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Performance of lambs grazing an annual Mediterranean pasture or fed supplements based on olive oil cake or maize and its influence on system outputs

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Abstract. Three lamb feeding strategies were compared, including finishing of suckling lambs on an annual Mediterranean pasture (GRAZE), weaned followed by a concentrate plus hay diet (CONC), or weaned and fed a concentrate with 33% dry olive oil cake plus hay (CAKE). Grazing lambs averaged a liveweight gain of 334 g/day during the 28-day experimental period, which was higher ($P < 0.05$) than that of CONC and CAKE (283 and 276 g/day, respectively); however, there were no differences in empty body or dressed carcasses weights due to dietary treatment. The feed conversion of the olive seed cake supplement (kg supplement/kg gain) was lower ($P < 0.01$) than that of the maize-based supplement. Despite some significant differences between carcasses traits, all were small and of little commercial consequence. Simulation modelling of whole-system performance suggested that early weaning of lambs followed by concentrate feeding would reduce the finishing period, marginally increase the liveweight of ewes and would have little effect on pasture availability. It was further concluded that olive oil cake can be a large proportion of concentrate diets without negatively affecting carcass quality.

Additional keywords: annual pasture, carcass quality, finishing, lamb, simulation.

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Introduction

A large proportion of Chile has a Mediterranean-like climate and olive cultivation is increasing rapidly, although from a low base compared with the Mediterranean countries. Current estimates indicate that 24 000 ha have been sown to olives, with a yearly oil production of 12 ton (OlivaChile 2010), and it is anticipated that the crop will continue to expand rapidly.

Despite the dietary advantages of olive oil, the disposal of its byproducts is associated with negative environmental impacts (Sansoucy 1985) and there is therefore an interest in developing sustainable uses of these resources. Several authors have reviewed these alternatives (Nefzaqui 1991; López Gallego 2002). Most of the byproducts can be used for feeding ruminants, but their nutritive value is highly influenced by the process used to extract the oil, and by the subsequent processing of the residues. The modern oil extraction process is a two-phase procedure that gives rise to a residue called 'crude olive oil cake' (OliveOilSource 2007) that still contains an appreciable amount of oil. Furthermore, the cake may be further extracted ('exhausted') and/or may be partially separated from the ground stones or bones. The 'partly destoned olive cake' (OliveOilSource 2007) is produced if some of the crushed seeds are removed from the paste after processing. This residue may contain around 50 g of crude protein, (CP)/kg DM, and a variable oil content of up to 120 g/kg (Salcedo, cited by López Gallego 2002). Similarly, partially deboned and exhausted cake may have 100 g CP/kg and 200 g/kg or more acid detergent lignin (ADL) (Aguilera *et al*. 1986). Despite the relatively high CP content, much of the nitrogen is associated with lignocelluloses (Molina Alcaide *et al*. 2003). The DM digestibility of the byproduct seldom exceeds 40% (Sansoucy 1985) but when incorporated into complete balanced rations, animal performance has been satisfactory (Hadjipanayiotou 1994; Khorchani *et al*. 1997; Molina Alcaide *et al*. 2005; Cabiddu *et al*. 2004; Chiofalo *et al*. 2004).

Around 10% of the Chilean sheep stock is located in proximity of the major olive oil-producing areas, and much of the stock is held by small farmers who face major difficulties in providing year-round feed of sufficient quality for finishing lambs due to the combination of highly seasonal forage production and highly degraded annual grasslands (Ovalle and Squella 1996) that seldom exceed a year-round carrying capacity of one sheep per ha. A 2008 survey of large, medium and small sheep farmers in the VI Region (Central Chile) confirmed these findings (Aguilar *et al.* 2008), and noted that when farms were classified according to the technological level achieved, the four

top of the five categories identified by discriminant analyses used some type of supplement.

