Promoting kangaroo as a sustainable option for meat production on the rangelands of Australia

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Implications

- As kangaroo meat is sourced from native wildlife, conservation of the species is important in developing sustainable meat harvesting. Landholders, conservationists, and commercial meat producers need to work together to achieve this goal.
- The production of high quality meat products from field-harvested carcasses can be augmented through a better understanding of the impact that field conditions and carcass handling have on final meat eating quality.
- Food safety is also paramount, with measures taken to minimize the impacts of parasitism and microbial contamination. Any breaches of inspection protocols can only serve to undermine consumer confidence and viability of the industry.

Key words: kangaroo, meat quality, rangelands, sustainability

Introduction

In Australia, the consumption of kangaroo (macropod; Macropodoidea) by the general population is still uncommon, even though the animal has long been utilized as a bush food by the Aboriginal people. European settlement during the 1800s and onward resulted in marked impacts on the lands of Australia and the agricultural practices that have shaped it. An important aspect of this settlement was the establishment of the sheep rangelands, a subset of arid and semiarid lands used for extensive grazing of sheep and cattle. Pastoralism formed the base of an emerging nation, with the economic growth of Australia being driven largely by wool exports. However, this also resulted in major ecological changes, such as major vegetation changes and a loss of many small marsupial species weighing <3 kg (Caughley et al., 1987). Nonetheless, larger species of kangaroo thrived, and it is believed that the altered grassland environment, combined with artificial watering points and, to some extent, the control of the dingo, contributed to this increase (Wilson et al., 1984; Jarman, 1994; Dawson, 2012).

During early settlement, kangaroo transitioned from an object of curiosity to being hunted for food and sport and eventually gained notoriety as a pest (Haigh, 1982). Intensive hunting took place and the onus to control the “nuisance” kangaroos was left to landowners (Denny, 1982). Eventually, public concern for the protection of kangaroos was raised, and in the 1950s and 1960s, legislation was enacted to control rather than encourage the destruction of kangaroos and wallabies. The responsibility for controls was assumed by the federal government, passing a national law for the protection of all species of native fauna, which also encompassed controls on exports of wildlife or wildlife-derived products; today in effect under the Australian Wildlife Protection Act 1982. These acts extended to the implementation of policies to allow for the regulated harvesting of abundant species. Accordingly, the kangaroo industry of Australia emerged, based on a legislated harvest of wild populations.

Interest in kangaroo as a source of red meat is increasing (Wilson and Edwards, 2008; Spiegel et al., 2010) not only because of the increased muscle yield and reduced muscle fat content (Hopwood et al., 1976; O’Dea, 1988), but because as a native grazing animal, it is well adapted to the Australian environment and thus makes economic sense. The climate of Australia is characterized by highly variable rainfall and aridity and thus marked fluctuations in pasture biomass. Kangaroos have evolved to survive under these conditions in which their population can vary markedly from season to season. As examples of adaptation, kangaroos are highly specialized feeders (Hume, 1982; Langer, 1988) that are able to utilize the coarse vegetation of the rangelands of Australia. Kangaroos are also saltorial, meaning they hop and thus are able to migrate with ease in search of food and water (Dawson, 1995). They have reduced basal metabolic rates compared with placental mammals (Hume, 1999), allowing for improved feed and water efficiencies. Furthermore, the ability of some kangaroo species to delay embryonic development through embryonic diapause when feed is scarce reflects a unique reproductive adaptation (Poole, 1975; Dawson, 1995).

Notwithstanding all of these desirable attributes, the kangaroo industry of Australia is the subject of public scrutiny, as the practice of harvesting wildlife for commercial gain provokes much controversy in the Australian community and abroad (Pople and Grigg, 1999), not to mention its impact on the well-loved wildlife icon that is the kangaroo. The promotion of kangaroo as a viable economic option for landholders is often questioned on the grounds that they are viewed as a pest rather than a self-sustaining resource (Grigg, 2002). However, the control of the numbers is believed to improve the sustainability of mainstream agricultural enterprises operating on the rangelands by reducing damage to crops and minimizing competition for feed on a landscape stocked to capacity with domesticated livestock (Collins and Menz, 1986). This belief still holds true today (Khairo et al., 2008; Cripps, 2014). Thus, the question raised is: *How should kangaroo, a unique species suited to the vagaries of the Australian environment, be promoted as a sustainable option for meat production on Australia’s rangelands?* The answer is provided through

