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Chain of Thought

Knowledge…Innovation…Action Vol.2 No.3 Dec 2009

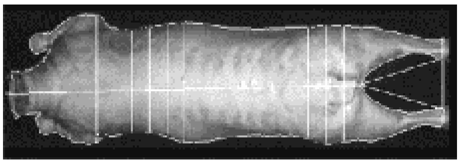
Welcome to our December newsletter

In this issue…

A year ago, I published a note in my blog about the reasons we had to be optimistic about 2009. One of such reasons was that the plan set by Kevin Rudd to stimulate the Australian economy may work. And work it did. The latest treasury estimates indicate that without the stimulus, the Australian economy would have contracted in each of the last four quarters, shrinking by 2 % during the past year. Instead, it grew by 0.5 %. And despite the fact that the profits before income tax for the overall manufacturing sector fell to a seven-year low of $17.1bn in 2008-09, Australia's $100bn food, grocery and beverage sector not only weathered the global recession, but also experienced growth. The agri-food sector grew 3% between June 2008 and June 2009, with food manufacturing increasing by 5.4% over the same period. Recession or no recession, we all have to eat.

However, new challenges ahead loom for the industry: the Australian Food and Grocery Council predicts that electricity costs will increase between 20-40% in the next years, as a result of the mandatory renewable energy target. And although repeated calls for a National Food Industry Strategy have been issued in the past 2 years by various organisations, this has not eventuated and the fragmentation in initiatives to tackle food security, food safety, innovation, sustainability and export markets is evident in the Australian environment. In a way, the agri-food sector is a victim of its own success and the current policy efforts seem to follow the old maxim, “If it ain't broke, don't fix it!”. This is not exactly the proactive attitude that we would expect for an industry that employs more than 3 % of all employed people in Australia, paying annual salaries and wages of about $14 billion.

Notwithstanding the logic of “we still have to eat” that worked so well during 2009, an increase in production costs can only be passed onto consumers.



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Supermarkets may resort to increase their food imports and Australian producers could see a reduction of their share in both export and domestic markets. This is not good for either consumers or the domestic-focused food industry.

So, here is my Christmas wish for a strong leadership at all levels (i.e. Government, industry, innovators) and a coordinated plan on the quest for a sustainable and strong agri-food sector in Australia.

Please send your feedback to info@food-chain.com.au. As always, feel free to forward this newsletter to colleagues that may find it of interest.

Merry Christmas and a fantastic 2010,

Silvia Estrada-Flores

Innovation in the fresh-cuts industry: drivers, trends and emerging technologies

The fresh-cuts industry in Australia encompasses over 20,000 fruit and vegetable growers that supply fresh produce to over 300 processing companies. Most of the production attends the needs of the domestic market, which attracts sales of $160 million per year, or 5% of the fresh category.

The fresh-cuts sector is not immune to the highly complex issues that the food industry is facing in several areas, illustrated in Figure 1. For example, the Consumer Goods Forum[1] surveyed nearly 600 retail and manufacturing decision makers across food and consumer goods industries in 54 countries. In 2009, the economy ranked first, followed by food safety and corporate responsibility[2]. The last two have consistently ranked in the first places in the past two years.

The economy definitely worries both retailers and manufacturers in the fresh-cuts industry. According to McKinna et al.[3], manufacturers and retailers handle operating margins equivalent to about 4-5% of a total annual profit pool of $160 million. Farm financing, logistics and marketers seem to benefit the most in the fresh-cuts chain, with operating margins ranging from 8 to 10%.

Adding to this complexity, food safety issues and corporate responsibility are also top-of-mind concerns for consumers. This consumer behaviour is not to be taken lightly: I recently attended a rural conference that dealt with food production, health and climate change. The conference was attended by the expected crowd of farmers, policy makers and researchers, but a noticeable amount of concerned consumers also attended. I believe that, while the general public is warming up to make food choices that lead to improvements in environmental footprints and nutritional benefits, they are doing so after receiving information through forums that used to be the realms of food researchers and policy makers. As a consequence of this involvement, we may see this year some growth in food purchases that align to ethical and health buying.

