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Nutritional Value of Dehydrated Foods[1]

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THE SEARCH for new and improved methods of preserving foods for consumption at a later time is a continuing activity of the Armed Forces in order to assure adequate nutriture of military personnel. Certain characteristics required of military subsistence—ease and speed of preparation in the field, long shelf-life, and economy of space—have counterparts in the desired characteristics of convenience foods for the civilian market. Military interest in dehydration stemmed primarily from the potential savings in weight of foods moved and stored, for, of the 1800 lb. purchased per man per year for mess-hall feeding, about 70 per cent is water. Secondarily, many foods were expected to be more stable and palatable after dehydration than after thermal processing, and some new foods could be added to the packaged ration system.

Prior to dehydration, all vegetables and some fruits are blanched to inactivate enzymes, fix color, and remove extraneous materials and gases. Sulphites or sulphur dioxide are frequently added at this stage to improve product stability. The cooking of foods usually causes chemical changes in heat-sensitive constituents, such that water is released, and, if the food is to be cooked before eating, it is often advantageous to remove some water initially by this procedure. The pre-cooking procedure also yields a product which requires little field preparation, improving military utility.

Dehydration is usually accomplished by vaporizing water with the addition of heat, transferring the water to the food surface, and removing the water vapor from the surface. In tunnel and belt dehydrators used, for example, for drying diced potatoes, carrots, cabbage, and pre-cooked beans and rice, the product is exposed to a moving stream of heated air in the temperature range of 140° to 200°F. When the material to be dried can be made into a paste, such as mashed potatoes and tomato purée, it may be spread on a rotating, steam-heated drum. Liquids are frequently dispersed in fine droplets and dried in an upward-flowing warm air stream. This spray method is normally applied to milk, eggs, and coffee. Some liquid products which are quite sensitive to heat, such as fruit juices, can be dried successfully by the vacuum process at lower temperatures, because reducing the air pressure lowers the boiling point of water.

A further reduction in chamber pressure to about 1 mm. of mercury permits drying in the frozen state with the water passing directly from a solid to a vapor phase. This process of freeze-drying results in the least change in the physical characteristics of the product and is finding increasing usefulness in the dehydration of problem foods, such as meats and some vegetables.

A cursory review of the techniques involved in dehydration shows several steps in which nutrient losses might be anticipated. Leaching of all water-soluble compounds can occur in washing and some blanching procedures. Heat treatment is damaging to most of the major vitamins, protein, and essential fatty acids, with destruction usually accelerated in the presence of air and light. Nutrient stability is also influenced by the acidity or alkalinity of the product, and/or by the presence of active enzymes and such processing aids as sulphite. However, some

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or all of these potentially damaging agents are encountered in all conventional methods of preservation.

It became necessary, then, to determine whether dehydrated foods are at least equally as nutritious as the other processed foods they will supplant. Ideally, they should be better. Therefore, studies were carried out to ascertain the composition of these products and to compare nutritional quality of foods processed by accepted methods and methods competing for adoption. Additionally, human feeding tests were conducted for evaluation of the digestibility and physiologic adequacy of typical foods by Drs. Roy Korn and Richard Eckhardt at the Chicago West Side Veterans Administration Hospital.

Procedure

Since valid comparisons can be made only when all samples derive from the same starting material, a study was conducted in which three processing methods were applied to portions of a single lot of product. Five representative foods of animal origin—chicken, beef, pork, shrimp, and bacon—and four plant products—cabbage, carrots, corn, and green beans—were chosen. Tests were made on the raw products and after dehydration, irradiation, and the usual thermal process. In most cases, samples were dehydrated both in the raw and cooked state; irradiated samples were either enzyme-inactivated or fully cooked before irradiation. Except for bacon, all animal products were frozen before dehydration under reduced pressure. All vegetables were exposed to heated air to accomplish dehydration. Cabbage was the only product which was not thermally processed in a can. The starting material in four instances—chicken, shrimp, green beans, and corn—was a commercially frozen product rather than a fresh sample. The samples were then cooked by a method appropriate to the product and again analyzed for their contribution of certain of the major vitamins.

Details of processing are given below. For brevity, samples classes have been coded as follows: A, dehydrated in the raw state; B, precooked, dehydrated; C, irradiated after enzyme-inactivation; D, precooked, irradiated; and E, conventionally canned. Code 1 refers to processing treatment, code 2 to preparation for serving.

I. Bacon.
   A. Dehydrated in the raw state. No sample.
   B. Not dehydrated but comparable product; prefried bacon loses some moisture in frying and no further processing is required.
      1. Combination cured for 6 days; smoked for 18 hr.; sliced; cooked at 350°F. in an oven until crisp; and sealed in cans at 25 in. vacuum.
      2. Heated in an oven for 15 min. at 400°F.
   C. Irradiated after enzyme-inactivation.
      1. Dry cured for 16 days; smoked for 24 hr.; sliced; rolled in parchment; and sealed in cans at 10 in. vacuum.
      2. Broiled at 550°F. for 4 min. on one side and 1½ min. on the other.
   D. Precooked, irradiated.
      1. Combination cured for 6 days; smoked for 18 hr.; sliced; cooked at 450°F. in an oven until crisp; and sealed in cans with an oxygen scavenger.
      2. Same as I. B.2.
   E. Conventionally canned.
      1. Dry cured for 16 days; smoked for 24 hr.; sliced 9/64 in. thick; rolled in parchment; sealed in 401 x 411 cans at 25 in. vacuum; and pasteurized at 165°-170°F. for 2 hr.
      2. Same as I. C.2.

II. Beef (fresh chuck cut into 1 x 1 in. strips and ground through ¼ in. plate grinder).
   A. Dehydrated in the raw state.
      1. Made into 3¼-oz. patties; frozen at —42°F.; and freeze-dehydrated.
      2. Rehydrated 20 min.; drained; and grilled 2½ min. on each side at 450°F.
   B. Precooked, dehydrated.
      1. Placed in loaf pans and cooked for 55 min. in a retort at 212°F. to an internal temperature of 145°-155°F.; cooled at 40°F. for 4 hr.; frozen at —42°F.; sawed into ½-in. slices; and freeze-dehydrated.
      2. Rehydrated 20 min.; drained; and grilled 2 min. on each side at 450°F.
   C. Irradiated after enzyme-inactivation.
      1. Made into 3¼-oz. patties; cooked for 25 min. in a retort at 205°F. to an internal temperature of 165°F.; and sealed in cans at 15 in. vacuum.
      2. Heated in a double boiler for 20 min. and then grilled 2 min. on each side at 450°F.
   D. Precooked, irradiated.
      1. Made into 3¼-oz. patties; fried in deep fat for 6 min. at 300°F.; and sealed in cans at 15 in. vacuum.
      2. Grilled for 1¼ min. at 450°F. on each side.
   E. Conventionally canned.
      1. Made into 3¼-oz. patties; fried in deep fat for 1 min. 20 sec. at 350°F.; sealed in 300 x 409 cans at 20-22 in. vacuum; and heated for 90 min. at 250°F.
      2. Cans were placed in a boiling water bath for 30 min. and contents drained.