The combination of a large amount of little used olive residues with the need to intensify and differentiate fat lamb production has attracted interest, and Vera *et al*. (2009) demonstrated that supplementing lambs with olive oil cake significantly improves the fatty acid profile of subcutaneous fat and, by inference, that of other tissues as well. Thus, the objective of the present work was to compare three contrasting lamb finishing systems and determine if the incorporation of a relatively large amount of olive oil cake into lambs' rations would alter their performance relative to a conventional concentrate diet or as supplement to an annual pasture. Lastly, several production scenarios were simulated to assess the influence of supplementing lambs on various system variables.

Materials and methods

The experiment was conducted at the Hidango Research Field Station (INIA), located in Central Chile (34°06′S, 71°47′W, 296 m.a.s.l.), that has a distinct Mediterranean climate and vegetation. The trial was carried out during the spring season, between 20 October and 17 November 2006, following an 8-day adaptation period to the diets.

Treatments

Three finishing systems were compared in a completely randomised experiment using 36 Suffolk lambs with an initial age of 80 ± 4 days, and 25.1 ± 2.5 kg initial bodyweight. The three systems were: (a) suckling lambs kept with their mothers on an annual grassland during the spring season (GRAZE); (b) lambs weaned and stall-fed a control, concentrate ration, CONC, and (c) weaned lambs stall-fed an olive cake-based ration, CAKE (Table 1). The two concentrate supplements were designed to have similar levels of protein and digestible energy estimated from acid detergent fibre (ADF) (Donker 1989). The cost of the CAKE ration was ~80% of that of CONC.

The olive oil cake was manually processed as it emerged from a continuous, two-phase oil extraction plant. It was immediately passed through a screen to remove part of the ground stones, mixed with vitamin E (0.8 g/kg) and stored in air tight containers in a freezer (−4°C) until further processing. The partially destoned cake was then dried in a forced air oven at 60°C to constant weight, followed by grinding and mixing with the remaining ingredients of the ration. Since both supplements were prepared in small batches, samples of each (12 in total) were obtained for chemical analysis (Table 2). Chemical analyses of all feed samples were carried out as per AOAC (2005), whereas the *in vitro* DM digestibility was determined by the Tilley and Terry (1963) procedure.

Ewes and lambs in GRAZE were continuously grazed on a 19-ha, deferred, annual grassland together with similar, non-experimental animals, at a stocking rate of 11 ewe equivalents per ha. Feed intake of grazing animals was not measured. The botanical composition of the pasture was estimated along four transects using the point quadrat method in three dates during the experimental period. Forage on offer was estimated by clipping eight quadrats of 0.4 by 0.6 m each, randomly located and parallel to the transects. Forage growth was measured by clipping four areas of 0.4 by 0.6 m each within 1.2 by 1.2 by 1.0 wire cages. All forage samples were dried at 60°C for 24 h.

Animal management

Lambs allocated to CONC and CAKE were housed in 1.4-m^2 individual pens for the duration of the experiment. The animals were gradually introduced to their diets over an 8-day period until they reached the target amount of ration. Adaptation to the experimental diets was uneventful. Experimental animals were weighed at 7-day intervals, before the morning feeding. The two concentrate diets were offered once a day in the morning, in amounts estimated to satisfy their calculated maintenance and growth requirements in slight excess. The amount offered was adjusted weekly, beginning with 1080 g/day (as fed) in Week 1, and ending with 1300 g/day in Week 4. Orts were collected daily before the morning feeding, weighed, dried, and pooled weekly for each animal. All samples were dried in a forced air oven at 60°C for 24 h. Water was continually available and animals were checked 3 times per day. No health problems were detected, with the exception of poor growth in two animals of GRAZE due to unidentified causes.

All animals were slaughtered at the end of the experimental period following approved, humane procedures over a 2-day period. They were weighed immediately before slaughter (slaughter weight, SW).

Carcass measurements and analyses

Immediately following slaughter, the hot carcasses were weighed (hot carcass weight; Cañeque and Sañudo 2005). The full and

Table 1. Composition of the CONC and CAKE concentrate rations (g/kg DM, except where specified)

Ingredients	CONC	CAKE
Ground alfalfa hay	251	0
Ground maize	267	146
Molasses, liquid	97	97
Soybean meal	275	323
Olive oil cake	0	323
Sodium bicarbonate	9.7	9.7
Long chopped alfalfa hay[A]	97	97
Complete mineral and vitamin supplement (g/day.animal)	5	5

[A]Medium quality, stemmy hay.