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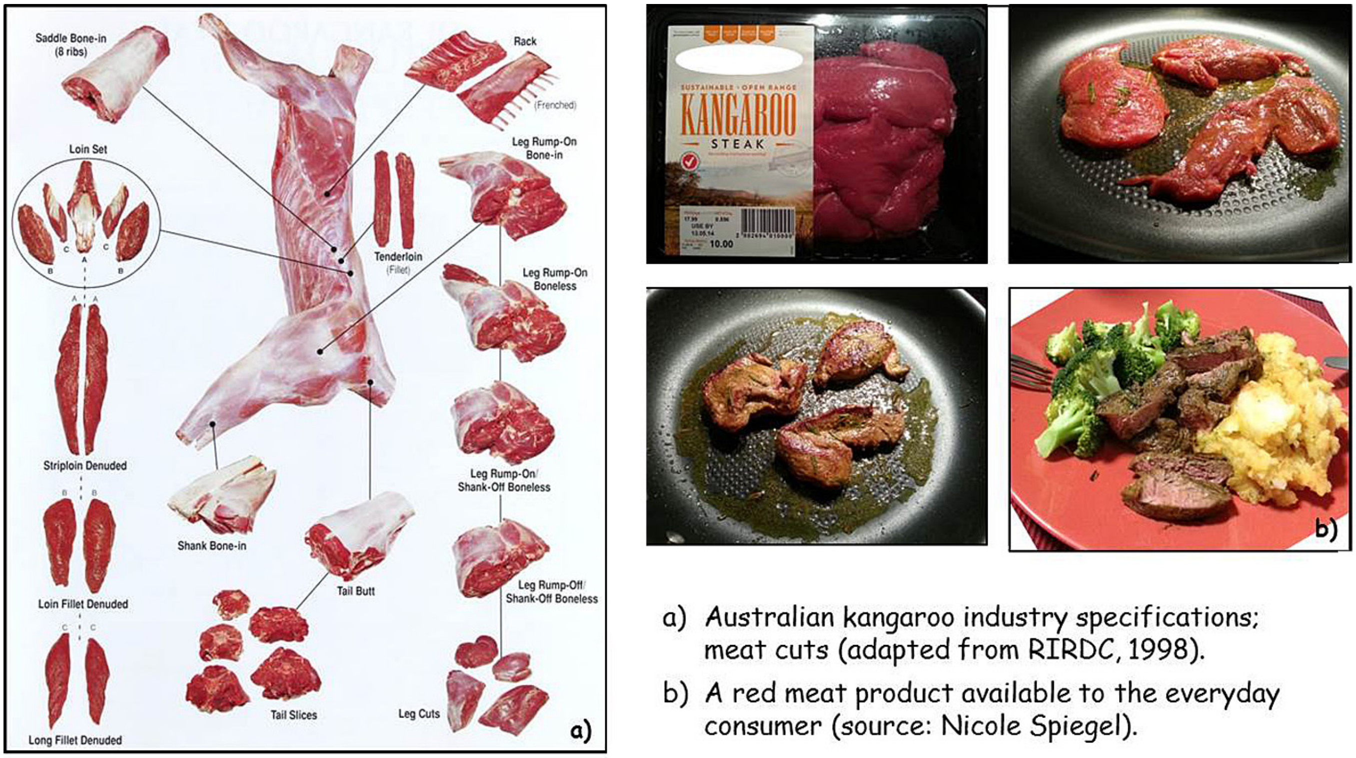

a) Australian kangaroo industry specifications; meat cuts (adapted from RIRDC, 1998).
b) A red meat product available to the everyday consumer (source: Nicole Spiegel).

Figure 1. Kangaroo meat for human consumption in Australia and for export.

greater acceptance of this concept by the wider community, possibly through the development of a kangaroo industry national research initiative. Research would focus on developing our understanding of kangaroo ecology, population dynamics, and the commercial opportunities that are the subject of this review. At the end of the day, there will always be trade-offs, but the opportunities to utilize this resource to human advantage are undeniable.

This paper considers the economic viability of the kangaroo industry in Australia and more specifically meat production and quality attributes of kangaroo meat. Describing how the industry operates and identifying opportunities to improve meat quality may well boost the promotion of kangaroo meat, through the supply of a safe and consistent line of meat products for consumers. For this to occur, kangaroo populations have to be carefully managed to ensure that a sustainable balance of their numbers remains in harmony with their grazing environment.

Table 1. Some Australian emerging animal industries: value of production and trade (RIRDC, 2009). The gross value of production (GVP) and trade is shown for each industry. The combined total value (inclusive) of production of new and emerging industries is shown with other industries not listed including buffalo, camel, and crocodile.