III. Chicken.
   A. Fresh, frozen chicken thawed in cold water overnite at 40°F.
      1. Skinned and boned; stuffed into casings; frozen at —42°F.; sawed into ½-in. thick slices; and freeze-dehydrated.
      2. Rehydrated 30 min. in a salt solution; simmered for 50 min. in the same solution; and drained.
   B. Same as III. A.
      1. Simmered for 50 min.; cooled at 40°F.; skinned and boned; dipped in boiling water; packed into metal molds; frozen at —42°F.; sawed into ½-in. thick slices; and freeze-dehydrated.
      2. Rehydrated for 30 min. in a boiling salt solution and drained.
   C. Fresh, frozen chicken thawed in a continuous stream of cold tap water.
      1. Cooked in a retort on trays to an internal temperature of 160°F. (approximately 25

min.); sealed in cans at 15 in. vacuum.
2. Simmered for 30 min. in a salt solution, drained, and boned.

D. Same as III. C.
1. Breasts were roasted for 1¾ hr.; legs and thighs were roasted for 1 hr. and 10 min. at 350°F.; sealed in cans at 15 in. vacuum.
2. Boned (to be added to hot white sauce).

E. Fresh, frozen chicken.
1. Cooked in a retort on trays at 212°F. for 35 min.; skinned and boned; 1½ lb. of meat put in 401 x 411 cans with 6 oz. of salted broth; sealed under 5 in. vacuum; and heated for 2½ hr. at 240°F., and water cooled.
2. Cans placed in a boiling water bath for 30 min. and contents drained.

IV. Pork loin (boned and fat trimmed to ¼-in. thickness).

A. Dehydrated in the raw state.
1. Rolled loosely in laminated aluminum foil; frozen at −42°F.; sawed into ½-in. thick slices; and freeze-dehydrated.
2. Rehydrated for 30 min.; drained; blotted; and grilled on each side for 2 min. at 450°F.

B. No sample.

C. Irradiated after enzyme inactivation.
1. Cooked for 50 min. in an oven at 212°F. to an internal temperature of 165°F.; sliced ½ in. thick; and sealed in cans at 7-12 in. vacuum.
2. Grilled on each side for 3 min. at 450°F.

D. Precooked, irradiated.
1. Oven-cooked for 2½ hr. at 325°F. to an internal temperature of 185°F.; sliced ½ in. thick; and sealed in cans at 7-12 in. vacuum.
2. Grilled on each side for 2 min. at 450°F.

E. Conventionally canned.
1. Sliced ⅝ in. thick; deep fat fried at 350°F.; sealed in 300 x 200 cans with 15 ml. salted water at 25-28 in. vacuum; and heated for 50 min. at 250°F.
2. Cans placed in a boiling water bath for 30 min. and contents drained.

V. Shrimp (fresh-frozen, peeled, deveined).

A. Dehydrated in the raw state.
1. 6-lb. blocks sawed into ½-in. thick slices and freeze-dehydrated.
2. Rehydrated for 30 min., boiled for 4 min., and rinsed in cold tap water.

B. Precooked, dehydrated.
1. Thawed in a continuous stream of cold tap water; cooked for 4 min. in boiling water; immediately showered with cold water; drained; frozen at −18°F.; and freeze-dehydrated.
2. Rehydrated for 15 min. and rinsed in cold tap water.

C. Irradiated after enzyme-inactivation.
1. Thawed as in V.B.1.; cooked in boiling salted water for 2 min.; cooled; and sealed in cans at 28 in. vacuum.
2. Boiled for 3 min., then rinsed in cold tap water.

D. Precooked, irradiated.
1. Thawed as in V.B.1.; cooked in boiling salted water for 10 min., cooled; and sealed in cans at 28 in. vacuum.
2. Rinsed in cold tap water.

E. Conventionally canned.
1. Blanched in boiling brine for 10 min.; sealed in 300 x 407 cans with 2% salt solution at 5-10 in. vacuum; and heated for 25 min. at 240°F.
2. Same as V.D.2.

VI. Beans, green (Tendergreen, fresh-frozen).

A. Dehydrated in the raw state.
1. Steamed at 212°F. for 4 min.; dipped in sulphite solution for 2 min.; drained for 2 min.; and frozen at 0°F.; dehydrated for 45 min. at 190°F. dry bulb—90°F. wet bulb low velocity followed by 4½ hr. at 145°F. dry bulb—90°F. wet bulb medium velocity; and sealed in cans under vacuum.
2. Added to boiling water with the pan partially covered; allowed to simmer for 10 min.; then drained.

B. Precooked, dehydrated.
1. Steamed for 9 min. and treated as in VI.A.1.
2. Added to boiling water; stirred; allowed to stand in covered pan for 25 min.; drained.

C. Irradiated after enzyme-inactivation.
1. Steamed for 4 min. and sealed in cans under vacuum.
2. Added to cool water, heated to 180°F., and drained.

D. Precooked, irradiated.
1. Steamed for 9 min. and treated as in VI.C.1.
2. Same as VI.C.2.

E. Conventionally canned.
1. Steamed for 4 min.; sealed in 307 x 409 cans with hot 1%-salt solution; processed at 240°F. for 25 min.
2. Can contents heated to 180°F. and drained.

VII. Cabbage (Copenhagen, outer leaves and core removed before dicing).

A. Dehydrated in the raw state.
1. Dipped for 1 min. in sulphite solution; dehydrated at 140°F. dry bulb—90°F. wet bulb for 4½ hr.; and sealed in cans under vacuum with desiccant.
2. Preparation for serving.
   a. Cold: rehydrated with cool water; refrigerated for 30 min.; drained.
   b. Hot: added to cool water, brought to a boil in a partially covered pan; simmered for 10 min.; drained.

B. Precooked, dehydrated.
1. Dipped 1 min. in a sulphite solution; steamed at 212°F. for 3 min.; and dehydrated as in VII.A.1.
2. Added to boiling water; stirred thoroughly; allowed to stand for 10 min.; drained.

C. Irradiated after enzyme-inactivation.
1. Packed into polyethylene casings, sealed, and casings sealed in cans. After irradiation, cans were punctured.
2. Preparation for serving.
   a. Cold: chilled.
   b. Hot: added to boiling water; brought to a boil in a covered pan; simmered for 7 min.; drained.

