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Vitamin retention in microwave cooking and cook–chill foods

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The process of cook–chill is defined and the time-temperature conditions are stated. The length of time the food requires to be reduced in temperature from 80 to 15°C has a direct effect on ascorbic acid retention; rapid chilling is therefore recommended. Some vitamin losses also occur in chilled storage; these are reviewed. The mechanisms by which microwaves heat food are explained. Where the microwave heating causes a reduction in the severity of time–temperature conditions and/or less water is used there is the potential for increased retention of heat-labile and water-soluble vitamins when microwave heating is used as compared to conventional cooking. Results from a number of studies are presented to verify these statements.

THE COOK–CHILL PROCESS

Cook–Chill is defined as 'a food service or catering system based on the cooking of food followed by fast chilling, storage in controlled low-temperature conditions above freezing point 0°C to +3°C and subsequent reheating immediately before consumption' (DHSS, 1989).

The conditions recommended for cook–chill systems are outlined on Fig. 1. The control of time–temperature conditions, so that safe food of maximum quality is produced, cannot be overstressed.

All raw materials should be of high quality. The initial cooking should ensure destruction of any pathogenic microorganisms present. Post-cooking rapid chilling should control growth of microorganisms. Cross-contamination should be avoided at all stages and particularly between raw and cooked food. Storage and distribution conditions for cooked food should ensure its quality and safety. Reheating and service procedures should ensure the food's safety and are crucial to its palatability; they should be carefully monitored.

In other countries different requirements for the chilling conditions are known; these are shown in Table 1 (Bognar, 1990).

Clearly, the process is designed to produce safe food but the subject of this paper is vitamin retention. The DHSS Guidelines also give advice on nutritional quality and stress the need to minimise nutrient loss within the confines of a safe process. Temperature is of prime importance with regard to the growth of microorganisms and the rate of change in vitamins.

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The vitamin content of the final product is dependent upon

(1) the quality of the original raw material;
(2) the extent and nature of processing (including chilling and reheating); and
(3) the storage conditions.

Although published work with regard to safety and nutritional losses tends to relate to cook–chill catering systems, the findings are also relevant to the chilled prepared foods sold in the retail chain. Recently, there has been a growth in this market.

The airline catering industry has moved from cook–freeze and warm holding almost exclusively to cook–chill methods (Glew, 1990). The shelf-life required in this situation is almost never more than 24 h and most frequently less than 8 h.

The recommended DHSS procedure is that chilling should commence as soon as possible after completion of cooking and (in any event within 30 min of leaving

Table 1. Requirements for chilling times and storage temperature of cooked foods–chilled meals, pasteurised–chilled meals and sous-vide-type[a]

Country	Chilling times	Storage Temperature (°C)
Denmark	From 65°C to 10°C in 3 h	<5
France	From 70°C to 10°C in 2 h	0–3
Germany	From 80°C to 15°C in 2 h (From 15°C to 2°C in 24 h)	2
Sweden	From 80°C to 8°C in 4 h	3
UK	From 70°C to 3°C in 1·5 h	3

[a] From Bognar, (1990).

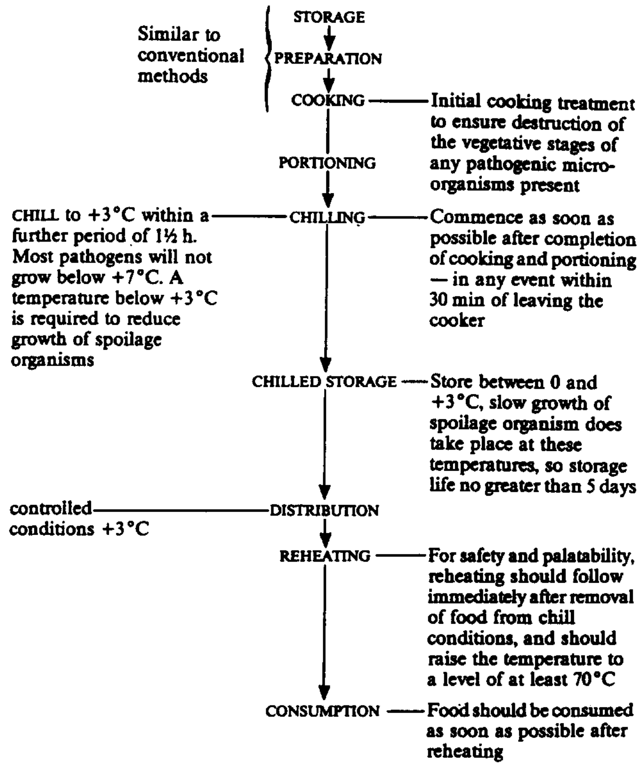

Fig. 1. The conditions recommended for cook–chill stems. (Adapted from Hill (1987).)

