Effect of Oxygen Uptake on Quality of Cooked, Freeze-Dried Combination Foods

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The effect of oxygen uptake on the quality of eight cooked, freeze-dried combination items used in Armed Forces operational rations was determined. The products were packed in cans with different vacuums and stored at 100° F. Evaluations made at intervals during a six-month period included technological panel ratings, rehydration ratios, and analysis of headspace gas. Positive statistical correlations were found between oxygen uptake and flavor and odor ratings. Slopes of the regression lines for all eight items were almost identical. However, no correlation was found between oxygen uptake and rehydration ratios. Several items exhibited antioxidant properties which suggests that further work on formulations combined with oxygen uptake studies will result in improved storage characteristics for this type of freeze-dried products.

Adverse effects of oxygen uptake on the quality of freeze-dried foods have been noted by many investigators. Sharp (1953) mentioned that dehydrated meat must be kept in an oxygen-free atmosphere. Harper and Tappel (1957) pointed out that a large quantity of oxygen is absorbed during the deterioration of freeze-dried beef, but they did not draw any conclusions as to a practical limitation on oxygen to ensure storage stability. Wuhrmann *et al.* (1959) and Tappel *et al.* (1957) noted that the storage stability of freeze-dried foods is improved when the foods are packed in a nitrogen atmosphere. Olcott (1962) stated that there is a rapid loss of palatability when freeze-dried meat and fish are stored in oxygen or air. Smithies (1962) stated that in an oxygen-free atmosphere, freeze-dried meat products suffer only a slow change in quality over periods of several months but air storage of these products can bring about spectacular decreases in rehydration. In general, three major factors determine the type and extent of deterioration reactions in freeze-dried foods: residual moisture level, headspace oxygen content, and duration of storage at elevated temperatures (Thompson *et al.*, 1962). However, in an investigation into the deterioration of freeze-dried beef, chicken, carrots, and spinach, it was found that exposure to oxygen was the most significant factor in degradation of freeze-dried products stored at elevated temperatures (Roth *et al.*, 1965).

The deteriorative reactions which occur in freeze-dried meats are not the typical oxidative rancidity reactions such as those that occur in fresh and frozen meats. Andrews and Trenk (1962), using a model system approach, established that interactions occur between proteins and autoxidizing unsaturated lipids and that cross-linking of proteins takes place. Andrews and Thomson (1962), Andrews *et al.* (1965), and Karel and Tannenbaum (1966) continued this work and have shown that several naturally occurring products exert substantial antioxidant activity in preventing the reactions.

Both Roth *et al.* (1965) and Hanson (1961) showed that freeze-dried foods vary in their tolerance to oxygen. Since foods are complex mixtures, it could be expected that some should be more resistant to oxidation than others. For this reason and because the lower the headspace oxygen specified for freeze-dried foods, the higher the cost, it was decided to test the oxygen uptake and resulting organoleptic properties of eight freeze-dried combination foods used in military operational rations and similar to some contemplated for the commercial market. The items tested were beef hash, beef stew, beef with rice, chicken and rice, chicken stew, chili con carne, pork with potatoes, and spaghetti with meat sauce.

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EXPERIMENTAL

The products were made in accordance with Interim Purchase Description IP/DES S-36-6 Food Packet, Long Range Patrol, dated April 20, 1966. The total amount of each product needed for the investigation was made in a single batch and dehydrated in one freeze-dehydrator chamber in order to minimize processing variations. Dehydration was to less than 2% moisture and the vacuum in the chamber was broken with nitrogen. Freeze-dehydration conditions were 120° F. platen temperature with radiant heating and a pressure of 400 microns. Packaging was in No. $2^1/_2$ cans and was accomplished within four hours after the dehydrator was opened.

Twenty-five cans each containing 125 grams of product were closed at each vacuum. Vacuums used were 30, 28, 26, 24, 22, 20, and 0 inches. The cans closed at 30 inches were evacuated three times with 30 seconds dwell each time and flushed back with nitrogen the first two times. The other cans were closed as soon as the gauge indicated the required vacuum. The vacuums actually attained corresponded to approximately 1, 2, 3.5, 5, 6, 7, and 21% oxygen if the cans had been gas packed. The cans were then stored at 100° F. and five cans of each vacuum withdrawn for evaluation at 0, 2, 4, 12, and 24 weeks. The storage temperature is a standard requirement (with storage for 6 months) in development of freeze-dried meats for Armed Forces use. Moisture content of the stored product was 1 to 2%.

