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The Gaseous Environment of Packaged Fresh Meat

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Over the last few years there has been an increase in the amount of fresh meat packaged at some stage before reaching the consumer. This may be done for reasons of economy of labour and storage space, or it may be a means whereby meat can be marketed in a more convenient form. The aim of packaging is to get meat to the consumer in a clean, useable condition and this normally involves holding the meat in a new environment. An important factor in this new environment is correct control of low temperature, a pre-requisite for satisfactory storage of all meat, whether packed or not, but the particular aspect which is to be discussed here is the modification of the gaseous atmosphere surrounding the meat. The composition of this atmosphere influences the colour of meat and determines the type and extent of microbiological spoilage during storage. Gases dissolve in meat according to their partial pressures and reactions in the meat may consume or produce gas; the package itself may be permeable to gas. The internal atmosphere is therefore an equilibrium of the gas exchanges between meat and package.

Attractive display of pre-packed fresh meat requires the colour to be acceptable to the consumer. This colour is determined by relations between the pigment myoglobin and oxygen. In presence of the latter, myoglobin may be converted to either the oxygenated form, oxymyoglobin, or the oxidised form, metmyoglobin. The relative amounts of these two pigments depend on the partial pressure of oxygen. Bright red oxymyoglobin is favoured by high concentrations of oxygen, while at low concentrations, brown metmyoglobin predominates. The optimum level of oxygen for the latter oxidation is 4 mm Hg (Brooks, 1938). In a piece of meat exposed to oxygen, both reactions take place; at the surface, where oxygen is freely available, oxymyoglobin is produced and this pigment extends inwards until, at a point where the partial pressure is low, brown metmyoglobin is formed. Beyond this where oxygen has not penetrated, reduced myoglobin persists.

The depth of penetration (d) of oxygen into muscle is governed by the partial pressure (C_o) of gas at the surface, rate of utilization (A) of oxygen by the tissue and the diffusion constant (D), according to

$$d = \sqrt{\frac{2C_o.D}{A}}$$

Lowering the temperature of storage increases the depth of penetration since it increases the solubility of gas in the meat and reduces the respiration demands of the tissue. Although the pigment removes some oxygen from the atmosphere, the main role of myoglobin is to carry the gas to the respiring tissue, where enzyme systems continue to consume oxygen after death with production of carbon dioxide. Rates of respiration vary with species and individual muscles, and are affected by conditions both before and after slaughter. In freshly killed muscle, the respiration rate is high, but in post-rigor meat the rate falls to a continuing, lower rate. It is difficult in practice, therefore, to predict precisely what the oxygen demands of a piece of meat will be.

A certain amount of oxygen is present at some time in all commercial packages of meat and systems differ in the amount of oxygen available in the package initially, and during subsequent storage. The various methods of packaging may be considered from the viewpoint of gas exchanges and the effect which these have on colour of meat and its keeping quality during storage.

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Air

Fresh meat pre-packed for retail sale is usually displayed in plastic or paper trays, overwrapped with plastic film. Initially, the meat is surrounded by air, and the gas permeability of the overwrap is high enough to ensure an abundant supply of O_2 to the meat. If the permeability is too low, and the supply of O_2 is restricted, its partial pressure soon drops to a level favouring the formation of metmyoglobin and so limits the attractive display life of the meat. Landrock & Wallace, (1955) calculated that a minimum O_2 permeability of 5000* was necessary for retention of oxymoglobin during normal periods of display. Although meat pre-packed in this way retains its attractive appearance for at least a week when held at $0^{o}C$, temperature control in refrigerated cabinets is usually so inadequate that meat cannot be displayed beyond 2 days. Not only does the colour deteriorate but the aerobic conditions in the package encourage rapid microbiological growth.

This type of packaging can hardly be regarded as modification of the package atmosphere, as the objective is to admit the maximum amount of O_2 while preventing moisture loss. The inhibitory potential of the CO_2 produced by the meat is not realised, since the gas permeability of films is such that CO_2 cannot be retained while allowing free access of O_2.