the cooker. The food should then be chilled to between 0°C and +3°C within 90 min. A rapid chilling device is required to achieve these conditions. There are some exceptions with regard to large joints of meat: the recommended procedures for meat are clearly specified in the DHSS guidelines.

Delay in chilling

Table 2 shows the results of the effect of a delay prior to the commencement of chilling on ascorbic acid retention in a number of vegetables (Mottisaw, 1983, 1987; Blackwell, 1985; Fort *et al.*, 1988).

Losses of thiamin are reported to be smaller and in the range of 1–2% (Fort, 1990).

Chilling times

A study has been done on vitamin retention with respect to the effect of chilling time (Bognar, 1980). The vitamins ascorbic acid, thiamin and riboflavin were investigated. This work was done in Germany and the DHSS guidelines expect a more stringent chilling process than is reported in these findings (see Table 1). DHSS guidelines state that the chiller must be capable of reducing the temperature of a 50 mm layer of food from 70°C to +3°C or below in a period of 90 min when fully loaded.

Bognar (1980) recommended that the chilling phase from 80°C down to a centre temperature of 15°C should take no longer than 2 h and the drop in temperature from 15°C to 2°C no longer than 20 h; then ascorbic acid decreased no more than 20%.

The evidence for this recommendation was based on the following findings.

Ascorbic acid content was monitored in five model dishes. Three chilling times were achieved; in each case the temperature drop was from 80°C to 15°C. There was a 1–12% loss of ascorbic acid when the chilling time was 30 min, a 2–17% loss when the time was 2 h and a 10–38% loss when the chilling time was 5 h. In the chilling range of 15–2°C losses increased only by 2–6% in spite of much longer chilling times.

The results were analysed statistically and there was a significant correlation and linear regression between the ascorbic acid retention and chilling time in the temperature range of 80°C to 15°C. The losses of ascorbic acid in this range were between 3·5 and 8·5%/h, i.e. average losses of 5·5%/h of ascorbic acid (see Fig. 2), depending on the kind of dish.

The thiamin and riboflavin contents of gravy, mashed potatoes and spinach remained unchanged during both a chilling time of 30 min and one of 2 h when the temperature was reduced from 80°C to 15°C. Only after a 5 h chilling time and further chilling down to 2°C were the vitamin contents reduced; thiamin by 9–12% and riboflavin by 2–13%.

Table 2. Vitamin C losses caused by delay in chilling—Simulated and operating conditions[a]

Food product (dish)	Loss in % related to values after cooking	
	Delay 18–25 min	Delay 50–60 min
Broccoli	—	28
Cabbage	9–27	13–39
Peas	22	35
Roast potatoes	—	19
Potato chips	—	3–8

[a] Data taken from Mottishaw (1983, 1987); Blackwell, (1985); Fort *et al.* (1988); Bognar (1990).

