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Nutrition in Food Processing

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I. Introduction

The beginning of civilization can be looked upon as the point in time where man became less dependent upon his environmental factors and could devote time to pursuits other than caring for his immediate needs. Independence of his local environment in one respect meant that he could provide for himself a food supply adequate to carry him over periods of poor hunting or very inclement weather. The initial approach was the domestication of animals and the storage of grains. Hence, the elements of food processing date back to the time that man concerned himself with the storage of food. Early man preserved his food supply by smoking, curing, and dehydration and these basic methods are still utilized. Preservation methods are a trade-off between the advantages gained by having a reasonable food supply throughout a time period and the loss of available nutrients in the preserved food. The classic example of this trade-off was the early exploration of the world by sailing ships where processed foods were able to sustain the sailing crews, despite the fact that the food was deficient in vitamin C. Consequently, although the crews could be

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sustained, they were ravaged by scurvy. The ability to preserve fruit juices, particularly citrus, alleviated this nutritional problem.

The preservation of food affects its nutritional quality both favorably and adversely. Heat processing destroys thiaminase in fishes and fishery products, anti-trypsin factors in cereal grains, and biotin and iron binding factors in egg white. In heat processing of cereal grains the digestibility may be markedly increased, thus making both the proteins and carbohydrates of these products more available.

Generally, however, processing of food materials by fermentation, drying, freezing, thermal processing, or dehydration tends to decrease the supply of nutrients, particularly vitamins and minerals. Thermal processing or long storage times may significantly reduce the protein availability of foods while dehydration, accompanied or unaccompanied by smoking, may reduce the stability of the lipid components. Since there is an interaction between the carbohydrates, proteins and lipids, carbohydrate availability may also be affected by thermal processing [26].

II. Vitamins and Minerals

The content of vitamins and minerals in the processed food is determined initially by the nutrient content of the raw material. The raw food may vary widely in its content of vitamins based upon genetic variation and agricultural conditions. SENTI suggests that, although data are not available on the vitamin and mineral content of food materials and foods produced 3 or more decades ago, data on variability in present varieties would indicate that, if anything, the vitamin content of presently available food materials is higher due to the utilization of better agricultural harvesting conditions [22].

There still is, however, a wide variability in the vitamin and mineral content of commercially-grown food materials. Table I illustrates this wide variation. Carrots may vary 100-fold in their concentration of carotene, and melons may vary 20-fold in their concentration of ascorbic acid [22]. ANDERSON found a range of 1.8–29.3 mg of ascorbic acid per 100 g in samples of fresh tomato juice [1]. Similarly, BELL *et al.* found a 35-fold range of ascorbic acid concentration in different varieties of muscadine grapes [2]. Thus, the vitamin content of raw materials for processing shows a variability in many cases exceeding that found in normally processed foods.

In most cases, processing losses or modifications may be less than the differences found in the raw material. In most processing operations the foods

Table I. Compositional range (mg/100 g) in breeding lines and in commercial varieties

	Constituent	Breeding lines	Commercial varieties
Carrots	carotene	0–370	64–94
Cabbage	ascorbic acid	93	50–60
Musk melon	ascorbic acid	3–61	30
Tomatoes	ascorbic acid	50	15–25
Tomatoes	carotene	4	0.4
Sweet potatoes	carotene	5–22	5–12
White potatoes	ascorbic acid	30	8–15

are subjected to either heat or cooling for preservation purposes. In the case of vegetables, cooling is preceded by a heat inactivation step to prevent the enzymatic deterioration of the product. Adjustments may be made in pH and most of the preliminary processing operations are carried out anaerobically. Table II illustrates the effect of pH, air, light, and heat on vitamins; these being the usual environmental factors to which the food material may be subjected. Vitamin C is relatively unstable since it is easily oxidized. Most of the vitamins, with the exception of vitamin B_{12} and niacin, are unstable to heat. As a consequence, significant losses can be expected in any thermal operation such as blanching, drying, canning, etc. Where a vitamin is unstable with respect to light, such as riboflavin, significant losses can be expected in usual handling operations when the material is exposed to high temperatures (such as may be found in blanching operations) in the presence of light.

