CSIRO PUBLISHING

Animal Production Science
http://dx.doi.org/10.1071/AN12192

Effects of feeding different levels of chromium-enriched live yeast in hairy lambs fed a corn-based diet: effects on growth performance, dietary energetics, carcass traits and visceral organ mass

A. Estrada-Angulo[A], *Y. S. Valdés*[B], *O. Carrillo-Muro*[B], *B. I. Castro-Perez*[A], *A. Barreras*[B], *M. A. López-Soto*[B], *A. Plascencia*[B,D], *H. Dávila-Ramos*[A], *F. G. Rios*[A] *and R. A. Zinn*[C]

[A]Facultad de Medicina Veterinaria y Zootecnia, Universidad Autónoma de Sinaloa, Culiacán 1084, Sinaloa, México.
[B]Instituto de Investigaciones en Ciencias Veterinarias, Universidad Autónoma de Baja California, Mexicali 21100, Baja California, México.
[C]Department of Animal Science, University of California Davis, CA 95616, USA.
[D]Corresponding author. Email: aplas_99@yahoo.com

Abstract. Forty Pelibuey × Kathdin lambs (35.5 ± 0.4 kg) were used in a 56-day feeding experiment to assess the effects of feeding different levels of chromium-enriched live yeast (Cr-YC) on growth performance, dietary energetics, carcass traits and visceral organ mass. The Cr-YC source contained 5.5×10^9 colony forming units (CFU) and 0.40 mg of Cr per gram. Treatments consisted of a dry rolled corn-based finishing diet supplemented with 0, 1, 2 or 3 g Cr-YC/lamb.day. Total daily dosages were: 5.5×10^9 CFU and 0.4 mg; 1.1×10^{10} CFU and 0.8 mg Cr, and 1.65×10^{10} CFU and 1.2 mg Cr for supplementation levels of 1, 2 or 3 g Cr-YC/lamb.day, respectively. There were no treatments effects on dry matter intake. As the level of Cr-YC supplementation increased, average daily gain, gain to feed and dietary net energy were linearly increased, and observed/expected dry matter intake was linearly decreased. Chromium-enriched live yeast supplementation increased empty bodyweight (EBW), gastrointestinal fill and full viscera weight, but did not influence organ weights as a proportion of EBW (g/kg EBW). Cr-YC level did not affect carcass length, backfat thickness, kidney, pelvic and heart fat or body wall thickness, but increased hot carcass weight and *longissimus* muscle area. In general, treatment effects on percentage yield of wholesale cuts (tissue weight as a percentage of cold carcass weight) were small. However, Cr-YC decreased percentage flank. Chromium-enriched yeast supplementation enhances growth rate, *longissimus* muscle area, and dietary energetic efficiency in finishing feedlot lambs.

Additional keywords: feed additive, hair sheep breeds, *Saccharomyces cerevisiae*.

Received 5 June 2012, accepted 13 September 2012, published online 23 January 2013

Introduction

Concern over the use of regulated growth-enhancing drugs in feed formulations for livestock has furthered interest in the search for generally-recognised-as-safe alternatives. Among these, direct-fed microbials, such as yeast cultures (YC) have shown promise, although responses have not been consistent. In a few studies, YC supplementation enhanced the dry matter intake (DMI) and/or the growth performance of ruminants fed finishing diets (Krehbiel *et al*. 2003; Haddad and Goussous 2005). However, no beneficial effects of YC supplementation were observed in other cases (Zinn *et al*. 1999). Apparently, the efficacy of YC supplementation on finishing diets depends on the level of administration (Domínguez-Vara *et al*. 2009), the diet composition (forage : concentrate ratio; Galip 2006), and whether the YC is utilised alone or is enriched with minerals such as chromium (Cr) (Valdés-García *et al*. 2011). Cr potentiates the effects of insulin, and thereby, can alter carbohydrate metabolism and protein synthesis (Pallauf and Muller 2006). Chromium supplementation, as Cr propionate or Cr methionine, increased the percentage of carcass muscle and decreased carcass fat in pigs (Mooney and Cromwell 1995; Jackson *et al*. 2009) and feedlot cattle (Barajas *et al.* 2008). By adding inorganic Cr to the fermentor, yeast can combine the Cr into the intracellular proteins or polysaccharides during growth in the form of Cr-chelates, such as Cr nicotinate; which improves Cr bioavailability (Underwood and Suttle 1999). Therefore, positive effects such as enhanced lean tissue growth in finishing ruminants can be expected from the use of Cr-enriched live yeast. However, there is limited information available on the effects of high Cr concentration enriched live yeast supplemented at different levels on the growth performance and carcass characteristics in feedlot lambs. The objective of the present study was to evaluate the influence of high

Cr concentration Cr-enriched live yeast supplemented at different levels in high-energy diets fed to feedlot lambs on growth performance, carcass characteristics and visceral organ mass.

Materials and methods

This experiment was conducted at the Universidad Autónoma de Sinaloa Feedlot Lamb Research Unit, located in the Culiacán, México (24°46′13″N and 107°21′14″W). Culiacan is ~55 m above sea level, and has a tropical climate. All animal management procedures were conducted within the guidelines of locally approved techniques for animal use and care (NOM-051-ZOO-1995: humanitarian care of animals during mobilisation of animals; NOM-062-ZOO-1995: technical specifications for the care and use of laboratory animals. Livestock farms, farms, centres of production, reproduction and breeding, zoos and exhibition hall, must meet the basic principles of animal welfare; NOM-024-ZOO-1995: animal health stipulations and characteristics during transportation of animals; and NOM-033-ZOO-1995: humanitarian care and animal protection during slaughter process).

Animals and chromium-enriched yeast characteristics

Sixty Pelibuey × Kathdin lambs were received at the research facility 9 weeks before initiation of the experiment. Upon arrival the lambs were treated for parasites (Tasasel 5%, Fort Dodge, Animal Health, México) and injected with 1×10^6 IU vitamin A (Synt-ADE, Fort Dodge, Animal Health). Three weeks before the initiation of the experiment lambs were fed the basal finishing diet. Following a 9-week evaluation period, 40 lambs (35.5 ± 0.1 kg) were selected from the original group of 60 lambs for use in the study, based on the uniformity of weight and general condition.