Vacuum

It is now common practice to pack and store meat under vacuum to extend its storage life at refrigerated temperatures. Such packs have a limited amount of O_2 present initially, and replenishment during storage is restricted. The aim of vacuum packing is to reduce the volume of residual air sealed in with the meat. Since the packages are flexible, they tend to follow the contours of the meat so that pressure inside the package is seldom much less than atmospheric. The volume of O_2 is nevertheless very small, and it is very quickly consumed by the meat to give a low partial pressure at which the penetration limit of O_2 is very near the surface. Since the material of the package has a low permeability the O_2 entering is not sufficient to prevent the formation of a thin layer of metmyoglobin, 2-3mm thick, on the surface of the meat. However the pigment in the underlying meat is still the original myoglobin and the brown metmyoglobin on the surface is not thick enough to obscure the purple interior.

The method of achieving the vacuum pack, whether by a Cryovac process or by a vacuum chamber sealing process, does not greatly affect the meat's storage performance. The materials used for the package are of similar O_2 permeability (50-70), so that all will give vacuum packs in which the bulk of the meat is purple, with a thin surface layer of brown metmyoglobin. More efficient removal of O_2 before sealing and more impermeable packages would reduce the thickness of the discoloured surface layer.

While O_2 is depleted, the respired CO_2 accumulates during the first few days after packing to a pressure of between 70-150 mm Hg and remains at this level throughout storage. The effect on microbiological development of this enriched CO_2 atmosphere will be discussed in another paper.

* cc-mil/metre^2-day-1atm.

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The main application of this packaging system to fresh meat has been in the storage and distribution of large boneless primal joints. The purple colour of the meat is no longer a disadvantage since exposure to air leads to rapid oxygenation, or blooming of the surface.

In addition, this type of packaging allows meat to be aged without the evaporative weight losses incurred when carcasses are hung. Differential ageing can be given to different parts of the carcass, and the bactericidal conditions in the package make accelerated ageing possible under correct conditions of the time and temperature. Tändler & Heinz (1970) recently defined these conditions and listed the advantages of the process. It is essential, however, that the meat destined for these packs, has minimum bacterial load if good keeping quality is desired.

Ball (1961) suggested that vacuum packed retail cuts could give the necessary extension of shelf-life to make centralized packaging of meat possible, Nevertheless, the system has not been adopted to any great extent, mainly because of the purple meat colour. It is interesting to note, however, that this colour has not prejudiced the sale, in U.S.A., of "chub" packs of raw, ground beef. This is packed under vacuum in impermeable, opaque plastic and is claimed to have a refrigerated life of several days.

Nitrogen

A disadvantage of vacuum packing is that the package may be subjected to a certain amount of strain. It is debatable whether vacuum packing increases the amount of drip exuding from meat but there is no doubt that the meat may be considerably distorted in this process, and the inert properties of nitrogen have led to its use with meat in an effort to gain the advantages of vacuum packing without the associated disadvantages. Impermeable packs are used as for vacuum but, after exhaustion of air, the package is flushed with N_2 and sealed. The main difference between this and vacuum packing is that in this case, the gas space around the meat is greater. Residual O_2 is consumed as before but gas permeating into the package is diluted by the N_2 atmosphere and the partial pressure of O_2 is lower than in vacuum packs. The metmyoglobin layer of the meat surface is consequently very thin so that the purple colour of the packed meat, and the red colour after exposure to air are very good. By the same token, however, the CO_2 produced by the meat is also diluted and microbiological spoilage would therefore be expected to occur earlier than in vacuum packs.

Carbon Dioxide

The processes so far discussed have relied on the accumulation of respired CO_2 to produce bactericidal conditions in the package. A considerable period may elapse before this level is reached however, and the addition of CO_2 to the initial atmosphere in the package has obvious advantages. The inhibition of spoilage by CO_2 enriched atmospheres (Haines, 1933) has been common practice for many years. In the 1930's CO_2 was added to shipments of chilled meat imported to the U.K. from Australia and New Zealand. Most commercial systems using CO_2 enrichment, involve prolonged storage of meat in refrigerated bulk containers

While CO_2 has been proved to be beneficial in reducing spoilage, the colour of meat is adversely affected if high concentrations are used (Brooks 1933). Kraft & Ayres (1952) observed that the ability of a package to retain CO_2 was closely related to keeping quality but that high concentrations gave discoloured meat. Pohja et al (1967) obtained extended storage life for meat packed in concentrations of 10-40% CO_2 in N_2 at +0.5°C. They observed that