D. Precooked, irradiated.
1. Steamed at 212°F. for 3 min.; sealed in cans at 12 in. vacuum.
2. Added to boiling water and heated to 180°F.; drained.

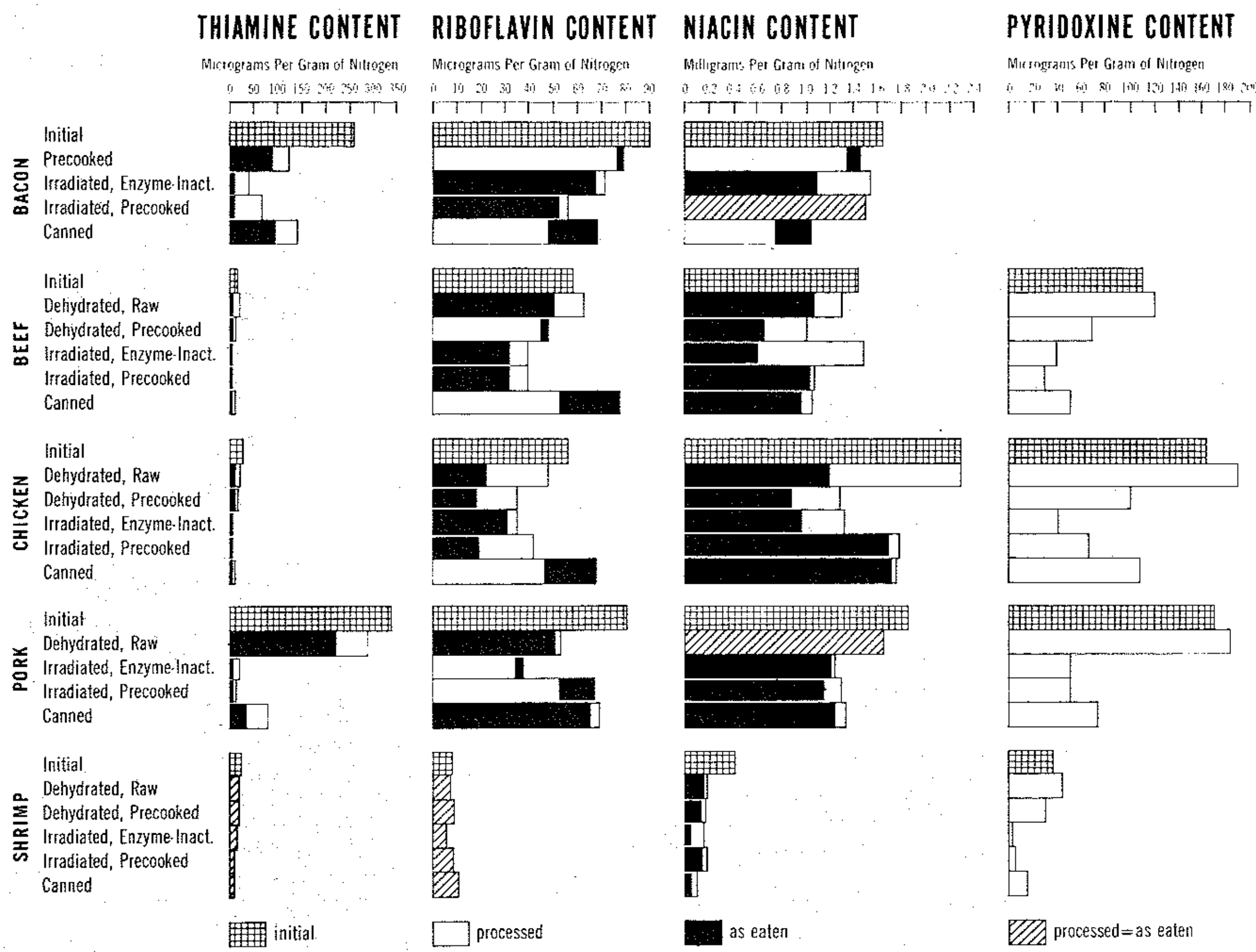

FIG. 1. *Thiamine, riboflavin, niacin, and pyridoxine content of processed animal products.*

E. Conventionally canned. No sample.

VIII. Carrots (Imperator; fresh-topped, peeled and sliced ⅛-3/16 in. thick).

A. Dehydrated in the raw state.
1. Steamed at 212°F. for 5 min.; dipped in sulphite solution for 1 min.; dehydrated at 165°F. dry bulb—90°F. wet bulb for 5 hr.; sealed in cans under vacuum with desiccant.
2. Added to cool water; brought to a boil; covered; simmered for 12 min.; drained.

B. Precooked, dehydrated.
1. Steamed at 212°F. for 15 min. and treated as in VIII.A.1.
2. Added to boiling water in a covered pan; stirred every 5 min. for 20 min.; drained.

C. Irradiated after enzyme-inactivation.
1. Steamed for 5 min.; cooled to 50°F.; and sealed in cans under vacuum.
2. Added to cool water; heated to 180°F.; and drained.

D. Precooked, irradiated.
1. Steamed for 15 min. and treated as in VIII.C.1.
2. Same as VIII.C.2.

E. Conventionally canned.
1. Steamed for 5 min.; packed in 307 x 409 cans with hot 1% salt solution; exhausted for 5 min. at 180°-200°F.; sealed and processed at 240°F. for 30 min.
2. Can contents were heated to 180°F. and drained.

IX. Corn (Golden Bantam; frozen, whole kernel).

A. Dehydrated in the raw state.
1. Dipped in a sulphite solution for 1½ min.; dehydrated for 5 min. at 200°F. dry bulb—150°F. wet bulb; for 13 min. at 200°F. dry bulb—120°F. wet bulb; for 20 min. at 170°F. dry bulb—110°F. wet bulb; for 30 min. at 150°F. dry bulb—110°F. wet bulb; for 10½ hr. at 150°F. dry bulb—90°F. wet bulb; for 9¾ hr. at 120°F. dry bulb—85°F. wet bulb; sealed in cans under vacuum with desiccant.
2. Added to boiling water and allowed to stand for 30 min., brought to a boil; simmered for 20 min., and drained.

B. Precooked, dehydrated.
1. Steamed for 12 min., sprayed for 1 min. with a sulphite solution and freeze-dehydrated for 4 hr. Then air dried for 4½ hr. at 150°F. dry bulb—90°F. wet bulb and for 9¾ hr. at 125°F. dry bulb—85°F. wet bulb. Sealed in cans under vacuum with dessicant.
2. Added to boiling water; covered; allowed to stand for 25 min.; drained.