Animal industries (not inclusive)	Year	GVP A$'000	Value of trade Exports A$'000	Value of trade Imports A$'000
Game bird	2007	115,740	6,244	0
Game pig	2007	10,771	12,734	0
Goat (meat)	2006-7	57,208	89,035	846
Kangaroo	2007	43,913	73,566	0
Wallaby	2005-6	136	na	0
Total - *inclusive*		269,936	207,153	7,338

Meat Production

The export of kangaroo meat for human consumption took place in the 1950s and 1960s, but this was fleeting due to poor quality controls reported at the time (MacFarlane, 1971; Corrigan, 1988; Jarman, 1994). Opportunities were rekindled during the 1970s, and exports resumed from Australia in the early 1980s when the process of harvesting was refined and an internationally recognized Code of Practice for game meat production was established. Commonwealth legislation became known as the Game Poultry and Rabbit Meat Orders, made under the Export Control Act of 1982 (Andrew, 1988). Kangaroo meat for human consumption was legalized in Australia in the late 1980s (Lunney, 1988). Still to this day, kangaroo meat destined for the human food chain is predominantly exported (~80%), despite the range of products available to the Australian consumer (Figure 1).

The kangaroo meat industry is emerging (RIRDC, 2009) and, like other growing industries, brings opportunity, diversity, and resilience to the rural communities of Australia (RIRDC, 2010). Table 1 shows examples of other species used for meat production along with the kangaroo and the contributions to the Australian economy. The actual value of the kangaroo is boosted by the sale of skins as leather and hides.

Figure 2 shows the supply chain used to produce kangaroo meat; from field (i.e., from properties in the rangelands of Australia) to field chiller and subsequent delivery to an established game meat plant for processing. The harvesting of kangaroos is performed by accredited field processors (professional kangaroo harvesters), as per guidelines set by the Agriculture and Resource Management Council of Australia and New Zealand (ARMCANZ, 1997). The method of slaughter is performed according to a Commonwealth Code of Practice, endorsed by the Natural Resource Management Ministerial Council (Department of Environment, 2008). Kangaroos are harvested (i.e., shot) from the rangelands of Australia at night while grazing. A

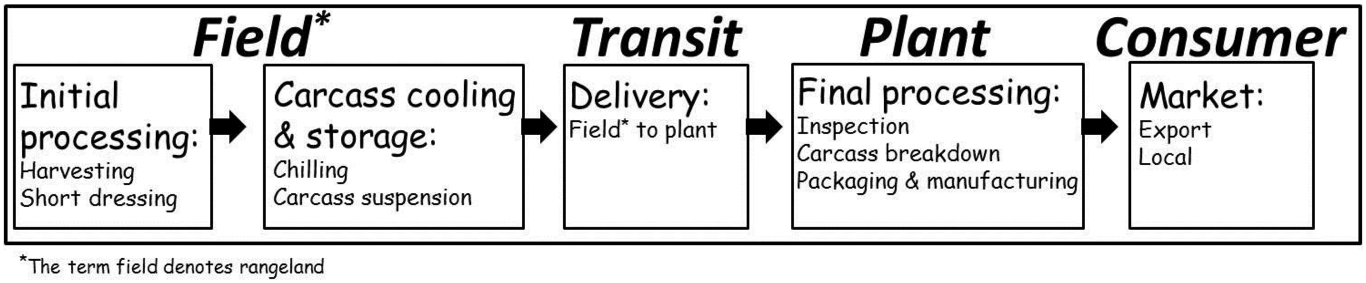

Figure 2. Kangaroo meat production supply chain.

spotlight is used to aid with selection and harvesting and to daze the animal momentarily in an upright position to ensure the accurate delivery of a bullet to the head and instant death. The method of slaughter is not associated with any lairage stress, as animals are shot in their grazing environment.

Once the animal is shot, the carcass is bled and placed on the outside of the hanging frame located on the back of the harvester's four-wheel-drive utility vehicle (requirements as per ARMCANZ, 1997). Evisceration, also known as field dressing, is performed and involves the removal of the gastrointestinal tract but can also include the removal of feet up to the carpal and tarsal joints and tail. The heart, lungs, liver, and kidneys remain intact as they are later inspected at the processing plant. After dressing is complete, harvesters are required to carry out a post-mortem inspection (ARMCANZ, 1997). The eviscerated carcass is then placed inside the open rig and suspended via a pelvic spike as shown in Figure 3a. Skins remain on, providing a barrier that prevents desiccation and external contamination of the carcass. The rig remains open to allow for cooling of carcasses in the field. After the completion of a harvest, carcasses are then transferred into a field chiller for temporary storage; see Figure 3b.

