New food processing technologies: from foraging to farming to food technology

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The 'daily bread' for over six billion people today is largely derived from plant sources. The history of plant use reaches back uninterrupted to our earliest hominid ancestors. There is a long tradition of regarding the origins of agriculture (Flannery, 1973) as an important stage in the development of human society. Whilst acknowledging its significance, an equally profound revolution has passed unnoticed, this is the revolution in food processing and technology. The theme of the present paper is to discuss new 'food technologies' and the impact they have had, and are likely to have, on our society. Before we examine the 'new' food technologies, it is instructive to review the stages that man has passed through in the exploitation of plants and animals as food.

Human food acquisition strategies can be broadly described as a transition from hunting and gathering (foraging), i.e. depending on wild plants and animals, to agriculture (farming), i.e. domestication of plants and animals (Fig. 1). The lifestyles of our ancestral hunter–gatherers were such that they had little need of methods of food preservation. However, with the domestication of plants and the evolution of farming, the need to preserve and store foods became inevitable. The foods we consume are predominantly of biological origin, i.e. from plants and animals. Unless effective methods of preservation are used, microbiological and/or enzymic changes will render the food inedible.

Evidence of early food use and methods of food preservation may be gleaned from archaeological, ethnographic or written sources. Whilst archaeological sources may supply evidence of the type of plant and animal use, ethnographic studies are more likely to provide richer social and biological insights into our distant past. For example, the Australian Aboriginals were the largest known group of hunter–gatherers who lived in isolation for almost 50 000 years (Kirk, 1981).

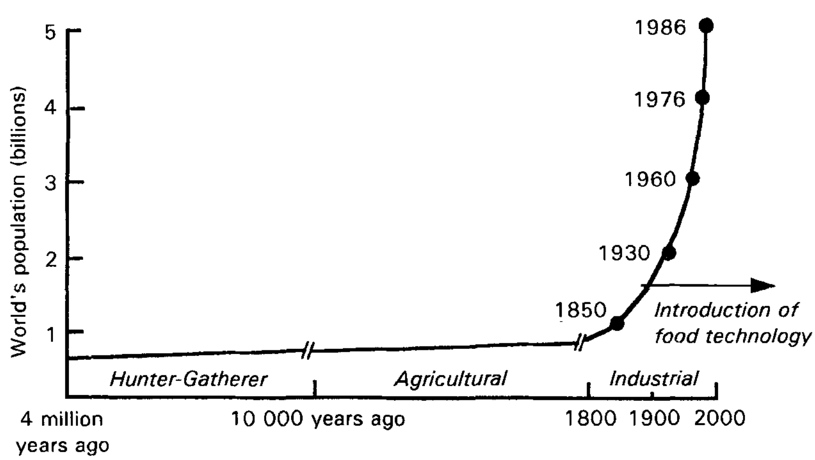

Fig. 1. Foraging to farming to food technology.

There are undoubtedly risks in trying to reconstruct the past by studying present day hunter–gatherers. These extant hunter–gatherers are people, even today, living untouched by modern day technologies. Table 1 shows the range of plant species used by two hunter–gatherer groups, the Alyawara from Central Australia and Tlokwa of Botswana (Grivetti, 1979). A striking feature of these groups is the large number of plant species used by them to obtain their food and nutrient needs. More importantly, hunter–gatherers do not rely on any particular plant source as a food staple. Seeds, flowers, leaves, roots, barks, animals and insects are all major sources of food. In this context, a food staple may be defined as a food source that contributes significantly to the energy content of the diet.

A significant feature of the transition from hunting and gathering to plant domestication, implying human intervention to genetically or phenotypically modify plants, was a dramatic reduction in the number of plant species cultivated. As agriculture developed, the practice of cultivating several cereals and crops by man, was replaced by an agricultural system that encompassed fewer and fewer variants. This is well illustrated in Table 2.