Table 2. Chemical composition of the two concentrate diets and of the long chopped alfalfa hay offered (g/kg DM)

n.d., not determined. n.s., not significant

	CONC	CAKE	*P*-value[A]	Alfalfa hay
Crude protein	219.0	191.1	0.05	143.0
Ether extract	18.7	82.3	0.01	n.d.
Neutral detergent fibre	287.8	327.2	0.05	543.0
Acid detergent fibre	153.3	142.4	n.s.	n.d.
Acid detergent lignin	31.2	67.3	0.01	n.d.
Ash	78.2	93.6	0.05	n.d.
In vitro DM digestibility	776	714	0.01	606

[A]Statistical comparison applies to CONC versus CAKE rations.

empty gastrointestinal tract was also weighed. A full carcass characterisation, as frequently practised in Spain was carried out (Cañeque and Sañudo 2005) but only the major parameters are reported. The half carcasses were hanged at room temperature for 6–8 h after which the pH and temperature were measured between the 4th and 5th lumbar vertebrae. They were then refrigerated at 4°C for 24 h after which they were weighed (chilled carcass weight, CC). Dressing percentage was calculated as the CC/SW ratio.

Carcass measurements included: back fat depth on the 13th rib, and rib eye area. The ultimate pH (Wulf *et al.* 2002) was also measured after 24 h in storage at 4°C, between the 4th and 5th lumbar vertebrae. The colour and firmness of subcutaneous fat was visually evaluated around the tail, and the meat colour on the *Recto abdominis* muscle.

Statistical analyses

All statistical analyses were carried out with SAS (2003). Variables such as liveweight that were repeated over time were analysed using a split-plot design, whereas the remaining variables were analysed as a completely randomised design. Percentages referred to the carcasses showed heterogeneous variances, and values were transformed (square root) before statistical analysis.

Simulation modelling of pasture growth and animal performance

Early weaning of lambs followed by finishing based on stall-fed diets may influence physical outputs of other system's components such as liveweights of ewes, their reproductive performance and subsequent pasture conditions. A well tested and validated simulation model of pasture growth (Castellaro 2003; Castellaro and Squella 2006) was used to generate monthly pasture growth rates for moderately degraded annual grassland. These were input into a widely tested model of sheep production (Aguilar *et al.* 2006), together with data representative of a 200-ha farm with a stocking rate of one sheep per ha. The base scenario (Base) reproduced closely local conditions, including no supplementation of the stock, rotational grazing over three paddocks, initial ewe liveweight equal to that of the mean initial weight observed in the physical experiment and sale of lambs at 32 kg liveweight. Using the same initial conditions, a second scenario simulated weaning lambs at 80 days of age (80d) followed by stall feeding with a diet containing 9.2 MJ/kg DM and 170 g CP/kg DM until reaching the target sale weight of 32 kg. The last scenario differed from the previous one only in that weaning occurred at 60 days of age (60d). Simulation runs were started in February of each year, coinciding with the beginning of the mating season. Outputs examined included ewe liveweights, time to reach the target sale weight, and pasture availability.

Results

Pasture performance

The experimental pasture had an *Acacia caven* tree story and an herbaceous layer composed of *Hypochaeris radicata* (33%), *Trifolium glomeratum* (21%), *Bromus hordeaceus* (13%), *Vulpia bromoides* (8%), *Hordeum berteroanum* (6%), *Lolium rigidum* (5%), and traces of other species. Throughout the experimental period, forage on offer vary slightly around the mean of 634 ± 139 kg DM/ha, whereas the daily growth rate was 20 kg DM/ha.day. If it is estimated that lactating sheep averaging 50 kg liveweight consume 0.035–0.04 kg DM/kg (ARC 1980) it can be inferred that the pasture was close to equilibrium in terms of growth and forage removal by animals.