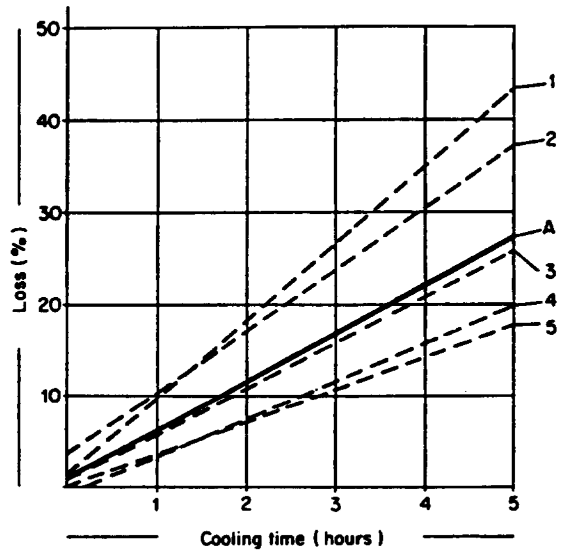

Fig. 2. Losses in ascorbic acid content during cooking of meals from 80°C down to 15°C centre temperature regression–analysis. (1) Mashed potatoes ($y = 1{\cdot}0 + 8{\cdot}4x$); (2) boiled potatoes ($y = 3{\cdot}2 + 6{\cdot}7x$); (3) spinach ($y = 0{\cdot}7 + 4{\cdot}1x$); (4) Brussels sprouts ($y = 1{\cdot}0 + 5{\cdot}0x$); (5) gravy + 20 mg ascorbic acid ($y = 0{\cdot}2 + 3{\cdot}5x$); (A) mean value of all meals ($y = 0{\cdot}8 + 5{\cdot}3x$). (Reproduced from Bognar (1980).)

Factors which affect chilling time are

(1) size, shape, weight of food and construction material the container;
(2) food density and moisture content;
(3) heat capacity of the food and the container;
(4) thermal conductivity of the food;
(5) the design of the chiller which affects chilling speed;
(6) temperature of the food entering the chiller; and
(7) whether the container is provided with a cover.

A detailed study by Paulus *et al.* (1980) showed the effect of filling height in standard trays with regard to chilling time, and faster chilling does preserve more ascorbic acid. These results support the need for monitoring the actual system in operation. Figure 3 demonstrates the effect of filling height and shows that the chilling time required is directly proportional to the filling height of the product. The head space volume above the product has an insulating effect and is therefore another factor to be considered. Reduction of the head space height from 15 mm to 10 mm results in time savings of about 15%. Therefore, minimising the head space has heat transfer and quality advantages.

Clearly, the temperature of the chilling medium also influences the chilling rate. Therefore, it is advantageous to choose a chilling medium as cold as possible without freezing the product.

Chilled storage and vitamin retention

Although in detail the results of nutrient retention and the cook–chill process reported by various workers do not agree, there is a common trend with regard to losses on chilled storage when the food is packed in air,

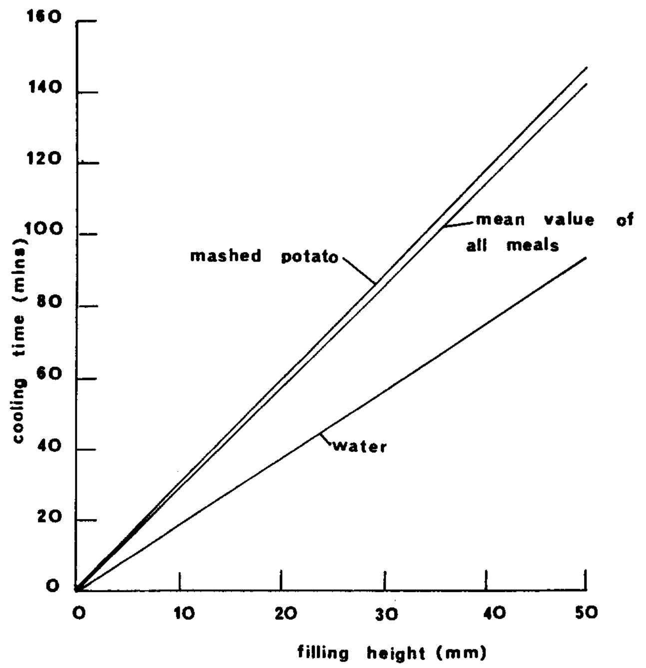

Fig. 3. Time required for chilling (nitrogen 0°C) of meals in trays ($\frac{1}{2}$ Gastronorm) from 80°C down to 15°C centre temperature as a function of filling height with constant head space of 20 mm. (From Paulus *et al.*, (1980).)

i.e. progressive losses of ascorbic acid occur (Bognar, 1980; Hunt, 1984). Methods of analysis, variation in the origin of the food and processing conditions, all contribute to the lack of agreement (Hill, 1987).