Headspace gas analysis was performed by chromatographic means in accordance with the procedure outlined by Bishov

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and Henick (1966). Prior to analysis the cans were brought to room pressure with nitrogen and allowed to equilibrate overnight. Sample size was 250 to 500 μl. Experience indicates an anticipated error for the method of approximately ±0.25%. Results for the five cans of each level were averaged for reporting purposes.

Total headspace volume in the can was determined by compressing 125 grams of product in a laboratory press at 5000 lbs. per sq. inch for 10 seconds and subtracting the volume of the resulting bar from the total volume of the can. This method is not completely accurate; however, since the volume of headspace was so large in comparison with the absolute volume of the product and the evaluations were made by a taste panel, any resulting error was considered insignificant.

Taste panel evaluation was made by a 10-member technological panel rating the product on a 9-point scale for flavor, odor, and texture where the highest number was the most acceptable. The same panel was used for all evaluations. Product was rehydrated with 180° F. water for 5 minutes for tasting. Product in the cans used for the chromatographic analyses was used for the panel evaluation.

Rehydration value was obtained by rehydrating 125 grams of product with water at 180° F. for 5 minutes, draining the product for 1 minute on a wire screen with 1/8-inch square openings and reweighing. Rehydration ratio was calculated as weight of rehydrated product divided by weight of dry product.

RESULTS AND DISCUSSION

Table I shows the oxygen uptake and average panel flavor ratings for the eight items. Analysis of the data for flavor, odor, and texture showed that flavor was the controlling variable in that it was the first one to show a significant decrease as the oxygen uptake increased.

Analysis of variance results for flavor, odor, and texture (Table II) show that oxygen available and storage time at elevated temperatures are two important factors in the deterioration of freeze-dried foods. Beef with rice does not show a significant effect for odor and texture with vacuum nor any vacuum × storage interaction. This is undoubtedly because of the comparatively low oxygen uptake of this product. Vacuum × storage time interactions were significant for flavor and odor with the other products and in the same direction as the main effects. Rehydration ratios were not significantly different over the full vacuum and storage time ranges.

The Duncan Multiple Range test shows that with five of the eight items there is no significant difference at the 1% level between the flavor rating means at full vacuum through 26 inches. Chicken and rice, beef with rice, and chili con carne show no significant difference between full vacuum and 20 inches, which would suggest that these three items are less sensitive to oxygen than the other five. For all eight products where vacuum is shown to be significant in Table II for odor and texture, the Duncan Multiple Range test shows that there is no significant difference between full vacuum and 20 to 22 inches. Thus, in an over-all evaluation of the effects of available oxygen on the products, the effect on flavor would be the controlling factor.

Regression analysis shows that flavor and odor ratings by the technological panel are highly correlated with the oxygen uptake (Table III). Texture ratings did not correlate as well. Slopes of the regression lines for flavor and odor of all eight items are almost identical (Table IV) indicating that a given

Table III. Correlation Coefficients (r) for Oxygen Uptake *vs.* Technological Panel Results

Product	Flavor	Odor	Texture
Beef hash	0.873[a]	0.823[a]	0.578[a]
Beef stew	0.852[a]	0.879[a]	0.732[a]
Beef with rice	0.766[a]	0.657[a]	0.363[n.s.]
Chicken and rice	0.876[a]	0.920[a]	0.648[a]
Chicken stew	0.830[a]	0.823[a]	0.193[n.s.]
Chili con carne	0.585[a]	0.667[a]	0.344[n.s.]
Pork with potatoes	0.887[a]	0.853[a]	0.499[a]
Spaghetti with meat sauce	0.859[a]	0.889[a]	0.937[a]

[n.s.] Not significant at $P > 0.05$. [a] $P > 0.01$. D.F. = 27.