C. Irradiated after enzyme-inactivation.

1. Steam-blanched and sealed in cans.
2. Added to cool water, heated to 180° F., and drained.

D. Precooked, irradiated.

1. Steamed for 12 min. and sealed in cans.
2. Same as IX.C.2.

E. Conventionally canned.

1. Steamed 4 min., packed in 307 x 409 cans with hot 1% salt solution; processed at 240°F. for 25 min.
2. Can contents were heated at 180°F. and drained.

Results

ANIMAL PRODUCTS

Proximate analysis and vitamin content of the processed animal products are given in Table 1. In Figure 1, the B-complex content is compared on the basis of equivalent nitrogen. Initially, only pork loin and bacon contained substantial amounts of thiamine. In pork, this vitamin was retained well during freeze-dehydration and preparation for serving (Figure 1). In irradiated pork samples, 99 per cent was lost as prepared. About half of the thiamine in bacon was retained after prefrying and canning and 35 per cent of the initial content remained after cooking. Destruction due to irradiation of bacon was 80 per cent; 99 per cent was lost after cooking. The superior retention of thiamine in cooking of bacon as compared with pork loin chops may be related to the shorter cooking time due to thinness of the slices. In all products, thiamine retention was most favored by freeze-dehydration and least by irradiation.

All products except shrimp were high in riboflavin initially, and this vitamin was fairly stable during processing (Fig. 1). Little additional loss was encountered in products cooked by dry heat. In some instances, riboflavin increased after preparation, e.g., canned bacon, beef, and chicken. The phenomenon of increasing riboflavin content has been noted previously in this laboratory (5). The increase could be due to development of fluorescing compounds or to release of some bound form by heat. In either event, the compound fulfills the function of riboflavin in microbial systems; availability for higher animals is unknown. If this substance is actually riboflavin or its equivalent, canning would be the method of choice; otherwise, there is no uniform superiority of any method.

Niacin was also well preserved in processing, and no one method was consistently better than another (Fig. 1). Essentially, no additional losses were noted on preparation for consumption of pork chops and bacon. In beef and chicken, preparatory losses occurred in both dehydrated and enzyme-inactivated, irradiated products. In irradiated products as eaten, samples cooked before irradiation tended to be higher in niacin than those cooked after irradiation. It was reported previously that irradiated turkey showed less water-binding quality and larger "drip" losses on cooking than the non-irradiated product (6), which may account for this difference.

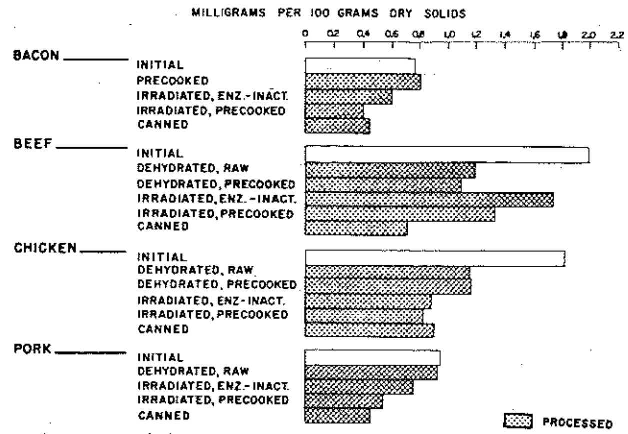

FIG. 2. *Alpha-tocopherol content of processed animal products.*

Content of lesser-known vitamins was assessed only after processing. Pyridoxine was completely stable in all products freeze-dried in the raw state (Fig. 1), and only 25 to 40 per cent was destroyed by precooking. In contrast, losses ranged from 65 to 100 per cent in irradiated samples, unrelated to prior cooking. Thermal sterilization resulted in 35 per cent loss in chicken, 55 to 60 per cent in beef and pork, and 75 per cent in shrimp. Obviously, freeze-dehydration is the preferred method for preservation of foods which make a significant contribution of vitamin B_6.

Pantothenic acid was reasonably stable, regardless of processing technique employed. No apparent loss of folic acid occurred; however, the initial content of this vitamin was too low to permit an accurate evaluation of its stability.

In all animal products, tocopherol content of dehydrated samples was greater than that of thermally sterilized counterparts (Fig. 2). The effects of irradiation varied, but in all cases irradiated products were equal or superior to the canned.

Findings in beef were different from all other products, in that the tocopherol of irradiated samples exceeded that of the dried material. The small particle size of ground beef permitted greater opportunity for oxidation and the dehydrated samples were not protected from exposure to air at any stage; irradiated samples were vacuum-sealed prior to treatment. Whether this accounts for the variance cannot be determined from present information, but the evidence is sufficiently suggestive that consideration should be given to investigating the quality of dried products processed in an inert atmosphere.

As shown in Table 2, the initial low content of polyunsaturated fatty acids was well preserved in processed beef and pork. Chicken, initially high in dienoic fatty acid, sustained a 20 per cent loss on dehydration and 30 per cent loss by irradiation or canning. Although of little nutritional signficance

TABLE 1 **Proximate composition and vitamin content of processed animal products**