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10-30% CO_2 produced a grey colour in meat after 33 days while 40% CO_2 discoloured the meat after only 19 days. Higher concentrations accelerated this colour change even further. Heiss & Eichner (1969) extended storage life slightly by treating the meat with a mixture of 8% O_2 + 92% CO_2 for 3 hours before packing. Partmann et al (1970) stored meat at 3°C and 7°C in mixtures of CO_2 and air. With concentrations of 30% and 70% CO_2, storage life was very good but colour was not acceptable. Deterioration of colour was more pronounced at the higher storage temperature.

The evidence suggests therefore that CO_2, while effective in extending storage life, cannot be used in concentrations above 20% if an attractive red meat colour is desired.

Oxygen

Although the dependance of the red oxymyoglobin pigment on an abundant supply of O_2 has long been recognised, comparatively few reports appear on the effect of enhanced O_2 concentrations on the keeping quality of meat. Fellers et al (1963) reported maximum redness in beef packed in 0.3 atm O_2 confirming earlier observations by Bratzler (1955) who had used higher concentrations. Zimmerman and Snyder (1969) followed up reports that hyperbaric O_2 inhibited enzyme respiration and attempted to use this effect to prevent formation of metmyoglobin in oxygen-depleted packages. Beef slices, treated with O_2 at 80 psi for 12 hours, were oxygenated throughout. When these slices were overwrapped in impermeable film, however, respiration appeared to proceed normally and O_2 depletion led to metmyoglobin formation. Similar slices held in the hyperbaric O_2 for 12 days were still completely oxygenated at the end of this period, but off-odours had developed which were attributed to either lipid oxidation or aerobic spoilage.

High concentrations of O_2 are certainly effective in holding the oxymyoglobin state but the stability of meat in these atmospheres was unsatisfactory and the technical problems involved in using high O_2 pressures are considerable.

Carbon dioxide and Oxygen

There are numerous examples in the literature of CO_2 being used in conjunction with modified levels of O_2 to extend storage life of meat, but most of these have been limited to O_2 pressures below that of air. In a recent study, Ledward (1970) stored sterile beef samples in atmospheres of enriched CO_2 and depleted O_2 and found that CO_2 pressures of 0.1 atm and higher did not accelerate metmyoglobin formation. There was, however, no attempt to combine the batericidal properties of CO_2 with the colour enhancement of high O_2 concentrations.

Brody (1970) reported indications, from several sources, that enriched CO_2 and O_2 mixtures gave good colour and keeping quality, but that oxidation of fat might be a problem.. No further information on the subject appeared, until 1970, when two patents (B.P. 1186,987; B.P. 1199,998) were granted covering the use of CO_2/O_2 mixtures in various proportions in packages of fresh meat. Both are concerned with low permeability containers designed, apparently, for retail distribution. A mixture of 20% CO_2 + 80% O_2 is claimed to keep the colour of meat red for up to 15 days at +4°C, during which time microbial spoilage is kept to an acceptable level ($< 10^7$ bacteria per g.). Lower concentrations of either gas were reported to be less

