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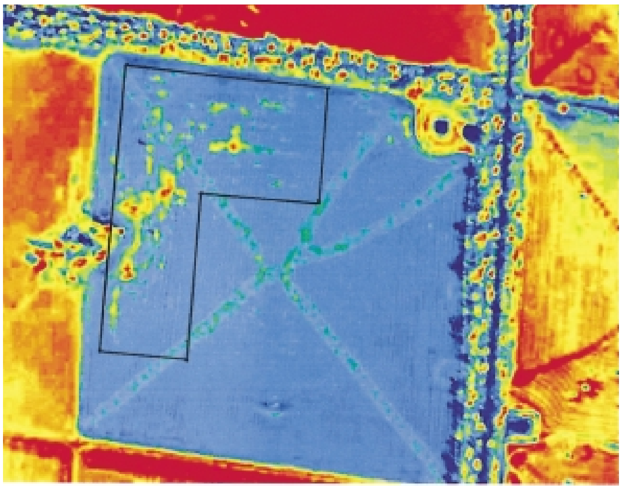

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Post-weaning growth of cattle in northern New South Wales 3. Carry-over effects on finishing, carcass characteristics and intramuscular fat

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Abstract. The effects of prior growth on subsequent growth and body composition of cattle potentially affect the profitability of growing cattle to meet specifications based on weight and fatness. The effects of different growth rates and patterns of growth between weaning (about 230 kg) and entry to finishing (average 400 kg) on growth rate, carcass characteristics and intramuscular fat content of steers finished on pasture and in a feedlot on a predominantly grain ration to 2 liveweights (520 kg, Korean and >600 kg, Japanese) are reported here. Over a period of 4 years (1994–1997), 1095 *Bos taurus* steers of 4 breeds (Angus, Hereford, Murray Grey and Shorthorn), were allocated to 1 of 3 grow-out pathways from weaning until entry into finishing. The pathways were based on introduced pasture (P1), with different animal growth rates induced by strategic supplementation with a pelleted concentrate feed (P2), or a forage crop (P3) (Ayres *et al.* 2001; Dicker *et al.* 2001).

In general, the mean growth rate of steers from the different growth pathways during finishing was inversely related to mean growth rate during grow-out. However, where the difference in liveweight at the end of grow-out was greater than 15 kg, increased growth rate during finishing was insufficient to permit complete catch up of liveweight by the end of finishing. There was no further compensation beyond 520 kg liveweight. Steers with better nutrition during grow-out tended to have more intramuscular fat at Japanese market weights, but lower retail meat yield. Steers finished on pasture had less fat thickness and intramuscular fat content than those finished on the grain based ration. Compared with P3 steers, there was a tendency for steers from pathways P1 and P2 to have lower intramuscular fat content in their *M. longissimus* at Japanesese market weights.

Additional keywords: pathways, compensatory growth, feedlot, pasture.

Introduction

Nutritional environment has a profound effect on growth and fatness of beef cattle (see e.g. Keele *et al.* 1992; Williams and Bennett 1995). In practice, the relationship between growth rate before finishing, and finishing performance, is managed by ensuring animals entering grain finishing are within a comparatively narrow range of liveweights and fat thickness. It is recognised that differences in growth before feedlot entry may be associated with different degrees of compensatory growth in the feedlot (Drouillard and Kuhl 1999) and fat deposition, hence yield of saleable meat (Carstens 1995). Williams and Bennett (1995) devised a general method of estimating total fatness (and proportionately marble score) of cattle grown out under different production conditions and from this, estimated feasible grow-out and finishing pathways for a range of genotypes of cattle under North American production scenarios. There are no comparable data available for cattle grown and finished under Australian conditions. It is not known if differences in growth before finishing (either in feedlot or at pasture) are related to variation in attributes such as intramuscular fat and meat quality. These attributes are increasingly used as determinants of carcass value, which is becoming an important component of the overall economics of beef cattle production.

The study reported here is a subset of the straightbreeding program of the CRC for Cattle and Beef Quality (Upton *et al.* 2001). Cattle from the southern collaborator properties were weaned and then transferred to NSW Agriculture's Glen Innes Research and Advisory Station, assigned to treatment combinations as described by Upton *et al.* (2001) and grown out on pasture as described by Ayres *et al.* (2001) and Dicker *et al.* (2001). In this environment, pasture quantity declines in mid to late winter, imposing a restriction

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Table 1. Date of first weighing, mean weight and age at first weighing, start and end dates of feed supplementation and last grow-out weighing

Cohort	Date of first weighing	Mean weight (kg)	Mean age (days)	Start of supplementation Forage	Pellets	End of supplementation Forage	Pellets	Last grow-out weighing
A94	06 June 94[A]	252	288	08 Aug. 94	05 Aug. 94	17 Oct. 94[B]	17 Oct. 94	18 Jan. 95
A95	28 June 95[A]	247	329	10 July 95	10 July 95	08 Nov. 95	08 Nov. 95	05 Feb. 96
A96	25 June 96	262	320	22 July 96	23 July 96	29 Nov. 96	14 Oct. 96	29 Nov. 96
A97	23 June 97	257	321	03 Dec. 97	25 Nov. 97	08 Jan. 98[B]	21 Jan. 98	02 Mar. 98

