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Meat preservation at depressed water activities.

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Water activity (a_W) is defined as the ratio of the vapor pressure of water (p) in the system to the vapor pressure of pure water (p_o) at the same temperature, $a_W = p/p_o$. When aquilibrium exists between the moisture concentration of a food and the relative humidity of its environment, water activity is directly relatable to the relative humidity as expressed in the moisture sorption isotherm. The relationship between a_W and the moisture concentration of a food depends on the chemical and physical properties of the food solids, on temperature, on the amount and nature of the soluble materials present, and possibly on whether equilibrium was established by adsorption or desorption.

As emphasized by Scott (1957) and more recently by Christian (1963) and by Loncien, Bimbenet and Lenges (1968), water activity is a significant factor in the growth of microorganisms. While many species of bacteria show optimum growth at water activities well below that of fresh meat, a_W about 0.99, most of the bacteria responsible for meat spoilage are progressively inhibited as a_W is decreased. Although a precise value is controversial, bacterial growth is generally restricted to values of a_W above 0.90. Common species of yeast and mold, however, may continue to develop until a_W is depressed to around 0.70. A number of commercial foods such as soft candies, marshmallows, jams, certain bakery products, raisins, dried figs, dried apricots and several types of dry sausage fall roughly into the a_W range of 0.90 to 0.70. Items within this range are conveniently referred to as *intermediate moisture* foods. Although not sterile, intermediate moisture foods are generally handled as shelf-stable items requiring no refrigeration.

Common intermediate moisture meat items such as peperoni, B. C. salami, and country style hams, owe their stability primarily to the addition of salt which after equilibration with the moisture of the meat is further concentrated by evaporation of moisture. Intermediate moisture meats of the types cited are too salty for general use as a major item of the diet. Intermediate moisture meat with relatively low salt content, such as jerky, has an exceedingly tough texture and a characteristic flavor which seriously

limits its acceptability. Except for prefried bacon, the commercial meat industry has shown little interest in the development of new intermediate moisture products or in advancing the technology of existing products.

Outside of the meat industry, the development of new intermediate moisture products has been stimulated by the availability of antimycotic agents, such as potassium sorbate, which are effective at concentrations permitted for consumption. Most of the development, however, has been directed to pet foods. As currently formulated these products contain about 25 percent moisture. They are somewhat plastic, easily masticated, nutritionally balanced and acceptable to dogs. A brief summary of an example drawn from a patent (Burgess and Mellentin, 1965) indicates the steps of preparation and provides an insight into their economic attractiveness. Thirty-two parts of ground meat by-products (e. g. beef tripe, gullets, udders) are cooked at 82—100 C with small amounts of sorbitol, propylene glycol, mono and diglycerides, fat, salt, mineral supplement, and potassium sorbate. The cooked components are mixed with 32 parts of soy flakes, 3 of milk powder, flavoring, vitamin concentrates, and coloring materials, and extruded in a desired configuration into an inexpensive plastic pouch which is subsequently sealed. Pet food prepared in this manner is distributed through normal market channels without refrigeration. These foods have proved virtually immune to microbiological deterioration. A sample of a major brand of intermediate moisture dog food was found to have a water activity of 0.85.

It is recognized that the sweet taste imparted by the concentration of sucrose or glucose used for the stabilization of pet foods in the intermediate moisture range is incompatible with our consept of normal meat flavor. It is likewise apparent that meats stabilized by a high concentration of salt have limited acceptance and can not be considered for use as a major part of the daily caloric intake. On the other hand, preservation in the intermediate moisture range offers a number of attractive features worthy of further consideration. Intermediate moisture meats can be prepared with relatively simple equipment, do not require sophisticated packaging and can be stored and transported without refrigeration. The work here reported is a part of a larger study initiated to explore the possibility of achieving preservation in the intermediate moisture range by using metabolizable organic additives and salt in combinations which eliminate or minimize the objectionable features of sugar or salt alone.

In considering the use of metabolizable compounds, guidance is provided by Raoult's law which, for non-dissociated sompounds, identifies the relationship between water activity and the amount of water and solute in a solution,

$$a_W = \frac{M_W}{M_W + M_S},$$

where M_W and M_S represent the number of moles of water and solute, respectively, in the solution. Since approximately 6 moles of non-dissociated solute are required to depress the a_W of a kg of water to 0.90, the organic, solute most have a moderately high solubility and preferably a low molecular weight. In addition, the solute must meet requirements for human consumption and have a relatively low taste impact which is compatible with the acceptability of the end-item. Glycerol was selected as the additive with the greatest probability for success.

Experimental observations are confined to pork and beef although similar results have been obtained with lamb, white meat of chicken, tuna, and a variety of vegetables. Well trimmed *L. dorsi* of pork and *M. semimembranosis* of beef were cut into rectangular pieces 1 cm thick. Preliminary experiments pointed to the feasibility of immersing the meat in a solution of defined composition such that after equilibration the meat would have a prescribed water activity and antimycotic content. Since the diffusional processes are accelerated by temperature, the meat was heated (cooked) in the solution.