In this environment, what innovation areas in the fresh-cuts supply chains we will see emerging in future years? I have selected three areas of discussion: mechanical harvesting, RFID-enabled traceability and food safety.

1. Automation and robotics in harvesting

Mechanical harvesting provides several advantages over hand-picking, primarily: (1) decreased risks of contamination by human contact at the field; (2) decreased labour needs; (3) flexibility on speed and timing of harvesting; and (4) the ability to work at night. For the Australian horticulture industry, the major points of interest are the ability to increase harvest rates and the reduction of workers in the field, with the associated cost reduction in salaries, training, sanitary measures on field and lifting aids, among others. These characteristics make mechanical harvest a very appealing proposition for farms which traditionally experience labour shortages during the harvest season.

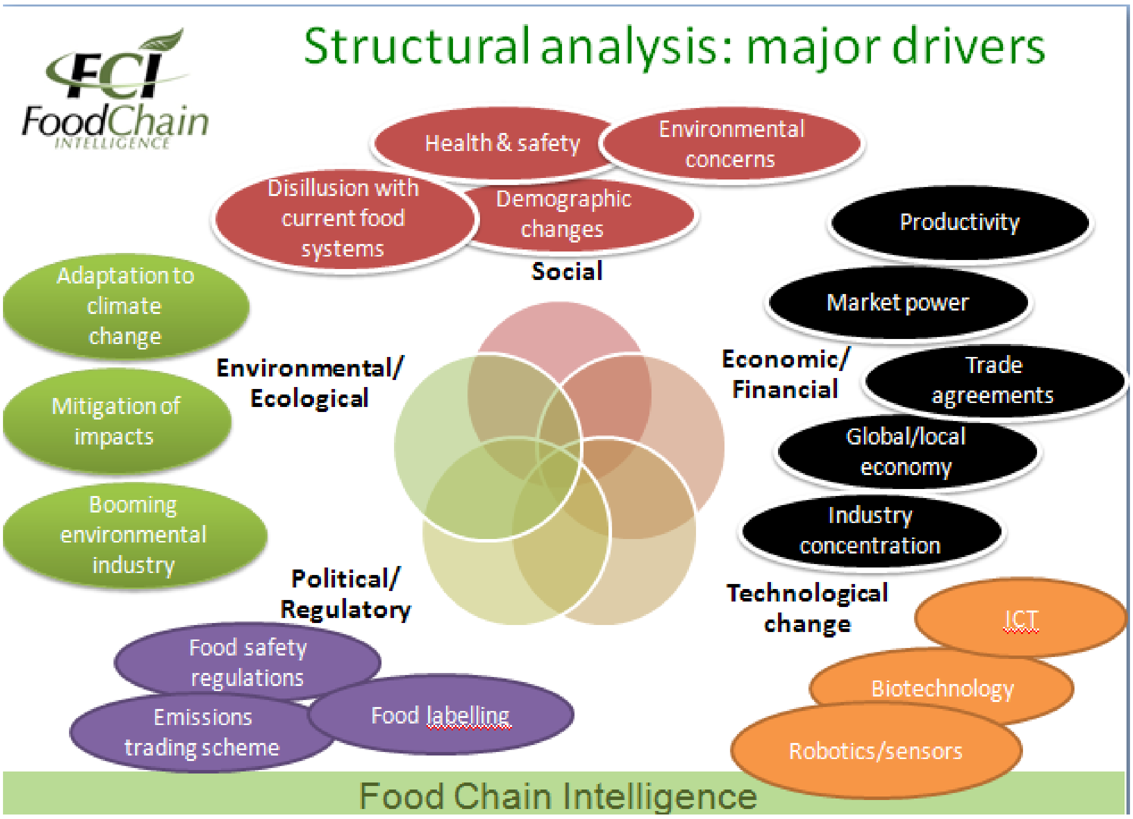

Figure 1. Structural analysis of the major drivers of change influencing the fresh-cuts industry.

The global push towards mechanisation of harvesting became evident to me when I visited Salinas, California. The first thing that stands out in the Californian leafy greens production (which supplies about 85% of the total leafy greens consumed in the US) is the large pool of trained human resources available for manual harvesting. For example, in a single harvesting line there could be up to twenty workers cutting, washing and packing lettuce from the fields at a remarkable speed.

