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FACTORS RELATED TO THE STORAGE STABILITY OF FOAM-DRIED WHOLE MILK. IV. EFFECT OF POWDER MOISTURE CONTENT AND IN-PACK OXYGEN AT DIFFERENT STORAGE TEMPERATURES

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SUMMARY

The flavor stability of foam-dried whole milk powders ranging from 2-5% in moisture content, packed in cans containing gases varying from nitrogen containing 0.2% oxygen to air, and held at storage temperatures ranging from 80 to 0 F was determined organoleptically. Low in-pack oxygen concentrations and low powder moisture content were found to reduce the rate of flavor deterioration at elevated temperatures, whereas high moisture levels favored flavor stability at moderately low storage temperatures. This stabilizing effect of moisture became more significant as the oxygen in the pack increased. This effect was not observed at 0 F. Actually, storage at this temperature seemed undesirable in the presence of oxygen. From the study it was concluded that the parameters used in this investigation could be manipulated to maintain an acceptable level of flavor in foam-dried whole milk powder during six months of storage.

A study of published data pertaining to the flavor changes in stored milk powders (4, 5, 7, 9) and other dehydrated foodstuffs (2, 3) shows that complex changes in the flavor stability of dried products can be expected by changing such parameters as the temperature of storage, the water content of the dried material, and the oxygen concentration in the containers.

This paper presents results obtained in an empirical study of the effect of varying the above-mentioned parameters on the flavor of stored foam-dried whole milk. This powder, when fresh, reconstitutes to a beverage approximating the flavor of commercial pasteurized milk.

MATERIALS AND METHODS

Possible variation in the composition of the milk supply during the course of the work was reduced by using mixed-herd milk from cows maintained on an invariant husbandry regime at the Agricultural Research Center at Beltsville, Maryland.

Whole milk powder samples were prepared from standardized milk, pasteurized by holding at 145 F for 30 min. The milk was concentrated to 50% solids, homogenized, injected with nitrogen, and vacuum-dried in the form of a foam.

Powder was obtained by breaking the dried foam through a 20-mesh screen. All production details were similar to those previously described (9), except that the actual drying operation was limited to a 2-hr interval. This resulted in the production of milk powder containing 5% moisture. This powder was split into four lots, one of which was retained for packing. The three other lots of powder were spread in ¾-in.-deep layers on stainless steel trays and dried to the desired experimental moisture levels. Details of this operation are shown in Table 1.

The milk powder samples thus obtained were packed in tin cans and stored in such fashion that samples containing 2, 3, 4, and 5% moisture were held at storage temperatures of 0, 34, 60, and 80 F in nitrogen-filled cans containing .2 and 1% oxygen and air. Packing methods used were those described earlier (11), except that evacuation of the cans was accomplished by holding samples under vacuum for only 10 min before filling with the desired gas. This prevented significant changes in the moisture content of the powders being packed.

Samples of the stored material were taken at two-month intervals, reconstituted, and subjected to organoleptic evaluation.

The type and intensity of the flavors in the reconstituted samples were determined by a panel of ten trained judges. Their sensory ex-

TABLE 1

Effect of drying conditions on moisture content and initial flavor of vacuum shelf dried whole milk

Drying technique no.	Drying conditions	Final moisture content of powder. Average of 4 replicates	Initial flavor score. Average of 4 replicates
		(%)	
1	As described in text	5.1	36.6
2	Portion of 5% moisture powder dried under pressure of 1 mm Hg for 30 min with shelf temperature held at 80 F	4.0	36.3
3	Portion of 5% moisture powder dried under pressure of 1 mm Hg for 10 min with shelf temperature held at 120 F, and 30 min with shelf temperature held at 80 F.	3.2	36.7
4	Portion of 5% moisture powder dried under pressure of 1 mm Hg for 20 min with shelf temperature held at 140 F, and 30 min with shelf temperature held at 80 F	2.1	36.7

perience was converted into flavor scores by use of a score-card. The significance of the scores was evaluated by use of statistical methods based on the analysis of variance. Exact details of these procedures have been previously published (10).

The moisture content of the powders was determined by use of the conventional toluene distillation technique.

In-package oxygen levels were measured using Haldane apparatus (6).

The entire experiment was repeated four times during the course of a calendar year and all results averaged in the computations.