STATE OF SAMPLE	MOISTURE (1)	PROTEIN (N x 6.25) (1)	FAT (1)	THIAMINE (2)	RIBO-FLAVIN (2)	NIACIN (2)	PYRI-DOXINE (3)	PANTO-THENIC ACID (2)	FOLIC ACID (1)	ALPHA-TOCO-PHEROL (4)
Bacon										
	← gm./100 gm.		→	← mcg./100 gm	→	mg./100 gm.	← mcg./100 gm.		→	mg./100 gm.
Raw	20.1	8.9	66.3	373	132	2.36		400		0.62
Processed										
Precooked	8.4	20.2	66.0	412	257	4.35		820		0.74
Irradiated after enzyme inactivation	15.9	8.6	70.7	63	101	2.10		290		0.52
Irradiated, precooked	12.6	21.6	59.3	227	197	5.18		860		0.36
Canned	8.3	20.3	65.2	453	154	2.36		520		0.41
As eaten, broiled										
Precooked	5.8	29.1	53.6	446	380	6.75				
Irradiated after enzyme inactivation	6.0	19.9	65.5	8	221	3.41				
Irradiated, precooked	6.1	29.3	52.0	13	254	7.00				
Canned	8.2	25.0	55.9	405	280	4.07				
Beef Chuck, Ground										
Raw	_61_*	17.7	20.2	52	170	4.10	300	460	3	0.79
Processed										
Dehydrated, raw	1.1	46.1	51.2	144	468	9.70	900	1010	11	1.18
Dehydrated, precooked	1.0	58.2	39.4	96	436	9.50	680	900	10	1.09
Irradiated after enzyme inactivation	_53_	27.1	18.3	4	176	6.48	160	400	2	0.82
Irradiated, precooked	_49_	31.7	18.0	7	210	5.51	170	500	3	0.68
Canned	_56_	24.9	18.3	11	216	4.25	200	420	3	0.31
As eaten, grilled										
Dehydrated, raw	41.7	29.9	25.3	7	246	5.12				
Dehydrated, precooked	44.5	29.9	21.9	10	236	3.05				
Irradiated after enzyme inactivation	47.4	29.2	21.2	7	148	2.79				
Irradiated, precooked	48.9	28.5	19.4	7	148	4.68				
Canned	55.3	28.9	14.1	8	368	4.45				
Chicken										
Frozen, raw	_77_	18.8	2.7	57	175	6.90	500	960	4	0.42
Processed										
Dehydrated, raw	1.5	84.0	13.6	198	665	30.80	260	3960	26	1.15
Dehydrated, precooked	1.2	88.2	10.5	122	518	18.40	140	1980	14	1.16
Irradiated after enzyme inactivation	_66_	28.4	4.2	2	169	6.10	180	980	4	0.30
Irradiated, precooked	_66_	28.7	3.9	5	202	8.25	300	1220	4	0.28
Canned	_71_	24.3	3.9	9	187	6.90	420	850	5	0.26
As eaten, simmered										
Dehydrated, raw	71.4	22.4	2.4	27	86	4.22				
Dehydrated, precooked	69.4	24.5	2.6	33	76	3.40				
Irradiated after enzyme inactivation	64.7	28.0	5.1	5	150	4.21				
Irradiated, precooked	59.0	30.7	6.8	5	102	8.35				
Canned	67.5	24.2	3.9	5	276	6.66				
Pork Loin										
Raw	58.0	16.1	26.8	865	211	4.82	440	700	<1	0.40
Processed										
Dehydrated, raw	1.0	46.1	51.1	2130	399	12.30	1360	730	2	0.93
Irradiated after enzyme inactivation	51.3	24.4	23.0	22	140	4.90	200	340	<1	0.37
Irradiated, precooked	46.2	21.2	32.4	17	185	4.47	170	300	<1	0.29
Canned	48.5	23.3	27.2	313	265	5.08	270	440	<1	0.22
As eaten, grilled										
Dehydrated, raw	35.9	30.6	32.6	1080	253	8.20				
Irradiated after enzyme inactivation	38.7	30.3	28.2	10	196	5.85				
Irradiated, precooked	37.4	27.9	33.6	15	304	5.10				
Canned	49.0	28.1	21.7	166	300	5.65				
Shrimp										
Frozen, raw	84.8	14.1	0.6	18	19	0.91	80	200	3	
Processed										
Dehydrated, raw	1.8	90.6	3.4	45	107	2.35	610	180	24	
Dehydrated, precooked	1.5	92.3	4.1	48	123	2.22	400	250	9	
Irradiated after enzyme inactivation	77.5	19.8	1.0	8	18	0.44	10	60	2	
Irradiated, precooked	74.0	24.1	1.0	7	20	0.57	15	70	2	
Canned	75.9	18.2	1.1	5	34	0.25	40	350	2	
As eaten, boiled, cold										
Dehydrated, raw	77.5	21.4	1.0	13	29	0.44				
Dehydrated, precooked	78.2	21.1	0.9	13	32	0.41				
Irradiated after enzyme inactivation	77.4	21.8	0.9	8	80	0.17				
Irradiated, precooked	77.0	22.9	1.0	5	32	0.50				
Canned	76.0	21.6	0.9	4	35	0.19				

*Italicized numbers are imputed from other data, not analytical values.

TABLE 2 **Polyunsaturated fatty acids in processed animal products (7)**

STATE OF SAMPLE	HEXAENE	PENTAENE	TETRAENE	TRIENE	DIENE	TOTAL
			Beef Chuck, Ground			
	←		*gm./100 gm. crude fat*			→
Raw	0.03	0.07	0.10	0.45	0.69	1.34
Processed						
Dehydrated, raw	0	0.08	0.09	0.50	0.74	1.41
Dehydrated, precooked	0.03	0.09	0.10	0.53	0.88	1.63
Irradiated after enzyme inactivation	0	0.08	0.11	0.45	0.54	1.18
Irradiated, precooked	0.09	0.05	0.07	0.36	0.83	1.40
Canned	0.01	0.07	0.10	0.40	1.03	1.61
			Chicken			
Frozen, raw	0.34	0.36	2.06	1.47	21.77	26.00
Processed						
Dehydrated, raw	0.26	0.27	1.17	1.46	18.35	21.51
Dehydrated, precooked	0.25	0.28	1.33	1.42	16.58	19.86
Irradiated after enzyme inactivation	0.26	0.21	0.78	1.16	16.22	18.63
Irradiated, precooked	0.25	0.25	0.77	1.26	14.94	17.47
Canned	0.21	0.21	1.04	1.42	14.72	17.60
			Pork Loin			
Raw	0.05	0.06	0.21	0.52	7.01	7.85
Processed						
Dehydrated, raw	0.06	0.04	0.21	0.50	6.02	6.83
Irradiated after enzyme inactivation	0.03	0.06	0.20	0.43	6.73	7.45
Irradiated, precooked	0.06	0.06	0.22	0.49	7.40	8.23
Canned	0.01	0.05	0.19	0.47	6.39	7.11
			Shrimp			
Frozen, raw	7.07	10.76	5.23	2.30	1.07	26.43
Processed						
Dehydrated, raw	5.84	7.01	3.50	1.63	1.34	19.32
Dehydrated, precooked	4.37	6.08	2.91	1.41	0.92	15.69
Irradiated after enzyme inactivation	2.91	3.64	2.39	1.56	0.83	11.33
Irradiated, precooked	2.18	3.43	1.66	0.87	1.14	9.28
Canned	1.68	1.86	1.21	0.56	0.46	5.77

because of the low level of total lipid in shrimp, the behavior of the unsaturated acids was most discriminatory of processing changes in this sample. Shrimp fat was highly unsaturated, the bulk of the polyunsaturated acids bearing five and six double bonds. Dehydration in the raw state resulted in 27 per cent loss, increasing to 41 per cent by precooking. Comparable irradiated samples showed 57 and 65 per cent decreases. The greatest decrement, 78 per cent, occurred in the canning procedure.