In normal cooking operations, such as might be expected in the home preparation of fresh vegetables, fruits, cereals, etc., losses as high as 100% of the vitamins may be encountered and it has been suggested that normal cooking losses of vitamins may generally be as high as 75%. In contrast, the losses expected from food processing are seldom in excess of 25% [14, 22]. Water-soluble vitamins such as thiamine, riboflavin, niacin and ascorbic acid are particularly subject to cooking losses but, if handled correctly in processing, these losses would be considerably smaller.

Handling prior to any processing may result in significant losses of vitamins despite modern operations in the actual processing phase. Table III illustrates this effect, showing that ascorbic acid losses in typical vegetables are a function of storage temperature and time of storage. Lowering the temperature of the raw materials for transportation to storage facilities results in a processed product of higher nutrient content. The immediate processing of

Table II. Stability of vitamins

Nutrient	pH 7	Acid	Alkaline	Air	Light	Heat
Vitamins						
Vitamin A	S	U	S	U	U	U
Ascorbic acid (C)	U	S	U	U	U	U
Carotenes (pro-A)	S	U	S	U	U	U
Cobalamin (B_{12})	S	S	S	U	U	S
Vitamin D	S		U	U	U	U
Niacin	S	S	S	S	S	S
Vitamin B_6	S	S	S	S	U	U
Riboflavin (B_2)	S	S	U	S	U	U
Thiamine (B_1)	U	S	U	U	S	U
Tocopherols (E)	S	S	S	U	U	U

U = unstable, S = stable.

Table III. Effect of storage on ascorbic acid content of green peas and snap beans

Vegetable	Temperature, °F	Storage time, days (mg/100 g) 0	2	6
Green peas	34–38	17	16	10
	46–48	20	16	10
	70–75	17	9	7
Snap beans	34–38	18	15	8
	46–48	18	11	6
	75–77	18	7	4

foods directly in the field is becoming more attractive, not only based upon the avoidance of nutrient losses but also on the basis of reduction in transportation costs, better organoleptic properties of the product, and the avoidance of the concentration of pollutants in large processing facilities.

In initial steps of processing, fruits and vegetables particularly are heated or blanched to inactivate the polyphenol oxidase systems, ascorbic acid oxidase systems and, in some cases, the lipases. Short-time blanching utilizing steam is generally to be desired since it prevents the losses of water-soluble nutrients and the destruction of the heat-labile enzymes. Both steam blanching and water blanching, however, are still used in the industry. For example, HEIN *et al.* cites the example that steam blanching of spinach for 2–2¾ min results in the retention of 88–100% of vitamins B_1, B_2, C and

Table IV. Retention of vitamins in vegetables blanched for commercial canning

Vitamins	Product	Retention, % Maximum	Minimum	mean
Ascorbic acid	asparagus	100	74	95
	green beans	90	50	74
	lima beans	83	54	72
	peas	90	60	76
	spinach	99	6	67
Niacin	asparagus	100	77	94
	green beans	100	60	95
	lima beans	98	68	81
	peas	96	59	73
	spinach	100	63	83
Riboflavin	asparagus	100	72	90
	green beans	100	70	95
	lima beans	100	59	76
	peas	87	67	75
	spinach	100	78	88
Thiamine	asparagus	100	79	92
	green beans	100	82	91
	lima beans	77	36	58
	peas	100	63	88
	spinach	100	67	85

niacin. Water blanching from $2^3/_4$–5 min showed a range of retention of 64–95%, while immersion blanching of spinach for 45 min showed a retention of only 6% in vitamin C [14]. Table IV shows similar variability between methods of blanching on a number of the more labile vitamins.

Minerals in food materials are generally stable. Their losses are usually related directly to the extent of leaching in the water used for processing.

Thermal processing in food has, in general, a negative effect on the retention of vitamins although heat processing is one of the better methods of preserving foods against microbiological deterioration. One of the more labile vitamins in heat processing is vitamin C, although the other heat-labile vitamins are similarly affected. Table V illustrates the typical losses of vitamin C during canning of tomato juice [9]. Vitamin C losses particularly are increased by the inclusion of oxygen during canning, or are the result of trace metals, particularly copper. Since a 10 °C rise in processing temperature results in almost a 10-fold increase in bacterial destruction but only a doubling in chemical reaction leading to the destruction of vitamins, flavors, etc.,

