Effect of replacing cereal based concentrates with fermented whole crop wheat and red clover silages in intensive finishing systems for British Blue cross Holstein steers

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1.0 Introduction:

In experiment 1, it was successfully demonstrated that, although cattle fed diets containing 750 g/kg DM fermented WCW had a lower growth rate than those fed cereal based concentrates (1.42 vs 1.59 kg/day respectively), the total feed costs (£284 vs £306) and margins (1.50 vs 1.47 £/kg carcase gain) were similar. Animal performance could potentially be maintained, and feed costs reduced further if vegetable protein supplements were partially replaced by red clover silage.

2.0 Objective:

To investigate the effect of replacing cereal based concentrates with fermented whole crop wheat and red clover silages in intensive finishing systems for British Blue cross Holstein steers.

3.0 Materials and methods:

3.1 Forage production:

During the summer of 2019, 4.8 ha of winter wheat (*Variety: Graham Redigro Pro 2018*) were grown at Harper Adams University. The crop was harvested on 25th July 2019 at approximately growth stage 85 (soft dough, Zadocks *et al.* 1974) with a dry matter content of 500 g/kg. The WCW was harvested by a local contractor using a self-propelled forage harvester fitted with a Kemper header. The cutting height was 15.2 cm and the crop was treated with the additive Wholecrop Gold (Biotal Ltd) at 2.0 litres/tonne prior to ensiling in an Ag-Bag. It was anticipated that approximately120 tonnes of fresh WCW (60 tonnes DM) was ensiled.

Approximately 9.2 ha of red clover (*Variety: Atlantis*) was sown on 14th May and cut on 21st August 2019. Following a 24-hour wilt, it was harvested with a dry matter content of 300 g/kg using a precision chop self-propelled forage harvester, and treated with the additive Axcool (Biotal Ltd) at 2.0 litres/tonne, prior to ensiling in an Ag-bag. It was anticipated that approximately 105 tonnes of fresh red clover silage (37 tonnes DM) was ensiled.

3.2 Animals and housing:

The trial was conducted at Harper Adams University between November 2019 and May 2020 using 60 British Blue x Holstein steers with an initial live weight of 400-450 kg at 12-15 months of age. All animals were grazed over Summer 2019. However, owing to lack of grazing and lower than anticipated live weight gains, all animals were housed and fed a concentrate-based diet for a few weeks prior to the experiment commencing.

3.3 Experimental design:

The 60 cattle were allocated by birth date and LW, to one of four experimental treatments formulated to supply 140 g CP/kg DM as follows:

1. Cereal based concentrate (Control, **C**)
2. 750 g/kg DM forage (100:0 WCW:RC); 250 g/kg DM concentrate (**WCW**)

3. 750 g/kg DM forage (670:330 WCW:RC); 250 g/kg DM concentrate (**RC33**)
4. 750 g/kg DM forage (330:670 WCW:RC); 250 g/kg DM concentrate (**RC67**)

Concentrate supplements were based on rolled barley, sugar beet pulp (0.87:0.13 DM) rapeseed meal and wheat distillers' dark grains (50:50 DM), and formulated based on preliminary NIRS analysis of the forages. Molasses (50 g/kg DM) was included in the control diet. However, this was reduced to 10 g/kg DM in the WCW diets. All concentrate supplements were provided by Wynnstay Ltd as course blends. The raw material and predicted chemical composition of the total mixed rations (TMR) and concentrate supplements are provided in tables 1 and 2.

The experiment was conducted in the Harper Adams University beef unit, with animals being housed in straw-bedded yards with five animals per pen (three pens per treatment). Treatments were randomly allocated to each pen, with pen being used as the experimental unit. Four pens were fitted with GrowSafe feeders, which facilitated the measurement of individual feed intakes in 20 animals (one pen per treatment). Prior to the experiment commencing, all animals were adapted to the control treatment and then adapted onto the experimental diets over a five-day period. All concentrates were fed as TMRs from troughs, with animals on all treatment being offered a small amount of straw in racks.

3.4 Experimental routine:

Each TMR was mixed twice or three times weekly (depending on aerobic stability) and fed *ad-libitum*, with refusals being weighed back prior to feeding. The weekly intake was calculated as the total offered, minus the total refusals. In pens fitted with GrowSafe feeders, each TMR was offered more frequently with individual intakes being recorded automatically. The amount offered during the subsequent week was calculated to supply 0.1 more than was consumed during the previous week. Live weight was recoded at the start of the experiment and at 30-day intervals until slaughter, with animals being weighed on two consecutive occasions at the beginning and end of the experiment. The target slaughter weight was 600-650 kg LW, with cattle being selected for slaughter by a competent person at fat class 3. Carcase weights, EUROP carcase classification were recorded at slaughter. Cattle were processed by ABP Food Products, Shrewsbury. Cattle were maintained on the experimental treatments for approximately 6 months until May/June 2020.