Examination of the data in Table 3, on essential and semi-essential amino acid content, reveals no destruction due to processing. In fact, there was a tendency toward increased amino acid content, particularly in chicken and pork, which was most pronounced in irradiated, precooked samples. Since the data are related to the nitrogen content of the products, it may be inferred that nitrogen was lost from sources other than these amino acids, by leakage or by conversion to volatile ammonia. Tsien and Johnson have reported (9) that glutamic acid, aspartic acid, serine, and glycine were destroyed in milk and beef by irradiation.

Important differences existed in the susceptibility of the protein of processed meats to the proteolytic enzyme, pepsin (Table 3). Only products dried in the raw state did not differ from their control samples. Processing methods showed the same rank order in all meats, dehydration producing least alteration and thermal sterilization, greatest. Decrement was smallest in beef and largest in shrimp, both in magnitude of change and number of amino acids affected. In all products studied, determination of phenylalanine or methionine alone would have discriminated among processing methods.

VEGETABLE PRODUCTS

Of the four vegetables studied, only cabbage contained a large amount of ascorbic acid, and this was well retained in the dehydrated products (Table 4). Following irradiation, however, no reduced ascorbic acid was present, most of the initial content having

TABLE 3 **Amino acid content of processed animal products (8)**

STATE OF SAMPLE	CYSTINE	HISTIDINE	ISOLEUCINE	LEUCINE	LYSINE	METHIONINE	PHENYLALANINE	THREONINE	TRYPTOPHAN	TYROSINE	VALINE
Milligrams per Gram Nitrogen											
Beef chuck											
Raw	81	199	337	461	586	148	234	265	99	206	359
Processed											
Dehydrated, raw	83	217	285	454	604	143	245	282	87	185	339
Dehydrated, precooked	85	197	302	480	612	145	254	286	81	195	359
Irradiated, enzyme-inactivated	85	190	348	520	676	165	228	312	84	194	376
Irradiated, precooked	74	189	318	447	612	139	232	274	58	181	335
Canned	76	214	315	450	585	150	256	293	64	181	359
Chicken											
Frozen, raw	72	180	338	502	586	178	234	281	86	218	322
Processed											
Dehydrated, raw	66	191	352	520	608	170	248	290	80	199	329
Dehydrated, precooked	74	195	366	563	636	175	268	298	85	221	357
Irradiated, enzyme-inactivated	64	164	327	501	569	159	247	279	74	259	322
Irradiated, precooked	90	240	474	725	824	242	361	402	101	232	458
Canned	78	188	360	518	614	181	262	298	98	265	354
Pork loin											
Raw	79	232	315	499	631	158	258	293	84	184	352
Processed											
Dehydrated, raw	70	269	349	494	639	151	242	294	104	192	358
Irradiated, enzyme-inactivated	83	210	376	506	664	158	260	291	99	198	387
Irradiated, precooked	85	233	416	594	758	194	309	329	111	246	440
Canned	79	248	379	518	679	169	256	312	102	200	399
Shrimp											
Frozen, raw	94	124	335	485	599	182	256	240	92	206	301
Processed											
Dehydrated, raw	84	138	350	507	633	188	262	272	89	218	320
Dehydrated, precooked	94	142	328	541	650	195	285	268	97	218	310
Irradiated, enzyme-inactivated	88	134	387	544	670	201	271	274	102	234	334
Irradiated, precooked	91	138	365	556	676	194	289	281	98	225	336
Canned	100	149	374	612	695	222	315	301	102	227	356
Percentage of Above as Free Amino Acids after *in Vitro* Pepsin Digestion*											
Beef chuck											
Raw	8	4	51	68	3	24	30	77	33	18	15
Processed											
Dehydrated, raw	7	4	60	68	2	23	27	72	37	18	16
Dehydrated, precooked	6	4	53	63	2	18	21	71	36	14	14
Irradiated, enzyme-inactivated	6	4	51	61	2	20	25	78	34	16	13
Irradiated, precooked	6	4	44	56	2	18	20	61	38	13	13
Canned	3	3	39	48	2	13	14	47	21	9	10
Chicken											
Frozen, raw	10	8	55	63	7	24	31	68	36	23	25
Processed											
Dehydrated, raw	10	6	54	63	4	24	27	65	38	22	20
Dehydrated, precooked	9	4	52	56	3	19	22	64	31	14	16
Irradiated, enzyme-inactivated	8	3	45	54	4	19	21	57	28	13	17
Irradiated, precooked	5	2	32	43	2	12	14	41	23	13	12
Canned	4	4	34	44	3	13	15	44	15	11	13
Pork loin											
Raw	10	4	50	64	3	24	30	74	36	20	18
Processed											
Dehydrated, raw	10	4	45	60	2	21	28	72	28	18	16
Irradiated, enzyme-inactivated	7	4	42	61	2	19	21	65	25	14	14
Irradiated, precooked	6	3	40	54	2	14	19	62	24	11	12
Canned	6	3	32	46	2	14	17	47	17	10	10
Shrimp											
Frozen, raw	8	7	57	71	6	26	30	83	32	18	20
Processed											
Dehydrated, raw	8	5	49	62	3	20	22	68	41	15	16
Dehydrated, precooked	7	4	50	55	2	17	18	66	36	14	15
Irradiated, enzyme-inactivated	5	4	38	53	2	15	20	63	19	11	13
Irradiated, precooked	4	3	35	47	2	14	17	58	17	11	12
Canned	4	3	29	41	2	11	13	49	23	10	11

*Acid or alkaline hydrolysis.

been converted to the oxidized form, reflected in the total content of 23 to 28 mg. per 100 gm. of these products. Most of the dehydroascorbic acid was destroyed on preparation of these irradiated samples for consumption.