[A]For A94, one herd was first weighed on 10 June 1994; for A95, some animals were weighed on 29 June 1995.
[B]Forage supplementation of A94 terminated on 17 October 1994, but recommenced from 19 December to 12 January 1995. Forage supplementation of A97 terminated 8 January 1998 but recommenced from 26 February 1998 to 7 March 1998 (257 days from first weighing).

on cattle growth. Practical options to overcome this seasonal growth restriction in this environment include provision of additional feed, which, in the study reported here, consisted of either a fodder crop or a pelleted concentrate (Dicker *et al.* 2001). These pasture and fodder options were used to generate divergent growth pathways in cattle being grown to an average liveweight of 400 kg, the entry weight in commercial practice for finishing export market cattle. The effect of divergent growth during grow-out upon growth during finishing and subcutaneous fat thickness, intramuscular fat content of *M. longissimus* and meat yield following finishing either on pasture or on a grain-based diet in a feedlot to about 520 kg (Korean) and >600 kg (Japanese) market end points are reported here.

Material and methods

Cattle and feed management during grow-out

The soils, pastures, pasture and feed management as well as cattle management strategies employed in this study have been reported elsewhere in this volume (Ayres *et al.* 2001; Dicker *et al.* 2001). Briefly, 4 cohorts of Angus, Hereford, Murray Grey and Shorthorn steers (A94, A95, A96 and A97) were grown via differing growth paths to an overall group mean target liveweight of 400 kg before finishing either on pasture or in a feedlot. Divergent growth paths were achieved by supplementary feeding high protein pellets (group P2), allowing access to a forage crop (P3) or by grazing pasture with no supplementation (P1). Additional feed (concentrate or forage) was provided during winter/early spring, about 100–200 days before the animals reached the target liveweight of 400 kg for entry to finishing treatments (Dicker *et al.* 2001), except in 1997 (cohort A97). In this latter cohort, P3 and P2 steers were given access to supplement or forage 3 months before finishing; P1 steers were subject to a higher stocking rate with no supplementation and so maintained only a low growth rate. These treatments resulted in a mean liveweight difference of 50 kg between supplemented (P2, P3) and P1 groups in cohort A97. Table 1 summarises the treatment of cattle during grow-out, including start and end dates of feed supplementation and the number of days from the initial until the final weighing during grow-out.

Cattle and feed management during finishing

Steers were grown out to an across-treatment average liveweight of 400 kg before trucking for finishing on pasture at the University of New England's McMaster field station (Warialda) or in the CRC research feedlot (Tullimba). A full description of the physical location and stock management at these properties is given elsewhere (Bindon 2001; Upton *et al*. 2001). At each location, cattle were split into 2 subgroups and finished to either an average liveweight of about 520 kg (Korean market specification, which for feedlot finishing included a minimum of 100 days grain feeding) or more than 600 kg (Japanese market specification, feedlot finish for over 150 days grain feeding). Pasture conditions at Warialda were not recorded, but in accord with industry practice, cattle were managed to have access to the best pastures available. In the feedlot, cattle were adapted to a grain diet over a period of 14 days, then offered a finisher diet comprising mainly dry rolled barley and milled sorghum hay. Detailed composition and estimated nutrient density are shown in Table 2.

Measurements

During grow-out, steers were weighed at about 3-week intervals corresponding to pasture assessment and movements between pasture blocks (see Dicker *et al.* 2001). Subcutaneous fat thickness at the rump (P8) and 12th/13th rib sites and cross-sectional area of *M. longissimus* at the 12th/13th rib site were recorded by ultrasound scanning (Robinson *et al.* 1992) on entry to grow-out, at the commencement of finishing and at the end of the finishing phase as described by Upton *et al*. (2001). All weights were directly off feed (full weights).

Table 2. Composition and nutritive value (mean ± s.d.) of ration fed during the finishing period in the feedlot

Component	Composition (%)	Nutritive value[A] (%)
Dry rolled barley	75.0	
Milled sorghum hay (50 mm screen)	10.5	
Protein pellets[B]	5.0	
Molophos[C]	8.0	
Powdered limestone	1.0	
Sulfate of ammonia	0.5	
Dry matter (% DM)[D]		87.9 ± 2.02
Crude protein (% DM)[D]		14.6 ± 1.46
Acid detergent fibre (% DM)		11.1 ± 1.72
Digestibility (% DMD)[E]		80.6 ± 1.35
Metabolisable energy (MJ/kg DM)[F]		12.1 ± 0.21

[A]Nutritive values are for 50 samples for period Feb. 1996–Jan. 1999.
[B]Protein supplement consisted of pelletted cottonseed meal (Cargill Australia).
[C]Molasses mix containing urea, Monensin and minerals (Ridley Corporation, Wacol, Qld).
[D]Determined by Agritech Laboratory Services Pty Ltd as Kjeldahl nitrogen × 6.25 (Toowoomba, Qld).
[E]Calculated from crude protein and acid detergent fibre contents (Oddy *et al.* 1983).
[F]Calculated from dry matter digestibility (as 0.15 × % DMD).