Research investigating the factors influencing the eating quality of meat from commercially field-harvested kangaroo (Wynn et al., 2004; Spiegel, 2008) has involved the tracking of carcasses through the entire meat production supply chain. This work showed variation in tenderness can be improved within the carcass, simply by suspending the carcasses by the tail, as opposed to suspension by a single leg during chiller storage (Beaton et al., 2001). The effect is similar to the effect of hanging beef carcasses by the aitch bone (so called tenderstretching) to maximize tension on commercially important muscles of the leg and loin regions (Taylor and Hopkins, 2011). The storage of carcasses in field chillers for 1 to 10 days provides a mechanism for the conditioning or aging of carcasses to improve tenderness by the breakdown of the myofibrillar structure of muscle, thereby improving eating quality. This process has been comprehensively investigated in beef carcasses (Koohmaraie, 1994; Koohmaraie and Geesink, 2006).

The temperature of storage also has important consequences for eating quality, not to mention food safety. Figure 4 shows temperature profiles for kangaroo carcasses tracked through the meat production supply chain (Spiegel, 2008). Temperature loggers were secured to the tail stump of carcasses, similar to that used in domestic meat production in monitoring carcass temperature. The ambient field temperatures during this winter collection fluctuated between 7.5 and 17°C (data not shown). Harvesting occurred within the hours of 1900 to 0500 hours, and the average time taken from slaughter to complete evisceration of carcasses was between 8 and 30 minutes. After harvesting, carcasses were placed under refrigeration, being transferred from the rig to the field depot within 2 hours of sunrise and suspended by the tail. According to ARMCANZ (1997) stipulations, carcasses must reach $\leq$ 7°C within 24 hours of being placed under refrigeration. Figure 4 demonstrates this, and also highlights the variable holding time that may occur between carcass batches, before delivery to the processing plant. This variability may have marked impacts on final eating quality, as already indicated.

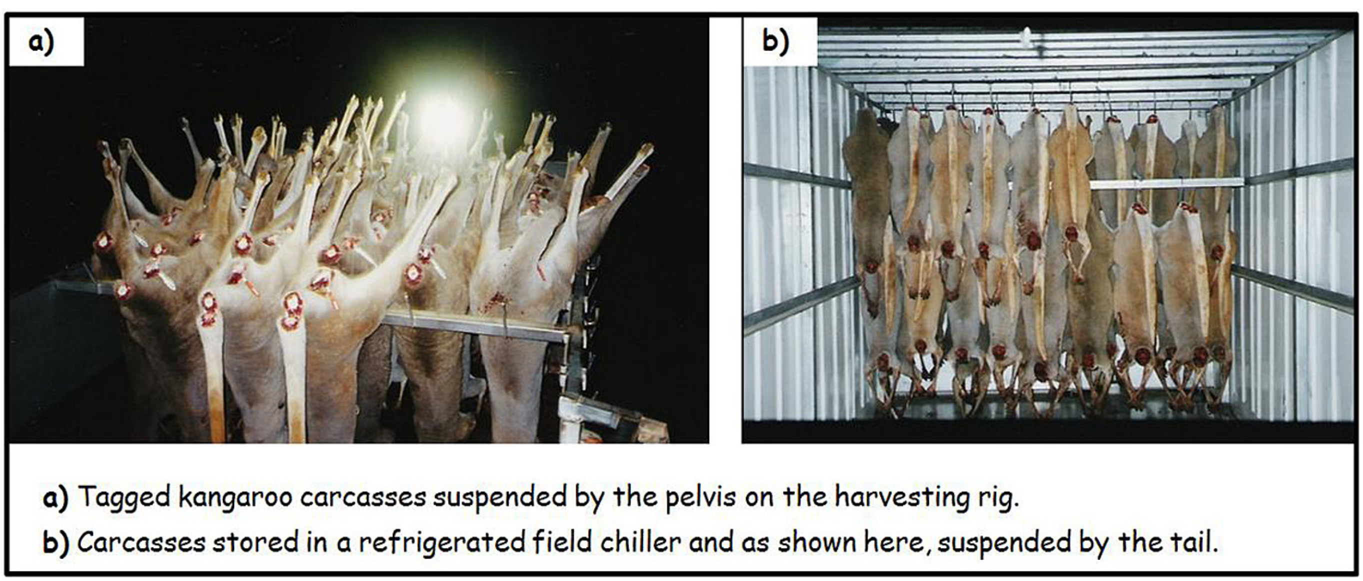

Figure 3. First stages of kangaroo meat production: field harvesting and temporary chilled carcass holding (source: Nicole Spiegel).