Despite the availability of human power, some of the largest fresh-cuts manufacturers are now testing mechanical harvesters that can harvest from 2,000 kg/hr to 7,000 kg/hr. The uptake of mechanical harvesters slowed down by the recession of 2009, but there is no doubt that the trend in Salinas is towards mechanisation.

Some examples of adoption of mechanical harvesters for fresh cuts operations in Australia include the Matilda Fresh Foods broccoli harvester, the lettuce harvester used by the Ruffo family in Bacchus Marsh and the VegeFresh harvester in the Lockyer Valley.

2. RFID-based tracking, traceability and monitoring

Traceability has two main components: tracking, which is the ability to follow the path of a traceable item through the supply chain as it moves; and tracing, or the ability to identify the origin, attributes, or history of a particular traceable item located within the supply chain by reference to records held [4].

It is generally agreed that, for a product to be traceable, the following information needs to be known (PMA, 2008): (1) a Global Trade Item Number (GTIN), which identifies who the “manufacturer” is (i.e., the owner of the brand that appears on the product case) and the type of product inside that case; (2) a lot number that specifically identifies the lot from which the produce came; and (3) the produce’s harvest or pack date (if that date is not already incorporated in the lot number). Additional information includes the shift, the packaging line and a "Best if Used By" (BIUB) date. This information can be carried across the supply chain in two forms: (a) a label that can be read by a human operator, or (b) a label that can be read by a machine. In the latter category, information can be carried in the form of a barcode or in the form of electronic data contained in a chip. RFID technologies are commonly used in the latter carrying technology.

Although RFID technology has been around since the 70s, its application in food and agriculture started in the late 80s[5]. The Australian livestock industry was ‘first mover’ in testing RFID systems for traceability purposes, but few cases have been reported for the horticultural industry. Most notably, Moraitis Fresh and Testarossa Packers (marketers and growers of tomato, respectively) tested an RFID system with the aims of gaining supply chain visibility, optimize communications with retail partners and improve IT-based business processes. However, the wider horticultural industry is yet to embrace RFID systems for traceability.

Some aspects that may have contributed to the slow uptake of RFID, particularly in combination with cold chain monitoring, include the difficulty in establishing a return on investment and the fragmentation of the supply chain in the implementation of innovation projects of this nature[6]. Dutch experiences with RFID for fresh fruit and vegetables indicate that RFID can help in getting more accurate anticipation of stock at distributors and stores, reduction of product loss of 10 %, additional sales due to improved shelf stocking, higher-quality product because of reduced delays in the supply chain, and reductions in delivery errors and associated costs [7].

3. Food safety

Outbreaks and cases of diseases associated to the consumption of fresh fruit and vegetables and unpasteurized juices have been documented with increasing frequency in many countries in recent years[8]. In a survey conducted in the USA, fresh produce accounted for the largest proportion (45%) of the foodborne illnesses cases registered from 1998 to 2006 (including sprouts) [9,10]. In terms of outbreaks, fresh produce was the third vector, behind eggs (48%) and seafood (25%).

Fresh-cuts that are consumed raw do not undergo a ‘killing step’ (e.g. blanching, steaming, cooking) and pathogens that would normally be eliminated through these operations remain in the product. Therefore, good practices during harvesting, processing and distribution are the best defence against contamination and proliferation of pathogenic microorganisms in fresh-cuts.

However, there are some postharvest technologies that can significantly reduce the risks of fresh produce outbreaks. One of such technologies is irradiation, a non-thermal treatment that is effective in eliminating internalized bacteria from different products. Low-dose gamma irradiation is very effective in reducing bacterial, parasitic, and protozoan pathogens in raw foods[11]. Irradiation as a method to reduce the microbial load and pathogen risks in lettuce was approved by the United States Food and Drug Administration (FDA) in August 2008.

Given that irradiation does not enjoying wide consumer acceptance, traceability and monitoring of product quality continue to be the main mechanisms that ensure safe supply chain conditions in the production of fresh-cuts.