The YC used (*Saccharomyces cerevisiae* N. strain 7907; Biotecap, Guadalajara, México) contained 5.5×10^9 colony forming units (CFU) and 0.40 mg Cr/g (air-dry basis).

Diet and experimental design

The basal finishing diet contained (g/kg DM basis): wheat straw, 60; sudangrass hay, 80; soybean meal, 75; dry rolled corn, 620; tallow, 35; cane molasses, 97; urea, 8; and mineral supplement, 25. The nutrient composition of the diet (DM basis) was: crude protein (CP), 135 g/kg (N × 6.25, method 984.13, AOAC 2000); neutral detergent fibre (NDF), 178 g/kg [Van Soest *et al*. 1991; corrected for NDF-ash, incorporating heat stable α-amylase (Ankom Technology, Macedon, NY, USA) at 1 mL per 100 mL of NDF solution (Midland Scientific, Omaha, NE, USA)]; ether extract, 64 g/kg (method 920.39, AOAC 2000); calcium, 71 g/kg (method 927.02, AOAC 2000) and phosphorus, 37 g/kg (method 964.06, AOAC 2000). The calculated net energy (NE) of maintenance (NRC 2007) and gain of basal diet were 8.58 and 5.86 MJ/kg, respectively. Upon initiation of the experiment, lambs were weighed before the morning meal (electronic scale; TORREY TIL/S: 107 2691, TOR REY Electronics Inc., Houston, TX, USA), and assigned to one of five weight groupings in 20 pens, with two lambs per pen. Pens were 6 m^2 with overhead shade, automatic waterers and 1-m fence-line feed bunks. Dietary treatments consisted of the basal diet plus 0 (control), 1, 2 or 3 g of Cr-YC/lamb.day. Doses of Cr-YC were hand-weighed using a precision balance (Ohaus, mod AS612, Pine Brook, NJ, USA), and were premixed for 5 min with minor ingredients (urea, limestone and trace mineral salt) before incorporation into complete mixed diets. The final product was mixed with the rest of ingredients in a 2.5-m^3 capacity paddle mixer (model 30910-7, Coyoacán, México). To avoid contamination, the mixer was thoroughly cleaned between each treatment. Dietary treatments were randomly assigned to pens within blocks. Lambs were weighed before the morning meal on Day 1 and Day 56 (harvest). Lambs were allowed *ad libitum* access to dietary treatments. Daily feed allotments to each pen were adjusted to allow minimal (<5%) feed refusals in the feed bunk. The amounts of feed offered and of feed refused were weighed daily. Lambs were provided fresh feed twice daily at 0800 and 1400 hours. Feed bunks were visually assessed between 0740 and 0750 hours each morning, refusals were collected and weighed and feed intake was determined. Adjustments to, either increase or decrease daily feed delivery, were provided at the afternoon feeding. Feed and refusal samples were collected daily for DM analysis, which involved oven drying the samples at 105°C until no further weight loss occurred (method 930.15, AOAC 2000).

Calculations

The estimations of dietary energetic and expected DMI were performed based on the estimated initial and final shrunk bodyweight (SBW), to convert to a SBW basis is assuming that SBW is 96% of full weight (CSIRO 1990; Cannas *et al*. 2004). Average daily gains (ADG) were computed by subtracting the initial BW from the final BW and dividing the result by the number of days on feed. The efficiency of BW gain was computed by dividing ADG by the daily DMI.

The estimation of expected DMI was performed based on observed ADG and SBW according to the following equation: expected DMI, kg/day = $(EM/NE_m) + (EG/EN_g)$, where EM (energy required for maintenance, MJ/day) = $[4.184 \times (0.056 \times SBW^{0.75})]$ (NRC 1985), EG (energy gain, MJ/day) = $[4.184 \times (0.276 \times ADG \times SBW^{0.75})]$ (NRC 1985), NE_m and NE_g are 8.58 and 5.86 MJ/kg, respectively (derived from tabular values based on the ingredient composition of the experimental diet; NRC 1985), and SBW represent full BW × 0.96, Cannas *et al.* 2004]. The coefficient (0.276) was estimated assuming a mature weight of 113 kg for Pelibuey × Kathdin male lambs (Canton and Quintal 2007). Dietary NE were estimated by means of the quadratic formula:

$$x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2c},$$

where $x = NE_m$, $a = -0.41EM$, $b = 0.877EM + 0.41DMI + EG$, and $c = -0.877DMI$ (Zinn *et al*. 2008) and, the results obtained were multiplied by 4.184 to convert to units of MJ.

Carcass and visceral mass data

Lambs were killed by severing the jugular vein and carotid artery. After sacrifice, lambs were skinned, and the gastrointestinal (GIT) organs were separated and weighed. After carcasses (with kidneys and internal fat included) were chilled in a cooler at –2 to 1°C for 48 h, the following measurements were obtained:

(1) carcass length (maximum distance between the edge of the ischio-pubic symphysis and anterior border of the first rib at its midpoint); (2) carcass depth (maximum distance between the sternum and the back of carcass, at the level of the sixth thoracic vertebra); (3) leg length (distance from the symphysis pubis to the tarsal-metatarsal joint); (4) body wall thickness (distance between the 12th and 13th ribs beyond the ribeye, five inches from the midline of the carcass); (5) fat thickness perpendicular to the *M. longissimus thoracis* (LM), measured over the centre of the ribeye between the 12th and 13th rib; (6) LM surface area, measure using a grid reading of the cross-sectional area of the ribeye between 12th and 13th rib, and (7) kidney, pelvic and heart fat (KPH). The KPH was removed manually from the carcass, and then weighed and reported as a percentage of the cold carcass weight (USDA 1982). Each carcass was split along the vertebrae into halves. The left side of each carcass was fabricated into wholesale cuts, without trimming, according to the North American Meat Processors Association guidelines (NAMP 1997). Rack, breast, shoulder and foreshank were obtained from the foresaddle, and the loins, flank and leg from the hindsaddle. The weights of each cut were subsequently recorded.

All tissue weights were reported on a fresh tissue basis. Previous data suggests that there is very little variation among fresh and dry weights for visceral organs (Neville *et al*. 2008). Organ mass was expressed as grams of fresh tissue per kilogram of final empty BW. Final EBW represents the final full BW minus the total digesta weight. Full visceral mass was calculated by the summation of all visceral components (stomach complex + small intestine + large intestine + liver + lungs + heart), including digesta. The stomach complex was calculated as the digesta-free sum of the weights of the rumen, reticulum, omasum and abomasum.

