteworthy that yolk solids in this category (e.g., commercial powder D) may have very little effect on batter fluidity as the yolk level is increased. 3) In a third category are samples with changes so extreme (commercial A stored 8 weeks at 100°F. or laboratory-prepared 45A, high-heat-dried) that their use actually causes the batters to become thicker than those obtained without yolk. Additionally, increasing the fluidities of these batters by increasing the water level does not yield satisfactory doughnuts.

The present protein solubility method is based on the percentage of the total nitrogen, as determined by the Kjeldahl method, that is filterable when the yolk is suspended in 10% KCl. It may be useful to simplify the technique by measuring turbidities in the filtrates in lieu of the more laborious nitrogen determinations. That a useful correlation exists is illustrated in Fig. 3.

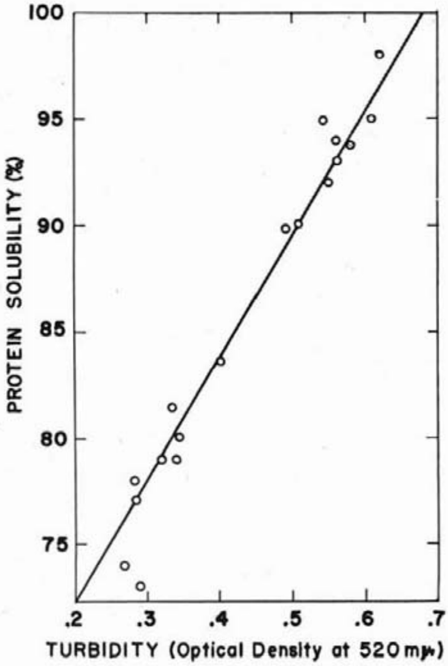

Fig. 3. Correlation between turbidity of filtrates in yolk protein solubility method and solubility as determined by Kjeldahl nitrogen determination.

Finally, viscosity measurements on the reconstituted powders should not be completely excluded. Thus, assuming that no frozen yolks were used in the preparation of spray-dried yolks, one might, as a first approximation, consider that yolk solids with viscosities less than 6,000 cps. (by the present method) fit into the first category above, between 6,000 and 30,000 in the second category, and greater than 60,000 in the third category. However, it is obvious that additional measurements would have to be accumulated and correlated with doughnut performance to establish the usefulness of this measurement.

Acknowledgment

The assistance of DCA Food Industries in furnishing supplies and loaning equipment is gratefully acknowledged. The interest and co-operation proffered by Larry Jents, formerly of DCA, is especially appreciated.

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