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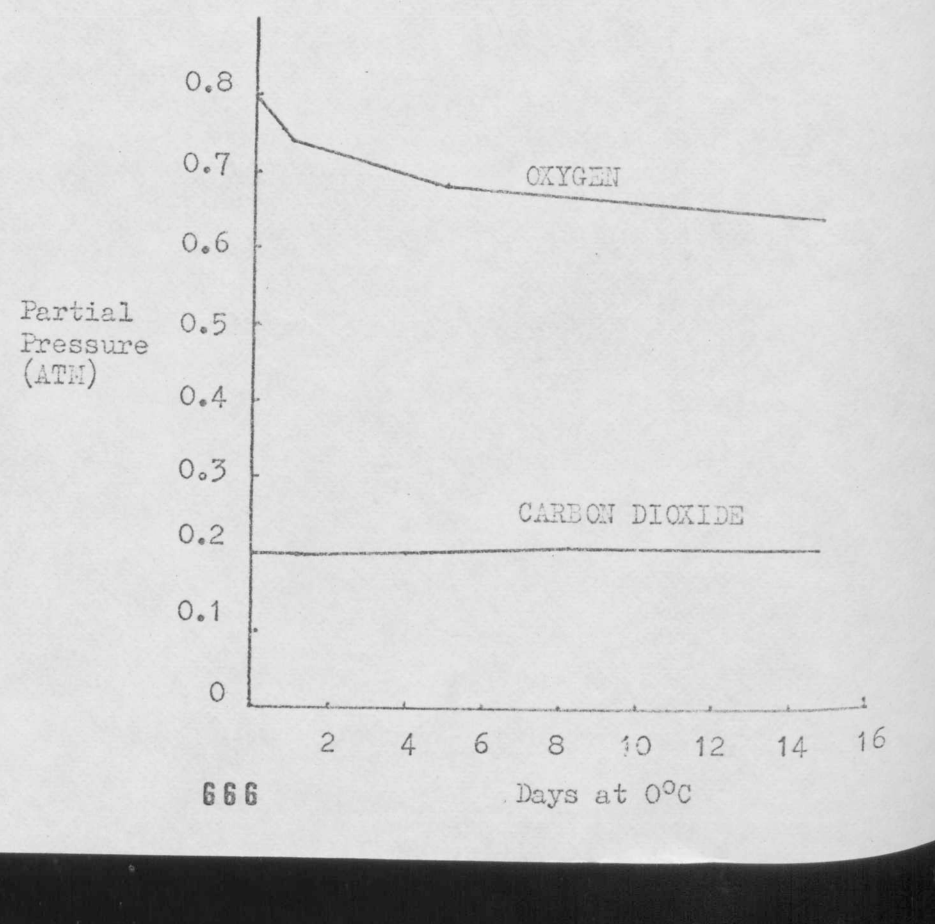
effective. The experiments described in these patents are interesting from the point of view of colour acceptability and microbiological levels, and no doubt the results will eventually be reported in greater detail.

Gas packing designed for colour retention depends on having a high initial O_2 concentration in a headspace whose volume is large enough to avoid serious depletion by respiration. The other important requirement is that the gas mixture must have easy access to the whole of the meat surface. Contact between container and meat restricts O_2 supply and leads to formation of patches of metmyoglobin. The uneven colour so produced is very unattractive and containers must be designed to ensure that all the meat is exposed and oxygenated. This technical problem is claimed to be overcome in these patents where retail packages are concerned, but it is difficult to visualize how this process could be applied with advantage to primal joints and other large pieces of meat where contact is almost inevitable.

Experiments have been carried out at the M.R.I. to investigate changes in the gaseous environment of fresh beef packed in CO_2/O_2 mixtures. Cylindrical samples of meat, 5.5 cm dia x 5.5 cm, were sealed in cans in such a way that their whole surface was freely exposed to the gases in the headspace. Cans which gave headspace volume to meat ratios of 0.9, 1.5 and 2.7 were used. By using cans the meat was completely isolated from outside atmosphere and headspace volume remained constant throughout the experiment. The gas mixtures used in these experiments were 20% CO_2 + 80% O_2, 20% CO_2 + 60% O_2 and 20% CO_2 + 40% O_2, with nitrogen making up the balance where necessary. Storage temperature in most cases was $0 \pm .5\,^{\circ}C$ and samples were removed periodically over 15 days. Analysis of headspace gas gave the pattern of change shown, for the high O_2 mixture, in Fig. 1. In all cases, the CO_2 pressure remained virtually constant throughout the 15 day storage period and only the O_2 pressure showed any significant change. The O_2 curves all indicated a quick depletion during the first day, followed by a slow decrease during the remainder of the storage period.

Fig. 1. Changes in partial pressure of oxygen and carbon dioxide in headspace of cans (Headspace to meat ratio = 1.5) during storage at 0°C. Initial mixture 20% CO_2 + 80% O_2.