Refrigerated storage and hypobaric and vacuum technologies

Food refrigeration reduces the deterioration of food products by itself. However, the modification of the atmosphere surrounding the product to decrease the oxygen available for microorganisms and enzymatic reactions in the food further contributes to preserve food quality[12].

The group of technologies used to decrease the oxygen around the food during refrigeration are known as modified atmosphere (MA) technologies, which include controlled atmospheres, the use of various degrees of vacuum and ‘true’ MA, in which a mixture of gases is added to the atmosphere.

Hypobaric storage is the reduction of pressure below atmospheric pressure (i.e. less than 1 atm) inside a food containment system (e.g. package, coldstore, shipping container, dedicated storage compartment). This technology is also known as low pressure (LP), sub-atmospheric, moderate vacuum or partial vacuum storage.

The principle of hypobaric storage is the extraction of air from an enclosed space to reach low pressures. In this sense, hypobaric and vacuum technologies act under the same principle. However, vacuum alone is not sufficient to keep quality in respiring produce, due to the metabolic processes of fruit and vegetables during storage. The application of vacuum in horticultural products is often used as a preamble to the use of other MA technologies (e.g. addition of sachets with ethylene/oxygen scavenging action or flushing with a pre-defined mixture

Table 1. Characteristics of vacuum and hypobaric storage of foods.

VACUUM STORAGE	*HYPOBARIC (LP) STORAGE*
• Food is placed in an enclosure with low gas permeability and air is removed. • The aim is to remove all air (i.e. oxygen) present in the containment system. • Elevated levels of carbon dioxide (10 -20%) can be produced by microorganisms as they consume residual oxygen or by respiring produce. • Vacuum decreases the microbial rate of growth due to increased concentrations of carbon dioxide, which in turn increase the pH of t he food. • The gas permeability of the containment system (eg. plastic film, seals, etc) eventually allows the entrance of oxygen into the system. Therefore, the system needs to re -establish vacuum conditions periodically or an oxygen scavenging system needs to be used. • Maximum benefit and ease of applicability for non - respiring materials (eg. meat, dairy, fish, roasted coffee) • In terms of respiring produce, vacuum storage acts a passive MA.	• Food is placed in and environment in which pressure, air temperature and humidity are precisely controlled. • The aim is to closely regulate the rate at which air is changed inside the storage environment. • Gases created by metabolic processes (e.g. ethylene, carbon dioxide, aromas) are constantly being flushed out of the containment system • A decrease of pressure will lead to a decrease in oxygen available for the respiration of fruit and vegetables, thus leading to low respiration rates and retarded ripening of fruit and vegetables • Low storage pressures will lead to low oxygen concentrations and low carbon dioxide concentrations • Oxygen concentrations below 1% lead to the inhibition of growth of aerobic bacteria and most fungi varieties; however, • LP does not kill moulds and bacteria. When the produce is e xposed to ambient conditions again, the microbial growth process will continue. • All gas levels are reduced and ethylene diffusion from the product is enhanced. Moisture loss is also reduced. • Improves quality in various respiring (e.g. Favourable produce in cludes cabbage, avocado, strawberry, peach, cherry) and non -respiring (e.g. lamb, beef, fish) products. • In terms of respiring produce, hypobaric storage acts as an active MA.

of gases). The characteristics of hypobaric and vacuum storage technologies are presented in Table 1.

Vacuum (as a passive modified atmosphere technology) is based on the development of high carbon dioxide/low oxygen atmospheres induced by the vacuum itself and the respiration process of the commodities stored. Therefore, this system is highly dependent on the product characteristics (i.e. type, quantity and ripeness), the system's permeability to oxygen and the storage temperature. Given its simplicity, it is highly unlikely that one system will work for all products. Undesirable consequences of incorrect application of vacuum to horticultural products include off-flavours, abnormal ripening, texture decay and development of some bacteria (including some anaerobic pathogens).

Advantages and disadvantages of hypobaric and vacuum storage

Low oxygen technologies have certain advantages over more traditional refrigeration methods and can increase the shelf-life of horticultural products by 50–400% by reducing respiration and ethylene production, delaying ripening and softening and reducing chlorophyll degradation, while at the same time maintaining organoleptic characteristics (taste, aroma, texture)[13].