Statistical analyses

Performance (gain, gain efficiency, and dietary energetics) and carcass data, were analysed as a randomised complete block design. The experimental unit was pen. The MIXED procedure of SAS (SAS Institute 2004) was used to analyse the variables. The fixed effect consisted of treatment, and pen as the random component. Whole cuts data were analysed using the MIXED procedure (SAS Institute 2004), in a model with treatment and pen as fixed effects and interaction treatment × pen and individual carcasses within pen by treatment subclasses as random effects, with the final hot carcass weight (HCW) as a covariate when it represented a significant ($P \leq 0.05$) source of variation. The mean of HCW to which the data are adjusted was 28.676 kg.

Visceral organ mass data were analysed using the MIXED procedure (SAS Institute 2004), in a model with treatment and pen as fixed effects and interaction treatment × pen and individual carcasses within pen by treatment subclasses as random effects. Treatment effects were tested for linear, quadratic and cubic components of the Cr-YC supplementation level. Contrasts were considered significant when the *P*-value was ≤0.05, and tendencies were identified when the *P*-value was >0.05 and ≤0.10.

Results

Quadratic and cubic effects were not significant ($P \geq 0.10$). Thus, the *P*-values for those components are not presented in the tables.

Growth performance

There were no treatment effects ($P = 0.59$) on DMI, averaging 1.18 kg/day. Observed DMI of the control (non-supplemented) lambs was 98% of that expected based on tabular estimates (NRC 2007) of dietary energy density and observed SBW and ADG (Table 1). This supports the practicality of the prediction equations proposed by the NRC (1985) for the estimation of DMI in relation of SBW and ADG in feedlot lambs. As the level of supplemental Cr-YC increased, ADG, GF and dietary NE increased (linear effect, $P \leq 0.04$), and observed/expected DMI decreased (linear effect, $P < 0.01$).

Visceral mass

Treatment effects on the empty BW and viscera weight are shown in Table 2. GIT fill averaged 7.6% of the final EBW (7.1% of non-adjusted final SBW), and was not affected ($P \geq 0.19$) by supplemental Cr-YC. However, Cr-YC supplementation increased (linear effect, $P \leq 0.05$) the EBW, GIT fill and full viscera weights. Cr-YC supplementation did not influence ($P \geq 0.18$) the organ weights as a proportion of EBW (g/kg EBW).

Carcass traits

The Cr-YC level did not affect ($P \geq 0.09$) carcass length, carcass width, leg length, back-fat thickness, KPH or body wall thickness, but increased (linear $P \leq 0.03$) the HCW and LM area (Table 3). Because final HCW represented a significant ($P \leq 0.05$) source of variation in analysis of wholesale cut weights (kg), it was used as a covariate in the analysis of treatment effects. Generally, treatment effects on percentage yield of wholesale cuts (tissue weight as a percentage of CCW) were small ($P \geq 0.23$; Table 4). However, Cr-YC decreased ($P = 0.03$) percentage flank.

Discussions

Dry matter intake

Previously (Phillips and VonTungeln 1985; Chang and Mowat 1992; Cole *et al*. 1992; Zinn *et al*. 1999) YC supplementation of shipping stressed cattle reduced sick days and/or enhanced feed intake during the initial receiving period (<35 days). However, subsequent effects on growth performance have been small or non-appreciable. Consistent with the present study, *S. cerevisiae* supplementation (3 g/day) did not affect the DMI in lambs fed a high-energy diet (74-day experiment; Haddad and Goussous 2005). Likewise, Adams *et al*. (1981) reported no differences in DMI of lambs fed a 50 : 50 forage : concentrate diet supplemented with 2.5% of live yeast (targeted 20 g/lamb.day of *S. cerevisiae*) during a 73-day growing-finishing period. Supplemental *Aspergillus oryzae* (1 g/day) did not affect DMI of lambs fed a high-energy finishing diet during a 72-day period (Zerby *et al*. 2011). In steers, supplementation with 10 g/day YC did not affect the DMI of steers fed a 74% barley-based finishing diet (Mir and Mir 1994). Likewise, Hinman *et al*. (1998) observed that YC supplementation did not affect DMI in yearling steers fed a barley- and potato-processing residue-based finishing diet. In their study, the feeding rate for live YC was 85 g/day for the first 28 days and 28 g/day from Day 29 to Day 115 (harvest).

Table 1. Treatment effects on growth performance and dietary energy

Basal diet supplemented to provide 0, 1, 2, or 3 g chromium-enriched live yeast culture per head per day. Dietary energetic and expected dry matter intake (DMI) estimations were performed based on the estimation of initial and final shrunk bodyweight (SBW), to convert to a SBW basis is assuming that SBW is 96% of full weight (CSIRO 1990; Cannas *et al*. 2004). Observed to expected dietary net energy (NE) ratio was computed by dividing NE observed between expected diet NE, which was estimated based on tabular values for individual dietary ingredients (NRC 2007). Expected DMI was computed as follows: DMI, kg/day = $(EM/NE_m) + (EG/EN_g)$, where EM = maintenance coefficient of 0.056 Mcal/$BW^{0.75}$ (NRC 1985) and EG is the daily energy deposited (Mcal/day) estimated by equation: EG = $[(0.276 \times ADG) \times SBW^{0.75}$, NRC 1985]. The divisors NE_m and NE_g are the NE of diet [calculated from tables of composition of feed (NRC 1985)]. Within rows, means followed by different letters are significantly different at $P < 0.05$

Item	Chromium-enriched yeast level (g per head per day)					Contrast *P*-value
	Control	1	2	3	s.e.m.	linear
Liveweight (kg)						
Initial	37.09	37.01	37.03	36.99	0.19	
Final	50.08a	50.66ab	51.85ab	53.60b	1.09	0.04
ADG (kg)	0.232a	0.244ab	0.265ab	0.297b	0.019	0.03
DMI (g/day)	1.185	1.132	1.197	1.204	0.049	0.59
Gain for feed (kg/kg)	0.196a	0.216ab	0.222abc	0.247c	0.009	<0.01
Dietary NE (Mcal/kg)						
Maintenance	2.01a	2.13b	2.20bc	2.27c	0.03	<0.01
Gain	1.38a	1.47b	1.51bc	1.59c	0.02	<0.01
Observed to expected dietary NE ratio						
Maintenance	1.00a	1.07b	1.10bc	1.14c	0.01	<0.01
Gain	1.00a	1.09b	1.12bc	1.18c	0.02	<0.01
Observed to expected daily DMI	0.98a	0.91b	0.88bc	0.84c	0.01	<0.01