In the period immediately before slaughter, animals were subjected to the protocol described by Perry *et al.* (2001). This included ultrasound scanning about 1 week before trucking to the abattoir in time to comply with minimum time in lairage, consistent with best practice at the slaughter works. All animals were slaughtered and electrically stimulated in accord with a standard protocol (Perry *et al*. 2001). Retail beef yield was measured directly after bone-out using cuts trimmed to 3 mm surface fat. Intramuscular fat percentage (IMF%) was measured on a sample of *M. longissimus* close to the 12th/13th rib site using near infrared spectroscopy (Technicon Infralyser 450, Bran and Luebbe, Australia) calibrated against Soxhlet extraction of fat in boiling chloroform for 24 h. The calibration equation explained 96% of variation in measured intramuscular fat percentage (Perry *et al.* 2001).

Statistical analysis

Grow-out. Measurements during grow-out were analysed for each intake cohort by fitting a mixed linear model:

$$\text{Gain} = \text{pathway} + \text{age} + \text{sire} + \text{breed} + \text{birth-herd} + \text{pathway.breed} + \text{pathway.birth-herd} \quad (1)$$

where growth pathway and age were fitted as fixed and all other terms including sire, breed (Angus and Shorthorn in A94; Angus, Shorthorn, Herford and Murray Grey in A95, A96 and A96) and birth-herd were fitted as random effects. Birth-herd was the herd in which steers were born and raised to weaning; each birth-herd contained only 1 breed.

For all cohorts except A97, 4 measurements of grow-out gain were analysed: (i) mean gain (kg) from first weighing until the end of supplementation; (ii) mean gain (kg/day) from first weighing until the end of supplementation; (iii) mean gain (kg) for the entire grow-out period; and (iv) mean gain (kg/day) for the entire grow-out period.

Model 1 was also fitted to ultrasound measurements of subcutaneous rump and rib fat at the P8 and 12th/13th rib sites at the end of the grow-out period, except that liveweight was used as a covariate, instead of age. Liveweight was fitted as a covariate to determine if differences in subcutaneous fat were greater than what would be expected due to differences between the liveweights of the different groups.

Finishing. Traits analysed were liveweight gain (kg and kg/day) during finishing, carcass weight (kg), retail meat yield (kg and % of carcass weight), intramuscular fat (%) of the *M. longissimus* muscle and ultrasound scan measurements of subcutaneous rump fat at the P8 site and 12th/13th rib fat measured 1 week before slaughter. In addition, total gain (kg and kg/day) from first weighing in grow-out to the final weighing at the end of finishing was analysed.

Performance during finishing is potentially influenced by all factors affecting growth during grow-out, as well as market category (Korean or Japanese), method of finishing (pasture or feedlot), and interactions of all the above. An analysis was therefore carried out of each cohort using REML (Robinson 1987) fitting as fixed:

growth pathway × market × finish + age
(for fatness traits carcass weight was fitted instead of age)

and the following terms as random:

sire + breed + birth-herd + brd.fin + brd.mark + brd.mark.fin + brd.mark.pway + brd.fin.pway + hrd.mark + hrd.fin + hrd.mark.fin + hrd.mark.pway + hrd.fin.pway + dofm

where pway is growth pathway, hrd is birth-herd, mark is market, fin is finish and dofm is date of measurement. The latter was fitted only if all animals in each market × finish combination were not measured on the same day.

Japanese market steers were older and heavier than Korean steers, and pasture-finished steers tended to be older than feedlot-finished steers. To avoid adjusting market and finish effects for age and weight, the covariates (age or carcass weight) were adjusted to mean zero for each market × finish combination, before fitting the above model.

In addition to the individual analyses of each cohort, a combined analysis was carried out of the 3 cohorts (A94, A95 and A96) in which the same management protocol was used, in order to investigate the consistency of effects over years.

Because of the large number of factors potentially affecting measurements, a screening analysis to estimate variance components was conducted using ASREML (Gilmour *et al.* 1998). All factors were fitted as random, including sire, breed, birth-herd, finish, market, intake cohort, growth pathway, day of measurement (if all animals in cohort × market × finish combination were not measured on the same day) as well as all 2, 3 and 4-way interactions of all factors except sire, which was fitted just as a main effect. Age (adjusted to mean zero for each cohort × market × finish combination) was fitted as a fixed covariate to account for age differences within each group. For subcutaneous and intramuscular fat measurements, carcass weight was also used as a covariate.

Once variance components had been estimated for all factors and interactions, complex interaction terms with estimated variance components not different from zero were dropped and the data re-analysed to determine the most important factors affecting the trait of interest. Best unbiased linear predictions (BLUP) of grow-out pathway, market and finish were calculated along with standard errors of differences (s.e.d.). Because of the major effect of market on total gain during finishing (kg) and fatness, variance components were also estimated with market as a fixed effect to determine other major influences. For rate of gain during finishing (kg/day), for which feedlot and pasture finishing systems were the major influence, finish was fitted as a fixed effect with all other terms fitted as random.