A disadvantage of all oxygen-decreasing technologies is that these can delay the growth of particular microorganisms (e.g. aerobic bacteria), but can also promote the growth of some anaerobic bacteria. For example, growth of *Listeria monocytogenes* in vacuum packaged meat stored at 5ºC, 1ºC and even –1.5ºC has been reported[14,15]. Heat shrink of vacuum packed meat has been linked to the growth of *Clostridium* spp and the "blown pack" spoilage, characterised by gas production and distension of the package during storage[16].

As a result of these findings, the Institute of Food Technologists prepared a report[17] for the US Food and Drug Administration about the microbial safety of products stored under MA. In this report, the major safety concern was the loss of sensory cues to spoilage provided by bacterial growth, thus foods could have acceptable organoleptic quality after MA storage, but still be unfit for consumption. To address this issue, it was recommended that MA should be combined with other hurdle technology strategies to further enhance food quality and safety.

Five pathogenic bacteria are known to grow on food below 5 °C (*Clostridium botulinum, Listeria monocytogenes, Yersinia enterocolitica, enterotoxigenic Escherichia coli* and *Aeromonas hydrophila*) and another five at temperatures just above 5 °C (*Staphylococcus aureus, Clostridium perfringens, Salmonella spp., Vibrio parahaemolyticus* and *Bacillus cereus*). From these, specific concerns regarding *C. botulinum* have been addressed by some codes of practice for vacuum packaged foods:

1) The Code of Practice for the Manufacture of Vacuum and Modified Atmosphere Packaged Chilled Foods[18] divides vacuum packed and modified atmosphere packed products into two shelf-life categories: i) those with a shelf life of 10 days or less at >3° to 8° C; and, ii) those with a shelf life of greater than 10 days at >3° to 8° C. The code recommends that vacuum packaged products with an intended shelf life of more than 10 days from point of manufacture should contain one or more specific controlling factors as well as a chill temperature below 10°C. Such factors can be the following: (a) a minimum heat treatment of 90°C for 10 minutes or its equivalent; (b) pH of 5 or less throughout the food; (c) salt level of 3.5% in the aqueous phase; (d) water activity of 0.97 or less through the food; and (e) any combination of heat and preservative factors which has been shown to prevent growth and toxin production by *C. botulinum*. The Code suggests no specific limitation on shelf life with regard to botulism hazard for products maintained at or below 3°C. This is suggested on the assumption that, while such temperatures might be maintained in factory storage, they can't be maintained with certainty during distribution, retail display and consumer storage.

2) In 1999 the European Chilled Food Federation set up a specialist working party to consider the safety of chilled foods that had been mildly heated in hermetically sealed packages. The working party concluded that for such foods safety can be assured by: i) a minimum heat process and a strict limitation of chill shelf life (up to 5 days) or, ii) for longer life products (greater than 5 days):

- by storage below 3°C,
- by heat treatment sufficient to deliver a 6 D reduction in numbers of spores of psychrotrophic strains of *C. botulinum* and storage below 10°C, or
- by intrinsic preservation factors (acidity, water activity, salt) shown to be effective in modelling or inoculated pack/challenge studies.

3) In 1992 the Australian Quarantine and Inspection Service developed a Code of Hygienic Practice for Heat-treated Refrigerated Foods Packaged for Extended Shelf Life. The Code recognises two categories of heat treated food packaged for extended life: i) those which have not received a heat treatment process for *C. botulinum* and/or which have been cooked before packing and the filling operation was not aseptic. The Code recommends that these products must be stored below 3°C and if this temperature cannot be guaranteed then this process option must not be used; ii) those which have received a heat treatment process for *C. botulinum* and, if cooked before packing, the filling operation was aseptic. The Code recommends that these products be stored below 5°C and the shelf life be limited to 10 days. (If the temperature is between 5° and 10°C the shelf life must be <5 days.)

By inference, all codes agree that if a storage temperature of 3°C or below can be assured, then the average extension to shelf-life would be within a 5 to 10 day limit.

