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Symposium on ‘Nutritional effects of new processing technologies’

Nutritional losses and gains during processing: future problems and issues†

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Developments in food technology and nutrition today are shaping our food supply in an unprecedented way. They have not only helped produce a variety of foods with varying taste and texture but also optimally retain the nutritional quality of food. Increased use of novel ingredients in the future manufacture of foods is likely to reduce the amount of micronutrients available in our diet. To combat this, food fortification may be more widely used. Collaboration between food technologists and nutritionists is imperative if we are to see the continued manufacture of wholesome food.

Food processing: Thermal processing: Nutritional quality: Food fortification

Over the years, much has been written about the nutrient losses in food processing (Bender, 1978; Karmas & Harris, 1988). Many of these publications have concentrated on describing the limits and range of losses encountered during processing, and methods to minimise these losses. In contrast, the present paper will describe how future food processing techniques are likely to: (a) impact on nutrient intake; (b) improve the nutritional quality of the diet.

‘It was the need to cook which taught man to use fire, and it was by using fire that man conquered nature,’ wrote Brillat-Savarin (1960). Cooking has been suggested as an important technological advance that enabled plant foods to be accessible to man (Stahl, 1984). The desire and need to preserve food has been a major concern of mankind. The objectives of food preservation are: (1) to extend shelf-life thereby prolonging the time when food can be consumed or distributed; (2) to improve flavour, texture and eating quality of foods; (3) to remove, inactivate or destroy toxins and microbes in food that cause spoilage; (4) to enhance or optimize the nutritional characteristic of foods. Each of these, to a lesser or greater extent, may be an important feature in food processing. For example, freezing is intended to retain both the eating quality and nutritional characteristics as close as possible to those of fresh produce. In contrast, canned foods are intended to provide variety and foods that may be eaten conveniently at any time of the day or year.

Evolution of food processes

Food processing has evolved over the centuries to meet the immediate requirements of the population (Table 1): (1) the prehistoric methods which required little or no equipment but preserved foods to overcome a seasonal shortage or store during a temporary glut; (2) the intermediate ‘old’ technologies which were more intensive and relied on a greater technology level and energy availability, but expanded the range of foods available; (3) the modern processes, with a greater degree of technological sophistication and scientific understanding, which could reduce the intensity of the process and give a further improvement in the quality of the food preserved. This mirrors man’s requirements for, primarily, a regular supply of food to cover inter-harvest periods (in climates where hunter–gathering is not possible) and, second, that food be of good quality.

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Table 1. Food processing (adapted from Henry & Heppell, 1998)

Traditional processes (prehistoric)	Intermediate 'old' technologies	Less-intensive processes
Sun-drying	Spray-drying	Freeze-drying
Oven drying		Aseptic (ultra-high temperature) processing
Smoking		Extrusion cooking
Salting		Microwave and radiofrequency heating
Pickling	Chemical additives	Ohmic heating
Fermentation		'Hurdle' technology
(Freezing and chilling)	Freezing	Chilling
	In-container sterilization (retorting)	
	Pasteurization (HTST)	Membrane processing
	Controlled atmosphere storage	Modified atmosphere packaging
		Irradiation
		Use of fluidized and sprouted beds
		'New' processing technologies

HTST, high temperature, short time.

Food preservation by heat

Heat is the most convenient way of extending the keeping quality of food. Heating food not only destroys microbes but also inactivates enzymes and toxins. Whilst the nutritional quality of foods (especially for some vitamins) may be reduced by heat processing, a judicious combination of high temperature and short time minimizes nutrient losses. A careful selection of the time and temperature combination from the thermal death time curve will optimize both the nutritional and sensory properties of food. This example highlights the food processors' conflict between maintaining food safety and preservation of nutritional quality.

Thermal processing

One example of the effect of change of process, and alteration of process variables, on the nutritional quality is in thermal processing. The older in-container process is well established, but gives a product measurably lower in the heat-sensitive vitamins than that produced by an ultra-high temperature (aseptic processing) method. Recent work has concentrated on extending aseptic processing to viscous foodstuffs and foods containing solid particles, to the extent that a large range of sauces, soups and stews can be produced, even whole spaghetti! It is also possible, using rapid heating, to produce sterile undercooked foodstuffs which, on reheating by the consumer, will result in an optimum quality on the plate. Within the aseptic processing technique, the micronutrient losses can be further minimized by: (1) using the fastest heating rate possible either by maximizing the heat transfer coefficient or by use of direct heating equipment (steam injection or infusion heating and 'flash' evaporation for cooling); (2) for foodstuffs containing solid particles, using either steam injection or ohmic heating systems which will maximize the heating rate within the particle; (3) minimizing the spread of residence times within equipment, especially the holding tube. There has been little research into methods to achieve this, but static mixers may help.

