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Projecting maximum profit endpoints of Australian feedlot cattle – Phase 1

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Executive summary

Projecting the endpoint at which a carcass of feedlot cattle will reach maximum profit requires accurate prediction or simulation models of feed intake, energy requirements and retention, and body composition throughout the feeding period. The present report is for phase 1 of a larger project aimed at developing tools to predict such a slaughter endpoint. Achieving this goal will require measuring energy and nutrients retained in the body of Australian cattle. This phase of the project describes the protocol for comparative slaughter of cattle to measure carcass composition and with this energy and nutrients retained.

This technique can be applied to serial slaughter trials which involve slaughtering animals serially throughout the production cycle (at different ages) to measure changes in body composition (muscle, fat and bones). This can then be used to estimate energy and nutrient retention and the cost of this process which ultimately allows predicting carcass attributes and value, and cost of production as the animal matures and reaches different carcass endpoints. Mathematical simulation models can then be evaluated or adapted to predict these trajectories and the carcass endpoint at which maximum profits will be achieved.

Body composition and nutrient retention is measured by physically dissecting an animal's body into non-carcass and carcass components, and then measuring the chemical composition of these. Non-carcass components include the blood, skin, head, feet, tail, internal organs (heart, lungs, spleen, reproductive organs, kidneys, liver), internal fat, gastrointestinal tract (trachea, oesophagus, intestines, omasum, abomasum, reticulorumen), and carcass trimmings. Carcass components are physically separated into bones, fat and muscle and these are weighed and sampled.

Section of the ribs are also obtained and physically separated, weighed and sampled to develop prediction equations of whole-body composition from smaller cuts following Hankins and Howe (1946) for the 9th to the 11th rib, or the Wholesale Rib section.

Chemical composition is performed for one composite sample of the non-carcass component, carcass component, Hankins and Howe rib section, and Wholesale rib section. These analyses include moisture, ether extract, total nitrogen, and nutrients of interest such as phosphorus, calcium, and ash.

The instruments required for this methodology include: 1) an industrial grinder to grind all bones, 2) an industrial cutter to finely grind all non-carcass components and the bones after ground in the industrial grinder, 3) a commercial meat grinder for the lean and fat of the carcasses, 4) large containers to collect all blood upon exsanguination and the internal organs and viscera, 5) liquid nitrogen to freeze samples for grinding, 6) aluminium trays and plastic containers to store samples, 7) butcher's and industrial saws and knives to cut the carcasses and dissect rib sections from carcasses, and bones from lean and fat, 8) freeze-drier.

The technique is the gold standard to measure body composition in animals because it is extremely accurate. However, it is labour intensive, and thus three animals could be killed per day with one day doing the non-carcass components and the day after doing the carcass components. Two teams, one for non-carcass and one for carcass components, of approximately seven people each may be needed for this task depending on experience with meat works.

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1 Background

Cattle feeders strive to produce beef that is consistent in cut size, has minimal waste fat, maximal red meat yield, is tender, tasty and safe and meet customer expectations day in, day out. This is often challenging given the diversity of cattle that arrive at the feedlot. Tools to assist sorting cattle for profit maximisation are needed, however this first requires accurate knowledge of feed intake and mature size (weight at specified chemical fat content) to predict carcass growth and composition of individuals.

The ability to predict animal performance and carcass endpoints can be achieved using simulation nutrition models such as the Beef Cattle Nutrient Requirement Model (BCNRM) by the United States National Academies of Sciences, Engineering, and Medicine (NASEM, 2016), the Cattle Value Discovery System (CVDS; Tedeschi et al., 2004) and the Ruminant Nutrition System (RNS; Tedeschi and Fox, 2018), amongst others. Despite these models being the most widely used worldwide to predict animal performance and profit, they have not been scientifically evaluated with Australian feedlot cattle.