Animal performance

The olive oil cake used in the experiment averaged (DM basis) 62 g CP/kg, 164 g ether extract (EE)/kg, 320 g neutral detergent fibre/kg, 255 g ADF/kg and 145 g ADL/kg. The CP content was less than anticipated based on earlier analyses and contributed to the small difference in CP between the two concentrate diets (Table 2). Except for the content of ADF there were significant differences between the two concentrate diets (Table 2) in terms of chemical composition and *in vitro* DM digestibility but both diets were estimated to satisfy the energy and CP requirements of the animals.

Voluntary DM intake of the CONC diet was significantly higher ($P < 0.05$; Table 3) than that of CAKE possibly due to the higher ADL content of the latter. There were also significant differences in the chemical composition of the diet consumed, except for ADF (Table 3). It is possible that the relatively high content of EE in CAKE, as well as the limited palatability of olive oil cake may have affected negatively the amount of CAKE ration consumed (Hadjipanayiotou 1994).

Weight gains for two animals of the GRAZE treatment that severely underperformed their contemporary non-experimental animals, and that were identified as outliers by the SAS procedure were eliminated. There were significant differences ($P < 0.05$) in liveweight gain between the three treatments (Table 4), with an overall mean of 295 g/day.head. The above results led to significant differences in the conversion efficiency (intake/gain) of the two concentrate rations were used, namely 3.77 and 3.48 kg DM intake/kg gain for CONC and CAKE, respectively ($P < 0.01$). Nevertheless, the weight of the gastrointestinal contents of CONC was larger ($P < 0.01$) than that of CAKE, resulting in no difference ($P > 0.05$) in empty body and carcass weights.

Differences in body and carcass measurements were few (Table 4), and even those that differed significantly were of scant magnitude. There were also few differences in the

Table 3. Diet on offer (concentrate mix + molasses + chopped hay), voluntary intake and chemical composition of actual intake by stall fed animals

Data are averages for 4 weeks and 12 animals per treatment. n.a., not applicable. n.s., not significant

Variable	CONC	CAKE	s.e.	*P*-value
DM offered (g/day.head)	1233	1234	n.a.	n.a.
DM consumed (g/day.head)	1095	1023	15.1	0.01
Composition of feed consumed (g/kg DM)				
Crude protein	197.4	171.0	1.0	0.01
Ether extract	16.3	68.1	0.3	0.001
Neutral detergent fibre	278.3	328.7	10.2	0.001
Acid detergent fibre	156.3	159.0	1.4	n.s.
Acid detergent lignin	36.9	69.9	8.9	0.001

Table 4. Animal performance and carcass parameters for the three treatments

Within rows, mean followed by different letters differ significantly ($P < 0.05$)

Variable	GRAZE	CONC	CAKE	*P*-value
Daily liveweight gain (g/head)	334a	283b	276b	0.05
Slaughter weight (kg)	31.6	32.4	31.0	NS
Chilled carcass weight (kg)	14.5	15.3	15.1	NS
Full digestive tract (kg)	7.281a	6.521ab	5.795b	0.002
Dressing percentage (%)	50b	51ab	52a	0.03
Backfat depth, 13th rib (mm)	0.98	0.93	1.03	NS
Rib eye area (cm^2)	16.4	16.9	17.2	NS
Ultimate pH	5.44	5.40	5.37	NS
Ultimate temperature (°C)	5.9b	6.7a	7.2a	0.01

weight of organs and tissues, the most important being those of pelvic and kidney fat, liver, kidney and skin (Table 5). All CONC and CAKE carcasses were judged to be 'soft', whereas 3 out of 12 GRAZE were graded 'oily' (χ^2, $P < 0.05$). Similarly, significantly more (χ^2, $P < 0.05$) CAKE and GRAZE meat samples were graded 'pink', as opposed to 'light pink' in CONC.