RESULTS

The general drying conditions used to obtain the experimental milk powder samples containing varying amounts of moisture and the average initial flavor score of the resultant products are shown in Table 1. From this it can be seen that drying sequences used and the final moisture content of the powder did not significantly alter initial flavor. All powders could be considered, at the start of the experiment, to have a flavor on reconstitution closely approximating that of fresh pasteurized milk.

The analysis of variance, as used to study the significance of numerical data pertaining to the flavor scores of milk reconstituted from stored powder samples, indicated significant interaction between many of the experimental variables. A separation of the mean flavor scores in these interacting sets was accomplished by use of Duncan's Multiple Range test. In each related group in Tables 2 through 4 those mean scores having a common letter in the ranking column are statistically indistinguishable.

The interaction between the moisture level in the packed samples and temperature of storage is presented in Table 2. In the compilation of the data for this table, the means contain the quadruplicate flavor score values from packs containing three levels of oxygen as obtained at the end of two, four, and six months of storage. The most interesting point in this table is that, when considering all packs over the entire storage period, a storage temperature of 34 F and relatively high moisture content is most conducive to flavor stability. High moisture content at high storage temperatures promoted the rapid flavor deterioration of the product.

The observed interaction between moisture content and duration of storage of the powders is also shown in Table 2. From this it can be seen that no one moisture level was capable of substantially halting the deterioration of the mean score of all packs with time. However, at the end of six months of storage the packs containing 4% moisture had a significantly

TABLE 2

Rank comparison of mean flavor scores of whole milk powders containing different amounts of water

Interaction of moisture content and storage temperature				Interaction of moisture content and duration of storage			
Moisture content	Storage temperature	Mean flavor score	Rank (5% level)	Moisture content	Duration of storage	Mean flavor score	Rank (5% level)
(%)	*(F)*			*(%)*	*(months)*		
4	34	34.97	A	4	2	34.77	A
5	34	34.74	A	2	2	33.92	B
2	34	34.00	B	5	2	33.80	B
4	60	33.77	B	4	4	33.69	B
4	0	33.30	C	3	2	33.68	B
4	80	33.12	C	3	4	33.12	C
3	0	33.05	C	2	4	32.76	CD
3	80	33.02	C	5	4	32.59	DE
2	0	32.89	CD	4	6	32.23	E
2	80	32.52	DE	2	6	31.96	F
5	0	32.49	DE	5	6	31.79	F
3	34	32.44	DE	3	6	31.34	G
3	60	32.26	E				
2	60	32.09	E				
5	60	31.55	F				
5	80	31.25	F				

TABLE 3

Rank comparison of mean flavor scores of whole milk powders packed in cans containing different concentration of oxygen

Interaction of in-pack oxygen concentration and storage temperature				Interaction of in-pack oxygen concentration and powder moisture content			
Oxygen concentration	Storage temperature	Mean flavor score	Rank (5% level)	Oxygen concentration	Moisture content	Mean flavor score	Rank (5% level)
(%)	*(F)*			*(%)*	*(%)*		
0.2	34	34.68	A	0.2	5	34.78	A
1.0	34	34.34	AB	1.0	5	34.44	AB
0.2	0	33.98	BC	0.2	4	34.12	BC
0.2	80	33.83	C	0.2	3	33.91	C
0.2	60	33.26	D	0.2	2	33.35	D
Air	34	33.10	DE	1.0	4	33.12	DE
1.0	0	32.94	DE	Air	5	33.11	DE
1.0	60	32.81	E	1.0	3	32.90	E
1.0	80	32.18	F	1.0	2	32.28	F
Air	0	31.87	F	Air	4	31.87	G
Air	80	31.40	G	Air	3	31.41	H
Air	60	31.25	G	Air	2	31.25	H

higher mean flavor score (MFS) than did the packs containing 2, 3, and 5% moisture.

When considering the interaction of in-pack oxygen level and powder moisture content, as presented in Table 3, it becomes apparent that the high moisture levels in the powder most significantly improve the mean score at the higher in-pack oxygen levels when flavor score values representing all storage times and temperatures are included in the average. The most notable flavor-stabilizing action of high moisture content can be observed in the air packs. Reference back to Table 2 would show that this beneficial effect would most likely occur at moderately low storage temperatures.