It was recognized that this procedure did not permit precise control of the amount of liquid phase remaining in the equilibrated meat. On the other hand the use of a procedure analogous to those used for the production of dry sausage was unattractive owing to the necessity for drying. Likewise the infiltration of freeze dried meat with a precise volume of solution of a specific composition was rejected as impractical for large scale application. No consideration was given to the alternative of equilibrating partially freeze dried meat with a suitable solution as suggested by Paynter and Olson (1967).

A known weight of raw meat was immersed in a specific weight of a solution containing a defined concentration of glycerol, water, sodium chloride, and an antimycotic, usually potassium sorbate. In early experiments 5 percent propylene glycol was included: this was eliminated because it imparted a bitter taste. Sodium chloride was included for its contribution to taste as well as for its effect on water activity. The meat and its immersion solution were heated to above 95 C, held for 15 to 30 minutes at this temperature, cooled, and held overnight in a refrigerator. After warming to room temperature, the pieces of cooked intermediate moisture meat were drained, weighed, and transferred to sealed containers for subsequent tests and evaluation. Observations based on water/salt ratios (Table 1) indicate that equilibration of the meat with its immersion solution was complete.

Representative examples of intermediate moisture meats are shown in Table 2. All items have a normal cooked meat appearance. In general, items with a_W above 0.80 are soft, moist, and tender but retain a fibrous structure normal to the original meat. With water activities below 0.80 there is a definite tendency toward a firm, dry texture. Odor of all meats is uniformly normal. Taste is somewhat sweeter than normal but recogni-

zable as cooked pork or beef. Flavor is improved by addition of soup or gravy base to the immersion solution. It is believed that intermediate moisture pork would be accepted as normal in a context of sweet and sour pork, or as barbecued pork or in other prepared items in which a slight sweetish taste is a normal characteristic. The beef is deemed acceptable for a number

Table 1. *Preparation of intermediate moisture pork*

Immersion Solution	200.0 g	$a_w = 0.73$
Water	45.0 %	
Glycerol	45.0 %	
NaCl	9.5 %	
Antimycotic	0.5 %	
Raw Pork	130.6 g	
Water	72.5 %	
NaCl	0.1 %	
Solution after Equilibration	230.3 g	$a_w = 0.80$
Water	61.6 %	
NaCl	6.28 %	
NaCl/Water	0.102	
Intermediate Moisture Pork	100.3 g	$a_w = 0.80$
Water	46.6 %	
NaCl	4.68 %	
NaCl/Water	0.100	

Table 2. *Intermediate moisture meats*

Meat	*Water %*	*Clycerol %*	a_w
Pork	23	29	0.72
	35	36	0.76
	47	23	0.80
	41	20	0.81
Beef	31	22	0.77
	39	21	0.80
	44	19	0.82
	36	22	0.82
	42	18	0.83
Lamb	40	20	0.86
Chicken (white meat)	43	21	0.84
Tuna	39	28	0.81

of casseroles or other combination dishes. The equilibration process is reversible. Immersion of intermediate moisture meat in a 2 percent salt solution followed by a brief heating, eliminates the taste imparted by the glycerol.

Samples of intermediate moisture pork and beef have been stored for 4 moths at 38° C without significant change in sensory properties. There was no evidence of microbial growth, oxidative changes or important changes due to browning. Standard plate counts performed on intermediate moisture pork and beef after storage for 4 months at 38° C reveal no more than 10 organisms per gram. Samples of intermediate moisture chicken have been inoculated with *S. aureus* (14,000/g), *E. coli* (6,000/g), *Salmonella* (7,400/g) and *Cl. perfringens* (12,000/g). After 4 months storage at 38° C viable organisms from each inoculation were fewer than 10/g.

On the basis of Table 2 no difficulty is anticipated in preparing intermediate moisture meat with a residual glycerol content of 18—20 percent. Cursory experiments with the application of mild pressures of 50 to 100 kg/cm^2 can be expected to depress the yield by about 5 percent and reduce the residual glycerol concentration to around 14 percent. The projected yield and composition of intermediate moisture meat is illustrated in Table 3.

Table 3. *Projected yield and composition of intermediate moisture meat*

Lean Meat	100 g		
Solids	28 g	72 g Water	
	24 g	Meat Solids	= 39 %
	27 g	Water	= 44 %
	9 g	Glycerol	= 14 %
	1.8 g	NaCl	= 3 %
	0.2 g	K Sorbate	=
Yield	62.0 g	Intermediate Moisture Meat.	

Aside from a detectable glycerol flavor, the intermediate moisture meat of Table 3 is expected to be completely acceptable for all uses except straight concumption without a sauce. Glycerol is readily metabolized by the body as a carbohydrate to yield 4.3 kcal/g. In human feeding experiments 14 graduate students were given 110 g of glycerol per day for 50 days with no recognized clinical or subjective effect (Miner and Dalton, 1953). In the product illustrated in Table 3 glycerol accounts for less than 30 percent of the total caloric value. It should be noted that the meat of Table 3 is virtually fat free. With meat at customary fat levels the caloric centribution of glycerol would be substantially less.

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