In regards to the risk of botulism, it has been suggested that time-temperature indicators integrated to refrigerated reduced-oxygen environments may be the only avenue to monitor the safety of foods stored under these conditions[19]. Performance targets for these indicators should be established with foods with the potential of developing *C. botulinum* (particularly seafood).

Specific issues for different types of products under low pressure (ie. low oxygen) conditions are addressed next.

Meat

- The colour of meat surfaces is a key visual quality parameter. The depth of the bright red layer of oxymyoglobin (the natural red pigment in red meat) will increase when stored at 0 ºC than when stored at 5 ºC.
- Low oxygen conditions will transform oxymioglobin (red) into myoglobin (purple), therefore, the visible colour of vacuum packaged meats is purple.
- Storage of meat at aerobic conditions (ie. with oxygen), slime becomes visible when numbers of surface bacteria reach 10^8 cm^{-2} and off-odours when numbers reach 10^7 cm^{-2}
- At refrigerated conditions (–1 ºC to +5 ºC), spoilage species of *Pseudomonas* and *Lactobacillus* can outgrow competing species under aerobic and anaerobic conditions, respectively.
- Vacuum-preserved meat should have a low pH (less than 5.8) to inhibit spoilage. If this is the case, the shelf life of large pieces of vacuum-stored beef and venison can increase by about fivefold over that achieved in normal refrigeration.
- For other meats and small cuts (eg. steaks), a twofold extension of shelf-life should be expected.
- Under vacuum conditions (temperature= 1 ºC), the shelf -life of pork meat has been reported as 2 weeks.
- The degree of vacuum has been reported as having no effect on sensory panel ratings.
- Under hypobaric conditions (pressure = 0.0132 atm, RH= 95% and temperature = 0 ºC), the shelf-life of pork meat has been reported to be 6 weeks.

Seafood

- At normal refrigeration conditions, the major spoilage organisms include *Pseudomonas, Moraxella, Acinetobacter, Flavobacterium* and *Cytophaga* species.
- The organisms of greatest concern for vacuum and hypobaric conditions is *C. bolutinum.*
- Studies have indicated that vacuum and MA systems alone are not capable of providing the safety required for extended storage of fish fillets with respect to outgrowth and toxin production by *C. Botulinum,* in the absence of a fail-safe mechanism by which storage temperature could be maintained at 3 ºC.

Listeria has been added to the list or microorganisms of concern due to its ability to grow in low oxygen, low temperature conditions.

Although it is not know whether the handling of seafood throughout the chain is congruent with the risks of vacuum-packaged chilled seafood, these products are routinely shipped and sold at retail level in Europe.

Horticultural products

- These are respiring products and their metabolic processes need to be taken into account to select the most adequate storage atmosphere.
- Decay in fruit and vegetables is caused due to the natural ripening of these products, postharvest disorders during storage and microbial issues.
- Reduction of oxygen to less than 10% provides a tool for controlling the respiration rate and slowing down decay, although oxygen still needs to be present within 1-3%, depending on the commodity.
- Dropping indiscriminately the levels of oxygen below 3% may lead to formation of acetaldehyde and ethanol, thus leading to off-odours and off-flavours.
- Carbon dioxide concentrations need to be carefully monitored. At CO_2 levels above 20%, a significant increase of anaerobic respiration may occur, leading to irreversible damage of the fruit/ vegetable (eg. brown stains in lettuce, internal browning and pitting of apples and blackheart of potato).
- Normally, the short shelf-life of fresh cuts offset microbial risks, but recent outbreaks of *E. Coli* in ready-to-eat bags of spinach and lettuce in the US[21] are a reminder of the risks posed by fresh cuts, if handling before consumption has been inadequate. Temperature abuse of MA-stored vegetables can result in anaerobic conditions, allowing growth and toxin production by *C. botulinum.* The danger, as per the case in seafood, is that botulinum toxin may be formed before overt spoilage. This has been reported in MA packed shredded cabbage stored at room temperature.
- No studies have been undertaken in regards to fresh cuts subjected to hypobaric storage. Tests have been conducted in whole fruit and vegetables.