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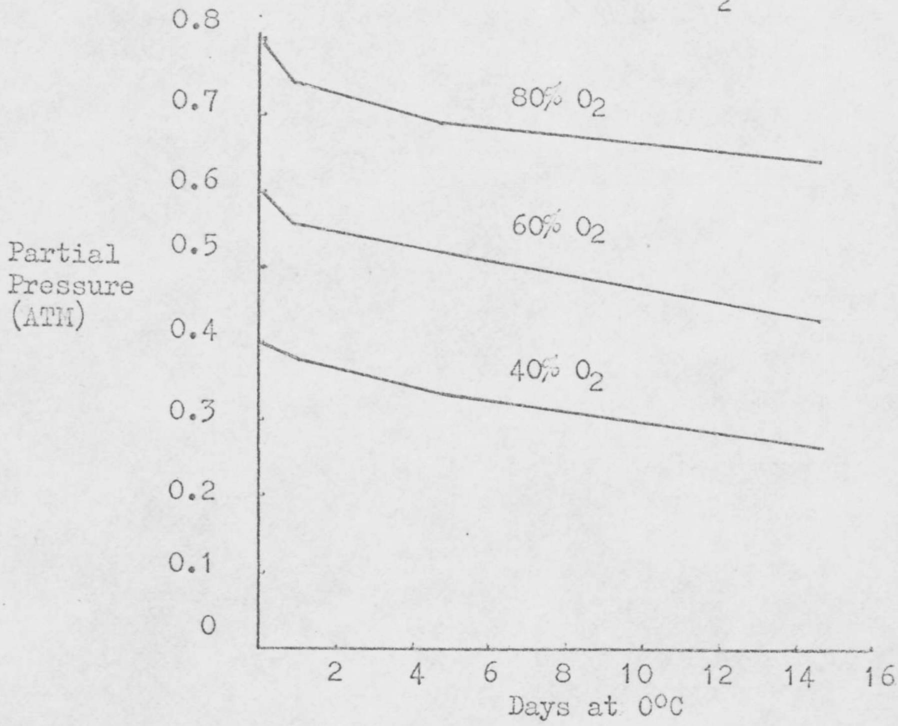
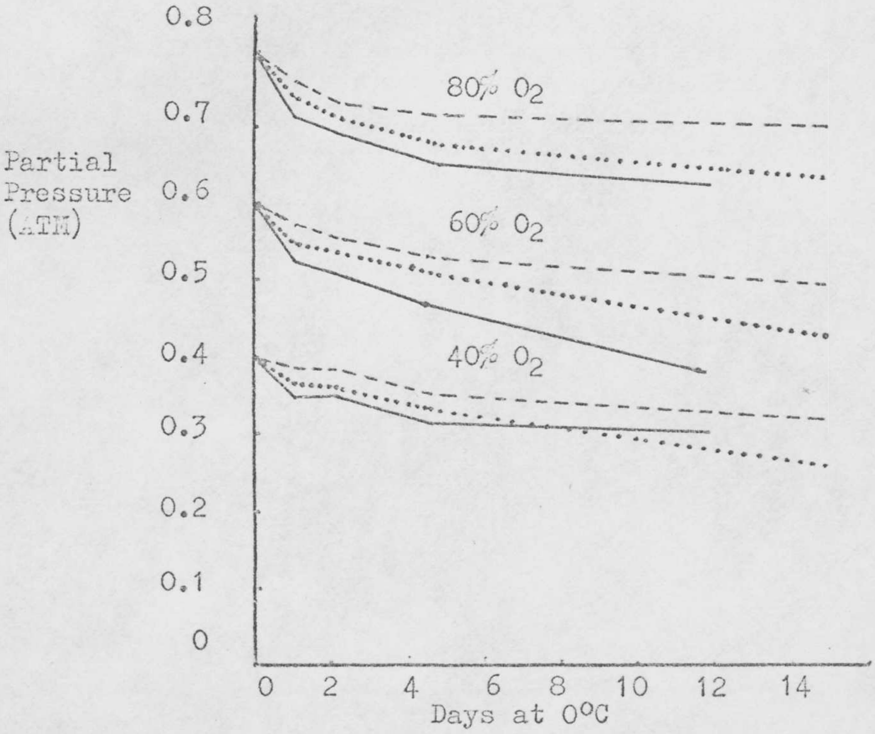
Varying the initial O_2 concentration changed only the level of the exchanges; the shape of the curves were similar (Fig. 2), although the depletion during the first day was slightly higher with the 80% O_2 mixture.