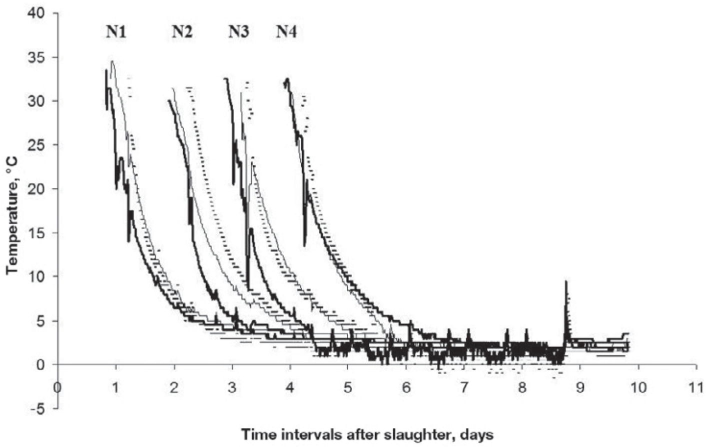

Figure 4. Temperature profiles of 12 representative kangaroo carcasses collected in the field over 4 consecutive nights of commercial harvesting; three carcasses logged/night (Spiegel, 2008). Temperatures are shown for the time immediately after slaughter and up to the time carcasses reached the processing plant. The intervening time included time held in temporary storage, transfer of carcasses from the field depot into a delivery truck, and delivery to the plant.

Harvest

The kangaroo industry is based on regulated harvests through a quota system, as legislated by the Australian Environment Protection and Biodiversity Conservation Act 1999 (DFAT, 2000). This, in turn, is prescribed by separate State Kangaroo Management Programs (**KMP**), based on population studies and estimates (Pople and Grigg, 1999) using different survey methods, such as aerial survey. The KMP are recurrently reviewed as a part of an overall National Plan of Management for kangaroos. Quotas are determined annually for each key kangaroo species in each location. Registered tags attached to the hide facilitate the identification of each animal from the point of harvesting through to the meat processing plant and allow for product traceability.

The four most abundant macropod species harvested from the mainland Australia include the red (*Macropus rufus*; Figure 5), eastern grey (*M. giganteus*), and western grey (*M. fuliginosus*) kangaroos, and a common wallaby, the common wallaroo or euro (*M. robustus*). Harvesters in Tasmania also utilize two species of wallaby, the Bennett's wallaby (*M. rufogriseus*) and the Tasmanian pademelon (*Thylogale billardierii*).

The primary driver of kangaroo population fluctuations is rainfall, as related to available pasture biomass; thus, populations can increase and decrease dramatically from one season to the next. Harvest quotas are not only determined according to population size and density but also according to trends and rainfall patterns (including long-term climate predictions) and are typically set at 10 to 15% of the estimated population in any region but can be as high as 20%. The three abundant larger species of kangaroo make up ~90% of the commercial harvest (Department of Environment, 2011). The combined kangaroo population for these species in the harvest zone across Australia can fluctuate between 15 and 50 million, depending on seasonal conditions. From 2001 to 2011, estimated populations for the abundant kangaroos (and including *M. robustus*) fluctuated between 23 and 57 million (Department of Environment, 2013).

Simulation studies by Caughley (1987) showed that harvesting of 10 to 15% of the red kangaroo population each year is sustainable, but any increase above this figure may place this species in jeopardy. Ideally, optimization of the tagging system is designed to hold the population at 60% of its natural carrying capacity (Shepherd and Caughley, 1987). A drought can have a similar effect with reductions of 40% or more in the population (Bayliss, 1987). In effect, the harvesting process is reducing the number of kangaroos that would otherwise be subjected to starvation when feed resources are limiting for the population. Numbers may also decline as a result of disease outbreaks, most of which remain uncharacterized; one that has been noted was caused by the viral infection choroid blindness (Dawson, 2012). Thus, a precautionary margin for error in ascertaining harvest yields is required, as well as the need to account for certain species differences such as home range, feeding patterns, and ability to reproduce.

Figure 5. Australia's red kangaroo: *Macropus rufus* (source: Megan Willis).

The total commercial kangaroo harvest quota in recent years has averaged ~4 million kangaroos per annum as calculated from 2007 through to 2012 (Department of Environment, 2013). Annual harvests are typically below quotas because of weaker market demand or the capacity of the industry to harvest the quota when environmental conditions, such as persistent wet weather, restrict the access of shooters to harvestable animal populations. Since 2001, the rate of harvesting has been around 65% of the set quota (Department of

Quality Attributes

The nutritional and sensory traits of kangaroo meat place it in a unique category for game meats.