Vacuum storage is only recommended as a measure to preserve fresh horticultural products when it is used in combination with other preservation technologies.

Dairy products

- Cheese is the generic name for a group of fermented milk-based products produced in at least 500 varieties around the world. This is the most representative dairy product to evaluate the effect of low oxygen technologies during storage.
- Cheese naturally contains microbial flora that is used to ripen the product in most cases, including bacteria and yeasts. Similarly to fruit and vegetables, the ripening of the cheese means that metabolic processes are taking place, with the generation of gases and volatiles.
- Light (both natural and artificial) is a primary factor for development of flavour changes and loss of nutritional components. The presence of oxygen is undesirable as it will continue the oxidation triggered by light and the growth of spoilage bacteria.
- Vacuum conditions are used to inhibit the growth of mould that produces mycotoxins, which are compounds that represent a health risk. However, some mycotoxin-producing fungi has been isolated from vaccum packaged cheese, such as *Cladosporium*, *Penicillium* and *Phoma.*
- "Very Hard" and "Hard" cheese types are ripened by bacteria and include Parmesan, Romano, Mozzarella, Edam, Jarlsberg, Gouda, Cheshire, Emmental and gruyere, between others. Vacuum packaging is commonly used for storing these products, to prevent bleaching and mould contamination, which produce undesirable flavour. Some mould species may also produce mycotoxins.
- "Semisoft" and "Soft" types of cheese include Brick, Muster, Trappist, Brie, Camembert, Roquefort, Gorgonzola and Stilton. For these, the storage conditions need to allow for the controlled passage of oxygen to promote mould development and permeability to carbon dioxide.
- "Fresh" cheeses include Cottage, Petit Suisse and Ricotta. Oxygen is present as a result of the processing technique, therefore vacuum-related technologies for preservation are not commonly used.

The relationship between pork quality and chilling systems

About 5.5 million pigs are processed in Australian abattoirs with a gross value of about AUD$944 million per year[22]. The pork supply chain has a fairly complex structure that encompasses several players and supply chain operations. Although biological factors such as reproductive traits and growth performance are key to pork quality, carcass processing also plays an important role.

Chilling of carcasses in abattoirs significantly influences pork quality. Australian processors cool pork carcasses in batch chillers, in which the main means of control is air temperature . In some cases, variable air velocity can be achieved. However, there are generally no means to control relative humidity and few installed chillers in the industry would be able to achieve air temperatures below zero.

Research in Australia and overseas, particularly in Europe, has demonstrated that carcass chilling can influence meat colour, rate of decrease of pH, skin colour and carcass shrink. Software that predicts the surface and centre temperature of pork carcasses during chilling have been developed by MIRINZ (now AgResearch) in New Zealand, by the UNSW in Australia and by the National Institute of Agronomy Research in France, amongst others.

Chilling of pork

The operational chilling parameters that affect the chilling rate in carcasses are air temperature, air velocity and relative humidity. Weight loss also has an effect on the chilling rate, due to the evaporative cooling effects. Cooling rates are also a function of the weight and fat cover of the carcass. Surface and deep butt temperature mainly depend on the air temperature and velocity.

Relative humidity has a more significant effect in carcass shrinkage than air temperature and velocity; for example, James and James[23] found that a reduction in relative humidity from 95 to 80% increased evaporative weight loss in beef sides of about 100 kg, over an 18 hr chilling cycle at 0°C by nearly 0.5%.

Various processes have been used for the chilling of carcasses. Delayed chilling (which consists of keeping intact carcasses out of the chill room for a given duration) has been investigated for pork[24], but the findings showed that meat toughness was an issue with this treatment for meats with a pH levels above 6.1. Spray chilling systems are widely used, particularly in North America for beef, lamb, poultry and pork[25]. The process involves the intermittent spraying of cold water onto carcasses during the initial 3-8 hrs post-slaughter, to reduce moisture loss by evaporation. The carcass surface remains wet, thus allowing enhanced heat transfer without the weight loss associated with "dry" chilling systems. Blast chilling, which consists of the use of an air tunnel with high air velocities, can result in toughening of pork. However, this toughening can be reduced if electrical stimulation is applied[26]. Rapid air chilling was reported to improve water-holding capacity in pork, particularly in comparison to conventional chilling. Rapid air chilling systems remove heat and slow down the pH decline; however, quality issues can still arise as a result of the extreme differences between surface and deep muscle temperatures, causing two-toned muscles (i.e. d darker colour at the meat surface and lighter colour internally) and cold shortening.