Simulated system performance

Early weaning, particularly 60d, induced increases in ewe liveweights of up to 5 kg or 10% of the initial weight. This increase coincided with the transition of winter to early spring, a time of critically low forage availability in real systems, thus allowing ewes to recover their weight earlier than Base animals (Fig. 1). Nevertheless, this did not translate in increased reproductive performance 4–5 months later, in the following mating season (not shown). The slightly increased grazing pressure associated with heavier ewes in 60d and 80d tended to decrease very slightly forage on offer (Fig. 2). Time to reach the target sale weight was reduced up to 32 days by weaning at 60 days of age (Fig. 3).

Table 5. Weight of selected organs and tissues of animals on the three treatments

Within rows, mean followed by different letters differ significantly ($P < 0.05$)

Tissue	GRAZE	CONC	CAKE	*P*-value
Pelvic and kidney fat (g)	113.8a	93.8a	164.2b	0.001
Skin (g)	2886b	3489a	3354a	0.003
Liver (g)	498.8c	629.2a	567.5b	0.0001
Kidneys (g)	101.3b	115.8a	117.9a	0.001

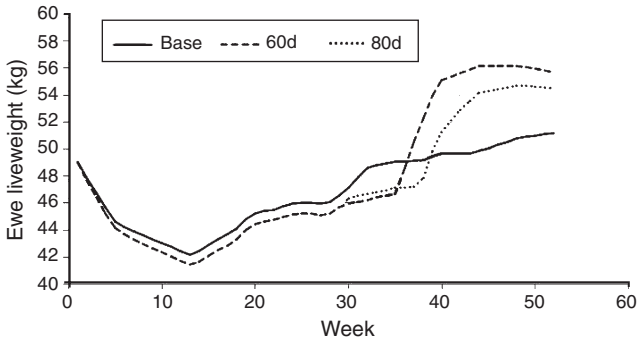

Fig. 1. Simulated liveweight change of ewes with time in three contrasting production scenarios (base = control scenario; 60d and 80d = lambs weaned at 60 and 80 days of age and stall fed, respectively).

Discussion

Production of quality lambs in the sub-humid region of Central Chile would benefit from the strategic and seasonal use of modest amounts of supplements (Aguilar *et al.* 2008), assuming that costs are low and are available locally.

López Gallego (2002) studied the effect of including 10, 20 and 30% olive oil cake in a concentrate that included also maize, barley and soybean meal when fed to male and female lambs of 18 kg initial liveweight for 31–34 days, and found that weight gains decreased with increasing cake proportion from 286 to 272 and 264 g/day.head, respectively, whereas concentrate consumption increased slightly from 1051 to 1126 g/day.head. On the contrary, in the present study using heavier, older lambs, only small differences were observed in terms of voluntary intake, despite the significantly larger content of ADL and EE of CAKE. Notwithstanding these differences, weight gains between a high quality ration (CONC) and the CAKE diet containing 33% olive oil cake were similar, to the extent that

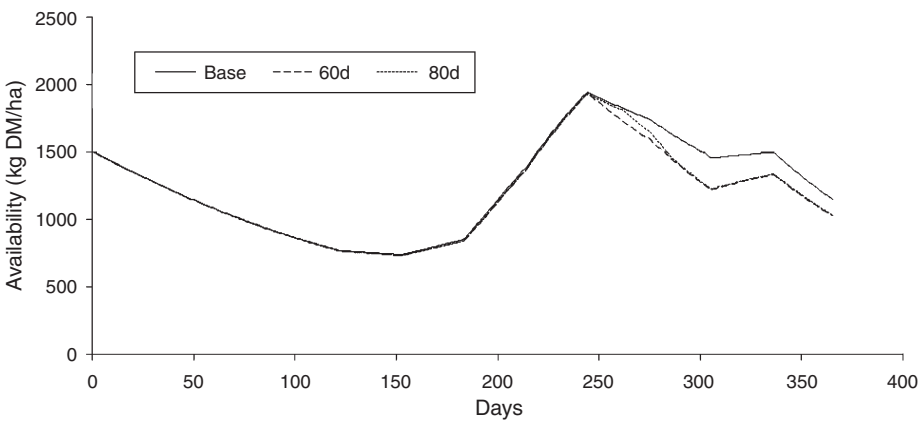

Fig. 2. Simulated change in forage availability over time in three contrasting scenarios (base = control scenario; 60d and 80d = lambs weaned at 60 and 80 days of age and stall fed, respectively).