A healthy product

Kangaroo is a healthy red meat alternative (O'Dea, 1988). This should be of no surprise as wild animals are subject to marked fluctuations in the availability of dietary energy sources. Under such adverse conditions, fat depots are severely depleted, resulting in very lean carcasses. Their yield of carcass or "dressing percentage" is much greater than in domestic species (Tribe and Peel, 1963; Hopwood, 1988). The fat content of kangaroo meat is as low as 2% (Ford and Fogerty, 1982) and is comprised of a high proportion of polyunsaturated fatty acids, namely linoleic and arachidonic acids (Sinclair et al., 1987; O'Dea, 1988; Butcher et al., 1990). This can be even greater when animals graze plants inherently high in n-3 fatty acids such as the native succulent purslane (*Portulaca oleracea*; Liu et al., 2000), which grows in some rangelands environments.

Kangaroo utilized as a resource does contribute to global food security, providing an important alternative source of both protein and iron and other nutrients. In addition, the promotion of kangaroo meat should assist with encouraging sustainable grazing systems on landscapes subject to degradation.

Eating quality

There is a dearth of information on the eating quality attributes of kangaroo meat and factors that impact these sensory qualities. An initial investigation by Marshall and McIntyre (1989) showed tenderness decreased with an increase in animal age. Subsequent studies have pursued the factors that cause the major variation in eating quality. Beaton et al. (2004), for example, showed a significant ($P < 0.01$) increase in total muscle collagen with increased carcass dressed weight in economically important leg muscles from kangaroo. Increased tenderness of meat cuts has commonly been associated with less collagen (or connective tissue) content of muscles, irrespective of species (Bailey and Light, 1989), and in turn, is muscle dependent and influenced by animal age. In the case of kangaroos, the greater collagen content in leg muscles with increased carcass dressed weight relates to increased muscle resilience during hopping; however there is an adverse consequence for eating quality. The impact is also expected to be greater in male kangaroos as sexual dimorphism causes marked differences in growth patterns between male and female kangaroos (Frith and Calaby, 1969; Lavery, 1985).

Sensory evaluations of kangaroo meat (Wynn et al., 2004; Spiegel, 2008) provided a benchmark study for the industry, building on the earlier work of Marshall and McIntyre (1989). Everyday consumers were used to evaluate the eating quality of kangaroo meat. Taste panels were conducted and data collected using standardized protocols developed for grading Australian beef (Polkinghorne et al., 1999; Thompson, 2002, 2004). For kangaroo, the overall eating quality of muscles associated with the hind limb (topside and silverside muscles respectively: *M. adductor* and *M. biceps femoris*) and grilled to a standard specification before tasting deteriorated with increasing carcass dressed weight, while the loin fillet muscle (*M. longissimus dorsi*) was not affected (Spiegel, 2008).

Consumer sensory scores for tenderness, juiciness, flavor, and overall liking were integrated into a single "palatability" index MQ4 score (Spiegel, 2008) based on methods developed for beef (Watson et al., 2008a,b). There is scope for the kangaroo industry to implement such a scoring system, which would then form the basis for a carcass grading system. Grading at the processing plant would provide industry with a marketing tool to improve the competitiveness of kangaroo meat products in an already crowded marketplace for game meats worldwide.

Figure 6 provides an illustrated insight into the merits of kangaroo based on such a grading system, notably being a product "acceptable for everyday consumption," but also with some product judged as "better than everyday" and "premium product." Thus, any products graded as unsatisfactory could be diverted to less valuable product lines such as manufacturing, boxed meat, or in the worst case, downgraded to pet meat. Thus, there would be clear delineation between better-graded primal steaks and fillets for higher-end markets and lower quality product.

Flavor was the most important sensory attribute driving consumer satisfaction, as indicated by a strong correlation between flavor and overall liking scores ($r = 0.9$; Spiegel, 2008). Interestingly, animal gender did not appear to be a key determinant of meat flavor. Clearly, the unique "gamey" flavor of kangaroo is of great significance to the consumer when selecting meat.