Table 2. Treatment effects on visceral organ weight

Basal diet supplemented to provide 0, 1, 2, or 3 g chromium-enriched live yeast culture per head per day. Full viscera = full viscera mass = (stomach complex + small intestine + large intestine + liver + lungs + heart) including digesta and mesenteric fat. Stomach complex = (rumen + reticulum + omasum + abomasums), without digesta. Intestines represent small and large intestine without digesta. Within rows, means followed by different letters are significantly different at $P < 0.05$

Item	Chromium-enriched yeast level (g per head per day)					Contrast *P*-value
	Control	1	2	3	s.e.m.	linear
Full final weight (kg)	50.08	50.66	51.85	53.60	1.04	0.01
Fill (kg)	3.51a	4.13ab	4.54ab	4.75b	0.15	0.05
Empty bodyweight (kg)	46.35a	47.03ab	48.22ab	49.70b	0.98	0.03
Empty bodyweight (% of full weight)	93.04	92.82	92.99	92.72	0.15	0.19
Full viscera (kg)	9.91a	10.73ab	10.76ab	11.20b	0.22	0.04
Organs (g/kg empty bodyweight)						
Stomach complex	31.52	32.83	31.17	33.27	1.32	0.56
Intestines	43.00	44.38	44.36	45.64	1.16	0.19
Liver	18.59	18.66	19.03	19.95	0.73	0.18
Kidney	2.64	2.70	2.69	2.56	0.03	0.75
Heart and lungs	23.62	22.64	21.68	22.79	0.97	0.27
Visceral fat	35.15	36.30	33.69	34.56	2.73	0.62

Growth performance

Whereas supplementation with probiotics has been reported to improve growth performance, including ADG, and/or gain to feed (GF) (Abdelrahman and Hunaiti 2008; Khalid *et al*. 2011), results have not been consistent. In agreement with the present study, lambs fed an 80% concentrate diet supplemented with 0.5 g/day YC (non-Cr enriched yeast with 20×10^9 CFU) had greater ADG (13.1%) and gain efficiency (7.3%) than non-supplemented lambs (Ding *et al*. 2008). Likewise, Haddad and Goussous (2005), using the same source of YC as that used by Ding *et al*. (2008) observed that supplementation with 3 g/day of YC increased the ADG (25.4%) and gain efficiency (16%) with no effects on carcass characteristics in fattening Awassi lambs fed an 80% concentrate diet. These improvements were associated with an increased digestibility of organic matter (5.9%), N (10.8%), and NDF (7%). Payandeh and Kafilzadeh (2007) observed increased ADG, but no effects on GF due to the YC supplementation of finishing lambs fed a high-energy beet pulp-based diet. Likewise, Abas *et al*. (2007) noted increased ADG without an effect on GF in finishing yearling lambs supplemented with 0.5 g/kg of YC (*Enterococcus faecium*). In contrast, numerous studies have reported no effect of YC

Table 3. Treatment effects on dressing percentage and carcass characteristics

Basal diet supplemented to provide 0, 1, 2, or 3 g chromium-enriched live yeast culture per head per day. Dressing percentage was computed as follows: dressing percentage = (hot carcass weight/FBW) × 100. Fat thickness was taken over the centre of the *M. longissimus* between the 12th and 13th ribs. Within rows, means followed by different letters are significantly different at $P < 0.05$

Item	Chromium-enriched yeast level (g per head per day)					Contrast *P*-value
	Control	1	2	3	s.e.m.	Linear
Replicates	10	10	10	10		
Hot carcass weight (kg)	27.42a	27.92ab	28.82ab	29.76b	0.59	0.02
Cold carcass weight (kg)	27.55	27.51	27.51	27.52	0.55	0.62
Dressing percent	54.75	55.04	55.63	55.57	0.43	0.79
M. longissimus area (cm^2)	14.04a	14.61ab	15.53bc	15.99c	0.30	0.03
Carcass length (cm)	67.9	66.3	66.4	66.2	0.61	0.38
Carcass width (cm)	31.4	28.6	29.7	29.3	0.97	0.27
Leg length (cm)	42.5	43.0	43.1	42.2	0.47	0.60
Kidney-pelvic fat (%)	2.72	2.61	2.54	2.87	0.19	0.31
Backfat thickness (mm)	2.34	2.89	3.25	2.93	0.19	0.23
Body wall thickness (mm)	14.21	14.59	13.80	14.70	0.37	0.84

Table 4. Treatment effects on yield of wholesale cuts

Basal diet supplemented to provide 0, 1, 2, or 3 g chromium-enriched live yeast culture per head per day. Within rows, means followed by different letters are significantly different at $P < 0.05$

Item	Chromium-enriched yeast level (g per head per day)					Contrast *P*-value
	Control	1	2	3	s.e.m.	linear
No. of lambs	10	10	10	10		
	Carcass and wholesale cuts weight (kg)					
Forequarter	6.3	6.1	6.2	5.7	0.18	0.11
Hindquarter	5.80	6.21	5.96	5.99	0.17	0.66
Neck weight	1.03	1.01	1.09	1.09	0.04	0.19
Shoulder	2.23	2.21	2.21	2.18	0.03	0.34
Shoulder IMPS206	1.35	1.31	1.27	1.25	0.04	0.11
Leg IMPS233	3.70a	3.82ab	3.88b	3.79ab	0.06	0.08
Loin IMPS231	1.11	1.12	1.08	1.11	0.02	0.66
Rack IMPS204	1.28	1.25	1.24	1.23	0.02	0.15
Flank IMPS232	1.04	0.97	0.99	0.93	0.03	0.03
Breast IMPS209 weight	0.39	0.32	0.37	0.34	0.03	0.11
	Whole cuts (% of cold carcass weight)					
Forequarter	22.08	21.29	21.64	20.10	0.60	0.13
Hindquarter	20.20	22.07	20.80	20.99	0.76	0.23
Neck	3.60	3.55	3.82	3.80	0.14	0.19
Shoulder	7.81	7.74	7.72	7.62	0.12	0.27
Shoulder IMPS206	4.69	4.55	4.41	4.34	0.15	0.15
Leg IMPS233	12.94	13.37	13.55	13.24	0.21	0.28
Loin IMPS231	3.88	3.90	3.70	3.87	0.08	0.38
Rack IMPS204	4.42	4.34	4.30	4.33	0.08	0.40
Flank	3.59a	3.37ab	3.43ab	3.24b	0.09	0.03
Breast IMPS209	1.33	1.10	1.30	1.18	0.08	0.72

supplementation on either ADG or GF of either light- (Kawas *et al.* 2007; Tripathi *et al.* 2008) or heavy-weight finishing lambs (Romero *et al.* 2009; Titi *et al.* 2008), or feedlot steers (Baumann *et al.* 2004).