Accurate performance prediction may bring value to the lot-feeder via:

- Profit/Loss modelling of cattle of different biological types at different carcass endpoints
- Sorting cattle into homogenous marketing groups (if critical mass of cattle present)
- Optimising days on feed of the sorted group to maximise carcase value over production costs
- Nutritional requirements can be accurately formulated to maximise performance of each pen

The above will allow:

- Improved decision making around feedlot production critical points
- Decrease within-pen variability by sorting animals to reach a common endpoint
- Reduce resource (feed and water) usage by feedlot operations
- Reduce nutrient excretion and greenhouse gas emission per unit of animal product

This project is the first phase of a multi-stage project to develop a model to predict maximum profit endpoints of Australian feedlot cattle to aid in cattle sorting decisions. Documentation by the project team of serial slaughter, dissection and analysis of the physical and chemical body composition is required prior to subsequent phases of the project. A study tour of serial slaughter experiments occurring at a partner overseas University occurred to document best practice methodology for the project. Future phases of the project will also assist in de-risking future Objective Measurement activities in beef by enabling a comparison of CT & DEXA calibrations back to current USA accepted chemical body grinds.

This University has been the most active group in the world practicing serial slaughter trials for comparative slaughter and chemical body chemical analysis of beef cattle during the last decade. Body chemical analysis by whole body grind, sampling and chemical analysis is the current Gold Standard for feedlot cattle growth biology and energetics. Subsequent phases of the project in Australia will aim to develop calibration curves for DEXA or CT based off this gold standard of chemical grinds, necessitating the trip to Brazil to observe the technique.

2 Project objectives

The objectives of Phase 1 of the project are as follows:

2.1 Document procedures of serial slaughter, physical and chemical body composition analysis of feedlot cattle

2.2 Produce a detailed written methodology for Phase 2 of the project.

3 Methodology

The methodology described below is required to estimate energy and nutrient requirements of cattle and several variations of the methodology exist depending on the objectives of the trials. For example, the objective may consist of understanding total energy, protein or minerals retained in the whole body of animals or retained in different body parts. The original methodology was published back in 1946 by Hankins and Howe.

3.1 Body weight (full, shrunk and empty)

Full body weight is obtained by weighing animals without feed withdrawal, whereas shrunk body weight is obtained by weighing animals after 16 to 18 hours of feed withdrawal. Finally, empty body weight is obtained after emptying all the contents of the gastrointestinal tract (GIT) after slaughter. Animals are stunned with a captive bolt gun (desensitized with a non-penetrating stunner) and killed by exsanguination on the jugular vein using approved, conventional humane procedures.

After the animal is slaughtered the methodology can be divided into 2 main parts, often done in 2 different days:

- Non-carcass procedures: done on the day of slaughter
- Carcass procedures: done after chilling the carcass for approximately 24 hours

Only half of the carcass is used for physical and chemical composition determination. The above two procedures result in the estimation of physically separable skin, blood, gastrointestinal tract, internal organs, fat, muscle and bone.

3.2 Non-carcass components (NC)

3.2.1 Blood (NC1)

Animals are desensitized with a captive bolt gun and slaughtered by exsanguination (i.e., cutting the throat and the carotid artery). All blood is collected in a large tared container until complete exsanguination has terminated and then weighed. The exsanguination process may take up to 2 minutes. Two blood samples of 100 mL each are obtained in a tared container. One of these samples is used to make up a composite sample of non-carcass components by % of body weight which is used for chemical analysis after freeze-drying. The other blood sample is kept as a backup (replicate) or be used for chemical analysis after freeze drying or immediately dried in a forced-air circulation oven (55 to 65°C for 48 hours). If using a forced-air oven, blood samples should be turned upside-down at the end of the first day and broken at the end of the second day decreasing particle size and allowing for proper drying.