Diet digestibility was determined in week 8 of the experiment using acid insoluble ash (AIA) as an indigestible marker (Block *et al.,* 1981). One pen of animals (5 animals) from each treatment (GrowSafe pens) was selected for faecal sampling. Faecal grab samples (were collected from each animal over a five-day period. For each animal, faecal samples were bulked, mixed and sub-sampled prior to freeze-drying and chemical analysis. Dry matter intakes were also recorded, and feed samples collected at the same time.

3.5 Chemical analysis:

Forage samples were taken weekly and analysed for DM content in order to ensure that the relative proportions of fermented WCW and RC silage in each TMR remain constant. In addition, both forage and concentrate samples were taken for chemical analysis monthly. These were stored at -20 °C until the end of the experiment. At the end of the experiment, samples of each forage and concentrate were bulked over two months, and sub-sampled for analysis by wet chemistry for dry matter (DM), crude protein (CP), oil A, ash, acid insoluble ash (AIA), neutral detergent fibre (NDF), acid detergent fibre (ADF), starch and gross energy (GE). In addition, forage samples were analysed for pH, NH_3-N and water-soluble carbohydrates. Bulked faecal samples were analysed for DM, CP, EE, ash, AIA and GE.

3.6 Statistical analysis and calculations:

The data were analysed by ANOVA as a randomised block design using Genstat 20. Regression, correlation and co-variate analysis were used as appropriate. Digestibility coefficients were calculated as follows:

$$\text{DM digestibility} = \frac{\text{AIA faeces (g/kg DM)} - \text{AIA feed (g/kg DM)}}{\text{AIA faeces (g/kg DM)}}$$

$$\text{Faecal DM output} = \text{DMI} - (\text{DMI x DM digestibility})$$

$$\text{Nutrient digestibility} = \frac{(\text{DMI x nutrient (g/kg DM)}) - (\text{DMO x nutrient (g/kg DM)})}{(\text{DMI x nutrient (g/kg DM)})}$$

Table 1:
Raw material and predicted chemical composition of the total mixed rations.

	Barley	100:0	66:33	33:66
Raw materials (g/kg)				
Whole crop wheat	---	840	475	208
Red clover silage	---	---	390	674
Rolled barley	721	38	74	95
Sugar beet pulp	102	6	10	14
Rapeseed meal	51	52	20	---
Wheat distillers	50	51	20	---
Molasses (cane)	57	7	6	5
Urea	---	---	---	---
Mins/vits	19	6	5	4
Chemical composition (g/kg DM)				
Dry matter (g/kg)	863	594	543	492
Crude protein	141	140	140	142
ERDP (0.5)	103	97	99	102
DUP (0.5)	20	19	17	16
Ether extract	24	25	22	20
Ash	59	61	70	79
NDF	239	453	429	406
Starch	417	222	201	176
ME (MJ/kg DM)	12.8	10.8	10.9	10.9
FME (MJ/kg DM)	12.3	9.2	9.3	9.5
ERDP/FME (g/MJ)	8.4	10.5	10.6	10.7
MP (<10.0 g/kg DM)	**86**	81	80	81
MP (>10.0 g/kg DM)	98	**78**	**76**	**76**

Table 2:
Raw material and predicted chemical composition of the concentrate blends.

	Barley	**100:0**	**66:33**	**33:66**
Raw materials (g/kg)				
Whole crop wheat	---	---	---	---
Red clover silage	---	---	---	---
Rolled barley	721	240	541	803
Sugar beet pulp	102	35	77	115
Rapeseed meal	51	322	150	---
Wheat distillers	50	318	149	---
Molasses (cane)	57	47	46	46
Urea	---	---	---	---
Mins/vits	19	38	37	36
Chemical composition (g/kg DM)				
Dry matter (g/kg)	863	876	870	864
Crude protein	141	270	187	114
ERDP (0.5)	103	193	135	84
DUP (0.5)	20	32	24	18
Ether extract	24	39	29	21
Ash	59	92	83	75
NDF	239	313	264	221
Starch	417	168	322	458
ME (MJ/kg)	12.8	12.7	12.6	12.6
FME (MJ/kg)	12.3	11.4	11.8	12.1
ERDP/FME (g/MJ)	8.4	16.9	11.4	6.9
MP (<10.0 g/kg)	**86**	155	110	**71**
MP (>10.0 g/kg)	98	**105**	**99**	95

4.0 Results:

4.1 Animal health and experimental problems:

No problems were encountered regarding animal health throughout the experiments. However, although feed and faecal samples were obtained for indirect estimation of diet digestibility using acid insoluble ash (AIA), they have not yet been analysed due to COVID-19.