The effect of the different process variables on the loss of thiamin, as an example, can be calculated by applying a mathematical model (Table 2).

Table 2. Loss of thiamin for different ultra-high-temperature (UHT) process variables (equal *F* value treatments)

Process		Loss of thiamin (%) by mathematical model
Canning		40–50
UHT (no RTD):	Slow heating	9
	Fast heating	1·3
Effect of RTD:	Laminar flow	12
	Turbulent flow	1·3
	Plug flow	0·9

RTD, residence time distribution.

In thermal processing there are options in the choice of process and, within that, process variables that will affect the nutritional quality of the product. This can also be shown to happen in most processing unit operations, not just for the example of processing given here. These effects are not always especially large, however, and may be eliminated by consumer abuse of the product during heating. This does not devalue the need to maximize the micronutrient value of the food where possible, however, especially as this correlates with organoleptic quality to a large extent. One key problem is to achieve this using appropriate food processing methods in parts of the world where increased micronutrient quality would improve public health. There is considerable scope for the interaction of nutrition and food engineering that should not be ignored; nutrition is rarely included in food engineering education and it would be advantageous if it had a higher profile.

Nutritional quality

Whilst some vitamins are destroyed when foods are processed, most of this loss is not due to heat processing *per se*. The losses are largely due to the nutrients being sensitive to pH, O_2, moisture, light, heat or a combination of these. The stability of vitamins varies enormously, ranging from little or no loss to complete destruction. Table 3 summarizes these observations. In general, most food processing technologies in use today do not result in major nutrient losses (Karmas & Harris, 1988). More importantly

Table 3. Stability of nutrients (adapted from Karmas & Harris, 1988)

Nutrient	Effect of pH			Air or O_2	Light	Heat
	Neutral (pH 7)	Acid (<pH 7)	Alkaline (>pH 7)			
Vitamin A	S	U	S	U	U	U
Ascorbic acid (C)	U	S	U	U	U	U
Biotin	S	S	S	S	S	U
Carotene (provitamin A)	S	U	S	U	U	U
Choline	S	S	S	U	S	S
Cobalamin (vitamin B_{12})	S	S	S	U	U	S
Vitamin D	S		U	U	U	U
Folic acid	U	U	S	U	U	U
Vitamin K	S	U	U	S	U	S
Niacin	S	S	S	S	S	S
Pantothenic acid	S	U	U	S	S	U
Pyridoxine	S	S	S	S	U	U
Riboflavin	S	S	U	S	U	U
Thiamin	U	S	U	U	S	U
Tocopherol (vitamin E)	S	S	S	U	U	U

S, stable (no important destruction); U, unstable (substantial destruction).

(or at least in Western societies), due to the variation in the type of food consumed, the consumption of processed foods is unlikely to influence human micronutrient status. Bender (1978) succinctly summarized it as follows: ‘There is general belief that when the housewife buys fresh food and cooks them herself she retains all the nutrients, whereas when the same food passes through the hands of the food processor these nutrients are largely if not completely destroyed. This belief is untrue like so many other popular beliefs in nutrition.’

Much of the current and future concern related to the role of food processing on nutrient composition of foods is associated with: (1) changes in the way in which food products are manufactured; (2) social and cultural changes in food consumption and meal patterns; (3) increased demand and interest in low-energy foods that have fat and sugar mimetics.

Changes in the way food products are manufactured

Until a few years ago, food processing involved the use of heat, freezing, salting, smoking or drying as a means of extending the shelf-life. Two new innovations have now merged into modern food processing. First, the use of new processing techniques such as food irradiation, high-pressure processing, ohmic heating and pulse electromagnetic techniques. Whilst many of these processes are likely to improve the nutrient composition of foods (due to reduced time and temperature of processing), the second innovation, i.e. the introduction of new food ingredients and fat mimetics, is likely to impact on our micronutrient intake substantially.

Table 4. Losses of nutrients in milling of wheat (mg/100 g) (adapted from McCance & Widdowson, 1960)

Nutrient	Percentage extraction		
	100	80	70
Thiamin	0·4	0·25	0·08
Riboflavin	0·16	0·08	0·05
Niacin	5·0	1·6	1·1
Pyridoxine	0·4	0·11	0·06

The way in which micronutrient (notably vitamins and trace minerals) intake in man may be compromised is highlighted by the following two examples. Until the advent of milling, most cereals were consumed by simple pounding or grinding. The objective of all milling is to separate the bran and germ from the starchy endosperm, which is ground to flour. The milling process inevitably removes very important micronutrients and also phytate and fibre. The extraction rate is used to define different types of flour. White flour is when the extraction rate is 75 % or less. If the extraction rate exceeds 80 %, the flour will contain some bran. If the extraction rate is 100 %, wholemeal flour will be produced. Table 4 illustrates that whole grains contain considerable amounts of vitamins and minerals. These decline sharply on milling. Highly-refined cereals have been known to produce micronutrient deficiencies in vulnerable groups, such as refugees (Magan *et al*. 1983).