Values for the beta-carotene content of raw and

TABLE 4 **Moisture and vitamin content of processed vegetables**

STATE OF SAMPLE	MOISTURE	BETA CAROTENE (2)	ASCORBIC ACID (2)	
			Reduced	Total
Green Beans				
	gm./100 gm.	← *mg./100 gm.*		→
Frozen, raw	92.5	0.12	3	4
Processed				
Dehydrated, raw	3.3	0.92	6	16
Dehydrated, precooked	3.4	0.87	10	15
Irradiated after enzyme-inactivation	89.8	0.28	0	4
Irradiated, precooked	89.6	0.23	0	4
Canned	93.2	0.26	0	1
As eaten				
Dehydrated, raw	88.6	0.52	0	2
Dehydrated, precooked	90.4	0.49	0	1
Irradiated after enzyme-inactivation	88.4	0.39	0	2
Irradiated, precooked	88.5	0.28	0	2
Canned	91.5	0.42	0	1
Cabbage				
Raw	91.8	1.76	38	42
Processed				
Dehydrated, raw	1.2	2.62	450	457
Dehydrated, precooked	2.4	2.31	361	378
Irradiated after enzyme-inactivation	92.1	0.56	0	28
Irradiated, precooked	92.4	0.53	0	23
As eaten				
Dehydrated, raw	88.0*	0.22	26	29
Dehydrated, precooked	86.9	0.19	27	25
Irradiated after enzyme-inactivation	91.9*	0.05	0	2
Irradiated, precooked	92.2	0.06	0	10
Carrots				
Raw	87.2	16.5	6	6
Processed				
Dehydrated, raw	3.5	133.2	29	32
Dehydrated, precooked	4.0	132.5	26	36
Irradiated after enzyme-inactivation	86.3	15.4	0	5
Irradiated, precooked	86.6	15.6	0	5
Canned	90.8	13.2	1	2
As eaten				
Dehydrated, raw	85.5	30.8	1	2
Dehydrated, precooked	85.0	30.0	1	2
Irradiated after enzyme-inactivation	86.4	17.8	1	3
Irradiated, precooked	86.7	18.2	tr	4
Canned	89.3	17.9	0	1
Corn				
Frozen, raw	68.3	0.51	9	9
Processed				
Dehydrated, raw	5.2	0.16	12	18
Dehydrated, precooked	3.8	0.19	13	16
Irradiated after enzyme-				3
inactivation	70.2	0.27	3	6
Irradiated, precooked	69.7	0.18	6	6
Canned	76.2	0.32	3	4
As eaten				
Dehydrated, raw	70.8	0.32	2	6
Dehydrated, precooked	70.2	0.32	2	3
Irradiated after enzyme-inactivation	* 72.2	0.12	3	5
Irradiated, precooked	72.2	0.12	3	5
Canned	73.6	0.25	2	3

*To be served raw; all other items heated.

processed vegetables are given in Table 4. The aberrant nature of these data is attributed to three factors: first, limitation in the precision of the analytical method; second, the greater difficulty experienced in extracting vitamins for analysis from vegetables in the raw state; and third, the possible action of destructive enzymes in raw vegetables released during homogenization. However, others have noted increased vitamin content (10, 11).

As prepared for serving, the beta-carotene in all products studied was highest in dehydrated samples. Canned and irradiated products were competitive except in the case of corn, where the canned product was higher. There was no consistent difference between samples processed in the raw state as compared with those precooked.

STORAGE STUDY

In a companion study, the retention of vitamins during extended storage of dehydrated beef and pork was investigated, as few ration components are consumed immediately on procurement. Control samples were held at –20°F., pending analysis, and the remainder at 70°F. or 100°F. for one year.

Boneless cuts from the butt end of the loin in U.S. Good beef and from light weight loin of pork were used. Both beef steaks and pork chops were cut ½ in. thick and trimmed to ⅜ in. of fat. The steaks were frozen and freeze-dehydrated at a plate temperature of 110°F. for 48 or 24 hr., yielding products of 2 per cent (Type A) or 8 per cent (Type B) moisture. An in-package desiccant (calcium oxide) was used to reduce the moisture content of the 8 per cent sample to 2 per cent or less and to maintain the low moisture content in all samples. All pork was freeze-dehydrated to 2 per cent moisture as described above. Beef was vacuum packed in cans and flexible packages and pork in cans only. For the cooking study, steaks and chops were rehydrated by soaking for 25 min. at room temperature and each side drained for 2 min. on absorbent paper. The rehydrated meats were then pan-fried without added fat at 370°F. for a total time of 2½ min. and turned each ½ min. Thawed, fresh frozen samples of both meat types were similarly cooked.

Composition of the processed and prepared materials is given in Table 5. Comparisons between processed and prepared products are shown, based on equal nitrogen content in Table 6. Initially, the thiamine and niacin in beef steak was comparable to that recorded for ground beef chuck, but riboflavin was somewhat lower. No significant loss of thiamine occurred during dehydration or cooking of either fresh or dehydrated steaks. Virtually total destruction occurred on cooking ground beef. The improved performance of steaks may be due to both piece size and lower cooking temperature. There was no cooking loss of riboflavin and only a marginal loss of niacin, as reported for the ground chuck.

Since before storage there was no significant difference between beef steaks freeze-dried to 2 per cent or 8 per cent moisture content, these were treated as one product in the storage study. Thiamine, riboflavin, and niacin were completely stable during one year of storage at 70°F. or 100°F., either in cans or flexible packages.

Pork loin used in this study contained equal thiamine, but more niacin and less riboflavin than the previous sample. No loss of the three vitamins occurred during dehydration. All vitamins in the

TABLE 5 Proximate composition and content of thiamine, riboflavin, and niacin of loin pork chops and beef steaks

STATE OF SAMPLE	NUMBER OF SAMPLES	MOISTURE	FAT	PROTEIN (N x 6.25 gm.)	THIAMINE	RIBOFLAVIN	NIACIN
Loin Pork Chops							
		←— *gm./100 gm.*		—→	←—*mcg./100 gm.*	—→	mg./100 gm.
Raw							
Fresh frozen	5	62.2 ±1.7*	16.3±1.0	20.2±0.3	100±11	133±26	7.49±0.44
Dehydrated	5	2.07±0.2	43.8±2.5	50.5±1.6	212±22	298±14	16.55±2.5
Cooked							
Fresh frozen	1	42.7†	26.0	4.71	61	150	7.4
Dehydrated, rehydrated	1	32.0	25.6	6.34	133	107	11.7
Beef Steaks							
Raw							
Fresh frozen	5	56.2 ±2.0	26.1±1.9	17.2±0.9	49± 3	117± 9	5.12±0.79
Dehydrated (Type A)	5	1.38±0.3	56.6±2.2	40.0±2.2	105±14	257±32	10.86±1.3
Cooked							
Fresh frozen	1	42.1	33.6	3.5	58	142	4.77
Dehydrated, rehydrated (Type A)	1	34.7	33.0	4.6	73	176	6.06

*Mean and standard deviation.
†Mean.

fresh product were reduced on cooking, but only riboflavin was significantly affected in the dehydrated. No storage losses were apparent.

The storage stability of these dehydrated meats was remarkable. Previously, this laboratory showed that, of the thiamine remaining after processing of military canned meat items, 39 per cent was destroyed during one year's storage at room temperature; and 66 per cent after only six months' storage at 100°F. (12). Riboflavin and niacin retention in the canned products ranged from 90 to 100 per cent and 85 to 95 per cent respectively.

