Effect of Storage Temperature on the Oxygen Uptake of Cooked, Freeze-Dried Combination Foods

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The effect of storage temperature on the oxygen uptake of eight freeze-dried combination meat items was determined. The products were packed in cans with different vacuums and stored at 40°, 70°, and 100° F. Headspace oxygen concentrations were determined at intervals during a 6 month period. Temperature, vacuum, and storage time significantly affected oxygen uptake of all eight products, but the relative importance of the three factors was different for each product. The products divided into two general classes. In the first class, which included beef with rice, chicken and rice, chicken stew, and pork with potatoes, the oxygen uptake was primarily due to vacuum and temperature. In the second class, which included beef hash, beef stew, chili con carne, and spaghetti with meat sauce, uptake was due primarily to vacuum and time. Spaghetti with meat sauce showed very little difference in uptake at different temperatures, whereas the difference with chicken and rice and chicken stew was substantial.

The adverse effects of oxygen on the quality of freeze-dried foods have been of concern since the beginning of the Armed Services program for the development of new freeze-dried operational rations. Sharp (1953) and Harper and Tappel (1957) point out that dehydrated meat absorbs oxygen and should be kept in an oxygen-free atmosphere. Olcott (1962) states that there is a rapid loss of palatability when freeze-dried meat and fish are stored in oxygen or air. Smithies (1962) states that in an oxygen-free atmosphere, freeze-dried meat products suffer only a slow change in quality over periods of several months, and air storage of these products can bring about spectacular decreases in total water uptake upon rehydration. In a study concerned with the deterioration of freeze-dried beef, chicken, carrots, and spinach, Roth *et al.* (1965) reported that exposure to oxygen appeared to be the most significant factor in the degradation of freeze-dried porducts stored at elevated temperatures.

Storage temperature is generally considered to have a very significant effect on the storage life of freeze-dried foods. Hanson (1961) reported results from a large number of studies and suggested that a dehydrated food which will keep for 2 yr at 60 to 70° F could be expected to last 12 to 18 mo at 80° F, 6 to 8 mo at 90° F, 3 mo at 100° F, and about 2 weeks at 120° F. These products were properly packaged with less than 2% oxygen in the headspace. Hanson also states that with low oxygen atmosphere, the actual storage life of a particular food at a particular temperature is profoundly affected by several factors such as moisture content, sugar content, processing conditions, and enzymic changes. Meat items to be accepted for use in operational rations are routinely storage tested for 12 mo at 100° F, at the U.S. Army Natick Laboratories and must receive satisfactory ratings from consumer-type taste panels at the end of this period. In general, the results from these studies agree with Hanson's suggestions (1961), except that properly designed cooked freeze-dried combination meat products appear to have much better storage stabilities and are less affected by storage temperature.

The Food Packet, Long Range Patrol is a light weight packet designed to be carried by the individual soldier in operational and combat situations, such as extended patrols where resupply is difficult or impossible. The main component of each packet is a freeze-dried flexibly packaged entré which can be eaten dry or rehydrated in 5 min or less with either hot or cold water in the flexible package. There are eight different menus which include freeze-dried beef hash, beef stew, beef with rice, chicken and rice, chicken stew, chili con carne, pork with potatoes, and spaghetti with meat sauce. Acceptance by troops in the field and particularly in Vietnam has been enthusiastic because of the high quality as well as the light weight. Since the packet is becoming increasingly important for operational feeding, a study was conducted storing the freeze-dried products for 6 mo with different oxygen concentrations at 100° F (Tuomy *et al.*, 1969). Quality (primarily flavor) deterioration was significantly correlated with oxygen uptake, but the uptake was substantially greater with some products than with others. To determine the effect of temperature on oxygen uptake, the original study was extended to include storage at 70° and 40° F.

EXPERIMENTAL

The products were made according to Interim Purchase Description IP/DES S-36-6 Food Packet, Long Range Patrol, dated April 20, 1966. Products stored at 100° F were those reported by Tuomy *et al.* (1969). The products stored at 70° and at 40° F were made in a single batch and dehydrated in one freeze-dehydrator chamber to minimize process variations. Dehydration was to less than 2% moisture, and at the end of the run 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 μ. The products were packaged in No. 2-1/2 cans within 4 hr after the dehydrator was opened.