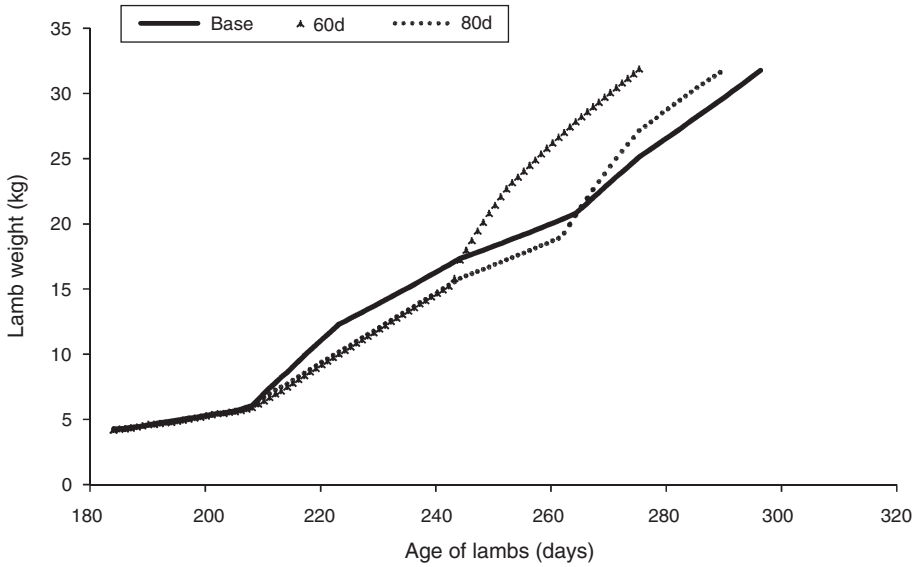

Fig. 3. Simulated age of lambs at the target sale liveweight of 32 kg in three production scenarios (base = control scenario; 60d and 80d = lambs weaned at 60 and 80 days of age and stall fed, respectively).

the efficiency of feed use in the latter treatment exceeded that of CONC. This finding contrast with the report by Momani Shaker *et al*. (2003) that found that Awassi male lambs fed a diet containing 25% olive oil cake had lower conversion efficiency than control animal. Using younger lambs, López Gallego (2002) reported that the conversion efficiency worsened with increasing proportions of olive oil cake in the diet, from 3.56 with no cake to 4.19 with 30% cake, which compares with 3.48 in the present experiment. These contrasting results may be associated with differences in the composition of the cake used, as discussed above, and the fact that López Gallego (2002) offered wheat straw ad lib, as opposed to chopped alfalfa hay in the present work. It should also be noted that detailed characterisations of 'destoned' olive oil cake were not found in the literature, and it would be expected that the extent to which stone fragments are removed from the crushed, extracted, paste would be variable depending on the efficiency of the initial crushing and subsequent removal of the stones. Later analyses based on careful hand separation and washing, revealed that the manual procedure used in the present experiment left 20% of finely milled stones in the cake (M. Villamor, C. Aguilar, R. Vera, I. Peña, unpubl. data). Furthermore, the relatively large EE content of CAKE did not decrease performance, despite its marginally lower consumption than the CONC ration. If the present data are compared with the results of López Gallego (2002), it may be speculated that the level of inclusion of olive oil cake in the CAKE diet may have approached the threshold value above which performance declines.