Clinical Study

The data on the moisture content of dehydrated foods as consumed show that some of the products are slightly lower than canned or freshly prepared items. This may be due to failure to reconstitute completely. It seemed advisable, therefore, to assess the digestibility of these foods and their influence on gastrointestinal irritability. Such studies were carried out under contract (13).

Three-day menu cycles were made up from a single lot of the following precooked, dehydrated foods:

Fruits and juices
- Applesauce
- Apricots
- Fruit compote
- Grapefruit juice
- Orange juice

Vegetables
- Cabbage
- Lima beans
- Mashed potatoes

Meats and entrées
- Bacon, prefried
- Beef
  - Ground, with onion gravy-and-potato hash
  - Sliced, with gravy
- Chicken
  - -and-rice casserole
  - Sliced with gravy
- Chili with meat and beans
- Macaroni and cheese
- Meat loaf with tomato gravy
- Spaghetti with meat sauce

Cereals
- Compressed cereal bar
- Macaroni
- Oatmeal
- Rice

Beverages
- Milk
- Cream
- Cocoa
- Coffee

Soups
- Chicken-rice soup
- Pea soup

Dessert—Butterscotch pudding

Hospital patients without gastrointestinal disease were provided 2800 calories daily[3]. This diet contained 112 gm. protein and 93 gm. fat. A control diet was made up from the normal hospital menu calculated to yield 105 gm. protein, 150 gm. fat, and 2800 calories. The dehydrated diet was served for six days, preceded by six days on the control diet. Urine and feces were collected daily and pooled for three-day periods. Diets, excreta, and rejected food were analyzed for nitrogen (1) and fat (14) as appropriate. Serum carotene levels were determined (15) as a further check on absorption.

[3]As proposed for military use, the daily menu yields 3400 to 3600 calories from the items listed, and, in addition, canned bread, dessert items, spreads for bread, and confections.

TABLE 6 Thiamine, riboflavin, and niacin relative to nitrogen content in loin pork chops and beef steaks during storage

STATE OF SAMPLE	NUMBER OF SAMPLES	THIAMINE	RIBOFLAVIN	NIACIN
Loin Pork Chops*				
		mg./gm. nitrogen	*mcg./gm. nitrogen*	*mg./gm. nitrogen*
Raw				
Fresh frozen	4	0.31±0.15†	41.8±10.7	2.33±0.17
Dehydrated	4	0.26±0.14	36.8± 4.0	2.04±0.26
Cooked				
Fresh frozen	1	0.13	18	1.57
Dehydrated, rehydrated	1	0.21	17	1.84
Dehydrated, stored at 70°F.				
3 months	1	0.27	31	2.54
6 months	1	0.32	35	2.01
9 months	1	0.25	37	2.00
12 months	1	0.22	34	1.75
at 100°F.				
3 months	1	0.20	42	2.31
6 months	1	0.35	34	2.03
9 months	1	0.22	28	2.18
12 months	1	0.14	36	1.70
Beef Steaks‡				
		mg./gm. nitrogen		
Raw				
Fresh frozen	5	17.8±2.2†	42.2± 3.7	1.85±0.25
Dehydrated				
Type A	5	16.8±3.4	41.0± 6.8	1.72±0.20
Type B	3	18#	40	1.75
Cooked				
Fresh frozen	1	17	40	1.36
Dehydrated, rehydrated, Type A	1	16	38	1.31
Dehydrated, stored				
Controls, Types A and B (−20°F.)	8	17.5±4.4	40.8±7.3	1.73±0.20
Stored at 70°F.				
Canned				
10 days	1	16	42	1.63
20 days	1	17	38	1.71
1 month	1	15	37	1.66
3 months	1	15	40	2.00
6 months	2	14	48	1.43
9 months	1	17	40	2.25
12 months	2	18	40	2.08
Packaged				
6 months	2	14	43	1.69
12 months	2	18	36	2.02
Stored at 100°F.				
Canned				
10 days	1	17	42	1.62
20 days	1	18	42	1.70
1 month	1	15	32	1.60
3 months	2	16	44	2.01
6 months	2	16	54	1.86
9 months	2	16	40	2.12
12 months	2	17	38	2.10
Packaged				
3 months	2	14	49	1.97
6 months	2	12	51	1.74
9 months	2	14	33	2.14
12 months	2	21	38	1.81

*Each sample was a composite of eight chops.
†Mean and standard deviation.
‡Each sample was a composite of seven steaks.
#Mean only.

TABLE 7 Metabolic data on hospital patients fed precooked, dehydrated foods

DATUM MEASURED	CONTROL DIET	DEHYDRATED DIET
Nitrogen (gm./day)		
Consumed	19.0	15.9
Urinary	14.6	11.5
Fecal	1.0	1.1
Balance	+3.4	+3.3
Apparent protein digestibility (%)	95	93
Fat (gm./day)		
Consumed	165.1	66.4
Fecal	4.9	2.4
Apparent fat digestibility (%)	97	96
Serum catotene (mcg./100 ml.)	153	171
Body weight (lb.)	183	184

were available. No differences between the dehydrated and control diets were apparent with respect to nitrogen balance, protein and fat digestibility, or serum carotene, and consumption was sufficient to maintain body weight. Such clinical events as occurred were not considered to be related to consumption of the dehydrated diet. The investigators reported: "Confirmation of the absence of induced irritability of the gastrointestinal tract during the period of study of the dehydrated foods was obtained by barium meal studies. The barium meals were given to subjects before and after the dehydrated food diet. Serial roentgenographic films were taken at ½-hr., 1-hr., and 2-hr. periods. There was no significant change in the appearance of the barium column or in the rate of passage through the stomach and small intestine after having been on the dehydrated food diet. Emptying of the stomach and motility of the small intestine were within normal limits. The normal continuity of the barium column and the normal mucosal pattern of the jejunum and ileum were preserved."

Finally, these foods have been tested under field conditions. Military personnel engaged in strenuous activity in a cold climate were issued 1⅓ rations per man per day, the dehydrated ration being compared with conventional canned rations (16). Intake was 4114 calories per day from the new ration and 4267 calories from the Combat Ration. There were no signficant changes in body weight, indicating that intake kept pace with expenditure during the six-week test period.

Summary

A comparison has been made of the nutrient content of various animal and vegetable products before and after dehydration, irradiation, and the conventional thermal processing. Data have also been presented on the effect of storage on dehydrated meat products, as well as the digestibility of dehydrated foods and certain functional characteristics.

In general, the results indicate that, among the methods and products studied, nutrient content is affected least by dehydration. Excellent vitamin stability was noted during storage of dried meats. No differences between dehydrated and normal foods were seen with respect to digestibility or support of nitrogen balance and body weight in man, nor were they noted to alter gastrointestinal irritability.

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