Fifty cans, each containing 125 g of product, were closed at each vacuum. Vacuums used were 30, 28, 26, 24, 20, and 0 in. The cans closed at 30 in. were evacuated three times with 30 sec dwell each time and flushed back with U.S. Pharmacopoeia grade nitrogen the first two times. The other cans were closed as soon as the gage indicated the required vacuum. The vacuums attained corresponded to approximately 1, 2, 3.5, 5, 6, 7, and 21% oxygen if the cans had been gas packed to atmospheric pressure. Half of the cans were stored at 70° F and half at 40° F. Five cans of each vacuum at each of these two temperatures were withdrawn for evaluation at 0, 2, 4, 12, and 24 weeks.

Headspace gas analysis was performed by a chromato-

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Table I. Analysis of Variance Significance and Components of Variance in Percent of Total Variance for Oxygen Uptake

Factor	Beef Hash		Beef Stew		Beef with Rice		Chicken and Rice		Chicken Stew		Chili Con Carne		Pork with Potatoes		Spaghetti with Meat Sauce	
	Sig.	%	Sig.	%	Sig.	%	Sig.	%	Sig.	%	Sig.	%	Sig.	%	Sig.	%
Vacuum (A)	*a*	30.3	*a*	40.5	*a*	22.1	*a*	16.8	*a*	11.6	*a*	30.1	*a*	37.3	*a*	44.3
Temperature (B)	*a*	8.4	*a*	12.5	*a*	22.3	*a*	23.4	*a*	30.4	*a*	14.8	*a*	14.6	*a*	2.7
Time (C)	*a*	15.1	*a*	16.5	*a*	14.6	*a*	3.7	*a*	8.7	*a*	20.4	*a*	6.9	*a*	14.4
AB	*a*	13.1	*a*	6.1	*a*	30.8	*a*	36.1	*a*	16.8	*a*	7.2	*a*	18.2	*a*	4.0
AC	*a*	30.8	*a*	16.2	*a*	2.7	n.s.	...	*b*	6.5	*a*	19.0	*a*	9.8	*a*	28.4
BC	*a*	2.1	n.s.	...	*a*	6.6	*b*	4.6	*a*	9.2	*a*	5.8	*b*	3.0	n.s.	...
Error	...	0.2	...	8.2	...	0.9	...	15.4	...	16.8	...	2.7	...	10.2	...	6.2

[a] = Significant at 1% level. [b] = Significant at 5% level. n.s. = Not significant at 5% level. *Levels:* Vacuum—30, 28, 26, 24, 22, 20, 0 in.; Temperature—40°, 70°, 100° F, Time—0, 2, 4, 12, 24 weeks.

Table II. Effect of Temperature on Oxygen Uptake as Shown by Available Oxygen Taken up by Eight Products Packed in Air and Stored for 24 Weeks at Three Temperatures

Product	Temperature and Percentages		
	100° F	70° F	40° F
Beef Hash	83	65	17
Beef Stew	95	53	45
Beef with Rice	31	10	7
Chicken and Rice	93	10	5
Chicken Stew	95	16	7
Chili Con Carne	57	30	29
Pork with Potatoes	99	92	26
Spaghetti with Meat Sauce	93	94	93

Table III. Multiple Regression Coefficients for the Linear Regression Oxygen Available, Temperature, and Time *vs.* Oxygen Uptake

Product	Correlation Coefficient (R_{123})
Beef Hash	0.745
Beef Stew	0.788
Beef with Rice	0.787
Chicken and Rice	0.612
Chicken Stew	0.668
Chili Con Carne	0.792
Pork with Potatoes	0.730
Spaghetti with Meat Sauce	0.760

graphic method in accordance with the procedure outlined by Bishov and Henick (1966). Prior to analysis the cans were brought to atmospheric pressure with nitrogen allowed to equilibrate overnight. Gas 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 each can was determined by compressing 125 g of product in a laboratory press at 5000-lb per sq in. for 10 sec and subtracting the volume of the resulting bar from the total volume of the can. It was recognized that this method is not completely accurate. However, since the volume of headspace gas was so large in comparison with the volume of the dry solids, any resulting error was considered insignificant.

RESULTS AND DISCUSSION

Analysis of variance results for the oxygen uptake are given in Table I. Percentages of variation assignable to each factor as determined by the method of Hicks (1956) are also given. The main factors of vacuum, temperature, and time were significant at the 1% level for all eight items. Most of the two factor interactions were significant at either the 1% or the 5% level. All of the interactions were in the same direction as the main factors.