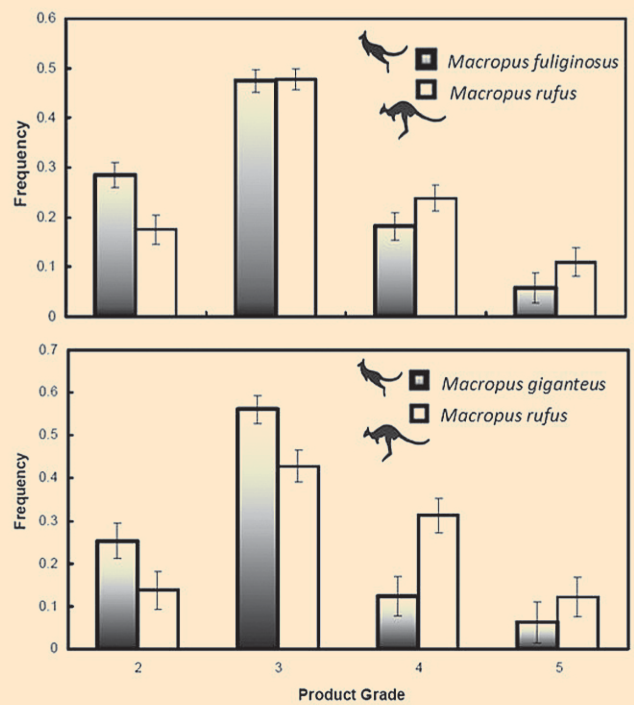

Figure 6. Grade distributions for grilled kangaroo meat, as assessed by untrained consumers. Standard error bars are shown for each distribution. Samples were graded as either 2 (unsatisfactory), 3 (good everyday), 4 (better than everyday), or 5 (premium product; Spiegel, 2008).

Environment, 2011). The capacity of the industry for the production of meat for human consumption has varied from 10,000 to 17,000 tonnes per year (RIRDC, 2009). Any further expansion in production is now being constrained by the number of field harvest staff willing to enter what is perceived as being a marginally profitable industry conducted in an isolated environment.

In setting quotas, it is important that the correct criteria for harvest are chosen to ensure that the age and gender structure of any population and its genetic diversity are preserved. For instance, the harvesting of only males (Cripps, 2014) or larger males for greater financial gain to harvesters and to meet a carcass weight restriction of greater than 12 kg set by the industry (Thomsen and Davies, 2007) has the potential to alter breeding dynamics within populations.

The Threat from Bacteria and Parasites

Since kangaroos are not subjected to routine husbandry practices, there is no control over parasites.

Kangaroos and wallabies can harbor a wide range of parasitic, bacterial, viral, and fungal diseases that are not apparent in a normal-looking animal. Grey kangaroos, for example, may be infected with 30,000 nematodes from 20 different species (Speare et al., 1989), which are predominantly found in the gastrointestinal tract. Other worm species are found in kangaroo carcasses with the large parasite *Pelecitus roemeri* often associated with the stifle joints. The prevalence of these infestations is associated with the activity of intermediate hosts such as tabanid flies, which in turn, are influenced by geographical location and season (CSIRO, 2009).

Toxoplasmosis and salmonellosis are two infections with public health significance for food industries in general. For instance, cysts from the toxoplasma protozoan parasite can survive in meats such as pork cooked to a “rare” level. Importantly, this degree of cooking is commonly used by chefs cooking kangaroo meat, fearful of drying out the meat through overcooking. This procedure really highlights the importance of food safety to protect the integrity of kangaroo meat as a product.

Other possible contamination can come from parasitic worms, such as trichinosis (e.g., *Trichinella spiralis*), taeniasis (roundworms and tapeworms), and echinococcosis. In some cases, freezing or otherwise sufficient cooking can safeguard against zoonotic infection; the larvae of *Trichinella spiralis*, a nematode of concern in pigs, for example, can be destroyed by freezing at −38°C for 2 minutes (Lawrie, 2006).

More comprehensive surveys of kangaroo processing plants have shown that the prevalence of *Salmonella* and *Escherichia coli* in carcasses is no worse than comparable beef carcasses and those of wild boar (Eglezos et al., 2007; Holds et al., 2008). Thus, careful handling of carcasses and then their checking by accredited inspectors ensures that health risks to the consumer are not worse than for the consumption of meat from any other species. These risks should be carefully checked in summer when greater ambient temperatures lead to the possibility for inefficient chilling of carcasses.

Economics

The commercial utilization of kangaroos is considered by some as one of the few rural ventures capable of economic return with minimal environmental impact (Grigg, 2002; Thomsen and Davies, 2005). Thus, the financial returns are more than just monetary, but the feasibility for kangaroo production alone on rangelands to meet protein demands is questionable. Managing total grazing pressure involves matching pasture supply with feed demands to ensure the maintenance of ground cover, soil fertility, and the persistence of deep rooting perennial native pastures. Without these measures, the economic viability of a grazing enterprise, regardless of industry, will be significantly reduced.