Index of compensation. An index of compensation was determined using equation 2 where P1 is liveweight of steers in P1, Pn is liveweight of steers in P2 or P3 and the subscripts *f* and *g* refer to liveweight gain during finishing and grow-out respectively (Wilson and Osbourne 1960):

$$\text{Index (\%)} = \frac{\text{Liveweight change during finish}}{\text{Liveweight change during grow-out}} = \frac{(\text{P1} - \text{Pn})_f}{(\text{Pn} - \text{P1})_g} \times 100 \quad (2)$$

Results

Grow-out. The pattern of liveweight change during grow-out of steers in cohorts A94, A95 and A96 has been described elsewhere in this volume (Dicker *et al.* 2001). Mean liveweight gain (kg and kg/day) during the period of supplementation, liveweight at the end of supplementation, and liveweight and fat thickness upon entry to the finishing phase are shown in Table 3. Data on animals from cohort A97 in which divergence in pattern of growth was induced by controlling access to pasture and supplement in the period about 90 days before entry to finishing are also shown in Table 3. A pictorial description of the pattern of growth of steers in the A97 cohort is shown in Figure 1.

Finishing. Liveweight a week before slaughter, rate of liveweight gain during the finishing period, carcass weight, retail meat yield, scanned rump (P8) fat thickness and intramuscular fat content of *M. longissimus* are shown in Tables 4 and 5. Table 4 shows estimated means by market (Korean and Japanese) and by finishing system (pasture and feedlot) after adjustment for herd of origin and breed

Table 3. Mean growth and fatness measurements of cohorts of Korean and Japanese market steers during grow-out on different growth pathways

Cohort	Mean end liveweight (kg)				Mean gain (kg)				Mean rate of gain (kg/day)			
	P3	P2	P1	s.e.d.	P3	P2	P1	s.e.d.	P3	P2	P1	s.e.d.
					Growth from beginning of grow-out to end of supplementation							
A94	353	333	320	5.3	107	87	71	3.2	0.80	0.65	0.54	0.02
A95	343	332	291	4.8	96	88	47	3.7	0.74	0.67	0.36	0.03
A96	362	348	332	4.8	103	88	72	2.9	0.66	0.56	0.46	0.02
					Growth from beginning of grow-out to end of grow-out							
A94	422	398	382	7.0	180	156	137	4.0	0.80	0.69	0.61	0.02
A95	419	394	362	4.4	173	151	120	3.3	0.78	0.68	0.54	0.01
A96	432	406	399	4.6	173	146	139	2.7	1.10	0.93	0.89	0.02
A97	427	428	376	4.2	173	174	124	3.4	0.70	0.70	0.50	0.01
Cohort	Mean P8 rump fat (mm)				Mean 12th/13th rib fat (mm)							
	P3	P2	P1	s.e.d.	P3	P2	P1	s.e.d.				
	Scanned fat measurements at end of grow-out											
A94	7.8	7.5	6.5	0.8	5.8	4.4	4.2	0.3				
A95	5.5	5.1	4.3	0.2	4.2	3.6	2.7	0.2				
A96	8.8	6.6	6.3	0.3	7.3	4.8	4.5	0.2				
A97	6.7	4.9	3.6	0.3	4.8	3.8	2.4	0.2				

separately for each cohort. Table 5 shows BLUP estimates of means, differences relative to P1 and s.e.d. for cohorts A94, A95, A96 on the basis that, in these cohorts, similar pasture and cattle management procedures during grow-out were used in successive years. Although seasonal conditions, pasture quality and quantity (Ayres *et al.* 2001), and realised growth rates (Dicker *et al.* 2001; and above) differed across years, it is reasonable to draw some inference from these cohorts on how the pattern of liveweight change during grow-out affected finishing performance and carcass and meat quality characteristics.

In general, mean liveweight gain during finishing of steers in the different nutritional pathways was inversely related to mean liveweight gain of the steers in these groups during grow-out (summarised in Tables 4 and 6). However, in A97 pathways P1 and P2 had identical mean gains during grow-out, but somewhat different gains during finishing. Liveweight of steers in P1 did not catch up to that of steers in P3 in any market or finishing system. For P1 compared with P2 steers, complete catch up generally occurred when the difference in liveweight between P2 and P1 steers was 15 kg or less at the end of grow-out. Liveweight compensation was