Table IV. Linear Regression Equations for Ml. Oxygen Absorbed (x) *vs.* Flavor Rating on a 9-Point Scale (y)

Product	Equation
Beef hash	$y = 5.86 - 0.035x$
Beef stew	$y = 6.46 - 0.032x$
Beef with rice	$y = 6.56 - 0.035x$
Chicken and rice	$y = 6.35 - 0.023x$
Chicken stew	$y = 6.17 - 0.030x$
Chili con carne	$y = 6.18 - 0.024x$
Pork with potatoes	$y = 5.81 - 0.024x$
Spaghetti with meat sauce	$y = 5.54 - 0.035x$

Table V. Correlation Coefficients (r) for Time *vs.* Log Mol Fraction of Oxygen Remaining

Product	Correlation Coefficient (r)
Beef hash	0.741[a]
Beef stew	0.916[a]
Beef with rice	0.680[a]
Chicken and rice	0.855[a]
Chicken stew	0.876[a]
Chili con carne	0.845[a]
Pork with potatoes	0.541[a]
Spaghetti with meat sauce	0.757[a]

[a] $P > 0.01$. D.F. = 27.

oxygen uptake will result in an equivalent decrease in organoleptic ratings for each product. However, the rate of uptake is not the same for all items. For example, at the end of 12 weeks at 100° F. in air pack, chicken stew had an oxygen uptake of about 37% of that available. Under the same conditions the uptake of spaghetti with meat sauce was about 91%. With the exception of beef and rice and chili con carne, all of the items had an oxygen uptake of well over 90% by the end of 24 weeks. Beef and rice had an uptake of about 31% and chili con carne about 57% in 24 weeks. This suggests that these two items possess better antioxidant properties.

To gain further insight into the oxygen uptake, the regression of time *vs.* log of mol fraction of oxygen remaining was calculated for each product. Correlation coefficients are shown in Table V and indicate a good linear relationship. Slopes of the lines are dissimilar and there does not seem to be a relationship between the slope and antioxidant properties of the products. This study, however, was not designed to investigate the mechanism of oxidation, but rather to determine the effects of the oxygen uptake upon organoleptic ratings.

The results of this study clearly confirm the adverse effects of oxygen uptake in freeze-dried combination items, and reinforce Armed Forces specification requirements restricting headspace oxygen to a maximum of 2% for operational rations where lengthy storage under possible adverse conditions must

Table I. Oxygen Uptake and Flavor Ratings for Eight Combination Meat Items during 24 Weeks at 100° F. with Different Amounts of Oxygen Available[a]