4.2 Diet composition:

The analysed chemical composition of the forages, concentrate blends and total mixed rations used in the experiment are presented in table 3. Both the WCW and RC silages were well fermented with a low pH and levels of NH_3-N. As predicted the WCW silage had a high DM content (500 g/kg) and a low CP content (84 g/kg DM), which was slightly lower than the value used in the initial diet formulation (97 g/kg DM). The composition of the RC silage was similar to predicted with a DM content of 328 g/kg and a CP content of 182 g/kg DM. The composition of the four concentrate blends was also similar to predicted, although the CP content was slightly lower. The analysed chemical composition of the four TMRs fed (Table 3) was very similar to that predicted except for CP which was slightly lower, with the mean values being 134 and 141 g/kg DM respectively.

4.3 Liveweight, liveweight gain and carcase characteristic:

The LW and LW gains of steers on each treatment are presented in table 4. There was no significant difference between treatment in initial or final LW, with the mean LW of steers starting the finishing the experiment being 459 and 650 kg respectively. Similarly, there was no significant difference between treatments in days to slaughter, although numerically steers offered diet C finished quicker (134 days) than those offered diets WCW and RC33 (139 days) and those offered diet RC67 (153 days). As a consequence of the above, there was no significant difference in total gain with the mean total gain of steers being 191 kg. However, owing to numerical differences in days to slaughter there was a trend (P = 0.075) towards differences in daily LW gain with steers offered diet C having a higher daily LW gain (1.45 kg/day) than those offered treatments WCW and RC33 (1.37 kg/day) and RC67 (1.23 kg/day) respectively.

The carcase characteristic of steers on each treatment are presented in table 5. As expected there was a highly significant difference between treatments in killing out percentage (KO%) ($P<0.01$) with steers offered diet C having a KO% of 54.4% compared to a mean of 52.6% in the three forage-based treatments. Carcase conformation and fat class are reported using a 15-point numerical scale relating to the EUROP conformation and fat class classification system, with a score of 8 being equivalent to ‘R=’ and ‘3=’ respectively. There was no significant difference between treatment in fat class, but steers offered diets C and RC33 had a significantly higher ($P<0.05$) confirmation score than those offered diets WCW and RC67.

4.4 Carcase weights and gains:

The initial carcase weight of steers on each treatment was calculated assuming a standard KO% of 47% with the final carcass weight being recorded at slaughter (Table 6). There was no significant difference between treatments in initial carcase weights. However, due to a higher KO%, steers offered diet C had a significantly higher ($P<0.05$) final carcase weight than those on the three forage-based treatments. Similarly, steers offered diet C had a higher total carcase gain and daily carcase gain ($P<0.05$) than those on the three forage-based treatments (139.4 kg and 1.06 kg/day vs mean of 125.8 kg and 0.88 kg/day respectively).

4.5 Dry matter intakes and feed conversion efficiency:

The total dry matter intakes, daily dry matter intakes and feed conversion efficiencies of steers on each treatment are presented in table 7. Steers offered diet C had a significantly lower total ($P<0.012$) and daily dry matter intake ($P<0.004$) than those offered the three forage-based treatments, with the dry matter intakes of steers offered diets WCW, RC33 and RC67 being similar. In addition, the feed conversion ratios were significantly lower ($P<0.001$) for steers offered diet C than those offered the three forage-based treatments, with the FCRs of steers offered diets WCW, RC33 and RC67 being similar.

Table 3:
Analysed chemical composition (g/kg DM) of the whole crop wheat, red clover silage, concentrate blends and total mixed rations used in the experiment.