Table 1. *Number of plant species used by hunter–gatherers*

	No. of plant species used	
Hunter–gatherer group	Total	Type
Alyawara (Central Australia)	92	36 Seeds 32 Flowers 26 Fruits 8 Roots
Tlokwa (Botswana)	126	22 Leaves and stalks 31 Roots 47 Fruits 23 Barks and resins 3 Mushrooms

Table 2. *Plants used as staple foods today*

Common name	Latin name
Rice	*Oriyza sativa*
Wheat	*Triticum spp.*
Maize	*Zea mays*
Sorghum	*Sorghum vulgare*
Millet	*Eleusine coracana*
Rye	*Secale cereale*
Oat	*Avena spp.*
Potato	*Solanum tuberosum*
Sweet potato	*Ipomoea batatas*
Taro	*Colocasia esculenta*
Yam	*Dioscorea spp.*
Cassava	*Manihot esculenta*
Sago	*Metroxylon spp.*
Arrowroot	*Maranta arundinaceae*
Teff	*Eragrostis tef*
Bread fruit	*Artocarpus altilis*
Barley	*Hordeum vulgare*

Today, our global population relies heavily on merely seventeen food staples. This is a dramatic reduction in the use of plant species since our hunter–gatherer past, and places a greater reliance on a narrow range of food staples. In theory, such a drastic reduction in plant species use should have led to serious nutritional deficiencies. Indeed, this is true in many developing countries where a limited range of plant foods, cultivated and available, restricts the quality and quantity of food consumed, leading to micro- and macronutrient deficiencies (Latham, 1979).

In modern Western societies, the main cereal staples are wheat, maize, rice, barley and oats, with potato being the only root crop staple. How did modern man transform and transmute such a limited range of plant species into a myriad of foods (over 30 000 food products) as seen in a well-stocked supermarket? It is modern food technology that has enabled us to transmute foods that are both palatable and nutritious.

The food technologist is the modern day alchemist. Using the noble grasses (*Gramineae*; i.e. wheat, barley, millet, oat, maize and rice), he has transmuted these base grasses into foods of unimaginable complexity and taste. These foods not only have unique physico-chemical structures, but also have unique organoleptic properties. Table 3 illustrates a selected list of foods that may be prepared using a single staple, wheat. An important feature of food technology is the ability to transform the staples into endproducts of distinct nutritional and culinary properties. Take the example of wheat, whose composition and structure is all too familiar. In the hands of the food technologist, it is transformed into over 1500 different foods of distinct gustatory and nutritional properties (Faridi & Faubion, 1995). Whilst wheat may be unique in its versatility to be transformed into different foods, it is equally easy for the reader to conjure up a range of foods that may be manufactured using rice or maize. Modern man has replaced plant species variety (as in the case of the hunter–gatherer) with food variety (foods made from single plant species into diverse foods); this is the story of modern food technology.

Table 3. *Selected list of foods manufactured from wheat*

White bread	Pitta bread
Cookies	Chapatti
Crackers	Poori
Pretzel	Parotha
Doughnut	Upma
Breakfast cereals	Naan bread
Pasta	Rava idli
Baguette	Ravadosa
Roll	Tempura batter
Croissant	Halwa
Brioches	Jalebi
Stollen	Roti
Scone	Tanoor bread
Cake	Baladi bread
Shortbread	Barbari bread
Noodles	Couscous
Waffle	Bulgar
Pancake	Bameah
Steamed bun	Kanofeah
Dumpling	