Bognar (1980) quoted ascorbic acid losses for different products of between 3·3% and 16%/day on storage at 2°C. Losses in boiled potatoes and in spinach both prepared under large-scale conditions were approximately three times the value obtained for samples prepared under model conditions.

Ascorbic acid retention in school meals of between 12 and 69% after 4 or 5 days chilled storage was reported by Turner *et al.* (1984).

Retention of thiamin, riboflavin and retinol is much higher than for ascorbic acid. Bognar (1980) found insignificant losses of retinol in liver during storage of up to 5 days at +2°C and figures of 0·6–2·5% (various foods) loss per day for riboflavin and 0·3–4·4% (various foods) per day for thiamin.

Augustin *et al.* (1980) studied vitamin retention in cooked, chilled and reheated potatoes. Although they noted losses of folic acid and ascorbic acid after chilling for 6 h, they did not find any difference between chilling for 6 h and 24 h. It is pertinent to note, however, that the chilling and chilled storage were a merged process; at the end of preparation and cooking the potatoes were placed in a refrigerator at 5°C.

Other factors which have been attributed to cause nutritional loss are oxidation and storage temperature. Bognar (1980) found if nitrogen was used instead of air as the cooling medium, 11% lower losses were recorded in cooling boiled potatoes down to 5°C in more than 5 h; further cooling down to 2°C still showed 8 % difference to cooling on air. Mottishaw (1983), however, did not show a conclusive advantage when cooling in nitrogen was compared with cooling in air. However in both these experiments the cooling was faster; under both conditions the cooling was from 90°C to 3°C in 90 min.

MICROWAVE HEATING

Microwaves are electromagnetic waves which fall into that part of the electromagnetic spectrum occupied by TV and FM broadcasting.

The frequency used for domestic microwave cookers is 2450 MHz, thus the wavelength is 12·2 cm (or 4·2 in).

The International Telecommunications Union has established two frequencies which can be used for cooking and food processing: 2450 ± 50MHz is used worldwide, 896 ± 10 MHz is used in the UK and 915 ± 13MHz is used in the USA (Decareau & Peterson, 1986). The shorter frequency of 896 or 915 MHz has a wavelength of approximately 33 cm (12·9 in) and this frequency is useful for industrial applications.

Food cooked by microwaves involves the generation of heat inside the food through a series of molecular vibrations. There are two mechanisms: dipole rotation and ionic polarisation (Decareau & Peterson, 1986).

Dipole rotation has been described as an attempt by asymmetric dielectric water molecules to align themselves with a rapidly changing alternating electric field. The molecules in the microwave paths oscillate around their axes in response to reversal of the electric field which occurs 915 or 2450 million times/s. The oscillation creates intermolecular friction that results in the generation of heat. Polar materials such as food or water which exhibit a high degree of intermolecular motion are characterised as 'lossy' (derived from the dielectric loss tangent, which is a measure of the angular change of the polar molecule when the electric field changes direction).

The amount of 'lossiness' depends upon the radiation frequency, temperature and nature of the material. Increased lossiness of material can be directly related to increased absorption of microwave energy and hence heat production. Water serves as a good example of a lossy material which heats easily in a microwave field.

Ionic polarisation occurs when ions in solution move in response to an electric field. Numerous collisions will occur when the electric field is alternating at microwave frequencies. These collisions cause heat to be generated and cause a rise in temperature of the dielectric material. One example on a small scale is the heating of cellular fluid in vegetables. This mechanism of heating is of less importance than dipole rotation.

Microwaves can be absorbed, transmitted or reflected. Materials which transmit microwaves include glass, paper, china, plastic and ice. Metals reflect microwaves.

The geometry of the food, or the shape of the container for food which is not solid, has a marked effect on the uniformity of heating. It is important to avoid sharp corners and thin edges on the food and containers. If the diameter of spherical or cylindrical food is 20–60 mm the centre will become much warmer than the surface because of a concentration effect, e.g. in meat balls (Ohlsson & Risman, 1978).

The ability of microwaves to penetrate is limited in most foods to 10–15 mm from each side. Hence, for rapid microwave heating in less than a few minutes for one serving, the maximum thickness is limited to 20–30 mm (Ohlsson 1976). Very thin layers, e.g. 7–8 mm, are often heated too rapidly. Special dishes can be used for plated meals by adjusting the height of compartments to reduce temperature differences.