	WCW	RC	Control	WCW	RC33	RC67
Forages and concentrate blends						
pH	4.5	4.7				
NH3-N (% TN)	5.1	4.6				
Dry matter	500	328	868	874	867	866
Crude protein	84	182	135	266	174	107
Oil A	11	16	17	41	22	15
Ash	46	122	67	78	78	61
CF			93	92	85	81
NDF	412	389	284	310	272	260
ADF	276	376	164	195	149	138
Starch	290	19	344	159	304	437
Water soluble carbohydrate	12	8				
Total mixed rations						
Dry matter			868	593	548	506
Crude protein			135	130	131	138
Oil A			17	19	15	15
Ash			67	55	74	88
NDF			284	387	371	362
ADF			164	256	270	292
Starch			344	257	226	192

Table 4:
Effect of dietary fermented whole crop wheat and red clover silage proportion on liveweight (kg) and liveweight gain (kg) of British Blue cross Holstein steers.

	Control	WCW	RC33	RC67	SED	P
Initial live weight	457.8	458.7	461.5	460.1	4.27	0.834
Final live weight	652.0	651.9	648.2	649.5	5.29	0.862
Growth period (days)	134	139	139	153	9.5	0.290
Age at slaughter (months)	18.3	18.5	18.7	18.9	0.20	0.098 T
Total gain	194.2	193.2	186.8	189.3	5.63	0.561
Daily gain (kg/day)	1.45	1.39	1.35	1.23	0.066	0.075 T

Table 5:
Effect of dietary fermented whole crop wheat and red clover silage proportion on carcase characteristics of British Blue cross Holstein steers.

	Control	WCW	RC33	RC67	SED	P
Killing out percentage (%)	54.4	52.2^{a}	53.3^{a}	52.5^{a}	0.004	0.008
Conformation score*	7.0^{b}	5.8^{a}	7.1^{b}	6.4^{ab}	0.36	0.034
Fat score*	7.0	6.7	7.6	6.8	0.44	0.297

Table 6:
Effect of dietary fermented whole crop wheat and red clover silage proportion on carcase weights (kg) and carcase weight change (kg) in British Blue cross Holstein steers.

	Control	WCW	RC33	RC67	SED	P
Initial carcase weight	215.2	215.6	216.9	216.3	2.01	0.834
Final carcase weight	354.6	340.0[a]	345.3[a]	341.0[a]	4.05	0.039
Total carcase gain	139.4	124.4[a]	128.4[a]	124.7[a]	4.15	0.034
Daily carcase gain (kg/day)	1.06[b]	0.90[a]	0.94[ab]	0.82[a]	0.055	0.024

Table 7:
Effect of dietary fermented whole crop wheat and red clover proportion on dry matter intakes (kg) and feed conversion ratios (kg feed/kg gain) of British Blue cross Holstein steers.

	Control	WCW	RC33	RC67	SED	P
Total dry matter intake	1241	1697[a]	1777[a]	1789[a]	121.4	0.012
Daily dry matter intake (kg/day)	9.37	12.16[a]	12.84[a]	11.69[a]	0.559	0.004
Live weight feed conversion	6.45	8.78[a]	9.56[a]	9.50[a]	0.450	0.001
Carcase feed conversion	8.89	13.57[a]	13.78[a]	14.29[a]	0.683	<0.001

4.5 Dietary component intakes:

The intakes of different dietary components by steers on each treatment are presented in table 8. As expected there were highly significant differences (P<0.001) in the total and daily intakes of different dietary components of steers on each treatment. Steers offered diet C received no WCW or RC silage and steers offered diet WCW received no RC silage. The amounts of WCW and RC silage in the three forage base diets reflected the diets formulated.

4.6 Feed costs:

The forage and concentrates costs and the calculated costs of the experimental diets are presented in table 9. Forage costs (£/tonne utilised DM) were derived from the Kinghay Forage Costing Report 2020. Concentrate costs reflected the bulk delivery of the concentrate blends Wynnstay Ltd. The cost of RC silage (£141/tonne DM) production was higher than that of WCW silage production (£110/tonne DM). The cost of the concentrate blends ranged from £231 to £272/tonne DM and reflected the relative inclusion of protein supplements with the WCW blend having the highest cost and the RC67 blend having the lowest cost. The cost of the overall diets reflected the relative inclusion of the different forages and concentrate blends, with diet C having the highest cost (£233/tonne DM) and diets WCW and RC33 having the lowest cost (£151 and £152/tonne DM respectively).

Using these costs, the total costs associated with rearing steers on each treatment were calculated as the total feed intake (tones) multiplied by the diet costs (£/tonne DM). There was no significant difference between treatments in total diet cost (£). However, numerically the total diet costs of steers on the three forage-based treatments were lower than those offered diet C (£268 vs £289 respectively). When expressed as £/day these differences tended towards significance (P<0.055), with the daily diet cost of steers offered the three forage-based treatments being lower than those offered diet C. (mean 1.86 vs 2.18 £/day respectively).