Figure 7. Modified fencing and watering points that hold and water cattle but aim to exclude kangaroos (source: Raymond Stacey).

The fact that kangaroos are part of sheep and beef grazing systems provides an opportunity for landholders to become involved in the kangaroo industry to supplement their income. This is certainly feasible where harvesting is approved. It is also not possible for graziers to have ownership over wildlife grazing their land, and therefore, managing them to ensure a regular income from their harvest is problematic. Despite this, landholders still need to account for their presence in developing a management strategy for their grazing systems, including land reclamation, which comes at a cost. For instance, this might involve temporary destocking of sheep and cattle or earlier rotation of stock to account for the grazing pressure from the kangaroos (see Norbury and Norbury, 1993 and Norbury et al., 1993). Figure 7 shows the extent that some landholders go to limit pasture and water availability for kangaroos.

Many ideas have been proposed regarding the utilization of kangaroos such as switching from rearing sheep to kangaroos (Grigg, 1988, 2002), farming kangaroos (Shepherd, 1983), and involving native Aboriginal peoples in managing populations with its associated social benefits (Thomsen and Davies, 2005). Establishing groups of commercial harvesters to form kangaroo cooperatives is another idea to consider (Cooney et al., 2009). Ecotourism is another opportunity (Croft, 2000) for the use of well-managed rangelands supporting kangaroo populations. The subject is far from simple, but the overarching priority is nevertheless ensuring best management of the land where production practices are in harmony with the maintenance of biodiversity. The management of ecosystems should be integrated and not just driven by a single enterprise (Jarman, 1994).

Challenges

Development of a flourishing industry producing meat of the highest quality from animals harvested from a natural environment raises a number of challenges. Development of our understanding of the nutritional requirements of the kangaroo and then ensuring they are able to obtain these within a rangelands environment will be important in understanding how nutrition might impact meat quality. Consistency of growth trajectory through to slaughter has been identified as a key determinant of eating quality in beef cattle (McIntyre et al., 2009), and it is highly likely that a similar relationship exists with the kangaroo.

Going hand in hand with eating quality is food safety. Maintaining a strict monitoring system from the point of harvest to the point of sale to the consumer requires a process of control implemented to provide quality assurance. In Australia, the application of the Hazard Analysis Critical Control Points (HACCP) methodology is common place for food industries. For the kangaroo industry, more rigorous methodologies may need to be considered, as a single incident of food poisoning through the ingestion of meat contaminated with salmonella, for example, has the potential to decimate the export market of Australia for this game meat overnight. The process of field dressing of carcasses and then the retention of a bacterial-loaded skin on the carcass for days in a fully loaded chiller is a practice that presents a major challenge to the industry to modify. Perhaps complete skin removal and then spraying the newly exposed carcass with a water-repellent coating may improve microbial safety significantly. Harvesting of carcasses during wet conditions may also exacerbate the potential for contamination (Eglezos et al., 2007).

The roles and responsibilities for ensuring food safety extend not only to the harvesting and processing industry, but also to government inspection services and to training of the consumer. As an example, consumers should practice their own hygienic handling of raw meat at home and ensure sufficient cooking of meat; ideally cooking to reach 65°C for 10 minutes is required to kill bacteria and 70°C to avoid parasitic infection (Lawrie, 2006).

More research into kangaroo health and the monitoring of diseases is needed, such as the incidence of toxoplasmosis, as is further research to ensure minimal risk of carcasses from bacterial spoilage.

The challenge of understanding meat quality and factors that control it in the kangaroo is a major issue for the industry. Storage and conditioning of meat products in air and moisture impermeable films are yet to be tested; this would assist the industry greatly in improving eating quality, controlling microbial contamination, and facilitating transport of the product to distant marketplaces. Advances in this area may yet allow an emerging kangaroo meat industry to become a major supplier of high quality, free-range animal protein for the discerning consumer worldwide.

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Nicole Spiegel studied agricultural science at the University of Sydney, developing an interest in animal nutrition and sustainable meat production systems on Australia's rangelands. This led to a Ph.D. study investigating factors influencing the quality of meat from kangaroos, a benchmark study for the industry. In 2009, Nicole was appointed by ACIAR (Australian Centre for International Agricultural Research) and Murdoch University to manage studies of mineral status of grazing sheep, yaks, and smallholder dairy cattle in Tibetan grasslands, and in 2013, she was appointed as a grazing land management scientist for Australia's northern beef grazing systems. Her current research is focused on land condition assessments, pasture growth modeling, forage budgeting, and feed utilization.

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