Table V. Retention of vitamins in tomato juice heated in canning process

Vitamin	Number of tests	Retention, % maximum	minimum	average
Ascorbic acid	90	90	35	67
Thiamine	18	100	73	89
Riboflavin	17	100	86	97
Niacin	17	100	83	98
Carotene	7	74	60	67

Table VI. Effect of processing method on nutrient retention

	Beans	Beef	Tomato juice
Pyridoxine			
Initial (μg/1000 g)	64.1	126.6	412.5
Retention HTST process, %	93.0	98.3	100
Retention conventional process, %	86.7	94.2	100
Thiamine			
Initial (μg/100 g)	93.8	150.0	167.1
Retention HTST process, %	87.1	95.0	100+
Retention conventional process, %	55.9	78.4	97

HTST = high temperature short time.

high-temperature short-time sterilization is receiving increasing attention. In conventionally sterilized products heat transfer is very slow, particularly when the products are non-liquid. Since the heat enters the product through the periphery of the container, the material close to the edge is subject to far more drastic heat than that required to achieve sterility. By sterilizing the product prior to packaging it is possible to subject the entire food material to the same heating-cooling cycle. This then results in considerable decrease in destruction of vitamins while at the same time producing products which are sterile. Table VI illustrates the retention of pyridoxine and thiamine in 3 products sterilized by high-temperature short-time methods, contrasted with conventional canning methods [8].

The actual process of dehydration does not cause major losses in vitamins. The newer methods of dehydration, such as puff-drying or freeze-drying, preserve to an even larger extent the vitamin content of the products. The

addition of sulphur dioxide in the dehydration process to preserve color results in an increased retention of vitamin C since this compound inhibits the peroxidase which is the major cause of the loss of the vitamin. However, the addition of sulphur dioxide causes a major loss in thiamine [3]. Since most products which are dehydrated and sulphured are not major sources of thiamine, the overall effect of its addition is a beneficial one. Table VII illustrates the losses of a series of vegetable products which have been dehydrated [14]. In this table, the majority of the losses occurred during the blanching operation rather than during dehydration. As an example, sweetcorn retained 91% of the thiamine after dehydration; but the majority of the 9% which was lost was lost in the blanching operation rather than the actual dehydration. In the illustration, the dehydration procedure involved the use of forced air cross-flow tunnel dryers.

MATTSON compared the losses occurring at various steps of processing and utilization [17]. Of all the losses incurred in between harvest and the utilization of the food, the major losses in vitamin C occurred during the cooking operation. In the case of peas, the cooking operation destroyed 66% of the vitamin C. In comparison, the air-dried product lost 65% of its vitamin C content. In comparing the cooked product made from the fresh, frozen, canned, air-dried and freeze-dried products, the retention percentages, respectively, were 44, 39, 36, 25, and 35%. It is obvious, therefore, that one of the most important factors in the destruction of vitamin and nutrient contents of foods is the final preparation of the foods prior to eating.

The freezing process, like the dehydration process, does not in itself destroy vitamins. The major loss occurs during the blanching to inactivate enzyme changes prior to the freezing. Storage at —18 °C or lower results in an excellent retention of the vitamin content of the product. Storage temperatures above —9 °C, however, will result in the loss of easily-oxidizable vitamins over a period of time. As an example, storage at —9 °C resulted in the destruction of 50% of the original vitamin C in asparagus, peas, and lima beans during 6 months of storage.

Vitamin losses during storage and distribution of canned or frozen foods vary widely dependent upon the temperatures encountered during their distribution. SOMERS and FARROW suggest that riboflavin and niacin retention in canned products such as asparagus appear to be more adversely affected by storage time than storage temperature, while the retention of ascorbic acid in canned tomato juice was very markedly decreased by higher than room temperature [6, 25]. Carotene was somewhat less affected by either storage time or temperature.