3.2.2 Skin (NC2)

Upon termination of the exsanguination, the animal's hide is removed and weighed including tail but not feet and head as this is easier to do on a table separately. Extra care should be taken with the amount of fat or lean tissue remaining in the hide. Both depots would account for subcutaneous physical and chemical fat depots, and protein, fat and water depots towards the empty body weight (EBW). A representative sample from the hide (25 x 25 cm from the left rump of each animal) should be taken for chemical analysis. Alternatively, after weighing the hide, take 4 samples x 10 cm^2 from the legs' region and 1 sample x 1 cm^2 from the skin of the head. Then cut all samples in small pieces (1 cm^2), grind with liquid N, freeze dry, and save for composite sample of the non-carcass components.

3.2.3 Head, feet and hooves (NC3)

Head, feet and hooves are skinned off and weighed separately. The head and feet are then coarsely ground in a grinder, then cut into a finer paste using a cutter. The industrial grinder had dimensions of approximately 1.20 m long x 0.70 m wide x 0.70 m deep and grinds the bones to approximately 5 cm x 5 cm pieces. The industrial cutter has approximately 0.5 m radius and 0.2 m deep in its deepest part with blades strong enough to cut through pieces of bones coming from the grinder. Following homogenisation, samples are taken (2 samples x 200 g each), weighed, grind using liquid nitrogen, and then freeze-dried for dry matter (DM) and later chemical analysis. These samples are saved for a composite sample of the non-carcass section. The tail will go with internal organs.

3.2.3.1 Head

The head is separated from the carcass and should be dissected as well. The head is separated into three portions: soft tissues (e.g., brain, eyes, salivary glands, facial muscles), bones, and hide, and weighed accordingly. Head bones should be cut into 2 x 2 cm2 by sawing with a tape saw and subsequently sampled. Soft tissues should be ground using a meat grinder, homogenized, weighed, and sampled (approx. 200 to 400 g). Alternatively, weight, remove the hide to be composited with the body hide, then place head in industrial grinder with feet, and sample.

3.2.3.2 Feet

Feet are separated from the carcass, weighed and set aside to be joined with remaining limbs, and randomly sampled (one forelimb and one hindlimb). Feet should be dissected into three portions: soft tissues (e.g. tendons), bones, and hide, and weighed accordingly. Feet bones should be cut into 2 x 2 cm^2 by sawing with a tape saw and sampled (approx. 200 to 400 g). Alternatively, weigh, remove the hide to be composited with the body hide, then grind together with head, and obtain a composite sample. This sample should be representative in terms of the proportion of bone, muscle, teeth, cartilage and tendons.

Another option is to pass the sample after the industrial grinder through an industrial cutter (until a paste is achieved. Two samples of 200 g are then obtained, frozen, freeze-dried, grinded and used for composite non-carcass components.

3.2.4 Internal organs (NC4)

After the skin, head and feet are removed from the body, all internal organs should be weighed to determine the EBW. The ratio obtained by dividing EBW and SBW from a baseline group should be used to estimate the initial EBW of the remaining animals in the trial to compose the data set.

Carcasses are eviscerated, with viscera split into gastrointestinal tract (GIT), internal visceral fat, non-GIT (internal organs), and tail.

3.2.4.1 Internal visceral fat (NC4.1)

The visceral fat consists of mesenteric physically separated fat from the GIT which needs to be weighed separately. Internal fat can also be weighed with kidney, pelvic, and heart fats. Once weighed, internal fat is mixed with internal organs and the rest of the GIT and passed through the industrial cutter.

3.2.4.2 Gastrointestinal tract (NC4.2)

The GIT components are oesophagus, rumen, reticulum, omasum, abomasum, duodenum, jejunum, ileum, colon, and rectum.

After the GIT was separated from internal fat, the GIT is cleaned out (flushed with water) and re-weighed prior to cutting and grinding. The cleaned digestive tract should be free of fat and any feed or faecal particle matter before weighing and grinding. The clean-up of the GIT is crucial to obtain EBW by the summation of all fractions taken during the whole process (SBW = EBW + digesta). EBW is the sum of all carcass and non-carcass components and weight of digesta is SBW – EBW.