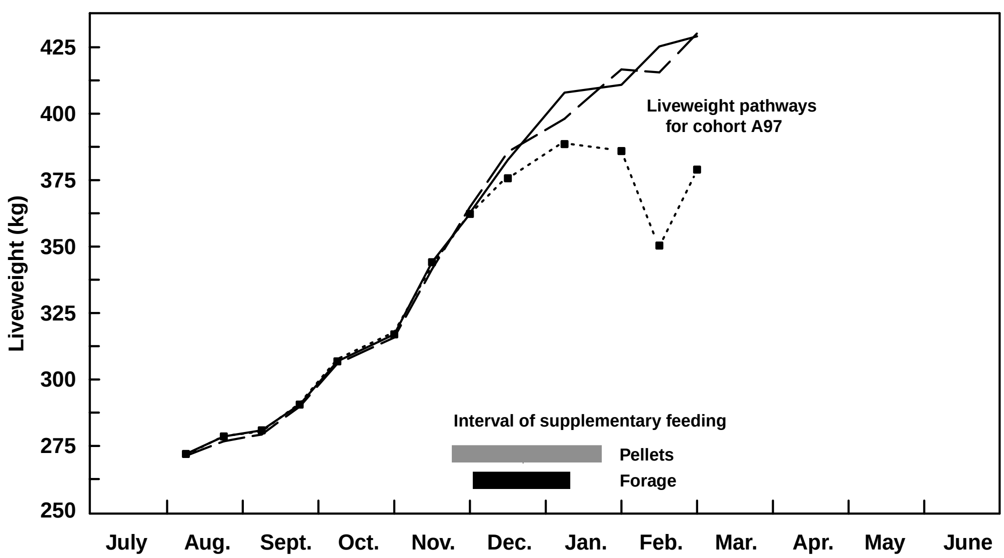

Figure 1. Post-weaning growth pathways (1997–98) for *B. taurus* cohort A97 for pathways P1 (■), P2 (dashed line) and P3 (solid line). Intervals of supplementary feeding are indicated.

Table 4. Growth and fatness measurements at slaughter of cattle grown out on pasture plus forage (P3), pasture plus pellets (P2) or pasture only (P1) for the Korean and Japanese markets and finished either in the feedlot (F) or on pasture (P)

Measurement	Finish	Korean market				Japanese market			
		P3	P2	P1	s.e.d.	P3	P2	P1	s.e.d.
				Cohort A94, n = 150					
Finishing gain (kg/day)	F	1.21	1.26	1.44	0.06	1.27	1.28	1.40	0.06
	P	0.56	0.63	0.68	0.07	0.63	0.62	0.75	0.07
Pre-slaughter weight (kg)	F	547	529	518	22	631	590	601	22
	P	529	518	494	23	587	566	603	24
Carcass weight (kg)	F	300	288	278	12	349	334	331	12
	P	279	267	259	13	320	304	325	13
Retail meat yield (%)	F	67.8	68.8	69.5	0.9	60.9	62.9	62.3	0.9
	P	69.5	69.7	69.9	1.0	67.1	66.1	66.6	1.0
Scan P8 fat	F	12.5	10.9	11.3	1.1	15.3	15.6	15.5	1.2
(adjusted carcass wt, mm)	P	9.9	10.8	10.6	1.3	14.7	14.5	13.3	1.3
Intramuscular fat	F	n.a.	n.a.	n.a.	n.a.	6.2	5.3	5.6	0.8
(adjusted carcass wt, %)	P	5.8	4.3	4.1	1.7	6.1	5.8	5.6	0.9
				Cohort A95, n = 345					
Finishing gain (kg/day)	F	1.18	1.29	1.37	0.04	1.09	1.19	1.21	0.04
	P	0.63	0.66	0.73	0.05	0.68	0.70	0.73	0.04
Pre-slaughter weight (kg)	F	563	556	533	12	609	601	580	13
	P	556	537	521	13	616	593	563	13
Carcass weight (kg)	F	305	301	286	8	345	341	331	8
	P	295	283	275	8	321	310	295	8
Retail meat yield (%)	F	65.0	64.5	65.4	0.7	63.2	63.6	64.0	0.7
	P	66.7	66.9	67.3	0.7	65.4	65.4	66.9	0.7
Scan P8 fat	F	11.7	11.6	12.3	0.8	16.2	16.2	17.0	0.8
(adjusted carcass wt, mm)	P	12.2	12.3	12.8	0.8	13.3	13.9	12.7	0.8
Intramuscular fat	F	6.4	6.8	6.8	0.8	7.5	7.4	6.8	0.8
(adjusted carcass wt, %)	P	5.5	5.2	5.0	0.8	5.6	5.0	4.6	0.8
				Cohort A96, n = 287					
Finishing gain (kg/day)	F	1.06	1.14	1.23	0.05	1.14	1.21	1.21	0.05
	P	0.40	0.45	0.52	0.05	0.57	0.61	0.64	0.05
Pre-slaughter weight (kg)	F	566	550	565	13	659	650	627	13
	P	543	525	533	14	606	589	593	13
Carcass weight (kg)	F	302	291	294	8	353	347	333	8
	P	282	275	277	8	323	307	312	8
Retail meat yield (%)	F	62.5	63.2	62.9	0.6	n.a.	n.a.	n.a.	n.a.
	P	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Scan P8 fat	F	12.8	13.2	13.2	1.1	15.4	15.0	15.3	1.1
(adjusted carcass wt, mm)	P	10.2	9.5	9.8	1.2	16.5	15.3	14.9	1.2
Intramuscular fat	F	5.7	5.7	5.5	0.5	9.5	8.5	9.0	0.5
(adjusted carcass wt, %)	P	5.2	4.6	4.8	0.5	6.7	5.8	6.0	0.5
				Cohort A97, n = 313					
Finishing gain (kg/day)	F	1.60	1.32	1.69	0.06	1.29	1.26	1.45	0.06
	P	0.65	0.64	0.79	0.06	0.68	0.63	0.79	0.06
Pre-slaughter weight (kg)	F	562	533	516	12	630	619	596	12
	P	570	573	551	12	606	608	596	12
Carcass weight (kg)	F	290	270	258	6	332	328	315	6
	P	302	301	289	6	322	321	309	6
Retail meat yield (%)	F	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
	P	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Scan P8 fat	F	14.5	14.7	12.1	1.0	15.6	16.4	14.9	1.0
(adjusted carcass wt, mm)	P	12.6	12.1	12.2	1.0	15.7	14.5	14.9	1.0
Intramuscular fat	F	5.2	4.7	4.7	0.5	7.8	7.3	7.3	0.5
(adjusted carcass wt, %)	P	3.2	3.2	3.3	0.5	4.2	4.0	3.8	0.5