Table VII. Average retention of thiamine, riboflavin, niacin, and pantothenic acid in vegetables during dehydration, expressed as percentage of content in the fresh vegetable before blanching

Vegetable	Thiamine		Riboflavin		Niacin		Pantothenic acid	
	blanched,	dehydrated,	blanched,	dehydrated,	blanched,	dehydrated,	blanched,	dehydrated,
	%	%	%	%	%	%	%	%
Snap beans	93	88	93	89				
Beets	84	80						
Carrots	83	59	98	92	93	93	100	94
Sweetcorn	95	91	96	91				
Onions	1	84	2	95	3	88	4	91
Green peas	93	90	92	87				
Potatoes	80	60	100	100		94	100	100
Potatoes	68	77						
Sweet potatoes	1	2		89	4	100	5	72
Rutabagas	86	83						

In a study of the retention of vitamins in frozen products undergoing storage, SOMERS and FARROW indicated that storage time of over a year for frozen materials is improbable and that there is a 94% probability that the frozen products will be consumed in 10 months or less [25]. Under these conditions if the temperature is held at —20 °C, losses in ascorbic acid appear to be less than 15% during the 12-month period. Carotene and the B vitamins appear to show very low losses under conditions which are acceptable for limiting the losses of ascorbic acid. Estimates of the B vitamin retention following a year of storage at —18 °C range from 90% in asparagus and peas to 70% in broccoli and green beans to 50% in spinach and cauliflower. The major factors affecting loss at these low temperatures are the oxygen permeability and light transmission characteristics of the packaging material. BENDER substantiates that in hermetically sealed containers the residual oxygen is used primarily to oxidize vitamin C [3]. Approximately 1 ml of air is sufficient to oxidize 3.3 mg of ascorbic acid. After the residual oxygen has been removed by this oxidation, the rate of loss approaches zero unless storage conditions are such that a browning reaction may take place. The importance, thus, of reducing retained oxygen content in processed food materials is evident.

III. Proteins

The effect of the proteins of food substances by either the outright destruction of amino acids in the protein or by rendering the proteins and amino acids less available physiologically are reactions which are generally chemical in nature, and recent publications suggest that the mechanism by which some of the changes are brought about are free radical in nature [26, 27, 28]. These protein reactions are very much enhanced by the presence of other food constituents such as carbohydrates. In the carbohydrate-protein or fat-protein reactions the chemical assay of the foodstuff may indicate little or no loss of various amino acids yet biological tests may in contrast indicate severe changes in biological activity. Amino acids may be destroyed in protein under conditions of severe heat, although they may also be lost more slowly under conditions of storage at warm temperatures. Short-chain peptides and amino acids tend to react more rapidly than their equivalent proteins. The proteins themselves may show substantial differences in reactivity in reactions causing the lowering of their nutritive values.

The loss of nutritive value when proteins or protein-rich foods are heated with carbohydrates has been studied by many workers [5, 26, 16, 18].

The browning reaction consists of a complex series of sequential reactions yielding first intermediates, such as amino ketoses which themselves are colorless, but later products varying from furfurals to deeply-colored melanoidin substances. The consequences of these reactions are, as indicated before, a decrease in the availability of amino acids, a decrease in digestibility of proteins, a decrease in the biological value of proteins beyond which can be accounted for the decrease in digestibility loss of amino acids as measured by chemical analysis and, possibly, the build-up of toxic materials as a result of the browning reaction.

The browning reaction, or Maillard reaction, may also lead to a loss of the palatability as well as the production of undesirable changes in the physical properties of food. On the other hand, browning is purposely sought in most baked and fried foods. Maple syrup owes its flavor and color to the browning reaction. The distinctive caramel flavors derived from dairy products result from the browning of milk or milk components. Thus it is clear that, while browning may affect the nutritional value of foods, it may also enhance the acceptability of man's food. A major portion of the work on the change of the nutritive value of proteins in relation to processing has been done on milk since milk and milk protein appears to be particularly susceptible to detrimental changes in nutritional value. MAURON *et al.* determined the nature and extent of amino acid alteration in milk manufactured by 4 widely-used processes: spray-drying, roller-drying, evaporation, and condensation (sweetened condensed milk) [18]. The destruction of amino acids was measured by comparing the amino acid content of fresh and processed milk samples after acid hydrolysis or after enzyme digestion. Inactivation was measured by comparing the percentage of amino acids liberated enzymatically in fresh and processed milk. Of the 3 heat-labile essential amino acids – tryptophan, methionine and lysine – only the last was seriously affected. Lysine deterioration was due both to destruction and to inactivation. The authors reported relatively higher losses of lysine in the evaporated and roller-dried milk than in the sweetened condensed or spray-dried milk. ERBERSDOBLER suggested that roller-dried milk compared to spray-dried milk contained less available lysine, cysteine, histidine, and methionine while the other amino acids decreased only very slightly [10]. Spray-drying caused only a slight decrease in lysine.