Meat pH

Pork experiences a quicker pH decline that other types of meat [27]. This has long been known to influence the colour characteristics of pork, and has provided the basis for two of the most well-known inferior meat quality grades, namely dark, firm and dry (DFD) and pale, soft and exudative (PSE) meat. Fast cooling of pork immediately after killing will decrease the rate of pH decline[28]. Empirical correlations of pH value as a function of time postmortem and surface treatments (eg. chilling, scalding and singeing) have been published[29].

Meat colour

As mentioned previously, PSE is a processing fault usually associated with stress susceptible pigs, caused by a very rapid fall in pH while the muscle is still at an elevated temperature. Many researchers have investigated ultra rapid chilling as a means of countering PSE.

Ultra rapid chilling using air temperatures of -30°C for 4 h[30], -32°C for 100 min[31], -20°C for 1.5 h[32], followed by the remainder of chilling time at 2 to 4°C, was shown to improve the colour of pork that was subject to PSE. However Taylor et al[33] found no effect of rapid chilling (-20°C for 2-3 h) on meat colour.

Experimental trials conducted to find ways to reduce the variability of Australian pork colour for the Singapore and Japanese export markets showed that low voltage electrical stimulation and warmer chilling regimes were beneficial in yielding acceptable colour scores for the Singaporean market. However, the increase in food safety risks and weight loss need to be addressed under these conditions[34].

Skin colour

Anecdotal information indicates that some export markets (particularly Singapore) prefer pork carcasses with a light skin colour. The degree of drying has been detected as a major contributor to skin colour, therefore the company has attempted to achieve lighter colours by reducing air velocities during the final stages of the chilling cycle.

Little published work exists regarding the effect of chilling conditions on pig carcass skin colour. Investigations regarding the application of spray chilling found no effect on internal meat colour. However spray chilling did produce a lighter skin colour[35], thus confirming the link between skin colour and humidity during chilling.

Simple correlations of colour as a function of temperature during chilling have been obtained with the combination of digital images and statistical or neural network analysis[36].

Carcass shrink

Rapid chilling has been shown to reduce carcass shrink (or weight loss), which can average from 1.85 to 100 g. Taylor et al.[33] demonstrated reduction in evaporative weight loss of 0.5% by chilling at -20°C for 2 to 3 hours, followed by 1°C for 24 hours. This result was supported by other investigators using similar rapid chilling regimes. Cryogenic immersion cooling with liquid nitrogen for 1 to 3 minutes, followed by chilling at 1°C reduced carcass shrink. Spray chilling could lead to a significant decrease of weight loss, while increasing cooling rate of the muscles in the loin and ham.

Although many of the findings discussed focus on the effects of ultra-rapid chilling, none or few plants in Australia have the capability of routinely applying sub-zero temperatures during their chilling cycles. Improvements in chilling technology should address this gap, provided that the return on investment (i.e. the increase in pork carcasses exports or premium vs. capital and operating costs of ultra-rapid chilling) is investigated.

References and notes

[1] The Global Consumers Forum emerged in June 2009 after the fusion of CIES (a food and consumer goods industry body), and the Global CEO Forum and the Global Commerce Initiative (GCI), two global retailer and manufacturer collaborative platforms. The new association unites the world's leading consumer goods retailers and manufacturers and many regional specialists and independents. Its mandate is to develop common positions on key strategic and practical issues affecting the consumer goods industry, to focus on non-competitive collaborative process improvement and to provide a network for thought leadership and knowledge exchange.

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[9] A case defines a person, time and place of illness. An outbreak is an occurrence encompassing two or more cases linked by a common source, propagation, behavioural aspects or zoonotic causes. The average of cases per fresh produce outbreak in Australia is 34.

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