Whilst milled cereals have a reduced micronutrient content, they are of little nutritional consequence to most people living in the Western world. The expanded use of highly-refined food ingredients in future, however, is likely to further reduce micronutrient intake in subjects even living in the Western world.

In contrast to using milled cereals and legumes in food production there has been in recent years an intensification in the manufacture of foods from isolated protein, fat and carbohydrates. There is an increasing trend to manufacture foods that taste, feel and look like the ‘original’ food, but are made from isolated food ingredients. Numerous soft drinks (‘lookalike orange juice’), snack foods (‘lookalike potato product’) and fat spreads are made this way. The reason for this trend in food manufacture is that the use of food ingredients allows for strict quality control in the final product. The down side is the almost complete loss of any micronutrients in these foods (the isolated protein, fat and carbohydrates are almost completely devoid of micronutrients). The health implications of this dramatic loss of micronutrients could be substantial. A practical solution has been to fortify these foods to compensate for the poor micronutrient levels.

In many industrialized nations the health burden has slipped away from infectious diseases to chronic disease, such as cardiovascular disease, hypertension and cancer. Food technology and nutrition have a pivotal role to play in combating these diseases by providing food with the appropriate amount of micronutrients and phytochemicals, which are known to reduce the development of chronic diseases.

Food fortification

Food fortification may be broadly defined as the process whereby one or more nutrients are added to foods to maintain, improve or enhance the quality of a diet consumed by a group, community or population. The term fortification is sometimes loosely used to include the terms ‘enrichment’ and ‘nutrification’. The primary objective of all these terms is to enhance the nutritional quality of the food by direct addition of various nutrients. Food fortification has been widely used by the food industry for over 50 years. For example, in 1941 the US Food and Drug Administration issued guidelines for the enrichment of wheat flour. Since this time, many countries in North America and Europe have routinely added micronutrients (notably B vitamins, Fe and Ca) to their milled flour (Henry & Seaman, 1992).

Recent advances in food fortification are essentially due to two major developments: (1) the commercial production of various vitamins and premixes at relatively low cost; (2) the development of the process technology necessary for the successful addition of these nutrients to various foods.

A major issue in food fortification is the selection of an appropriate vehicle for food fortification. In selecting a food for fortification, the following factors need to be considered: (1) the food should be consumed in adequate quantities and on a regular basis by the target population; (2) variation in the quantity of the food consumed should be minimal between subjects; (3) the food should be produced and processed at a few centres to ensure regular monitoring; (4) the added nutrient should not react with the food; (5) the food should remain stable and show no changes in flavour after fortification; (6) the technology for fortification of the food should be relatively simple. More and more of our foods are likely to be fortified in future in order to compensate for the serious losses of micronutrients in our foods.

Low-fat and -energy foods that contain fat mimetics and sugar substitutes are widely available in the market today. These are likely to increase in the future, due to a greater demand for low-energy food in the face of increasing obesity. The fat-like substances are composed of fatty acids esterified with carbohydrate, alkyl glycosides or polyols. Examples include olestra, sucrose fatty acid ester and salatrim. Initial use of olestra reduced blood levels of vitamins A, D, E and K and carotenoids (Blackburn, 1996). This has now been corrected by fortifying olestra with some of these vitamins (Callaway, 1998). This example highlights two important points. First, the need for close synergy between food technology and nutrition in product development (in order to avoid unforeseen nutritional consequences). Second, to note how the addition of minor ingredients (olestra) in the diet can have a major impact on human vitamin status.

The development of functional foods is another example of close collaboration between food technology and nutrition. Few functional foods have generated more interest than phytosterols and phytostanols. When consumed as a part of a normal diet, these phytosterols reduce cholesterol in man. An example of a product that contains phytosterols is Benecol®.

Science and technology have access to unprecedented reservoirs of technical knowledge and powerful tools that can shape the foods we eat tomorrow. Interdisciplinary research and close collaboration with academia and industry, and the education of the public are major tasks for both food technologists and nutritionists of today and tomorrow. The Surgeon General’s Report on Nutrition and Health (US Department of Health and Human Services, 1988) commented that ‘the food industry can contribute to improving the quality of the nation’s diet by increasing the availability of palatable, easily prepared food products that will help people follow dietary guidelines.’ This is the greatest challenge facing both the food industry and nutritionists.

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