4.7 Carcase value and margins:

The carcase value and margins are presented in table 10. Diet costs, £/kg LWG and £/kg carcase gain, were calculated as the diet costs divided by either the total LWG or total carcase gain respectively. There were no significant differences between treatment in diet costs expressed as £/kg LWG or £/kg carcase gain. However, numerically steers offered diet WCW had the lowest lower costs (1.32 and 2.04 £/kg LWG and carcase gain respectively) and steers offered diet RC67 had the highest costs (1.48 and 2.23 £/kg LWG and carcase gain respectively).

Carcase price (£/kg) and value (£) was corrected to reflect national beef prices over the slaughter period (AHDB deadweight cattle price report for Great Britain 09/08/20 to 15/08/20). The slight variation in carcase price (P=0.063) reflect slight variations between treatments in carcase classification with steers offered diet WCW having a slightly lower conformation score than those offered the other three treatments. As a consequence, steers offered the WCW diet had a significantly (P<0.05) lower carcase value. Although, statistically significant, this is not consistent with the results of experiment and thought to be an anomaly.The carcase gain value was calculated as carcase price (£/kg) multiplied by total carcase gain (kg). Steers offered diet C had a significantly higher ($P<0.05$) carcase gain value than those offered the three forage-based diets. This largely reflects differences in KO% and total carcase gain.

Margin over feed were calculated by subtracting total feed costs (£) from carcase gain value (£) and expressed as either £/kg LWG or £/kg carcase gain. There were no significant differences between treatments in all the margins calculated. However, numerically the margin £/kg carcase gain were slightly higher for steers offered diets C, WCW and RC33 (1.70, 1.66 and 1.67 £/kg carcase gain) than they were for steers on diet RC67 (1.51 £/kg carcase gain)

Table 8:
Effect of dietary fermented whole crop wheat (WCW) and red clover (RC) silage proportion on fermented whole crop wheat, red clover silage and concentrate dry matter intakes (kg) in British Blue cross Holstein steers.

	Control	WCW	RC33	RC67	SED	P
Total dry matter intake	1241	1697[a]	1777[a]	1789[a]	121.4	0.012
Daily dry matter intake	9.37	12.16[a]	12.84[a]	11.69[a]	0.559	0.004
Total WCW DM intake	0.00	1273	892	444	84.7	<0.001
Daily WCW DM intake	0.00	9.12	6.45	2.90	0.145	<0.001
Total RC DM intake	0.00	0.00	441	898	75.1	<0.001
Daily RC DM intake	0.00	0.00	3.18	5.87	0.138	<0.001
Total concentrate DM intake	1241	424[a]	444[a]	447[a]	65.6	<0.001
Daily concentrate DM intake	9.37	3.04[a]	3.21[a]	2.92[a]	0.402	<0.001

Table 9:
Effect of dietary fermented whole crop wheat (WCW) and red clover (RC) silage proportion on the cost of diets fed to British Blue cross Holstein steers.

	Control	**WCW**	**RC33**	**RC67**	**SED**	**P**
WCW cost (£/t utilised DM)*	110	110	110	110	---	---
RC cost (£/t utilised DM)*	141	141	141	141	---	---
Concentrate cost (£/t DM)	233	272	248	231	---	---
Diet cost (£/t DM)	233	151	152	156	---	---
Total WCW cost (£)	0	140	98	49	9.32	<0.001
Total RC cost (£)	0	0	62	127	10.6	<0.001
Total concentrate cost (£)	289	115[a]	110[a]	103[a]	15.2	<0.001
Daily WCW cost (£)	0	1.00	0.71	0.32	0.019	<0.001
Daily RC cost (£)	0	0	0.45	0.83	0.019	<0.001
Daily concentrate cost (£)	2.18	0.83	0.80	0.68	0.096	<0.001
Total diet cost (£)	289	255	271	279	19.1	0.415
Total diet cost (£/day)	2.18	1.83[a]	1.95[a]	1.82[a]	0.112	0.055

Table 10:
Effect of dietary fermented whole crop wheat (WCW) and red clover (RC) silage proportion on the diet costs, carcase value and margin over feed for diets fed to British Blue cross Holstein steers.