3.2.4.3 Internal organs (NC4.3)

Internal organs (non-GIT components) include liver, gallbladder, heart, lungs and trachea, kidneys, reproductive tract (penis/testes/udder), diaphragm, spleen, and tail. These are weighed separately from the rest of the non-carcass components, and then mixed with the internal fat and GIT in the cutter.

3.2.4.4 Composite sample of internal organs and viscera (NC4)

Internal organs, tongue, internal fat, GIT and tail are mixed and ground in the cutter to make a fine paste (approx. 20 to 40 min), then sampled (2 samples x 200 g on aluminium pan), frozen and freeze-dried. Alternatively, these 3 non-carcass components can be sampled separately by proportional weight.

3.2.5 Non-carcass composite sample (NC sample)

The non-carcass composite sample includes proportionally the following samples of NC1, NC2, NC3, and NC4 for chemical analyses. This composite sample is made up after freeze-drying.

3.3 Carcass components

The carcass is split into two identical longitudinal halves and weighed within 2 hours of slaughter (hot carcass weight; HCW). After a 24- or 48-h chill, carcasses are weighed again (chilled carcass weight, CCW). The right carcass is commercialized whereas the left carcass is processed as described below (Hankins & Howe, 1946). New scanning technologies can be used at this stage to scan the left half carcass such as RGB-IR, DEXA, etc. Alternatively, the right carcass can be used to obtain information on the commercial cuts (weight, size, dimensions, and chemical composition). A hot sample of m. longissimus lumborum can also be taken for metabolomics, transcriptomics, genomic and meat quality analyses of colour, shear force and texture by standard measures (Honikel, 1998; Perry et al., 2001).

3.3.1 Carcase trimming (C1)

The half hot carcase is trimmed to remove blood clots and hanging pieces of tissue, and the carcase weighed hot (HSCW) within 2 h of slaughter. Other carcass trimming such as those in Aus-Meat can be done if these are weighed and sampled to be added to the carcass components. Collect, weight, put in the cutter to make a paste, take 2 samples of 200 g each on an aluminium tray, freeze dry, save for composite sample of the carcass.

Alternatively, the carcass trimmings can be considered as part of the non-carcass components (common in Brazil) together with internal organs, viscera, etc. and used to make up that composite sample. The non-carcass composite sample is made up of blood, head and feet, skin, trimmings, and internal organs. These five samples are stored in separate containers at -20 C until freeze-drying and then combined to make up the composite sample after freeze-drying and final grind before chemical analysis.

3.3.2 Carcase quartering and MSA measures

Half-carcases are cut at the 13^{th} rib (Perry et al., 2001), with the resulting four quarters set aside for scanning (e.g. DEXA) and further dissection. The *m. longissimus lumborum* (LL) is used for pH measurement with chilled storage duration (pH ultimate at 24 h; MLA, 2017). The other Meat Standards Australia (MSA) measurements can then be taken on an oxygen-exposed rib surface such as the Hankins & Howe (HH) section (9^{th}-11^{th} rib; Hankins & Howe, 1946) - rib fat depth (RFD), eye muscle area (EMA) and MSA/AUS-MEAT marbling (MLA, 2017). Ossification can also be measured on the rear quarters (lumbar and sacral vertebrae) (AUS-MEAT, 2018; MLA, 2017). Meat and fat colour

can be taken using colour chips (AUS-MEAT, 2018) or objectively (L*, a*, b*) using a Minolta Chromameter (Perry et al., 2001).

3.3.3 Wholesale rib (WSR) and Hankins & Howe (HH) sections

Sectioning of the wholesale rib in Australia uses the 5th to 13th rib (MLA, 2017) however the WSR in the US includes the 6th to 12th rib section cut similarly to the Hankins and Howe's (1946) procedure as described by Shackelford et al. (1995) and Koch and Dikeman (1977). The HH section uses the 9th to 11th rib from the wholesale rib section (Hankins & Howe, 1946) and both sections take place following grading. These are marked and processed separately from the main carcase quarters for bone, muscle and fat analyses. The HH section is, however, a component of the wholesale rib and whole carcase, as the wholesale rib is a component of a whole carcase.