The basis for inconsistencies in growth performance responses to non-mineral-enriched YC supplementation is not certain. In the majority of cases, changes in digestibility as result of yeast supplementation, was the main argument used to explain the difference in weight gain and/or GF observed for YC-supplemented diets (Khalid *et al.* 2011). The efficacy of YC supplementation may depend, in part, on chemical composition of the diet (Wohlt *et al.* 1991; Piva *et al.* 1993; Ding *et al.* 2008). Increasing the level of non-structural carbohydrates (grain, molasses, high-starch by-product feeds, etc.) in the diet may decrease fibre digestion through its influence ruminal pH and associated effects on the specific growth rates of cellulolytic bacteria. The predicted ruminal pH for the basal diet used in the present experiment is 5.82 (NRC 1996; Level 2). Growth of cellulolytic bacteria is optimal at ruminal pH of greater than 6.5. Between pH of 6.5 and 6.0, the specific growth rate decreases 14%/h for every 0.1-unit decrease in ruminal pH. Cellulolytic bacteria do not grow at ruminal pH below 6.0 (Russell and Wilson 1996).

The negative effects of diet on ruminal fibrolytic capacity may be partially overcome with YC supplementation. YC supplementation increased the concentration of ruminal cellulolytic bacteria (Dawson *et al.* 1990), and *in situ* (Williams *et al.* 1991), *in vitro* (Ruf *et al.* 1953), and *in vivo* (Zinn and Borquez 1993) NDF digestion.

YC supplementation of finishing diets at levels greater than 10×10^9 CFU/g increased in ADG and/or GF (Haddad and Goussous 2005; Ding *et al.* 2008). In the present experiment, ADG and GF were enhanced at supplementation level of 1 g/day. head (5.5×10^9 CFU).

Response to YC supplementation is also affected by type of YC utilised (alone or combined with minerals such as Cr or selenium; Domínguez-Vara *et al.* 2009). Previous reports indicate that Cr supplementation as Cr propionate or Cr methionine, improved ADG and feed efficiency in pigs (Lindemann *et al.* 1995; Mooney and Cromwell 1995; Jackson *et al.* 2009), and feedlot cattle (Barajas *et al.* 2008). Consistent with our findings, Valdés-García *et al.* (2011) reported no effect of Cr-YC supplementation on DMI, but linear improvements on ADG, GF, and dietary NE in finishing feedlot heifers fed a similar diet supplemented with 0, 10, 20 and 30 g/head.day Cr-YC. Likewise, Pechová *et al.* (2002) observed greater (26.8%) ADG in finishing bulls supplemented with 0.013 mg Cr/kg BW/day from Cr-YC during the initial 136 days of a finishing experiment. In contrast, Domínguez-Vara *et al.* (2009) did not observe an influence on growth performance of feedlot lambs supplemented with 0, 0.25, or 0.35 mg Cr/head from Cr-YC. Swanson *et al.* (2000) reported that supplementation with 0.10, 0.20, or 0.40 mg of Cr from Cr-YC did not affect ADG or GF in steers fed a corn silage-based diet. However, the maximum daily supplemental Cr intakes (mg Cr/kg BW) in these latter two studies (Swanson *et al.* 2000; Domínguez-Vara *et al.* 2009) were low (0.009 and 0.010 mg, respectively).

Previous studies (Petersen *et al.* 1987; Cole *et al.* 1992) demonstrated that YC supplementation may reduce urinary mineral excretion and increase total daily metabolisable minerals and retention. Nevertheless, the bioavailability of even chelated Cr may be low. Holland (1982) observed that 55% of ingested Cr was excreted by rats fed Cr-enriched yeast, and of the remaining 45%, only half could be detected in body tissues.

Visceral organ mass and carcass traits

Romero *et al.* (2009) observed that supplementation of feedlot steers with 0.18 mg/kg of DM of Cr via Cr-YC increased the carcass dressing percentage. In contrast, Titi *et al.* (2008) observed decreased dressing percentages in lambs supplemented with YC at rate of 12.5 g/day.head.

Consistent with the present study, Kitchalong *et al.* (1995) observed that supplementation with 0.25 mg/kg of Cr tripicolinate did not affect heart, liver, kidney or pelvic fat weight of feedlot lambs. The addition of 0.2 mg/kg of Cr as Cr nicotinate increased head, liver, and kidney weights, and decreased the internal fat weight in fat-tailed lambs (Mostafa-Tehrani *et al.* 2006). Gentry *et al.* (1999) observed greater kidney weight, but reduced liver weight in lambs supplemented with Cr tripicolinate in high-protein diets (12.9% CP). However, they did not observe those effects of Cr supplementation on carcass characteristics with Cr supplementation of low-protein diets (9.0% CP).

As discussed previously, the effect of YC supplementation, alone (not enriched with Cr), on carcass characteristics (Jones *et al.* 1997; Kawas *et al.* 2007; Payandeh and Kafilzadeh 2007; Titi *et al.* 2008; Zerby *et al.* 2011), wholesale cuts (Titi *et al.* 2008; Whitley *et al.* 2009), or visceral mass (Belewu and Jimoh 2005) of feedlot lambs has been small and non-appreciable. Thus, is expected that the changes in carcass measures in the present experiment are more directly related to Cr intake, *per se*.