EARLY METHODS OF FOOD PRESERVATION

Food preservation techniques have been known to man since antiquity. The use of fire to cook, heat and dry foods may be described as the earliest form of food processing. Foods may be processed by exposure to dry heat (e.g. roasting) or wet heat (e.g. boiling) or cooked in oil (e.g. frying). Whilst the scientific foundations of nutrition may be traced to the work of Lavoisier, in contrast the major breakthrough in food technology had to wait until 1803. Until the 19th century, all methods of food preservation relied heavily on creating an environment unsuitable for microbial growth (e.g. use of salt, sugar, spices, acid, fermentation, drying). The concept of 'canning', first introduced by Nicholas Appert, was a revolution. It differed from all known methods of food preservation by killing the microbes by heat and hermetically sealing the container, thus avoiding subsequent contamination. The ability of heat to extend the shelf-life of foods was first described by Nicholas Appert between 1803 and 1809. Appert methodically filled and sealed bottles with meat, beans and peas and used thermal sterilization to extend their keeping quality. Appert published his seminal work *L'Art de Conserver* in 1810 (Thorne, 1986). It was in England that his ideas were warmly received and developed. By 1810, a patent was granted to Peter Durand of London entitled 'Of preserving animal food, vegetable food and other perishable articles, a long time from perishing or becoming useless' (Thorne, 1986). As early as 1813, these 'preserved foods' were used by His Majesty's ships.

PRESENT DAY FOOD TECHNOLOGIES

Food processing and preservation are generic terms that cover all aspects of extending the shelf-life of foods. The micro-organisms that cause food spoilage may be arrested by using the following three main methods:

(a) physical methods (e.g. heat, freezing, dehydration);
(b) chemical methods (e.g. pH, Redox potential, preservatives, CO_2);
(c) a combination of (a) and (b).

Table 4 shows a simple chronological classification of food processing and preservation techniques. They illustrate the wide range of technologies presently used by the food

Table 4. *A chronological classification of food processing and preservation*

'Old' processes (since pre-history)	Current processes
Sundrying	Spray drying
Oven drying	Freeze-drying
Smoking	Canning
Salting	Aseptic processing
Pickling	UHT pasteurization
Fermentation	UHT sterilization
Freezing	Extrusion cooking
	Irradiation
	Microwave heating
	Reverse osmosis
	Osmotic dehydration
	Modified atmosphere packaging
	Freezing or chilling

UHT, ultra-high temperature.

Table 5. *Nutritional concepts leading to technological innovations*

Pulsed electric field
Ohmic heating
Oscillating magnetic field
Light pulses
High ultrasonic hydrostatic pressure
Active packaging
Natural anti-microbial compounds from animals or plants
Supercritical CO_2
Polycationic polymers

industry. Many of these technologies were the outcome of the 'technological revolution' of the pre- and post-war periods (1940–1950). Moreover, the space programme (1950–1990) also brought in its wake technologies that were soon to become a part of our food industry's currency. Heat processing is widely used by the food industry to extend shelf-life and maintain microbiological safety. It is well recognized that thermal treatment is detrimental to texture, aroma, flavour and the nutritional quality of foods. An increasing consumer demand for 'fresh-like' foods, coupled with greater awareness of nutrition (i.e. low energy, low sugar, low salt) has stimulated the development of new food technologies (Table 5) that are based on the technology which produces 'minimally-processed foods'.

DEVELOPMENT OF NEW FOOD TECHNOLOGIES

Whilst the term 'minimally-processed foods' covers foods produced by a range of technologies and preservation techniques, the main feature of these processes is to have minimal effect on texture, flavour and nutrition of food, whilst retaining high preservation qualities. A careful inspection of Table 4 indicates that a large proportion of the preservation techniques in use today rely heavily on removing water (dehydration, spray or freeze drying, reverse osmosis, osmotic dehydration), or the addition of sugar or salt humectants to reduce water activity (a_w). This removal of water increases the energy density of food. This is well illustrated by examining Table 6. In contrast, the energy density of foods consumed by our hunter–gatherer ancestors rarely exceeded 7·9 kJ (1·9 kcal)/g (Table 7).

To the food processor, the reduction in moisture content and the control of a_w in foods is the key to enhanced shelf stability. Table 8 shows the close relationship between moisture content, a_w and shelf-life of foods (a_w may be defined as the ratio, vapour pressure of pure water : vapour pressure of a solution). However, to the consumer today, the desire to eat low-energy 'lite' foods (i.e. foods low in energy density) is compelling (Rolls, 1991).