Vacuum, Inches	30		28		26		24		22		20		0	
Time, Weeks	O_2 uptake, ml.	Flavor rating	O_2 uptake, ml.	Flavor rating	O_2 uptake, ml.	Flavor rating	O_2 uptake, ml.	Flavor rating	O_2 uptake, ml.	Flavor rating	O_2 uptake, ml.	Flavor rating	O_2 uptake, ml.	Flavor rating
							Beef Hash							
0	0	6.2												
2	3	6.3	3	6.6	4	5.6	7	6.2	8	5.7	7	5.5	24	5.1
4	3	6.1	7	6.1	10	6.3	14	4.7	14	5.5	19	6.0	43	4.3
12	5	6.3	0	5.2	6	4.4	20	5.2	21	4.7	21	4.4	73	3.1
24	2	5.8	8	6.2	16	5.5	26	3.9	27	4.4	30	4.9	131	1.6
							Beef Stew							
0	0	6.5												
2	1	6.9	11	6.4	16	7.1	21	6.6	22	6.4	28	5.7	49	4.5
4	2	6.7	11	6.2	22	6.3	20	4.4	31	5.6	35	4.6	27	4.3
12	5	6.4	14	6.3	25	5.4	34	4.9	42	4.4	55	4.3	108	3.3
24	6	6.6	15	6.3	26	6.2	35	4.8	44	4.2	56	5.0	154	2.3
							Beef with Rice							
0	0	6.8												
2	0	7.0	1	6.3	2	6.4	3	5.8	3	6.5	6	6.7	18	5.8
4	1	7.0	5	6.6	6	6.1	5	6.0	7	6.1	8	6.3	24	5.1
12	0	6.9	7	6.3	10	6.0	6	6.5	13	6.1	16	6.4	23	5.8
24	1	5.9	11	6.4	14	6.1	15	6.3	20	5.9	23	5.8	49	5.0
							Chicken and Rice							
0	0	6.7												
2	2	6.7	2	6.6	7	6.3	7	6.2	8	5.8	10	6.0	50	5.4
4	3	6.4	5	6.1	11	6.6	13	5.7	16	6.4	19	6.0	41	4.1
12	0	6.6	3	5.2	13	5.9	23	5.4	30	5.6	39	5.2	137	3.3
24	4	6.3	6	6.2	18	6.1	26	5.8	33	6.2	44	6.1	144	3.1
							Chicken Stew							
0	0	6.7												
2	6	6.4	3	6.7	5	5.9	9	5.7	10	5.8	16	6.0	24	4.9
4	4	6.7	11	6.5	9	6.4	17	4.7	20	6.3	19	6.1	33	4.9
12	8	6.5	13	5.7	13	4.7	20	4.6	26	5.5	30	5.4	56	4.7
24	9	6.0	15	5.5	21	5.1	34	4.5	39	4.6	56	4.1	143	2.5
							Chili Con Carne							
0	0	7.0												
2	4	6.6	3	6.3	4	6.0	10	6.2	1	6.1	9	5.6	21	5.2
4	4	6.2	2	6.0	7	6.5	9	6.0	9	5.3	10	5.8	30	3.9
12	1	6.6	2	6.3	14	6.1	17	5.3	21	4.9	18	4.9	62	3.1
24	5	6.5	7	6.1	21	6.2	28	6.1	36	6.0	37	5.4	89	5.5
							Pork with Potatoes							
0	0	6.4												
2	0	6.4	4	5.8	10	6.1	16	5.8	21	5.3	23	4.6	42	3.5
4	2	6.4	6	6.0	14	5.5	31	4.5	39	4.5	47	3.8	148	2.4
12	2	6.2	5	6.1	16	5.7	30	4.7	41	4.4	50	4.1	150	2.1
24	2	5.0	6	6.0	17	6.0	30	4.7	41	5.0	50	4.3	158	3.1
							Spaghetti with Meat Sauce							
0	0	6.3												
2	3	6.3	6	5.3	4	6.0	4	4.6	7	5.0	5	5.1	44	3.1
4	2	5.8	0	5.9	4	5.2	7	5.1	8	4.6	10	4.7	61	2.9
12	3	6.5	6	5.9	11	6.2	15	5.2	18	4.8	22	4.3	143	1.4
24	6	6.3	10	6.0	17	5.4	24	3.4	33	3.2	39	2.5	147	1.0

[a] Flavor ratings are the average of 10 responses. Oxygen uptake is for 125 grams of product and is the average of 5 determinations.

Table II. Analysis of Variance Results for Eight Combination Meat Items

Product	Vacuum[a]			Storage Time[a]			Vacuum X Storage Time[a]		
	Flavor	Odor	Texture	Flavor	Odor	Texture	Flavor	Odor	Texture
Beef hash	a	a	n.s.	a	a	a	a	a	n.s.
Beef stew	a	a	b	a	a	b	a	b	n.s.
Beef with rice	a	n.s.	n.s.	a	a	a	n.s.	n.s.	n.s.
Chicken and rice	a	a	a	a	a	b	a	a	n.s.
Chicken stew	a	a	n.s.	a	a	a	a	a	n.s.
Chili con carne	a	a	b	a	a	a	a	a	n.s.
Pork with potatoes	a	a	n.s.	a	a	n.s.	a	a	n.s.
Spaghetti with meat sauce	a	a	a	a	a	a	a	a	a

[a] a, $P > 0.01$; b, $P > 0.05$; n.s., not significant at $P > 0.05$.

be anticipated. The results also show that certain products, such as beef with rice, possess antioxiodant properties making them less susceptible to oxidative deterioration than other products. Investigation of these antioxidant properties should lead to improved formulation of other products allowing for a larger margin of error in their handling and packing. Since this study was conducted only at 100° F., storage stability of the products under other storage conditions such as refrigeration cannot be established directly from the results.

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