Effects of Cr-YC supplementation of lambs on carcass characteristics and yield of wholesale cuts has not been previously reported. Cr appears to potentiate insulin action by enhancing its binding to target cell receptors, and also by improving its post-receptor signalling, contributing to enhanced lean tissue growth (Debski *et al.* 2004; Pechová and Pavlata 2007). Accordingly, increased carcass leanness and LM area in pigs (Page *et al.* 1993; Mooney and Cromwell 1995), and increased carcass leanness in birds (Sahin *et al.* 2002, 2003) have been consistent responses to Cr supplementation. Likewise, Cr supplementation increased glucose uptake, enhanced protein synthesis (Pollard *et al.* 2001), and reduced body fat (Barajas *et al.* 2008; Valdés-García *et al.* 2011) in feedlot cattle fed conventional finishing diets.

Romero *et al.* (2009) did not observe an effect of Cr-YC supplementation (0.18 mg/kg of DM of Cr) on measures of LM area, and external and internal fat deposition in feedlot steers. Domínguez-Vara *et al.* (2009) observed increased HCW weight, LM area and carcass protein levels, and decreased carcass fat in finishing lambs supplemented with 0.25 mg/kg of Cr plus 0.3 mg/kg of selenium from Cr and selenium-enriched yeast. However, supplementation with Cr alone did not affect the carcass characteristics.

Supplemental Cr requirements of ruminants have not been established (NRC 1997, 2007; Murdoch *et al.* 2006). In the present study, the average consumption of supplemental Cr per kg of BW was 0.019 (range from 0.009 to 0.028). This represents at least a 2-fold increase over that of dosages used in other studies where there was no consistent effect on growth performance or carcass traits in cattle supplemented with enriched Cr yeast (Swanson *et al.* 2000; Domínguez-Vara *et al.* 2009; Romero *et al.* 2009). Thus it appears that optimal levels of supplemental Cr required to enhance growth performance and carcass characteristics in ruminants may be greater than those proposed for pigs.

Conclusions

Chromium-enriched yeast supplementation markedly enhances the growth performance, dietary NE, HCW and LM area in finishing feedlot lambs. Maximal response (gain and efficiency) was observed when Cr-YC was supplemented at the rate of 3 g/day (1.65×10^{10} CFU and 1.20 mg of Cr).

References

Abas I, Kutay HC, Kahraman R, Toker NY, Ozcelik D, Ates F, Kacakci A (2007) Effects of organic acid and bacterial direct-fed microbial on fattening performance of Kivircik-Male yearling lambs. *Pakistan Journal Nutrition* **2**, 149–154.

Abdelrahman MM, Hunaiti DA (2008) The effect of dietary yeast and protected methionine on performance and trace minerals status of growing Awassi lambs. *Livestock Science* **115**, 235–241. doi:10.1016/j.livsci.2007.07.015

Adams DC, Galyean ML, Kiesling HE, Wallace JD, Finkner MD (1981) Monensin on liquid dilution rate, rumen fermentation and feedlot performance of growing steers and digestibility in lambs. *Journal of Animal Science* **53**, 780–789.

AOAC (2000) 'Official methods of analysis.' 17th edn. (Association of Official Analytical Chemists: Washington, DC)

Barajas R, Cervantes BJ, Velazquez EA, Romo JA, Juarez F, Rojas PJ, Peña FR (2008) Chromium methionine supplementation on feedlot performance and carcass characteristics of bulls: II. Results including trough hot and humidity season in the Northwest of Mexico. *Proceedings of Western Section of Society American of Animal Science* 59, 374–375.

Baumann TA, Radunz AE, Lardy GP, Anderson VL, Caton JS, Bauer ML (2004) Effects of tempering and a yeast-enzyme mixture on intake, ruminal fermentation, *in situ* disappearance, performance, and carcass traits in steers fed barley-based diets. *The Professional Animal Scientist* **20**, 178–184.

Belewu MA, Jimoh NO (2005) Blood, carcass and organ measurements as influenced by *Aspergillus niger* treated Cassava waste in the diets of West African dwarf goat. *Global Journal of Agriculture Science* **4**, 125–128.

Cannas A, Tedeschi LO, Fox DG, Pell AN, Van Soest PJ (2004) A mechanistic model for predicting the nutrient requirements and feed biological values for sheep. *Journal of Animal Science* **82**, 149–169.

Canton JG, Quintal JA (2007) Evaluation of growth and carcass characteristics of pure Pelibuey sheep and their cross with Dorper and Kathdin breeds. *Journal of Animal Science* **85**(Suppl. 1), 581.

Chang X, Mowat DN (1992) Supplemental chromium for stressed and growing feeder calves. *Journal of Animal Science* **70**, 559–565.

Cole NA, Purdy CW, Hutcheson DP (1992) Influence of yeast culture on feeder calves and lambs. *Journal of Animal Science* **70**, 1682–1690.

CSIRO (1990) 'Standing Committee on Agriculture. Ruminants Subcommittee. Feeding standards for Australian livestock. Ruminants.' (CSIRO Publications: Melbourne)

Dawson KA, Newman KE, Boling JA (1990) Effects of microbial supplements containing yeast and lactobacilli on roughage-fed ruminal microbial activities. *Journal of Animal Science* **68**, 3392–3398.

Debski B, Zalewski W, Gralak MA, Kosla T (2004) Chromium-yeast supplementation of chicken broilers in an industrial farming system. *Journal of Trace Elements in Medicine and Biology* **18**, 47–51. doi:10.1016/j.jtemb.2004.02.003

Ding J, Zhou ZM, Ren LP, Meng QX (2008) Effect of monensin and live yeast supplementation on growth performance, nutrient digestibility, carcass characteristics and ruminal fermentation parameters in lambs fed steam-flaked corn-based diets. *Asian-Australasian Journal of Animal Sciences* **21**, 547–554.

Domínguez-Vara IA, González-Muñoz SS, Pinos-Rodríguez JM, Bórquez-Gastelum JR, Bárcena-Gama R, Mendoza-Martínez G, Zapata LE, Landois-Palencia LL (2009) Effects of feeding selenium-yeast and chromium-yeast to finishing lambs on growth, carcass characteristics, and blood hormones and metabolites. *Animal Feed Science and Technology* **152**, 42–49. doi:10.1016/j.anifeedsci.2009.03.008

Galip N (2006) Effects of dietary S*accharomyces cerevisiae* live yeast culture supplementation on ruminal digestion and protozoa count in rams fed with diets with low or high ratio forage/concentrate. *Revue de Medecine Veterinaire* **157**, 609–613.