Table 6. *Changes in energy density during transformation of foods using food processing*

	Energy density (kJ/g)		Energy density (kJ/g)
Fresh strawberries	1·1	Strawberry jam	11·0
		Freeze-dried strawberries	12·9
Raw potato	3·1	Potato crisps	22·8
Maize: 'corn on the cob'	2·8	Corn (maize) chips	21·6
Fresh milk	2·8	Condensed milk	13·9
		Dried-milk powder	20·3

Table 7. *Energy density of foods eaten by hunter–gatherers or agro-pastorialists*

	Energy density (kJ/g)
Fruit*	
(ranging from melons to bananas)	0·6–4·6
Leafy vegetables	0·8–1·3
Root crops	
(Cassava (*Manihot esculenta*), yam (*Dioscorea spp.*), taro (*Colocasia esculenta*), sweet potato (*Ipomoea batatas*)	5·8–4·6
Milk	2·9
Meat (beef)	8·2

* Range of values for fruits.

Table 8. *Moisture content of foods and their water activity (a_w)* and relationship between a_w and shelf-life*

Product	Moisture content (%)	a_w
Fresh meat	70	0·99
Wheat flour	14·5	0·72
Dried vegetables	5	0·20
Dried-skimmed-milk powder	3·5	0·11
	a_w	Shelf-life
	0·95	1–2 d
	0·85	1–2 weeks
	0·75	1–2 months
	0·65	1–2 years

* Vapour pressure of pure water : vapour pressure of a solution.

How can the conflicting interests of the food processor (i.e. to reduce moisture content and thus increase the energy density of foods), and the consumer (i.e. to increase moisture content and thus reduce the energy density of foods), be reconciled? This challenge has been met by the development of new 'food technologies'.

NEW FOOD TECHNOLOGIES

The new food technologies (Table 5) are sometimes called 'non-thermal processes' or 'minimal processing' or technologies to produce 'fresh-like' products. These technologies aim to meet the strict requirements of food safety, and consumer demand for the following attributes:

more convenience, ease of storage;
higher quality, better flavour, texture and appearance;
fresher;
more natural;
nutritionally healthier;
safer (Overview, 1993; Gould, 1995).

High-density pulsed electric field (PEF): concept and application

The use of PEF is gaining considerable popularity since it represents an alternative to thermal processing of food. PEF involves the passage of high voltage, in short bursts, into foods placed between two electrodes. The electric field is normally applied at ambient or refrigerated temperature for less than 1 s. In this process, there is little or no heating of food, leaving the product 'fresh-like' and retaining its physico-chemical and nutritional properties. Castro *et al.* (1993) have suggested that PEF may be the most important 'new' development in non-thermal processing of foods. Bacterial inactivation is believed to be due to structural changes to the cell membrane and pore formation. The application of PEF requires two components: first a pulsed power supply, and second a treatment chamber. Normally, low voltage is converted to high voltage and stored in a capacitor. The energy stored can then be discharged instantaneously. In the chamber, liquid food is passed between two electrodes spaced 5 mm apart. The liquid to be processed (e.g. milk) flows at the rate of 200–500 ml/min with a PEF intensity of 80 kV/cm, pulse width 0·5–5 s, and the pulse repetition rate of 0·1–10 Hz. Using this technique, the following foods have been successfully processed: orange juice, milk, apple juice, apple-juice concentrate, green-pea soup and liquid eggs.