Rank correlation analysis of the components of variance in Table I indicates that the eight products can be divided into two general classes. In one class, which includes beef with rice, chicken and rice, pork with potatoes, and chicken stew, the major portion of the variance was caused by vacuum, temperature, and the vacuum X temperature interaction. In the other class, which includes all of the other products, the major portion of the variance was cause by vacuum, time, and the vacuum X time interaction. This division into classes is of great importance when the end use of the product is considered. The Armed Forces are very much concerned with long term storage for contingency and reserve stocks. In this case refrigerated storage is commonly used and time in storage becomes of paramount concern. On the other hand, operational rations must be designed to meet the possibility of high temperature storage in various parts of the world. At the present time very little is known as to why the products react differently, and it is evident that much more information is needed in this area.

Table II, which shows the percent of available oxygen taken up by the eight products packed in air and stored at three temperatures, illustrates the wide difference in responses of the items. As noted by Tuomy *et al.* (1969) the oxygen uptake of beef with rice and chili appears to proceed at a significantly slower rate at 100° F than does the uptake of the other six items, but the responses of chicken and rice and chicken stew are similar at 70° and 40° F. On the other hand, spaghetti with meat sauce shows no change in oxygen uptake at the three temperatures under these particular conditions.

Multiple linear regression equations were calculated from the data using oxygen available (X_1), temperature (X_2), and time (X_3) as the independent variables, and oxygen uptake (Y) as the dependent variable. The resulting equations had the form of $Y = A + BX_1 + CX_2 + DX_3$. As shown in Table III, the multiple regression coefficients (R_{123}) ranged between 0.61 and 0.79 for the eight items, indicating good linear relationships. Analysis of variance showed that the contribution of each of the independent variables in each case was significant at the 1% level. The equations developed can be used as an indication of storage stability, assuming that oxygen uptake is correlated to taste panel ratings (Tuomy *et al.*, 1969). However, there are so many possible variations in formula, processing, etc., plus inherent variations in subjective ratings obtained by taste panels, that only very general indications can be obtained. Furthermore, the equations were developed from data obtained in a 6-mo storage period and extension of the time used in the equations beyond 6 mo cannot be justified. Regardless of this, the equations can be very useful in setting up broad guidelines for storage limitations.

Inspection of the raw data indicates that the dependence of oxygen uptake on temperatures and on time is probably curvilinear. However, the multiple correlation coefficients were not significantly improved when various functions of time and temperature were used in the equations.

Table IV shows the correlation coefficients (r) for the linear regression of time on log of mol fraction of oxygen remaining. In all cases, with the exception of chicken stew at 40° F, the coefficients are significant at the 1% level at each temperature. With chicken stew at 40° F, the oxygen uptake was so low that the points tended to cluster. The coefficients indicate a very good linear relationship, a relationship usually considered criterion for a first order reaction. While it is very doubtful that the oxygen uptake is a simple first order reaction, this study indicates that the reactions involved are not the classical fat rancidity reactions, since these are not first order reactions.

The results of this study show that combination items have different oxygen uptakes under the same storage conditions which suggests that products with improved storage stability for particular uses can be designed. Unreported inhouse work has shown that commonly used antioxidants are comparatively ineffective in slowing down oxygen uptake in the eight products examined in this study. Comparison of the formulas for the products with their oxygen uptake sheds very little light on the reasons for the uptake differences. For example, spaghetti with meat sauce has been shown by this study as well as many informal observations to be the most susceptible product to oxygen of the eight. This probably can be attributed to the 19% tomato paste in the wet formula. However, chili con carne contains 12% tomato paste and it is one of the products most resistant to oxygen. In addition, oxygen uptakes of individual components do not seem to carry through to the formulated product. For these reasons another study has been started in which the products will be broken down into components and groups of components processed in the same way as in the complete product. In addition, effects of some process conditions such as cooking temperature will be investigated. From this study it is hoped that information will be developed so that products with improved resistance to oxygen uptake can be developed.

Table IV. Correlation Coefficients (r) for Time *vs.* Log Mol Fraction of Oxygen Remaining at Three Temperatures

	(r)		
Product	**100° F**	**70° F**	**40° F**
Beef Hash	0.741	0.672	0.669
Beef Stew	0.916	0.659	0.738
Beef with Rice	0.680	0.761	0.734
Chicken and Rice	0.855	0.449	0.540
Chicken Stew	0.876	0.761	0.201
Chili Con Carne	0.846	0.624	0.841
Pork with Potatoes	0.541	0.824	0.733
Spaghetti with Meat Sauce	0.863	0.854	0.686

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