Cereal grains supply a significant portion of the total protein of the world. These proteins generally have limited nutritive value with a predominant deficiency in lysine. Unfortunately, from the processing standpoint, lysine is the amino acid or protein which is most susceptible to heat

Table VIII. Effect of temperature of processing and raw materials on the PER of wheat-milk mixtures

	Averages of 10 rats		PER
	weight gain	protein intake	
1. Mixture of low-protein wheat with NFDM	57.7	25.3	2.28
Mixture I processed at 132 °C	46.8	24.7	1.89
Mixture I processed at 143 °C	36.5	21.7	1.68
2. Mixture of high-protein wheat with NFDM processed at 132 °C	30.1	21.3	1.41
Mixture II processed at 143 °C	10.0	16.5	0.60
Casein control	25.1	11.3	2.31

damage [21]. BENDER discusses the loss of lysine in the baking process of bread [3]. He demonstrated that lysine in bread is lost progressively. Short baking times contributed essentially little or no loss, while baking for 50 min at 232 °C resulted in the loss of 30% of the lysine added as fortification to wheat flour. He also cited the fact that, in the baking operation, a considerably higher percentage of the lysine added as a fortifying ingredient is lost than that contained in the wheat protein. The same factor of increasing losses of added lysine is experienced when non-fat milk solids are added as a source of fortifying lysine.

Many cereal products are now being processed by utilizing high-temperature, short-time cooking units such as might be exemplified by the extrusion technique or roller processing. An example of the losses that might be incurred in the extrusion processing of wheat with added lysine is shown in table VIII [8]. In the example cited, the processed mixture was 9 parts of wheat to 1 part of non-fat dry milk solids, giving a protein content of approximately 17% in the formula as extruded. It is to be noted that, with equivalent resonance time, a 10 °C change in jacket temperature decreased the protein efficiency ratio by 12%. In an alternate experiment using a wheat flour of higher protein content, the decrease in protein efficiency ratio with the same 10 °C rise in temperature was 58%. There is no doubt that this may be an extreme example since both wheat protein and non-fat milk solids are particularly susceptible to heat damage. Nonetheless, the criticality of processing temperature and composition of the original cereal protein is exemplified by these values.

STEWART *et al.* measured the effect of heat damage to oat preparation [29]. Drum-dried oats were determined to have a PER of 1.6 while rolled oats had a PER of 1.5. On the other hand, puffed oats which were treated at 198 °C with steam had a resultant PER of 0.3, amply illustrating the effect of high temperatures on protein degradation in cereal products.

CARPENTER *et al.* determined the availability of lysine in ground nuts for use in treatment of kwashiorkor [7]. They confirmed the earlier results that the inclusion of milk powder in the baking of biscuits resulted in a large proportion of the epsilon NH_2 groups of the lysine units in the final product becoming unavailable. If the dry skim milk was added after cooking, the proportion of the lysine remaining biologically available was considerably greater. The results of a biological assay with chicks confirmed the finding that the availability of lysine had been lowered to the extent shown by the chemical available in lysine method. In contrast to the 'available lysine content', the total lysine content by chemical hydrolysis was not apparently different in the 2 biscuits, thus indicating the general inadequacy of the determination of total lysine as a reflection of biological availability when applied to processed foodstuffs in general. BRESSANI *et al.* studied the effect of heat on the nutritive value of black bean protein and found that cooking for 10–30 min at 121 °C was optimal [4]. Longer cooking time decreased the nutritive value of the bean protein. The contents of lysine, methionine and valine, however, when chemically analyzed, were not changed by the cooking. They concluded, therefore, that the changes in nutritive value were due to changes in availability.

In contrast to the loss of nutritive value of cereal proteins upon heating, the changes in the nutritive value of protein of meat products appears to follow a different course. HELLER *et al.* determined the percentage of available lysine in pork, beef and lamb muscle both in raw samples and after standard cooking procedures [15]. From 74–92% of the lysine content of the meat was available after standard cooking procedures, indicating that normal cooking does not appreciably affect availability of lysine from muscle protein. Only after severe heat treatment, i.e. autoclaving for 16 h, was the amount of available lysine substantially reduced.