Ohmic heating: concept and application

Ohmic heating, sometimes called electrical resistance heating or Joule heating, uses electrical power to be transformed into heat energy. When an alternating electrical current is passed through food, it heats up the food system due to its electrical resistance. For the process to work efficiently, it requires electrodes to be kept in close contact with the food. The idea of using electrical current to generate heat in food is not new. Anderson & Finkelstein (1919) reported the use of ohmic heating to pasteurize milk. A resurgence of interest in ohmic heating has emerged due to two major events: first, the availability of improved non-fouling electrodes; second, consumer demand for 'fresh-like' or minimally-processed foods. Although ohmic heating cannot be truly classified as a minimal process, with careful design and operating conditions, the heat generated may be controlled to cause less damage to the food than conventional thermal processing. During conventional heat processing of viscous food, heating occurs from the surface to the interior, with considerable lag time in heat transfer between liquids and solids. When a solid–liquid mixture is conventionally heated, the temperature of the liquid phase will increase more rapidly than that of the particles. In marked contrast, with ohmic heating the solid particles gain heat faster than the liquid. This makes it an attractive process for high-temperature–short-time sterilization or pasteurization of particulate foods. Ohmic heating has been successfully used to process proteinaceous foods such as egg, cheese and surimi. It is also a useful method to thaw frozen fish products.

Modified-atmosphere packaging (MAP)

MAP to extend the shelf-life of foods was first commercially exploited in the UK by Marks and Spencers who, in 1979, launched their MAP meat products. Today, a range of foods from meat, fish, vegetables, bakery products and tea are sold in MAP. MAP may be defined as the process whereby air is replaced by different mixtures of gases; the major gases used are CO_2, O_2 and N_2.

New developments in modified atmosphere packaging. An innovative extension of MAP is the development of 'smart' films or 'active' or 'intelligent' packaging (Labuza, 1996). These packaging materials have the ability to absorb or emit gases, thereby extending the shelf-life of the product. Davies (1995) has classified the use of active packaging into the following categories: O_2 scavenger, CO_2 scavenger, CO_2 forming, aroma removal, off-flavour removal, ethylene removal, ethanol emitter, water removal and edible film. For example, O_2 scavengers are now used in the following foods: bakery products, smoked fish and meat, dried fish, potato chips, dried egg, spices and chocolates. Similarly, CO_2 generators or scavengers are used in various foods. High CO_2 levels (10–80 %) are used in meat, fish and poultry to limit surface microbial growth. All climacteric fruits produce ethylene; if this is removed, the fruits ripen slowly, thereby extending the shelf-life. Ethanol-emitting film (which acts as a surface anti-microbial) has been used to extend the shelf-life of cheese, semi-dried fish and bakery products.

High-pressure processing: pascalization

It is almost one century since Hite (1899) reported the use of high pressure to process and preserve milk. Subsequently, it was shown that peas and pears treated with pressures up to 400 MPa for 30 min remained edible after 5 years of storage. Whilst progress in the commercial exploitation of this technology has been slow, recent interest in minimally-processed food and developments in engineering technology has created a resurgence of interest (Knorr, 1995). High-pressure-processed food, especially high-acid foods such as fruit drinks and jams, have been available in Japan since 1990. Table 9 shows a list of foods processed using high-pressure processing. The pressures used for processing are in the order of 100–1000 MPa (100 MPa represents a pressure of 1·0 kbar).

CONCLUSION

Modern food technology has come a long way since hominid man first discovered the use of fire. The new preservation techniques outlined in the present paper are likely to play a significant role in our lives. An increasing demand for foods that are microbiologically safe

Table 9. *Current industrial applications of high-pressure-treated food products* (after Cheftel, 1993)

Company	Product	Processing conditions
Meidi-ya	Jams, fruit dressing fruit sauce (topping) yoghurt, fruit jelly	400 MPa, 10–30 min, 20°
Pokka Corp.	Grapefruit juice	120–400 MPa, 2–3 min, 20°
Wakayama Food Industry	Mandarin juice	300–400 MPa, 2–3 min, 20°
Nishin Oil Mills	Non-frozen tropical fruits ('freeze' at −18°)	50–200 MPa
Fuji Ciku Mutterham	Beef (tenderization)	100–150 MPa, 30–40 min, 20°

and nutritious, and a consumer demand to eat fresh-like products, provide considerable opportunity for technologists and nutritionists to be creative in this emerging science.

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