	Control	WCW	RC33	RC67	SED	P
Final liveweight (kg)	652.0	651.9	648.2	649.5	5.29	0.862
Final carcase weight (kg)	354.6	340.0[a]	345.3[a]	341.0[a]	4.05	0.039
Total live weight gain (kg)	194.2	193.2	186.8	189.3	5.63	0.561
Total carcase gain (kg)	139.4	124.4[a]	128.4[a]	124.7[a]	4.15	0.034
Diet costs (£/kg LWG)	1.50	1.32	1.45	1.48	0.080	0.203
Diet costs (£/kg carcase gain)	2.07	2.04	2.10	2.23	0.127	0.528
Carcase price (£/kg)*	3.77[bc]	3.71[a]	3.77[bc]	3.74[ab]	1.99	0.063
Carcase value (£)	1336[c]	1260[a]	1331[bc]	1275[ab]	16.2	0.014
Carcase gain value (£)	525.1	461.3[a]	483.5[a]	466.0[a]	15.22	0.020
Margin over feed (£)	236	206	213	187	18.6	0.172
Margin (£/kg LWG)	1.25	1.08	1.17	1.01	0.105	0.226
Margin (£/kg carcase gain)	1.70	1.66	1.67	1.51	0.123	0.491

5.0 Conclusions:

1. Overall performance of British Blue x Holstein steers on all treatments was good with cattle being slaughtered at 18 months with carcase weights of 340–350kg, exceeding the targets for 18-month beef production systems.

2. Final liveweights (mean 650 kg) were similar for animals on all treatments. However, steers offered the three forage-based treatment took longer to achieve slaughter weight. Consequently, daily LWG was 1.45, 1.39, 1.35 and 1.23 kg/day for steers offered diets C, WCW, RC33 and RC67 respectively.

3. Steers offered diet C had a higher KO% (53.4%) than those offered the three forage-based treatments (mean 52.6%). Consequently, steers offered treatment C (355 kg) had a higher carcase weight than those offered the forage-based diets (mean 342 kg).

4. Replacing cereals with 750 g/kg DM forage increased DMI from 9.38 kg/day for steers offered diet C to 12.16, 12.84 and 11.69 kg/day for steers offered diets WCW, RC33 and RC67 respectively.

5. The higher DMI intakes partially compensated for the reduced energy density (M/D) of the three forage-based diets. However, the lower daily LWG of steers offered diet RC67 suggests that the RC used had a lower ME content.

6. As a consequence of higher DMIs the feed conversion ratios of steers offered diets WCW, RC33 and RC67 were higher (8.78, 9.56 and 9.50 kg/kg respectively) than those offered diet C (6.45 kg/kg).

7. Total diet costs were lowest for steers offered diet WCW (£255) followed by diet RC33 (£271) and diet RC67 (£279). Diet C had the highest total diet cost (£289).

8. Overall margins were similar for steers offered diets C, WCW and RC33 but slightly lower for steers offered diets RC67.

9. The results confirm those of experiment 1 that similar levels of physical and financial performance can be achieved by replacing up to 750 g/kg DM cereal-based concentrates with high quality fermented WCW silage. In addition, RC silage offers a viable alternative to vegetable protein supplements.

10. The cost effectiveness of different dietary strategies depends on the relative costs of forages and concentrates.

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7.0 References:

AHDB (2016). *Stocktake Report*. AHDB Beef and lamb, Stoneleigh. Available at: http://beefandlamb.ahdb.org.uk/wp-content/uploads/2016/11/Beef-Lamb-Stocktake-Report-2016-281116.pdf

Bollar, B., Schubiger, F.X. and Jollinker, R. (2010). Handbook of Plant Breeding (5th edition). New York, Springer.

Block, E., Kilner, L.H. and Muller, L.D. (1981). Acid insoluble ash as a marker of digestibility for sheep fed corn plants or hay and for dairy cows fed hay *ad-libitum*. *Journal of Animal Science* **52 (5):** 1164-1169

Kim, E.J. Dawson, J.M., Buttery, P.J. and Scollan, N.D. (2000). Performance responses and body composition of beef cattle fed grass silage-based diets: An overview. In D Pullar (Ed), *Beef from grass and forage, BGS occasional publication No 35* pp 91-95.

Marsh, S.P. and Gibson, I. (2004). Whole crop wheat for intensive finishing beef cattle. *Proceedings of the British Society of Animal Science*: 190

Walsh, K., O'Kiely, P., Moloney, A.P. and Boland, T.M. (2008). Intake, performance and carcase characteristics of beef cattle offered diets based on whole-crop wheat or forage maize relative to grass silage or *ad-libitum* concentrates. *Livestock Science* 116: 223-236