Gentry LR, Fernandez JM, Ward TL, White TW, Southern LL, Bidner TD, Thompson L Jr, Horohov DW, Chapa AM, Sahlu T (1999) Dietary protein and chromium tripicolinate in Suffolk wether lambs: effects on production characteristics, metabolic and hormonal responses, and immune status. *Journal of Animal Science* **77**, 1284–1294.

Haddad SG, Goussous SN (2005) Effect of yeast culture supplementation on nutrient intake, digestibility and growth performance of Awassi lambs. *Animal Feed Science and Technology* **118**, 343–348. doi:10.1016/j.anifeedsci.2004.10.003

Hinman DD, Sorensen SJ, Momont PA (1998) Effect of yeast culture on steer performance, apparent diet digestibility, and carcass measurements when used in a barley and potato finishing diet. *The Professional Animal Scientist* **14**, 173–177.

Holland PN (1982) Absorption and tissue deposition of chromium and selenium from brewer's yeast in the mouse. MS thesis, Texas Tech. University, La Joya, CA.

Jackson AR, Powell S, Johnston SL, Matthews JO, Bidner TD, Valdez FR, Southern LL (2009) The effect of chromium as chromium propionate on growth performance, carcass traits, meat quality, and the fatty acid profile of fat from pigs fed no supplemented dietary fat, choice white grease, or tallow. *Journal of Animal Science* **87**, 4032–4041. doi:10.2527/jas.2009-2168

Jones BA, Neary MK, Hancock DL, Berg EP, Huffman J, Flanders JR (1997) Effect of zeranol implantation and yeast supplementation on performance and carcass traits of finishing wether lambs. *Sheep and Goat Research Journal* **13**, 15–19.

Kawas JR, Garcia-Castillo R, Garza-Cazares F, Fimbres-Durazo H, Olivares-Saenz E, Hernandez-Vidal G, Lu CD (2007) Effects of sodium bicarbonate and yeast on productive performance and carcass characteristics of light-weight lambs fed finishing diets. *Small Ruminant Research* **67**, 157–163. doi:10.1016/j.smallrumres.2005.09.011

Khalid MF, Shahzad MA, Sarwar M, Rehman AU, Sharif M, Mukhtar N (2011) Probiotics and lamb performance: a review. *African Journal of Agriculture Research* **23**, 5198–5203.

Kitchalong L, Fernandez JM, Bunting LD, Southern LL, Bidner TD (1995) Influence of chromium tripicolinate on glucose metabolism and nutrient partitioning in growing lambs. *Journal of Animal Science* **73**, 2694–2705.

Krehbiel CR, Rust SR, Zhang G, Gilliland SE (2003) Bacterial direct-fed microbials in ruminant diets: performance response and mode of action. *Journal of Animal Science* **81**, E120–E132.

Lindemann MD, Wood CM, Harper AF, Kornegay ET, Anderson RA (1995) Dietary chromium picolinate additions improve gain:feed and carcass characteristics in growing-finishing pigs and increase litter size in reproducing sows. *Journal of Animal Science* **73**, 457–465.

Mir Z, Mir PS (1994) Degradability quality of steers fed high-forage or high-grain diets and on feed digestibility and *in situ* effect of the addition of live yeast (*Saccharomyces cerevisiae*) on growth and carcass. *Journal of Animal Science* **72**, 537–545.

Mooney KW, Cromwell GL (1995) Effects of dietary chromium picolinate supplementation on growth, carcass characteristics, and accretion rates of carcass tissues in growing-finishing swine. *Journal of Animal Science* **73**, 3351–3357.

Mostafa-Tehrani A, Ghorbani G, Zarre-Shahneh A, Mirhadi SA (2006) Noncarcass components and wholesale cuts of Iranian fat-tailed lambs fed chromium nicotinate or chromium chloride. *Small Ruminant Research* **63**, 12–19. doi:10.1016/j.smallrumres.2005.01.013

Murdoch GK, Okine EK, Christopherson RJ (2006) Metabolic modifiers in animal nutrition: potential benefits and risks. In 'Biology of nutrition in growing animals. 4'. (Eds R Mosenthin, J Zentek, T Zebrowska) pp. 135–178. (Elsevier: Philadelphia)

NAMP (1997) 'The meat buyers guide.' (North American Meat Processor Association: Weimar, TX)

Neville TL, Ward MA, Reed JJ, Soto-Navarro SA, Julius SL, Borowicz PP, Taylor JB, Redmer DA, Reynolds LP, Caton JS (2008) Effects of level and source of dietary selenium on maternal and fetal body weight, visceral organ mass, cellularity estimates, and jejunal vascularity in pregnant ewe lambs. *Journal of Animal Science* **86**, 890–901. doi:10.2527/jas.2006-839

NRC (1985) 'Nutrient requirements of sheep.' 6th edn. (National Academy Press: Washington, DC)

NRC (1996) 'Nutrient requirements of beef cattle.' 7th edn. (National Academy Press: Washington, DC)

NRC (1997) 'The role of chromium in animal nutrition.' (National Academy Press: Washington, DC)

NRC (2007) 'Nutrient requirements of small ruminants. Sheep, goats, cervids, and New World camelids.' (National Academy Press: Washington, DC)

Page TG, Southern LL, Ward TL, Thompson DL Jr (1993) Effect of chromium picolinate on growth and serum and carcass traits of growing-finishing pigs. *Journal of Animal Science* **71**, 656–662.

Pallauf J, Muller AS (2006) Inorganic feed additives. In 'Biology of nutrition in growing animals. 4'. (Eds R Mosenthin, J Zentek, T Zebrowska) pp. 179–249. (Elsevier: Philadelphia, PA)

Payandeh S, Kafilzadeh F (2007) The effect of yeast (*Saccharomyces cerevisiae*) on nutrient intake, digestibility and finishing performance of lambs fed a diet based on dried molasses sugar beet-pulp. *Pakistan Journal of Biological Sciences* **10**, 4426–4431. doi:10.3923/pjbs.2007.4426.4431

Pechová A, Pavlata L (2007) Chromium as an essential nutrient: a review. *Veterinarni Medicina* **52**, 1–18.

Pechová A, Illek J, Indela M, Pavlata L (2002) Effects of chromium supplementation on growth rate and metabolism in fattening bulls. *Acta Veterinaria* **71**, 535–541. doi:10.2754/avb200271040535

Petersen MK, Streeter CM, Clark CK (1987) Mineral availability with lambs fed yeast culture. *Nutrition Reports International* **36**, 521–526.