n.a., data not available.

Table 5. Fitted values for market × finish (F, feedlot; P, pasture) × growth pathway (P3, P2, P1) for selected traits from the combined analysis of A94, A95 and A96

Trait		Korean market					Japanese market					
		P3	P2	P1	P3–P1	P2–P1	P3	P2	P1	P3–P1	P2–P1	s.e.d.[A]
Finishing gain (kg)	F	145	155	165	–19.9	–10.3	209	218	229	–19.9	–10.3	3.7
Finishing gain (kg)	P	124	133	143	–19.9	–10.3	186	196	206	–19.9	–10.3	3.7
Total gain (kg)	F	316	302	295	21.1	6.9	381	367	360	21.2	7.0	5.0
Total gain (kg)	P	298	284	277	21.1	6.9	361	347	340	21.2	7.0	5.0
Carcass weight (kg)	F	303	295	289	14.3	5.9	348	339	333	14.3	5.9	3.7
Carcass weight (kg)	P	288	278	274	14.0	4.6	322	313	308	13.9	4.6	3.7
Retail meat yield (%)	F	65.6	66.0	66.3	–0.7	–0.3	63.8	64.2	64.5	–0.7	–0.3	0.5
Retail meat yield (%)	P	67.2	67.5	67.9	–0.7	–0.4	66.6	66.9	67.3	–0.7	–0.4	0.5
Finishing gain (kg/day)	F	1.17	1.25	1.33	–0.15	–0.08	1.16	1.22	1.28	–0.12	–0.06	0.03
Finishing gain (kg/day)	P	0.56	0.61	0.68	–0.11	–0.07	0.65	0.68	0.72	–0.08	–0.04	0.03
P8 fat (adj cwt, mm)	F	12.1	11.9	12.0	0.1	–0.1	15.7	15.5	15.7	0.1	–0.1	0.4
P8 fat (adj cwt, mm)	P	10.8	10.7	10.7	0.1	–0.1	14.3	14.1	13.9	0.4	0.2	0.4
Rib fat (adj cwt, mm)	F	9.8	9.6	9.8	0.0	–0.2	12.3	12.2	12.2	0.1	–0.1	0.3
Rib fat (adj cwt, mm)	P	8.0	7.9	8.0	0.0	–0.1	11.0	11.0	10.9	0.1	0.1	0.3
Intramuscular fat (adj cwt, %)	F	6.3	6.1	6.2	0.1	–0.1	7.6	7.1	7.1	0.5	0.0	0.3
Intramuscular fat (adj cwt, %)	P	5.4	5.1	5.0	0.3	0.1	6.2	5.7	5.5	0.7	0.1	0.3

[A]Average s.e.d. between estimates for each market × finish × growth pathway.

evident in Korean steers (i.e. by 100 days on feed), no further catch up occurred in Japanese steers (Table 6).

At the end of grow-out, there were considerable differences in rump and rib fat thickness, even after adjustment to the same liveweight, with P3 steers having more subcutaneous fat than P2 which, in turn, had more subcutaneous fat than P1 steers. However, at slaughter, after adjustment for carcass weight, these differences were no longer statistically significant, except for P1 *v.* P3 in feedlot-finished Korean steers in cohort A97. The IMF% in *M. longisimus* (adjusted for carcass weight) tended to be less in steers from P1 compared with P3, especially for Japanese steers (Tables 4 and 5). Differences in retail meat yield as percentage of carcass weight due to grow-out treatment were small. There was a trend for P3 steers to have lower retail yield than those on P1, with P2 intermediate. This largely reflected differences in carcass weight and fat thickness (Tables 4 and 5).