3.3.3.1 Hankins & Howe (HH) section (C2)

The 9th to 11th rib belonging to the Hankins and Howe section is separated from WSR. Debone the HH and physically separate and weigh fat, lean and bone. Saw the rib bones into 2 x 2 cm^2, sub-sample, freeze dry, grind with N, save for composite sample (**HH1**). Grind the fat and lean through a mixer/grinder, freeze dry, save for composite (**HH2**). Composite HH1 and HH2 (**C1**) for chemical analysis.

3.3.3.2 Wholesale rib (WSR) section (C3)

Debone the remaining of the WSR. Saw the rib bones into 2 x 2 cm^2, sub-sample, freeze dry, grind with N, save for composite (**WSR1**). Grind the fat and lean through a mixer/grinder, freeze dry, save for composite (**WSR2**). Composite WSR1 and WSR2 (**C2**) for chemical analysis.

3.3.4 Remaining carcass (RC)

Physically separate fat, bone, and lean from each quarter of the remainder of the half carcass. Grind bone, take 2 samples of 200 g each, freeze, freeze-dry, grind with N, save for composite (**RC1**). Grind fat and lean, sample 2 samples x 100 g, freeze dry, save for composite (**RC2**). Composite C1, RC1, and RC2 for chemical analyses (**C4**).

3.3.4.1 Bone proportion

Soft tissue (fat and muscle) is excised away from bone as best as possible (Hankins & Howe, 1946), throughout each carcase quarter, wholesale rib and HH section. Bones are weighed for proportional composition calculation, ground first and then cut into a paste and finally sampled (2 samples x 200 g in aluminium tray), re-weighed, ground with liquid nitrogen and reweighed, and freeze-dried for DM prior to chemical analysis.

3.3.4.2 Muscle proportion

Lean muscle tissue is dissected away from fat tissue throughout each carcase quarter, wholesale rib and HH section. Muscle is weighed for composition, ground in a commercial grinder, sampled (2 samples x 200 g), re-weighed, freeze-dried, ground with liquid nitrogen and reweighed for DM prior to chemical analysis. The commercial meat grinder should be big enough to allow grinding the number of carcasses slaughtered per day, e.g. 3 carcasses should have a capacity of approximately 1,000 kg of meat per hour.

3.3.4.3 Fat proportion

Physically separable fat can be split into subcutaneous, internal and intermuscular fat (weight separately for each depot). Fat tissue is weighed for composition, ground in a commercial grinder, sampled (2 x 200 g), re-weighed, freeze-dried, ground with liquid nitrogen and reweighed for DM prior to chemical analysis.

3.3.5 Chemical analysis of intramuscular fat

After weighing the loin muscle from WSR, HH or rest of carcass, lean muscle tissue is sampled, frozen and then prepared for freeze-drying and grinding prior to chemical IMF determination as per Perry et al. (2001).

3.3.6 Carcass composite sample (CAR)

The carcass composite sample (CAR) includes proportionally the following samples of C2, C3, and C4. Note the C1 was included in the C4.

3.4 Empty body composition and chemical analysis

Empty body composition is the combination of NC and CAR proportionally to obtain empty body composition on both as is (wet) and dry matter basis.

3.4.1 Laboratory samples

All samples obtained during the slaughters are frozen until freeze-drying can be performed. Samples need to be weighed before and after freeze-drying to estimate DM content (e.g. from the aluminium trays). These samples are then ground using liquid nitrogen and a mortar or a blender. These samples are then placed in a metal container, mixed with liquid nitrogen and then grinded using and then normal procedures followed for chemical analysis. The composite sample for the non-carcass and carcass samples is prepared by mixing each of the components in the correct proportion.