Differences in the specific heat of food components are very obvious in microwave heating. Fat has a specific heat of 0·5 whereas water has a figure of 1·0, hence fat heats much more quickly than water. It is sometimes possible to use this property in product formulation.

There are some foods which heat well in a microwave oven with no adaptation, e.g. fish and vegetables (Hill, 1981). These foods have a high water content and will be cooked in a way which will resemble a moist cooking method.

Vitamin retention and microwave heating

A detailed review on 'The effect of microwaves on nutrient value of foods' by Cross and Fung (1982) stresses the need for researchers to standardise experimental conditions. They do, however, conclude that no significant nutritional differences exist between food prepared by conventional and microwave methods and state that any differences quoted in the literature are minimal.

The use of microwave heating may minimise warmholding which is clearly a nutritional advantage (Campbell *et al.*, 1958; Hill, 1981).

Vitamin retention in microwave heated-chilled foods

Dahl (1979) studied the cook–chill process and reheating by microwaves and measured the content of thiamin. The total loss of thiamin in meat loaf on processing was 30%; of this 10% was accounted for by microwave reheating.

Dahl-Sawyer *et al.* (1982) investigated cook–chill food service systems with conduction, convection and microwave reheat subsystems. They measured the vitamins considered to be the most unstable, thiamin and ascorbic acid. One hundred gram portions of precooked beef loaf, mashed potatoes and peas were processed through a laboratory simulation of a hospital cook–chill food service system with the three reheat subsystems.

The processes in the food product flow causing the largest nutrient losses were precooking in the case of beef loaf, reheating for peas, and 24 h chilled storage for potatoes. However, statistical analysis indicated no significant difference in nutrient retention of experimental products due to the methods of reheating.

Bognar (1990), however, pointed out that losses of vitamin C during the reheating of chilled meals are significant and depend upon the time taken to reheat and on the portion size. This was particularly distinct when microwaves were used for reheating. The ascorbic acid losses decreased from 36 to 17% and from 33 to 11% in boiled potatoes when only 200 g were reheated instead of 2 kg.

Various other studies have shown that vitamin C losses from 22 to 50% occurred during the reheating of chilled meals in convection ovens (Bognar, 1990).

Losses of ascorbic acid given for reheating vegetables in an infrared oven were 22% for cabbage, 15% for peas, 8% for boiled potatoes and 5% for roast potatoes (Fort, 1990).

Studies with respect to the change in vitamin A, B_1 and B_2 contents during the reheating of chilled meals indicate losses are generally less than 10% irrespective of the heating method used (Bognar, 1990; Fort, 1990).

Vitamin retention in vegetables

The main factor regarding the comparative cooking of vegetables is whether or not water has been used and if so, how much. Figure 4 shows the ascorbic acid retention in vegetables cooked by microwave and conventional heating. It can be seen that significant amounts of ascorbic acid have been extracted into the cooking water and in no case do these results show the microwave cooked vegetables to be appreciably better than those cooked by the boiling or pressure method

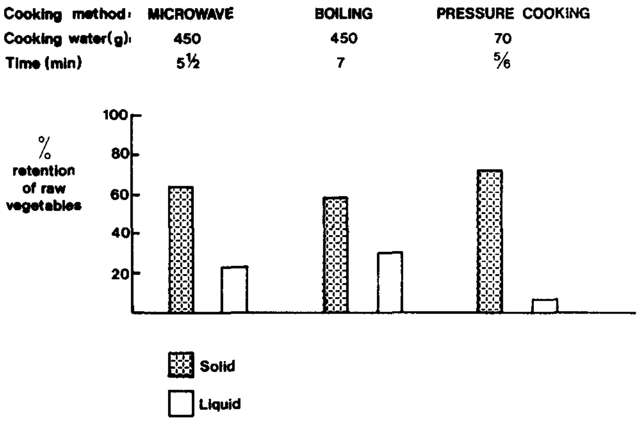

Fig. 4. Retention of ascorbic acid in broccoli. (From Thomas *et al.* (1949), reproduced by permission of the *Journal of American Dietetic Association.*

(Thomas *et al.*, 1949). Armbruster's (1978) work, however, does show a much higher retention of ascorbic acid but it can be seen (Table 3) that the microwave cooking method does not use any water.