Fig. 2. Changes in partial pressure of oxygen in head-space of cans initially containing 20% CO_2 with 40%, 60% and 80% O_2. Headspace to meat ratio = 1.5.



Further experiments under the same conditions but using other meat samples showed that, although the slow rates after the second day were reasonably constant, the O_2 depletion during the first day varied considerably. This was most likely a result of different respiration rates in the early period after packing. In all cases, samples were taken from the semimembranosus of 18 month old animals, 48 hours after slaughter. At this time tissue respiration rates may still be rather high in some cases. All samples had similar low bacterial counts (approx. 10^3 bacteria/g.). The effect which headspace volume has on O_2 changes is shown in Fig. 3, where three different can sizes were used to contain the meat. As expected, the depletion of O_2 was greatest in the smallest cans.

Fig. 3. Changes in partial pressure of oxygen in head-space of cans of different headspace volumes, initially containing 20% CO_2 with 40%, 60% and 80% O_2. Headspace to meat ratios were 0.9 (——), 1.5% (...) and 2.7 (- - -).



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In all these experiments, the colour of the meat surface was recorded photographically under standard conditions as well as being measured objectively at each examination time. Simultaneously, the depth of penetration of O_2 into the meat was measured directly in a section cut through the sample. From these observations it was clear that this depth, proportional to the square root of the O_2 pressure, was the important factor in producing a good red colour on the surface. For instance an initial O_2 pressure of 0.8 atm. gave an oxymyoglobin layer 10-12 mm thick after 2 days at $0^{\circ}C$. The depth of this layer did not decrease during storage and ensured that the intense, underlying band of metmyoglobin did not come to the surface. Throughout storage the less evident oxidation of the oxymyoglobin layer to metmyoglobin proceeded slowly but, since it occurred uniformly throughout the tissue it was not noticeable until present in a concentration >20% metmyoglobin. In slices of meat the O_2 may penetrate far enough to oxygenate the whole interior. Although not bright red, the uniformity of this colour makes it attractive and the slow change as the proportion of metmyoglobin increases is difficult to detect subjectively unless direct comparison can be made with fully oxygenated meat. This type of comparison was possible in these experiments where all samples had been photographed under standard conditions.

It is interesting to note that with the O_2 pressures and headspace volumes used in these experiments, the level of O_2 never dropped below 0.25 atm. during the 15 days' storage period. There was, therefore, always enough O_2 present in the package to oxygenate the surface of the meat. Nevertheless, in this experiment, the colour acceptability of the meat did not extend far beyond 8 days at $0^{\circ}C$. This was only slightly better than similar samples conventionally packed in oxygen-permeable wraps and held at the same temperature. In other experiments carried out, colour retention was found to be almost as good as that described in the patent specification. The variation in colour retention illustrates the danger of generalizing where fresh meat is concerned. With some meat, O_2 pressures of the order of .4-.6 atm., with adequate headspace volume may effectively retain a good colour for up to 2 weeks, but, if the process is to include all fresh meat, the best performance should come from one using the maximum amount of O_2 with the minimum quantity of CO_2 required to control bacterial spoilage.

Although the general principles involved in packing fresh meat in mixtures of CO_2 and O_2 are fairly well understood and equipment exists which can pack meat in this way, the successful introduction of this process may be held up by economical and technical problems. One which is always present with packages whose air has been replaced with another gas, is the difficulty in detecting packs which are not gas-tight. This is particularly important where long periods of storage are intended and where accidental changes in the composition of the headspace may not be accompanied by early changes in the colour of the meat. Another problem which has not been mentioned in reported experiments is the potential fire hazard which exists when O_2 is enriched beyond normal atmospheric level. Strict control would be essential, not only during the packing operation but also during storage and distribution of meat packed in this way.

Current interest in holding meat fresh for long periods ensures that the search for suitable methods for achieving this will continue. At this time it appears that modification of the gaseous environment, allied to controlled temperatures just above freezing, is the approach most likely to give the extension of storage and display life required for the advantages of centrally pre-packed fresh meat to be fully realised.

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The microbiology of packaged meat

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