The relatively high rate of liveweight gain by lambs grazing the Mediterranean pasture was the result of above average rainfall and good pasture production. Their performance was better than in the two stall-fed treatments, but this was clearly due to the significantly higher contents of the gastrointestinal tract of the grazing lambs, so that no significant differences were noted in terms of empty body and hot or cold carcass weights. Unexpectedly, the yield and commercial yield of the CAKE animals was large and significantly higher than in GRAZE, although differences between treatments were small in absolute terms. This trend coincides with the lack of significant differences in yield and carcass weight reported by López Gallego (2002) with increasing proportion of olive oil cake in the diet. In coincidence with the findings of López Gallego (2002), the CAKE diet modified slightly, but significantly, rump width and leg compactness, but differences were small and of little commercial consequence. Similarly, Momani Shaker *et al*. (2003) found that lambs fed a ration with 0.25 cake had very few differences with control animals in all the carcass parameters examined.

Some of the differences in the weight of the tissues (Table 5) may well reflect differences in the physiological condition of the lambs (suckling versus weaned and fed dry feeds), such as the weight of the skin, kidneys and liver, together with the effect of the metabolic load imposed by the diets, possibly reflected again in liver and kidney weights, as well as in the weight of the abdominal fat. It is well established that organ size is correlated with body size and level of production (Koong *et al.* 1985), and that the weights of the metabolically active organs such as the gastrointestinal tract and viscera are sensitive to nutritional manipulation (Koong and Ferrell 1990; McLeod and Baldwin 2000).

The ultimate pH of the carcasses (Table 4) was in all cases adequate for the inhibition of glycolytic enzymes, and was below the level associated with meat toughness (Wulf *et al.* 2002), whereas the higher ultimate temperature of CAKE and CONC carcasses may be associated with differences in fatty acid composition and their relative susceptibility to oxidation (Wood *et al.* 2004) but were still within the acceptable range.

Thus, the present results indicate that despite its nutritional limitations, locally produced olive oil cake can make as much as one-third of the concentrate diet, replacing traditional, more expensive, and imported feeds. It is also clear that carcass

yield and conformation were not altered by inclusion of cake in the ration while Vera *et al*. (2009) reported that cake feeding improved the fatty acid profile of subcutaneous adipose tissue. Lastly, it remains to be established if consumers would perceive differences in flavour and other organoleptic properties of the meat, although an untrained panel of naïve consumers failed to differentiate meat from the different treatments (C. Aguilar, R. Vera, R. Lira, unpubl. data). Nevertheless, it should be noted that preferences for flavour, colour and others differ widely among countries (Díaz *et al.* 2005) so that the final product needs to be adapted to specific market niches.

Aguilar *et al*. (2006) simulated over 100 scenarios of lamb production systems in the region, including the effects of stocking rates, supplementation strategies and variable costs of inputs and outputs. The authors concluded that in absence of supplementation, small farmers would have little latitude in altering stocking rates if they were to avoid severe decreases of forage on offer and pasture degradation (Ovalle and Squella 1996), whereas modest levels of concentrate supplementation were compatible with economic profits and pasture maintenance. These findings were confirmed by a later survey (Aguilar *et al.* 2008).

Give the extent of degradation of annual grasslands in Chile's Mediterranean region (Ovalle and Squella 1996) it was important to determine if changes in sheep management practices, and particularly the early weaning of lambs, would have a positive effect on the physical performance of extant systems. The results of the simulation runs showed a speedier recovery, and higher liveweights in early weaned ewes. Nevertheless, this increased weight translated into a heavier grazing pressure on existing pastures that precluded grassland recovery. This confirms the precarious equilibrium of these systems, associated with the small potential growth of degraded pastures during a relatively short growing season (Ovalle and Squella 1996) and confirmed by the measured growth rate in the present experiment. If the scenarios of global warming and climate change for Chile are correct, it is predicted that the region will receive less rainfall and that rainfall variability will increase (AGRIMED 2011). In this scenario, pasture yields will be lower and more erratic, thus increasing the need to supplement animals and adjust lambing, weaning and other animal and pasture management aspects. On the other hand, and if economic conditions allow, early weaning of lambs at 60 days of age followed by cake-based concentrate feeding would reduce the finishing period by 30 days, implying less reliance on grazed pastures, and earlier turnoff of more uniform, and higher quality, lamb carcasses to the market.

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