Prior to chemical analysis, all samples should be partially defatted by washing it successively with petroleum ether in a Soxhlet apparatus for pre-defatted dry matter (PDDM) accountability. The amount of fat lost during this procedure must be computed by weight differences and added to the final pool of crude fat for total crude fat estimation. Then, all samples should be ground using a ball mill and analysed for moisture (method 934.01; (AOAC, 2012), protein (method 920.87; AOAC, 1990), ether extract (EE; method 920.85; AOAC, 1990), and ash (method 924.05; AOAC, 1990) in order to determine the chemical composition of rib sections (WSR and HH), non-carcass, and carcass components. Calcium, phosphorus, magnesium, sodium and potassium contents can also be analysed as per AOAC standard measures (AOAC, 1990).

3.5 Spreadsheets required

3.5.1 Slaughter data

- Animal ID
- Date
- treatment
- Body ID

- Shrunk BW
- Weight of each internal organ: lungs, heart, spleen, kidneys, liver
- Weight of internal fat and meat trimmings
- Weight of tail, trachea, reproductive organs, mesentery
- Weight of the gastrointestinal tract: reticulorumen, omasum, abomasum, small intestine, large intestine
- Weight of tongue
- Weight of blood
- Weight of body skin
- Weight of head and feet with skin
- Weight of head and head without skin

3.5.2 Carcass Weights

- Animal ID
- Body number
- Left cold carcass weight
- Right cold carcass weight
- Aus-Meat and MSA grading
- Weight of hump
- Weight of meat and fat recovered from skin
- Weights of glands
- Weights of spinal cord
- Carcass trimmings
- Tendons
- Hankins and Howe: total weight, lean weight, fat weight and bone weight
- Wholesale rib: total weight, lean weight, fat weight and bone weight
- Whole left carcass: total weight, bone weight, lean weight and fat weight

4 Discussion

A technique to measure both physically separable fat, lean and bones, and chemical composition of animals was described in the present report. This technique is the gold standard for studies aiming at measuring energy and nutrient retention and their efficiency in animals. Most simulation prediction models used in the cattle industries around the world have been developed using this technique. These include Beef Cattle Nutrient Requirement Model (BCNRM) by the United States National Academies of Sciences, Engineering, and Medicine (NASEM, 2016), the Cattle Value Discovery System (CVDS; Tedeschi et al., 2004) the Ruminant Nutrition System (RNS; Tedeschi and Fox, 2018), CSIRO's Grazplan (2007), BR-Corte (Valadares Filho et al., 2016).

However, all these simulation models were developed with data collected elsewhere and there is uncertainty about their accuracy with the Australian feedlot industry. The technique described in the present report could be used to evaluate mechanistic mathematical models of animal growth, feed intake, feed efficiency, and carcass characteristics including marbling, P8 fat, carcass composition (fat, muscle and bone). Furthermore, with the large interest of the Australian cattle industries in technologies for objective carcass measurements, the methodology could be used to develop applications of these technologies beyond marketing and carcass grading. These include nutritional management, breeding, genetic evaluation, environmental management, and profit-driven decision making. Various applications of the technique are envisaged for the upcoming years particularly with

the advent of data generated by new technologies coupled with mathematical simulation models to improve productivity, animal welfare, profitability and reduce the environmental footprint of livestock production (Gonzalez et al., 2018).

5 Conclusions/recommendations

A medium- to long-term program needs to be established in Australia to develop a robust and complete database that can be used not only to determine carcass and non-carcass composition to improve predictability of empirical relationships used in simulation models but also evaluate novel equipment as they become available for use in the industry (e.g., DEXA, CT, NMR). The only gold standard to achieve this is with the body dissection technique to measure physically separable tissues and chemical composition as described in this document. Genetic selection may benefit of using this database therefore tissue samples should be frozen at -80˚C and stored for DNA/RNA analysis using high-throughput techniques for sequencing.

6 Key messages

- The gold standard to measure body composition of animals involves a complete dissection of body tissues and whole-carcass grinding for chemical analysis
- The technique is extremely accurate but complex and labour intensive
- This technique will allow developing databases under Australian conditions for many different applications including genetics, simulation models to aid in decision making, development of new technologies, and nutrition

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