An analysis of factors affecting finishing performance, carcass weight, fatness and intramuscular fat is shown in Table 7. The 3 largest sources of variation for each of the traits analysed, expressed relative to the amount of residual variation in the model, are shown. Grow-out pathway was the largest source of variation for gain during grow-out and birth-herd was second largest. It is clear that although many factors affected performance during finishing, the finishing system itself (pasture or feedlot) had the major effect on fat thickness and IMF%. For A97 steers, where pathways were applied towards the end of grow-out, grow-out pathway was the most important factor for gain (kg) during finishing. With respect to

Table 6. Difference in grow-out gain (kg) and finishing gain, and index of compensation (%) by market (K, Korean or J, Japanese) and finish (F, feedlot; P, pasture), (i) between pathway 1 and pathway 3 (P1–P3; P3–P1), (ii) between pathway 1 and pathway 2 (P1–P2; P2–P1)

Index of compensation was calculated using equation 2 as described in text

Cohort	Finish	Difference in grow-out gain, P3–P1 (kg)		Difference in finishing gain, P1–P3 (kg)		Index of compensation (%)		Difference in grow-out gain, P2–P1 (kg)		Difference in finishing gain, P1–P2 (kg)		Index of compensation (%)	
		K	J	K	J	K	J	K	J	K	J	K	J
A94	F	42.6	39.1	22.0	19.4	52	50	14.0	13.4	17.5	18.9	125	141
	P	53.2	37.3	20.0	31.9	38	86	35.8	11.9	7.6	35.1	21	295
A95	F	51.9	48.8	23.1	21.8	45	45	30.4	29.1	9.5	5.1	31	18
	P	56.0	54.0	19.5	12.9	35	24	34.6	30.3	14.0	7.4	40	24
A96	F	27.4	37.8	22.5	12.3	82	33	–3.7	13.5	13.1	0.7	–354	5
	P	38.2	34.2	28.3	21.1	74	62	6.2	8.5	15.1	8.1	244	95
A97	F	47.2	54.7	7.1	25.6	15	47	45.2	53.6	30.6	30.2	68	56
	P	47.5	47.7	29.5	31.1	62	65	51.3	54.1	32.0	43.8	62	81

Table 7. Largest 3 sources of variation (VC1, VC2, VC3) and percentages of residual variation (RV)

Abbreviations for variance components are: fin, finish (pasture or feedlot); mkt, market (Korean or Japanese); brd, breed; hrd, birth/weaning herd; pway, growth pathway; ch, cohort; sire, sire of steer; weighdate, date of last weighing, which, in a few cases where groups were too large for all animals to be slaughtered on the same day, may have differed by up to 1 week

For all traits except gain (kg/day) during finishing, market was fitted as a fixed effect, so not included in this list. For gain during finishing, finish was fitted as a fixed effect, so not included

Trait	VC1	RV (%)	VC2	RV	VC3	RV (%)
			Intake cohorts A94, A95, A96			
Grow-out gain (kg)	pway	106	hrd	25	sire	17
Finishing gain (kg)	fin	40	weighdate	19	ch.fin	17
Total gain (kg)	hrd	24	fin	18	sire	13
Retail meat (kg)	brd	18	ch	15	sire	10
Retail meat yield (%)	ch	238	fin	53	ch.mkt	34
Finishing gain (kg/day)	ch	33	pway	16	hrd.ch.mkt.fin	9
Scan P8 fat (mm)	fin	11	ch.mkt.fin	8	hrd	7
Scan rib fat (mm)	fin	17	ch.mkt.fin	15	sire	11
Intramuscular (IM) fat (%)	brd	27	ch.mkt.fin	26	fin	24
P8 fat (adjusted cwt, mm)	fin	25	hrd	14	ch.mkt.fin	9
Rib fat (adjusted cwt, mm)	fin	36	ch.mkt.fin	16	hrd	16
IM fat (adjusted cwt, %)	fin	36	ch.mkt.fin	29	brd	23
			Intake cohort A97			
Grow-out gain (kg)	pway	148	hrd	73	hrd.mkt.fin	4
Finishing gain (kg)	pway	41	fin.mkt	39	brd.fin	13
Total gain (kg)	hrd	47	fin.mkt	27	pway	13
Finishing gain (kg/day)	fin.mkt	27	pway	23	fin.mkt.pway	5
Scan P8 fat (mm)	sire	20	pway	11	brd.fin	11
Scan rib fat (mm)	fin.mkt	53	sire	15	pway	8
Intramuscular (IM) fat (%)	fin	139	fin.mkt	36	brd	32
P8 fat (adjusted cwt, mm)	Sire	23	brd.fin	8	brd.mkt	5
Rib fat (adjusted cwt, mm)	fin	39	fin.mkt	25	sire	18
IM fat (adjusted cwt, %)	fin	132	brd	36	fin.mkt	22

fatness traits, the interaction of market and finish (and sometimes with cohort, breed or pathway) was commonly observed as the second or third most important source of variation (Table 7). Nonetheless, despite some apparent patterns, the largest source of variation for the majority of traits was residual variation, i.e. variation between animals.

Discussion

The results presented here generally support the concept that compensatory growth occurs in cattle that have suffered a reduction in prior growth (see Ryan 1990 for review). Furthermore, they show that, depending on the extent of prior growth restriction, liveweight compensation may be incomplete. The observation that compensatory growth can affect fat thickness and carcass yield is not new (see Carstens 1995). The observation that prior growth rate can reduce intramuscular fat content of steers finished to the same carcass weight and fat thickness on pasture or in a feedlot to the heavy carcass weights (>330 kg) required for the Japanese market is consistent with earlier reports (Hedrick *et al*. 1983; Dikeman *et al*. 1985).