Vitamin retention in meat

Microwave ovens may have a temperature probe which can be used when cooking meat to measure the end temperature. Early work (Thomas *et al.*, 1949) showed greater losses of thiamin, riboflavin and niacin in beef roasts cooked by microwave heating than by conventional roasting. It is relevant, however, to note that the same internal temperature was used for both methods of cooking and the outside of the microwave roast was overcooked.

Many instructions recommend a standing period at the end of microwave heating to allow the temperature to equilibrate—this is particularly relevant for joints of meat (Decareau, 1975). Increased retention of thiamin and riboflavin has been reported (Decareau, 976) when different internal temperatures were used, e.g. 60°C for conventional and 32–49°C for microwave roasting depending upon the size of the roast. The standing period allows the considerable build-up of heat which occurs below the surface to be conducted inward after the microwave power has been turned off.

Later work by Decareau (1986) suggests it would be better to use a frequency of 915 MHz instead of 2450 MHz for cooking meat roasts. Computer simulation and mathematical modelling support the increased penetration by the microwaves at 915 MHz resulting in a shorter cooking time which should improve retention of heat-labile nutrients.

Many microwave cookers now have the facility for generating intermittent microwave power into the cavity. This should be beneficial from a flavour point of view for meat roasts and nutrient retention has been studied by Baldwin *et al.* (1976). Microwave energy was applied intermittently with a 3 min cycling for the microwave range operated at 220 V and a 6 min cycling for the microwave range operated at 115V. All roasts were cooked uncovered and achieved a final temperature of 70°C. They found the retention of thiamin, riboflavin and niacin was similar for the conventional and the microwave operated at 220V and both of these treatments were superior to the microwave 115V method.

Table 3. A comparison of the ascorbic acid content of vegetables after cooking by microwave and conventional methods of cooking[a]

Vegetable (fresh)	Weight (g)	Method of cooking	Time of cooking (min)	Reduced ascorbic acid (mg/100 g)
Broccoli	300	Microwave Cook covered on high stir after 3 min, rest for 5 min after cooking.	6	111.6
Broccoli	300	Conventional Add to 450 ml boiling water, cooked covered on high, stir after 10 min.	15	73.2
Brussels sprouts	300	Microwave Cook covered on high, stir after 2·5 min, rest for 5 min after cooking.	5	86.5
Brussels sprouts	300	Conventional Add to 250 ml boiling water, cooked covered on high.	10	73.5
Cauliflower	300	Microwave Cook covered on high, stir after 5 min cooking.	8	84.6
Cauliflower	300	Conventional Add to 400 ml boiling water, cooked covered on high, stir after 5 min cooking.	10	48.2
Parsnips	300	Microwave Cook covered on high, turn after 4 min Cooking.	8	14.1
Parsnips	300	Conventional Add to 250 ml boiling water, cook covered on high.	15	6.9

[a]Adapted from Armbruster (1978).

Vitamin retention in poultry

Chicken breasts cooked by microwaves were found to have significantly greater retention of vitamin B_6 compared with meat cooked by roasting in a conventional oven (Wing & Alexander, 1972). Hall and Lin (1981) also found the thiamin content to be higher in broilers cooked in a microwave cooker when compared to an electric oven and their results showed no difference between an 800 W and a 1600 W microwave cooker.

Turkey breast muscles heated to an internal temperature of either 75°C or 85°C in microwave and conventional ovens were found to have similar vitamin B_6 levels based on a dry weight basis (Bowers *et al.*, 1974).

CONCLUSION

The processing or cooking of food is always a compromise; microbiological safety must be considered as well as nutrient retention. Heating is frequently required to make the food safe to eat but this very process inactivates heat-labile nutrients. It may be convenient because of our life-style or preference to accept various nutritional losses in one or more items we eat although wise menu planning can ensure that the diet is adequate. Knowledge therefore of the extent of nutritional loss due to processing is vital if these choices are to be exercised.

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