Phillips WA, VonTungeln DL (1985) The effect of yeast culture on the post-stress performance of feeder calves. *Nutrition Reports International* **32**, 287–294.

Piva G, Belladonna S, Fusconi G, Sichaldi F (1993) Effects of yeast on dairy cow performance, ruminal fermentation, blood components, and milk manufacturing properties. *Journal of Dairy Science* **76**, 2717–2722. doi:10.3168/jds.S0022-0302(93)77608-0

Pollard GV, Mongomery JL, Bramble TC, Morrow KJ Jr, Richardson CR, Jackson SP, Blanton JR Jr (2001) Effects of organic chromium on protein synthesis and glucose uptake in ruminants. *The Professional Animal Scientist* **17**, 261–266.

Romero M, Pinos-Rodríguez JM, Herrera JG, García JC, Salem AZM, Bárcena R, Alvarez G (2009) Influence of zilpaterol and mineral-yeast mixture on ruminal fermentation and growth performance in finishing steers. *Journal of Applied Animal Research* **35**, 77–81. doi:10.1080/09712119.2009.9706989

Ruf EW, Hale WH, Burroughs W (1953) Observations upon an unidentified factor in feedstuffs stimulitory to cellulose digestion in the rumen and improved liveweight gains in lambs. *Journal of Animal Science* **12**, 731–739.

Russell JB, Wilson DB (1996) Why are ruminal cellulolytic bacteria unable to digest cellulose at low pH? *Journal of Dairy Science* **79**, 1503–1509. doi:10.3168/jds.S0022-0302(96)76510-4

Sahin K, Sahin N, Ondersi M, Gursu F, Cikim G (2002) Optimal dietary concentration of chromium for alleviating the effect of heat stress on growth, carcass qualities, and some serum metabolites of broiler chickens. *Biological Trace Element Research* **89**, 53–64. doi:10.1385/BTER:89:1:53

Sahin K, Sahin N, Kucuk O (2003) Effects of chromium, and ascorbic acid supplementation on growth, carcass traits, serum metabolites, and antioxidant status of broiler chickens reared at a high ambient temperature (32°C). *Nutrition Research (New York, N.Y.)* **23**, 225–238. doi:10.1016/S0271-5317(02)00513-4

SAS Institute (2004) 'SAS/STAT: user's guide statistic. Release 9.1.' (SAS Institute Inc.: Cary, NC)

Swanson KC, Harmon DL, Jacques KA, Larson BT, Richards CJ, Bohnert DW, Paton SJ (2000) Efficacy of chromium-yeast supplementation for growing beef steers. *Animal Feed Science and Technology* **86**, 95–105. doi:10.1016/S0377-8401(00)00142-5

Titi HH, Dmour RO, Abdullah AY (2008) Growth performance and carcass characteristics of Awassi lambs and Shami goat kids fed yeast culture in their finishing diet. *Animal Feed Science and Technology* **142**, 33–43. doi:10.1016/j.anifeedsci.2007.06.034

Tripathi MK, Karim SA, Chaturvedi OH, Verma DL (2008) Effect of different liquid cultures of live yeast strains on performance, ruminal fermentation and microbial protein synthesis in lambs. *Journal of Animal Physiology and Animal Nutrition* **92**, 631–639. doi:10.1111/j.1439-0396.2007.00759.x

Underwood EJ, Suttle NF (1999) 'The mineral nutrition of livestock.' 3rd edn. (CABI Publishing: New York)

USDA (1982) 'Official United States Standards for Grades of carcass lambs, yearling mutton and mutton carcasses.' (Agriculture Marketing Services, USDA: Washington, DC)

Valdés-García YS, Aguilera-Soto JI, Barreras A, Estrada-Angulo A, Gómez-Vázquez A, Plascencia A, Ríos FG, Reyes JJ, Stuart J, Torrentera N (2011) Growth performance and carcass characteristics in finishing feedlot heifers fed different levels of chromium-enriched live yeast or fed zilpaterol hydrochloride. *Cuban Journal of Agricultural Science* **4**, 361–368.

Van Soest PJ, Robertson JB, Lewis BA (1991) Methods for dietary fiber, neutral detergent fiber, and nonstarch polysaccharides in relation to animal nutrition. *Journal of Animal Science* **24**, 834–843.

Whitley NC, Cazac D, Rude BJ, Jackson-O'Crien D, Parveen S (2009) Use of commercial probiotic supplement in meat goats. *Journal of Animal Science* **87**, 723–728.

Williams PE, Tait CA, Innes GM, Newbold CJ (1991) Effects of the inclusion of yeast culture (*Saccharomyces cerevisiae* plus growth medium) in the diet of dairy cows on milk yield and forage degradation and fermentation patterns in the rumen of steers. *Journal of Animal Science* **69**, 3016–3026.

Wohlt JE, Finkelstein AD, Chung CH (1991) Yeast culture to improve intake, nutrient digestibility, and performance by dairy cattle during early lactation. *Journal of Dairy Science* **74**, 1395–1400. doi:10.3168/jds.S0022-0302(91)78294-5

Zerby HN, Bard JL, Loerch SC, Kuber PS, Radunz AE, Fluharty FL (2011) Effects of diet and *Aspergillus oryzae* extract or *Saccharomyces cervisiae* on growth and carcass characteristics of lambs and steers fed to meet requirements of natural markets. *Journal of Animal Science* **89**, 2257–2264. doi:10.2527/jas.2010-3308

Zinn RA, Borquez JL (1993) Interaction of restricted versus ad libitum access to feed on effects of yeast culture supplementation on digestive function in feedlot calves. *Proceedings of Western Section of American Society of Animal Science* **44**, 424–429.

Zinn RA, Alvarez EG, Rodriguez S, Salinas J (1999) Influence of yeast culture on health, performance and digestive function of feedlot steers. *Proceedings of Western Section of Society American of Animal Science* **50**, 335–337.

Zinn RA, Barreras A, Owens FN, Plascencia A (2008) Performance by feedlot steers and heifers: daily gain, mature body weight, dry matter intake, and dietary energetics. *Journal of Animal Science* **86**, 2680–2689. doi:10.2527/jas.2007-0561