From the observed interactions between in-pack oxygen levels and storage temperature, also presented in Table 3, it can be seen that the flavor-stabilizing effect of storage at 34 F becomes more marked as the amount of oxygen in the packs increases. The MFS of all moisture levels held at 0 F when averaged over the entire storage period were only slightly higher than those of samples stored at 60 and 80 F.

Examination of the interaction between duration of storage and the in-pack oxygen level,

TABLE 4

Rank comparison of mean flavor scores of whole milk powders at the end of various storage periods

Interaction of duration of storage and storage temperature				Interaction of duration of storage and in-pack oxygen concentration			
Duration of storage	Storage temperature	Mean flavor score	Rank (5% level)	Duration of storage	Oxygen concentration	Mean flavor score	Rank (5% level)
(months)	*(F)*			*(months)*	*(%)*		
2	34	34.89	A	2	0.2	34.86	A
2	0	34.23	B	2	1.0	34.05	AB
4	34	33.80	C	4	0.2	34.03	AB
2	80	33.77	C	4	1.0	33.34	B
6	34	33.43	CD	2	Air	33.22	B
2	60	33.26	D	6	0.2	32.93	B
4	0	33.12	DE	6	1.0	31.83	C
4	80	32.75	EF	4	Air	31.77	C
4	60	32.50	F	6	Air	30.74	C
6	60	31.56	G				
6	0	31.44	G				
6	80	30.89	H				

as presented in Table 4, shows that the air-packed samples deteriorate most rapidly in storage and must contribute substantially to lowering the MFS presented in Table 2.

The duration of storage also interacts with the storage temperature, but in a slightly more inexplicable fashion. Table 4 demonstrates that the MFS of all packs, averaging both moisture content and in-pack oxygen level, deteriorates slowest at a storage temperature of 34 F. In fact, the MFS of six-month-old samples held at 34 F was indistinguishable from four-month-old samples held at 0 F or two-month-old samples held at 80 F. It is somewhat surprising that the MFS of samples held at 0 F were indistinguishable from those of samples held at 60 F and that both were only slightly, but significantly, higher than those of samples held at 80 F six months.

To gain further insight into the meaning of these observed interactions, it is necessary to consider the characteristic flavors of the various stored powders which led to the formulation of the specific flavor scores.

In Figures 1 and 2 we have attempted to summarize the salient features of the observed flavor changes in the samples during storage as influenced by storage temperature, in-pack oxygen level, and powder moisture content. Only data pertaining to oxidized and stale flavors are presented, since these flavors contributed most to the judges' assignment of scores. The isometric projections clearly illustrate the almost reciprocal relationship that existed between the frequency of oxidized and stale flavors found in the stored samples. In a very general sense, high storage temperatures, high in-pack O_2 levels, and low moisture levels in the powder promoted the formation of oxidized flavor in the product. High storage temperatures, high moisture levels in the powder, and low levels of O_2 in the packs led to the development of stale flavors in the stored powders.

DISCUSSION

Our data demonstrate that in attempts to stabilize the flavor of whole milk powder, storage at extremely low temperatures may be unnecessary, or even undesirable. This is particularly true if considerable oxygen is present in the pack. The explanation for this observed effect is not obvious, but may be considered to be related to the physical state of the residual water in the pack. Our results, and those obtained by other investigators (9), clearly indicate that at temperatures above freezing the stability of whole milk powder against oxidative deterioration increased with increasing water content. The mechanism responsible for this protective effect is unknown, but it is apparently disrupted by physical changes in the powder that are associated with a physical change in some of the water it contains.

A more prosaic explanation of the observed decrease in flavor stability of milk powder at 0 F would be to suspect the integrity of the can seals at low temperature. We have obtained no data indicating that oxygen diffuses through the can seals at very low temperature.