ERBERSDOBLER *et al.* studied the influx of essential amino acids in the portal blood of rats fed lysine heated in the presence of glucose [5, 10, 11]. The amino acid concentration in the blood when compared to rats fed the non-heated protein showed a decrease of 37% for lysine, 45% for threonine, 50% for methionine, and 69% for isoleucine.

When casein was heated in the presence of glucose, a much smaller degradation of the amino acids was observed using the same technique; speci-

fically 71% for lysine, 71% for leucine, 72% for threonine, 72% for isoleucine, and 78% for methionine.

It is thus obvious that proteins heated or stored at high temperatures in the presence of carbohydrates undergo severe losses in availability in any of their amino acids. The absence of carbohydrates and proteins tends to be far more stable. Cereal grains normally have a high percentage of carbohydrates and therefore demonstrate a high degree of susceptibility to heat or storage damage and proteins.

In general, thermal processing of proteins in the presence of reducing sugars or the carbohydrates should be as mild as possible. Even the first products of the browning reaction (the Amadori rearrangement products) are relatively unavailable. In recent studies, SGARBIERI studied the absorption of 2 essential amino acids, L-leucine and L-tryptophan, which were synthesized, isolated and purified [23, 24]. Absorption studies with rats were performed using the complex synthesized with ^{14}C-labeled amino acids. The results showed that rats absorbed radioactivity from the Amadori complexes extremely slowly compared with the rate of absorption of the amino acids. The major absorption of radioactivity occurred in the large intestine compared to the absorption of the 3 amino acids in the small intestine. These results support the argument that the presence of carbohydrates, amino acids or proteins under relatively mild storage or processing conditions is easily rendered relatively unavailable.

The browning reaction, however, contributes rather specifically to flavor. Meat-like flavors are produced by the reactions of sulphur amino acids and carbohydrates, and the flavors of baked bread, roasted coffee and cocoa are all attributed to the products of the Maillard reaction.

IV. Carbohydrates and Lipids

As indicated earlier, carbohydrates may be made more digestible and thus more available by mild processing. Although losses may occur in carbohydrates during wet processing (leaching) these are, in general, minor. The major loss in carbohydrate availability is due to their interaction with protein and in most cases this is relatively minor, the major effect being in the protein constituents.

A further loss of nutritive value of foods and the possible development of toxic materials is caused by the oxidative degradation of highly unsaturated lipids. The degradation products of the lipids can react through the

other products of fat oxidation with amino acids and proteins. These result in the destruction of amino acids or the formation of linkages resistant to digestion.

Combinations of hydrogenous substances for oxidizing fat are a well-known cause of browning. Experiments by TAPPEL on a model protein and an oxidative catalyst hemoglobin or cytochrome demonstrated that shaking such a mixture in air at 37 °C for 1 or 2 days causes an extensive interaction of the protein with the oxidizing fat [30]. Yellow products were formed and ultimately insoluble, dark-brown copolymers were accompanied by appreciable destruction of the amino acids. These changes are reflected in a considerable form of the nutrient value of the food.

Conclusion

Processing losses, whether from thermal processing, blanching, freezing or drying, do decrease the nutritive value of a food. These losses must be viewed in their proper perspectives, however. The losses occurring in modern-day processing and storage are generally less than those which occur in normal home preparation of foods. While these losses in preparation and processing may well be compounded, the alternative in food processing may very well be the unavailability of foodstuffs at some times of the year. The marketing of all fresh foods in urban environments would also pose almost impossible problems. The contribution of a product must also be taken into consideration. For example, the loss of vitamin C in milk during storage may appear to be of importance yet the contribution of milk to the dietary supply of vitamin C is almost negligible. Therefore, in this perspective the destruction of the vitamin is of no particular consequence.

Improved methods of processing generally result in more attractive products of organoleptic importance. It is almost universally true that any improvement in the organoleptic properties of food results in better retention of their nutrients. Thus, the adoption of newer methods of processing usually results in better availability of nutrients (an exception may be iron).

Populations which adopt new food habits, such as the utilization of polished rice instead of browned rice, and who are dependent upon a restricted variety of foods may develop problems related to the new food supply which could conceivably be attributed to the processing operation but, in these cases, the problems may be solved by such means as fortification or enrichment.

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