It is important to be aware that the analyses presented here should be regarded as preliminary. The data from steers from cohorts A94, A95 and A96 represent repeated experiments. Although the same general pattern of growth between pathways was obtained in each of these years (see Dicker *et al.* 2001), the magnitude of the difference in liveweight between pathways, and in the rate of overall growth differed substantially (Dicker *et al.* 2001). Moreover, the data from cohort A97, in which divergence in growth immediately before finishing was obtained, is from a single year, although the experiment was subsequently repeated in a second year. Accordingly, it is intended that full appreciation, and practical application, of the results of the study reported here cannot be obtained until a joint analysis of animal growth, and pasture quantity and quality attributes (Ayres *et al.* 2001), is complete. Nonetheless, with the above caveat, it is instructive to compare results reported here with those observed elsewhere.

The phenomenon of compensatory growth, and associated effects on total content of carcass lean and fat, is well recognised in beef cattle (Carstens 1995). During the immediate catch up growth period, there is usually a reduction in fat deposition, but in the longer term, body composition returns to the expected pattern. However, cattle slaughtered during the period in which compensatory growth is occurring generally have different fat and lean content to that expected for their weight (Ball *et al.* 1997). In the studies referred to by Carstens (1995) and Ball *et al.* (1997), more extreme experimental treatments were imposed than in the present study. Accordingly, differences in fat thickness and retail meat yield as a consequence of growth pathway before finishing herein were less than in the studies referred to above. However, the present study does provide some additional insight insofar as it shows that complete catch up growth only occurred where the difference in growth at the commencement of finishing was about 15 kg. For larger differences in pre-finishing liveweight, partial compensation occurred (Table 6). Moreover, the data suggest that almost all of this occurred by the time Korean market liveweights were achieved (in the case of the feedlot steers, 100 days on feed). These results suggest that a pre-finishing liveweight difference due to growth rate during grow-out of more than 15 kg is unlikely to be completely made up, even though mean growth rate during finishing is increased in groups of steers with lower mean liveweight at the commencement of finishing.

Method of finish (feedlot or pasture) had the greatest effect on fat thickness and on intramuscular fat content in all groups. This is likely to occur for 2 reasons. First the high growth rate of feedlot-finished cattle predisposes them to increased fatness (see Keele *et al.* 1992 for summary). Second even at the same growth rate, cattle eating a grain-based diet deposit fat at a higher rate than cattle eating a forage-based diet (Tudor 1992; Sainz *et al.* 1995). This could be due in part to lower visceral mass leading to reduced maintenance needs in grain-fed cattle (Oddy *et al.* 1997), and to increased supply of glucose precursor molecules, which would improve efficiency of nutrient use for fattening (see Gill *et al.* 1984).

In the heavier Japanese steers, IMF% tended to be reduced relative to carcass weight in steers that came from P1 pathways compared with P3. There is no agreement in the literature as to the magnitude and direction of change of intramuscular fat with respect to other fat pools as a result of prior growth check. Trenkle *et al.* (1978) reported data on animals at the same liveweight but different ages, which suggested that those animals with a slower growth rate (i.e. were older at the same liveweight) had increased IMF%. However, that observation was unable to be repeated by Renk *et al.* (1986) who, as a consequence of Trenkle *et al.* (1978), specifically tested the hypothesis that intramuscular fat development was related to age.

Another study (Mandell *et al.* 1997) compared Charolais-cross steers finished for 42 days on alfalfa silage then 80 days on a high-grain diet with a similar group finished for 92 days on the high-grain diet. The former group spent 32 days longer in finishing, so were older but had similar carcass weights (314 *v.* 310 kg) and rib fat depths (7.4 mm), but 17% more intramuscular fat (51.7 *v.* 44.1 g/kg; s.e.d 3.4). In contrast, a third group of steers finished for 155 days on alfalfa silage produced carcasses averaging 394 kg, with 7.3 mm fat and 41.9 g/kg of intramuscular fat. This suggests that age, diet and growth rate can influence the results. In other studies (Hedrick *et al*. 1983; Dikeman *et al.* 1985) cattle finished on a high-grain diet following a period of backgrounding at lower growth rate had less intramuscular fat relative to fat thickness than those backgrounded at a higher growth rate.

The general consensus in the literature is that relative proportions of the fat pools in the body are unchanged as cattle grow (Johnson *et al.* 1972; Cianzio *et al*. 1985). However, the observations in the literature cited above, the present results, and in as yet unpublished data from the CRC for Cattle and Beef Quality, suggest otherwise. Considering the high premium paid in some markets for intramuscular fat content, this observation warrants further study.

The observations reported here are, with the exception of the intramuscular fat data, broadly consistent with the framework described by Keele *et al.* (1992), and employed by Williams and Bennett (1995) to describe the effects of growth rate on carcass composition. However, studies in which nutrient supply during the grow-out period varied both within and between seasons are notoriously difficult to generalise. Amalgamation of the data reported here with that of Ayres *et al.* (2001) and Dicker *et al.* (2001) into a systematic framework will be required to enable specific recommendations to be made. Nonetheless, this paper reports interesting new observations on the effect of growth rate before finishing under controlled conditions representing commercial practice in temperate zones of Australia. As such, the data provide a platform for development of recommendations to improve production of cattle to meet market specifications more consistently.

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