The staling of milk powder, found to occur in stored samples containing low levels of oxygen and high levels of moisture, can most probably be considered to arise from nonoxidative

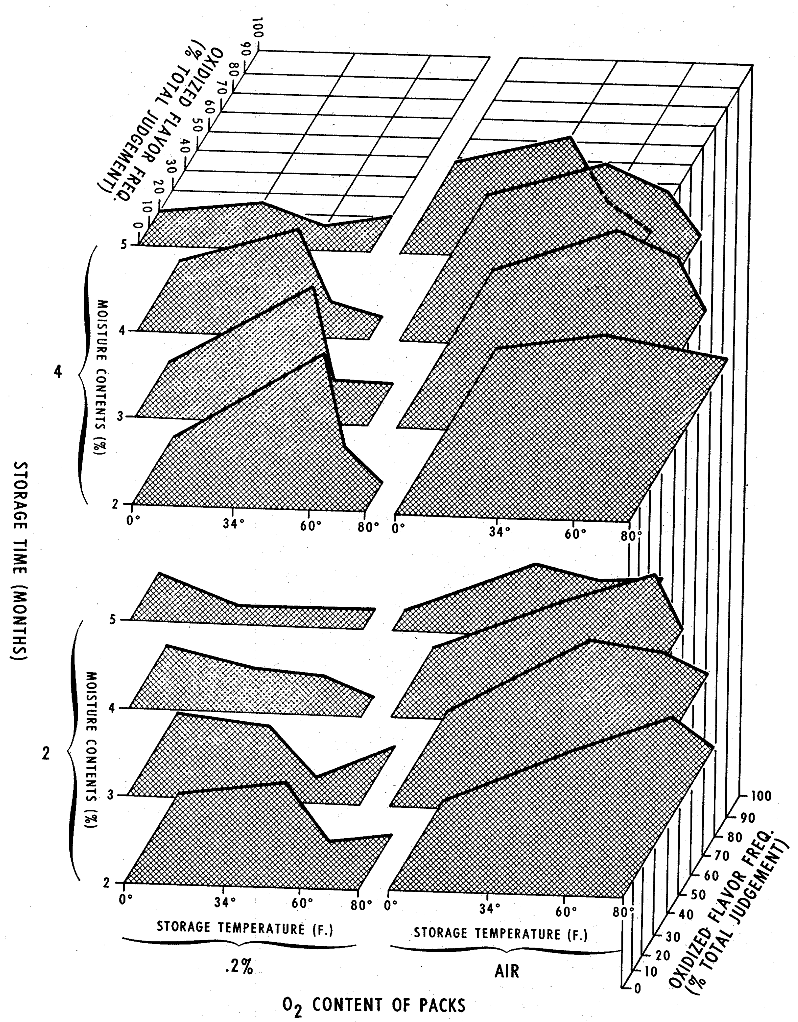

FIG. 1. Effect of moisture content, storage temperature, and oxygen level on oxidized flavor formation during storage of vacuum shelf dried whole milk.

changes in the powder constituents. Sugar-protein interactions associated with browning have been most commonly thought to be responsible for the development of this flavor. However, it is becoming increasingly apparent that nonoxidative changes can and do occur in the lipid phase of whole milk powder which give rise to flavors commonly classified as stale (8).

Our study indicates that the moisture content, storage temperature, and in-pack oxygen level cannot be simultaneously manipulated in such fashion as to allow six months of storage to elapse without flavor changes detectable by a panel of skilled judges. This does not imply that, for any storage temperature, in-pack oxygen levels and the moisture content of the powders cannot be adjusted to minimize the rate of flavor change. Evidence for this is shown in Figure 3, where part of the data incorporated in the interaction tables is presented in graphical form. This figure shows the beneficial effect of high levels of moisture when storage is carried out at 34 F, and demonstrates that flavor scores can be maintained above 35.5 during six months of storage.

At the time this study was made, it was impossible to reduce the oxygen content of packs to near-zero values without seriously reducing the water content of the powders. Therefore, some oxidized flavor was encountered in all packs during the course of the study. With the more recent development of a good in-pack oxygen scavenging system (1), it became possible to maintain powders of high moisture content in nitrogen containing undetectable

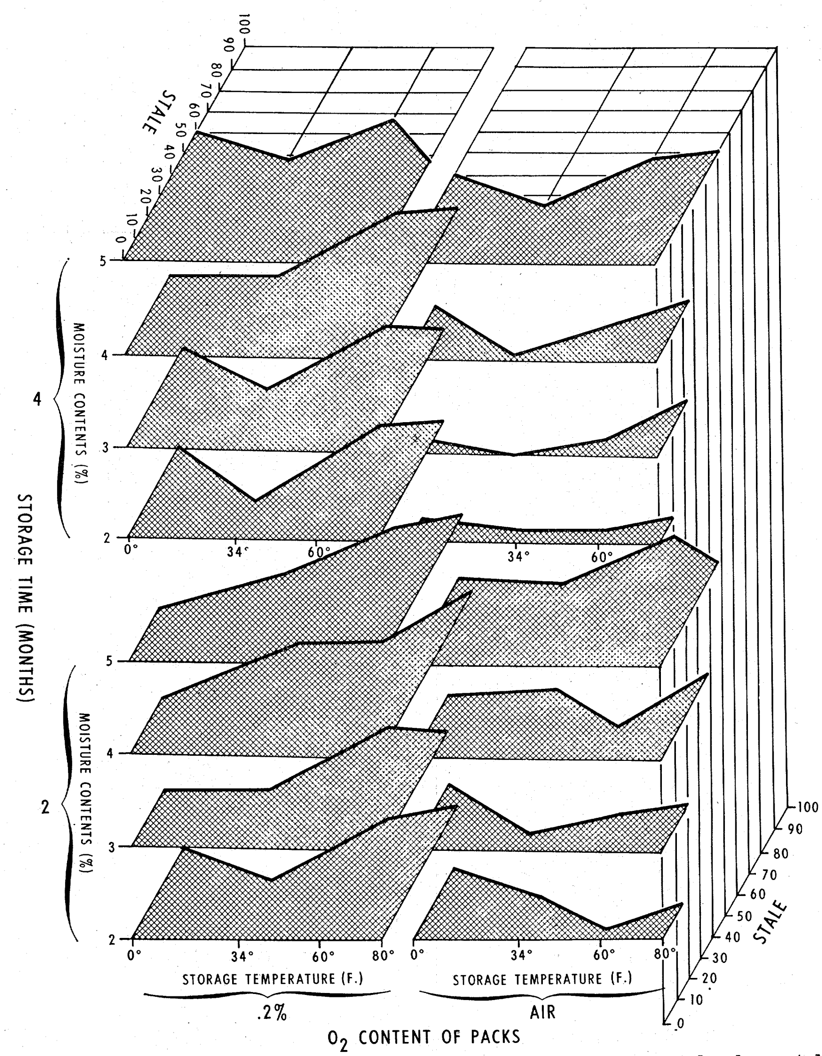

FIG. 2. Effect of moisture content, storage temperature, and oxygen level on stale flavor formation during storage of vacuum shelf dried whole milk.

levels of oxygen. As expected, these further studies, using foam-spray-dried milk, showed that oxidized flavor could be completely eliminated from stored milk samples; however, staling remained unchecked. Therefore, continued study, using a wider variety of powders and more efficient packaging methods, have not necessitated alteration of the conclusions drawn from the data reported here.

CONCLUSIONS

From results obtained in this study and previously published results of investigations of the flavor stability of a variety of foodstuffs, we conclude that whole milk so produced as to minimize physical and chemical change in the milk constituents during dehydration cannot be kept from deterioration during storage by a simple manipulation of either the moisture content of the powder, the oxygen level of the pack, or the temperature of storage. Judicious use of these parameters may at best slow the rate to the place where the material remains food-grade after six months of storage with the complete elimination of the oxidized flavor.

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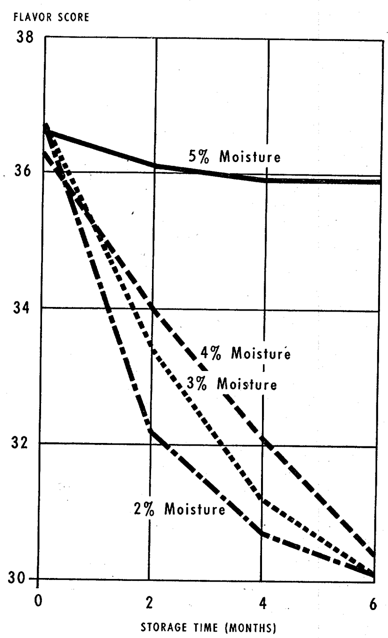

FIG. 3. Effect of moisture content on flavor score of vacuum shelf dried whole milk during storage at 34 F and 1% oxygen level.

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